Exhibit E

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ORIGINAL ARTICLE

WILEY

Sex differences in athletic performance emerge coinciding with the onset of male puberty

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Summary

Background: Male performance in athletic events begins to exceed that of age-matched females during early adolescence, but the timing of this divergence relative to the onset of male puberty and the rise in circulating testosterone remains poorly defined.

Design: This study is a secondary quantitative analysis of four published sources which aimed to define the timing of the gender divergence in athletic performance and relating it to the rise in circulating testosterone due to male puberty.

Data: Four data sources reflecting elite swimming and running and jumping track and field events as well as hand-grip strength in nonathletes were analysed to define the age-specific gender differences through adolescence and their relationship to the rising circulating testosterone during male puberty.

Results: The onset and tempo of gender divergence were very similar for swimming, running and jumping events as well as the hand-grip strength in nonathletes, and all closely paralleled the rise in circulating testosterone in adolescent boys.

Conclusions: The gender divergence in athletic performance begins at the age of 12-13 years and reaches adult plateau in the late teenage years with the timing and tempo closely parallel to the rise in circulating testosterone in boys during puberty.

KEYWORDS

age group, performance, puberty, swimming, testosterone, track and field

1 | INTRODUCTION

It is well known that men's athletic performance exceeds that of women especially in power sports because of men's greater strength, speed and endurance. This biological physical advantage of mature males forms the basis for gender segregation in many competitive sports to allow females a realistic chance of winning events. This physical advantage in performance arises during early adolescence when male puberty commences after which men acquire larger muscle mass and greater strength, larger and stronger bones, higher circulating haemoglobin as well as mental and/or psychological differences. After completion of male puberty, circulating testosterone levels in men are consistently 10-15 times higher than in children or women at any age.[1] The age at which sex differences emerge is reported as around the age of 12 from a study of individual Norwegian athletes in two running and two jumping events[2] and at 13-14 years in four track and field skills in Polish athletes[3]; however, the relationship to male puberty and circulating testosterone is not clear. This study investigates the age of the gender divergence in performance in elite swimming and a wider range of elite athletic events as well as a community-based study of grip strength among nonathletes to deduce the onset and progression of the gender divergence in performance of athletes and relates this to the timing and tempo of male puberty and the rise in circulating testosterone into adult male levels.

2 | MATERIAL AND METHODS

Four sources of published data were used in this study for which no ethics approval was required. The first was the US Age Group Swimming time standards which lists the prevailing time standard for entry to the top level (AAAA long course criteria) of all boys and girls events for individual years from 1981 to 2016 (accessed Oct 2016).

http://www.usaswimming.org/DesktopDefault.aspx?TabId=2628&Alias=Rainbow&Lang=en

Age groups were classified into five categories 10 and under, 11-12 years, 13-14 year, 15-16 years and 17-18 years. The seven events in common to all age groups were freestyle (50 m, 100 m, 200 m), backstroke, breaststroke and butterfly (all 100 m) and individual medley (200 m).

A second data source was the current world records for boys and girls between the ages of 5 and 19 years available at http://age-records.125mb.com/ (curated by Dominique Eisold, accessed Oct 2016). This included sufficient data to cover the timing of puberty onset with some pre- and postpuberty ages (ages 9-19 years) for a wide range of boys and girls track and field events. For this study, the running events included were 50 m, 60 m, 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 800 m, 1000 m, 1500 m, 1 mile, 2000 m, 3000 m and 2 miles. Only records recorded by fully automatic timing devices were included whether set indoor or outdoor or at altitude (>1000 m), but wind-assisted records were excluded from this analysis. The jumping events included were high jump, pole vault, long jump, triple jump, standing long jump.

The third data source was from a published study[1] in which serum testosterone was measured in over 100 000 consecutive serum samples processed over 7 years from a single pathology laboratory which was analysed to estimate male and female age-specific reference ranges across the full lifespan.

The fourth was a meta-analysis of secular changes in hand-grip strength in nonathletic children and adolescents from Canada and United States[4] using the data provided on 5676 males and 5489 females in 19 studies conducted between 1966 and 2009.

Data analysis was performed by analysis of variance and nonlinear curve fitting using NCSS 11 Statistical Software (NCSS LLC. Kaysville, Utah, USA). For each event used in this analysis, the age-specific record or age-group time standard was defined for boys (Tb) and girls (Tg) so the difference (expressed as a percentage) between boys and girls for any event was defined as D=(Tg−Tb)*100/Tg. For athletic jumping events, an analogous definition for record length was used (Lb for boys, Lg for girls) with the male advantage defined as D=(Lb−Lg)*100/Lg. For the athletic events where individual year age records were available across the age of puberty, the age-specific difference (as a percentage) for each year of age were pooled into running or jumping categories. For track and field performance, the pooled data were fitted to a four-parameter sigmoidal curve which allowed for asymptotic estimation of the lower (prepubertal) and upper (postpubertal) plateaus from the four parameters. In addition, the timing and tempo of the pubertal increase were defined by the start of puberty, defined as the time when 20% of the ultimate increase due to puberty had occurred (ED_{20}), and mid-puberty as the time when half the ultimate increase had occurred (ED_{50}). For swimming, the pooled gender differences for all strokes and distances were fitted by a smoothed spline curve. For hand-grip strength, the differences were fitted to a piecewise linear-quadratic curve with a single inflexion point.

3 | RESULTS

In swimming performance, the overall gender differences were highly significant with age group ($F_{4,360}$=1481, P<.0001) and stroke ($F_{4,360}$=11.9, P<.0001) as main (between) effects (Figure 1). There was no significant difference according to year (as a within factor, P=.99) so that for further analysis, years were taken as replicates. Using a sigmoidal curve fit for the overall gender differences pooling all strokes and distances, the ED_{20} was 11.4 years and the ED_{50} was 12.8 years.

Within a single stroke (freestyle), in addition to expected age-group effects ($F_{4,525}$=2174, P<.0001), there were also significant effects according to distance ($F_{2,525}$=231.5, P<.0001) whereby the age-group effects was significantly greater the shorter the event distance (Figure 2, 50 m>100 m>200 m, age group x distance interaction, $F_{8,525}$=55.9, P<.0001) (Figure 1). Similarly, for a fixed length of events (100 m) and after taking age-group effects into account, the four form strokes did differ significantly ($F_{3,700}$=12.9, P<.0001) producing significant

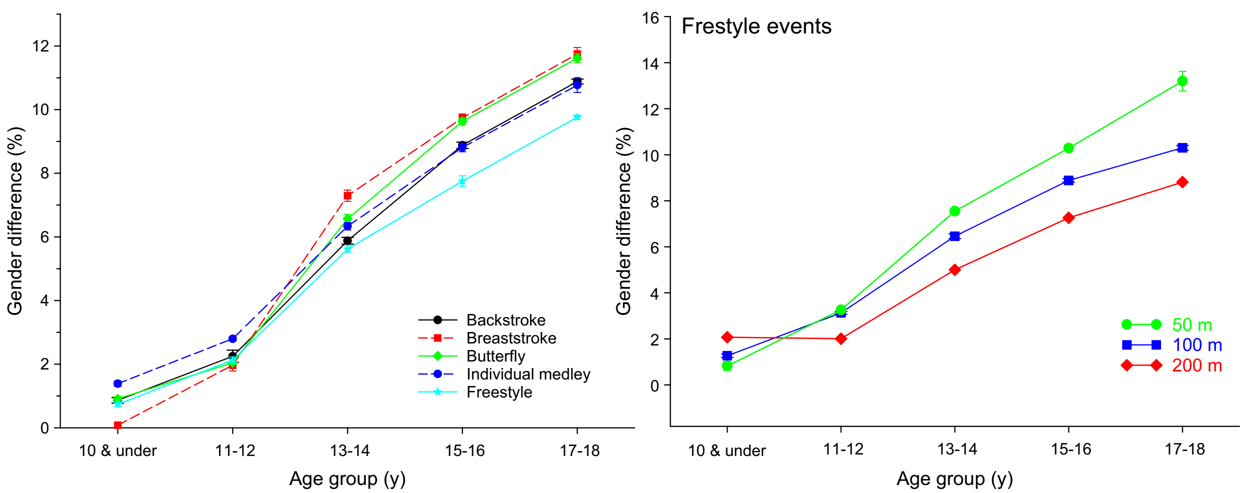

FIGURE 1 Gender differences in performance (in percentage) according to age group and stroke (left panel) or distance in freestyle events (right) in swimming events. Data shown as mean and standard error of the mean. Note greatest increase after the age of 12 years by age in breaststroke and least in freestyle and magnitude of increases are 50 m>100 m>200 m in freestyle events. [Colour figure can be viewed at wileyonlinelibrary.com]

differences between strokes (interaction $F_{12,700}$=23.4, P<.0001), the most prominent being for breaststroke, which displayed the greatest age-group effect, and butterfly followed by backstroke and then freestyle, which showed the least age-group effect (Figure 1).

In track and field athletics, the effects of age on running performance (Figure 2 upper left panel) showed that the prepubertal differences of 3.0% increased to a plateau of 10.1% with an onset (ED_{20}) at 12.4 years and reaching midway (ED_{50}) at 13.9 years. For jumping (Figure 2 upper right panel), the prepubertal difference of 5.8% increased to 19.4% starting at 12.4 years and reaching midway at 13.9 years. The timing of the male advantage in running, jumping and swimming was similar and corresponded to the increases in serum testosterone in males (Figure 2 lower panel).

To examine age of gender divergence in strength in an analogous data set from a nonathletic population (Canadian and US children and adolescents), the age trends in hand-grip strength showed a difference in hand-grip strength commencing from the age of 12.8 years onwards (Figure 3). Prior to the age of 13 years, boys had a marginally significant greater grip strength than girls (n=45, t=2.0, P=.026), but after the age of 13 years, there was a strong significant relationship between age and difference in grip strength (n=18, r=.89, P<.001).

4 | DISCUSSION

The present study shows that the gender divergence in performance for swimming and for running and jumping track and field events is very closely aligned to the timing of the onset of male puberty, which typically has onset at around 12 years of age.[5,6] These findings are consistent with reports on the timing of the gender differences in performance observed among Norwegian athletes in two running and two jumping events[2] and for track and field skills among Polish athletes.[3] This study extends the findings to swimming and a wider range of running and jumping track and field events. This timing is also consistent with the start of the gender divergence in fat-free (muscle) mass[7] and strength increases.[8,9]

In this study, the timing and tempo of male puberty effects on running and jumping performance were virtually identical and very similar

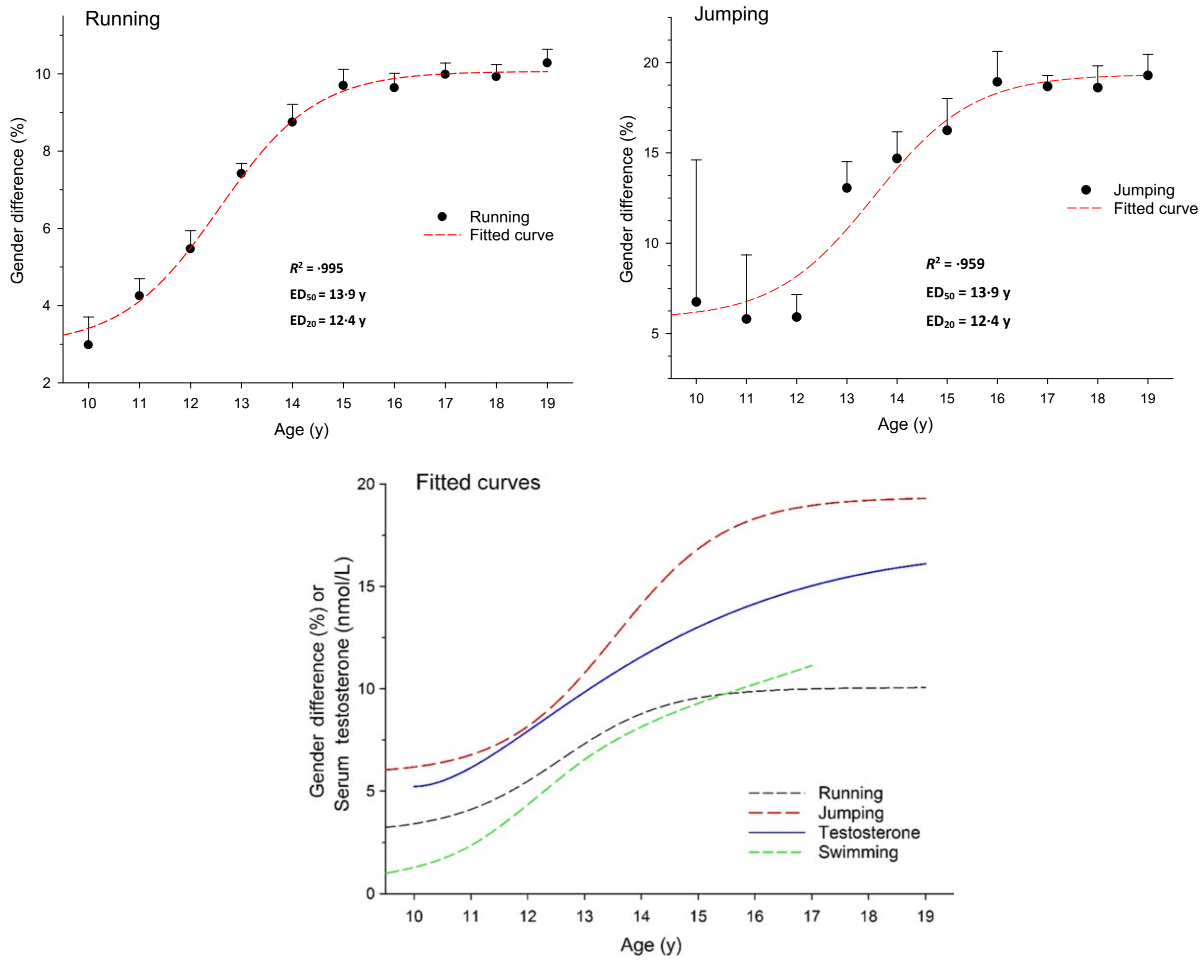

FIGURE 2 Gender differences in performance (in percentage) according to age (in years) in running events including 50 m, 60 m, 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 800 m, 1000 m, 1500 m, 1 mile, 2000 m, 3000 m and 2 miles (upper left panel) and in jumping events including high jump, pole vault, triple jump, long jump and standing long jump (upper right panel). Fitted sigmoidal curve plot of gender differences in performance (in percentage) according to age (in years) in running, jumping and swimming events as well as serum testosterone (lower panel). Data shown as mean and standard error of the mean of the pooled gender differences by age. [Colour figure can be viewed at wileyonlinelibrary.com]

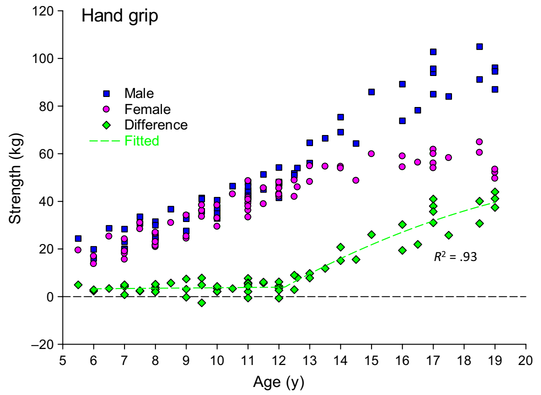

FIGURE 3 Hand-grip strength in children and adolescents from 19 studies including 5676 males (square) and 5489 females (circles) and the differences between male and females (diamonds) conducted between 1966 and 2009. The dotted line represents the fitted curve using a piecewise linear-quadratic curve fit with an automatically defined inflexion point at 12.8 years. [Colour figure can be viewed at wileyonlinelibrary.com]

to those in swimming events. Furthermore, these coincided with the timing of the rise in circulating testosterone due to male puberty. In addition to the strikingly similar timing and tempo, the magnitude of the effects on performance by the end of this study was 10.0% for running and 19.3% for jumping, both consistent with the gender differences in performance of adult athletes previously reported to be 10%-12% for running[10,11,12] and 19% for jumping.[12] The similar magnitude of the plateau effects observed for the oldest (postpubertal) stages in this study with mature adult gender differences suggests there are likely minimal if any further divergences in gender performance among athletes after the age of 20 years.

In the swimming events, despite the continued progressive improvements in individual male and female event records, the stability of the gender difference over 35 years shown in this study suggests that the gender differences in performance are stable and robust. These findings are consistent with a previous report of no narrowing of the gender gap in swimming event performance over more than three decades.[12] These findings contribute to discounting previous suggestions that the gender gap in performance of athletes was narrowing and might even disappear,[13] interpretations which were confounded by the increasing participation of females in elite sports through the 20th century that led to short-term accelerating improvement until women approached closer to contemporary female performance plateau.[12] The greater effect of male puberty on shorter freestyle events is consistent with the greater power demands of short sprint events than for longer freestyle events that involve more endurance. The consistent differences between form strokes over 100-m events, even after accounting for the very dominant age-group effect, suggest that the power demands on performance were most prominent in breaststroke and least in freestyle, presumably due to the different mechanical demands of the different strokes.

The gender divergence in hand-grip strength among nonathletic children and adolescents strengthens the view that these gender divergences are a feature of normal male puberty rather than being a feature that manifests only in elite athletes.

The similar time course of the rise in circulating testosterone with that of the gender divergences in swimming and track and field sports is strongly suggestive that these effects arise from the increase in circulating testosterone from the start of male puberty.[1] Somatic effects of male puberty differ in responsiveness to the postpubertal increase in serum testosterone. Muscle effects of testosterone have been established in well-controlled, interventional clinical experiments in healthy young[14,15] and older[16] men. Testosterone increases muscle mass and strength over weeks to months with a strong dose-response evident from below to above physiological testosterone doses and concentrations. Analogous findings are reported in androgen-deficient (hypogonadal) men administered testosterone replacement therapy[17] and in women receiving appropriately lower testosterone doses,[18] and observational dose-effect relationship between endogenous testosterone and upper or lower body muscle mass is reported in healthy men.[19] Most if not all sex differences in maximal oxygen uptake are explained by differences in muscle mass.[20-22]

Adult male circulating testosterone also has marked effects on bone development leading to longer, stronger and denser bone than in age-matched females.[23] However, testosterone effects on bone are slower in onset and probably less reversible than effects on muscle. For example, men achieve peak bone mass at the end of skeletal maturation only in the early 1920s, about a decade after the start of sustained exposure to adult male testosterone levels. Furthermore, while testosterone deficiency may lead to loss of bone density,[23] the overall structural framework of the skeleton is likely to change slowly if at all. Hence, the extent to which testosterone-induced bone changes contribute to the male advantage in adolescent athletic performance is unclear but is probably at least not maximal until the third decade of life by which time the gender differences are already stabilized.

A further biological advantage of adult male circulating testosterone concentrations is the increased circulating haemoglobin. Men have ~10 g/L greater haemoglobin than women[24] with the gender differences also evident from the age of 13-14 years.[25] Testosterone effects on haemoglobin are replicated by administration of exogenous testosterone in a dose-dependent fashion[26] within 1-3 months.[27] Like the effects on muscle, the erythropoietic effect of testosterone is relatively rapid and reversible in contrast to the slower effects on bone. Although a higher haemoglobin is likely to provide advantages in endurance rather than power events, it is unclear how much the relatively modest magnitude of this gender difference contributes to the male advantage in athletic performance.

Finally, exposure to adult male testosterone concentrations is likely to produce some mental or psychological effects.[28] However, the precise nature of these remains controversial and it is not clear whether, or to what extent, this contributes to the superior elite sporting performance of men in power sports compared with the predominant effects on muscle mass and function.

The strength of the present study is that it includes a wide range of swimming as well as track and field running and jumping events as well as strength for nonathletes for males and females across the ages spanning the onset of male puberty. The similar timing of the gender divergence in each of these settings to that of the rise in circulating testosterone to adult male levels strongly suggests that they all reflect the increase in muscular size and strength although the impact of other androgen-dependent effects on bone, haemoglobin and psychology may also contribute. Limitations of this study include that it could not extend to all swimming or track and field events due to the restricted participation of younger age groups in more gruelling events. Furthermore, the testosterone measurements were not from the individual athletes included in the analysis of available published data so that the comparisons are cohort-wise rather than based on individuals.

It is concluded that the gender divergence in athletic performance begins at the age of 12-13 years and reaches adult plateau in the late teenage years. Although the magnitude of the divergence varies between athletic skills, the timing and tempo are closely parallel with each other and with the rise in circulating testosterone in boys during puberty to reach adult male levels.

ACKNOWLEDGEMENTS

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CONFLICT OF INTERESTS

Nothing to declare.

REFERENCES

1. Handelsman DJ, Sikaris K, Ly LP. Estimating age-specific trends in circulating testosterone and sex hormone-binding globulin in males and females across the lifespan. *Annu Clin Biochem*. 2016;53:377-384.
2. Tonnessen E, Svendsen IS, Olsen IC, Guttormsen A, Haugen T. Performance development in adolescent track and field athletes according to age, sex and sport discipline. *PLoS ONE*. 2015;10:e0129014.
3. Malina RM, Slawinska T, Ignasiak Z, et al. Sex differences in growth and performance of track and field athletes 11-15 years. *J Hum Kinet*. 2010;24:79-85.
4. Silverman IW. The secular trend for grip strength in Canada and the United States. *J Sports Sci*. 2011;29:599-606.
5. Beccuti G, Ghizzoni L. Normal and abnormal puberty. In: De Groot LJ, Beck-Peccoz P, Chrousos G, et al., eds. *Endotext*. MDText.com, Inc.: South Dartmouth, MA; 2000.
6. Day FR, Bulik-Sullivan B, Hinds DA, et al. Shared genetic aetiology of puberty timing between sexes and with health-related outcomes. *Nat Commun*. 2015;6:8842.
7. Malina RM, Bouchard C, Beunen G. Human growth: selected aspects of current research on well-nourished children. *Ann Rev Anthropol*. 1988;17:187-219.
8. Sartorio A, Lafortuna CL, Pogliaghi S, Trecate L. The impact of gender, body dimension and body composition on hand-grip strength in healthy children. *J Endocrinol Invest*. 2002;25:431-435.
9. Henneberg M, Brush G, Harrison GA. Growth of specific muscle strength between 6 and 18 years in contrasting socioeconomic conditions. *Am J Phys Anthropol*. 2001;115:62-70.
10. Cheuvront SN, Carter R, Deruisseau KC, Moffatt RJ. Running performance differences between men and women:an update. *Sports Med*. 2005;35:1017-1024.
11. Seiler S, De Koning JJ, Foster C. The fall and rise of the gender difference in elite anaerobic performance 1952-2006. *Med Sci Sports Exerc*. 2007;39:534-540.
12. Thibault V, Guillaume M, Berthelot G, et al. Women and men in sport performance: the gender gap has not evolved since 1983. *J Sports Sci Med*. 2010;9:214-223.
13. Beneke R, Leithauser RM, Doppelmayr M. Women will do it in the long run. *Br J Sports Med*. 2005;39:410.
14. Bhasin S, Storer TW, Berman N, et al. The effects of supraphysiologic doses of testosterone on muscle size and strength in normal men. *N Engl J Med*. 1996;335:1-7.
15. Finkelstein JS, Lee H, Burnett-Bowie SA, et al. Gonadal steroids and body composition, strength, and sexual function in men. *N Engl J Med*. 2013;369:1011-1022.
16. Bhasin S, Woodhouse L, Casaburi R, et al. Older men are as responsive as young men to the anabolic effects of graded doses of testosterone on the skeletal muscle. *J Clin Endocrinol Metab*. 2005;90:678-688.
17. Bhasin S, Storer TW, Berman N, et al. Testosterone replacement increases fat-free mass and muscle size in hypogonadal men. *J Clin Endocrinol Metab*. 1997;82:407-413.
18. Huang G, Basaria S, Travison TG, et al. Testosterone dose-response relationships in hysterectomized women with or without oophorectomy: effects on sexual function, body composition, muscle performance and physical function in a randomized trial. *Menopause*. 2014;21:612-623.
19. Mouser JG, Loprinzi PD, Loenneke JP. The association between physiologic testosterone levels, lean mass, and fat mass in a nationally representative sample of men in the United States. *Steroids*. 2016;115:62-66.
20. Jones NL, Makrides L, Hitchcock C, Chypchar T, McCartney N. Normal standards for an incremental progressive cycle ergometer test. *Am Rev Respir Dis*. 1985;131:700-708.
21. Svedenhag J. Maximal and submaximal oxygen uptake during running: how should body mass be accounted for? *Scand J Med Sci Sports*. 1995;5:175-180.
22. Genberg M, Andren B, Lind L, Hedenstrom H, Malinovschi A. Commonly used reference values underestimate oxygen uptake in healthy, 50-year-old Swedish women. *Clin Physiol Funct Imaging*. 2016; doi: 10.1111/cpf.12377. [Epub ahead of print]
23. Vanderschueren D, Laurent MR, Claessens F, et al. Sex steroid actions in male bone. *Endocr Rev*. 2014;35:906-960.
24. Murphy WG. The sex difference in haemoglobin levels in adults - mechanisms, causes, and consequences. *Blood Rev*. 2014;28:41-47.
25. Krabbe S, Christensen T, Worm J, Christiansen C, Transbol I. Relationship between haemoglobin and serum testosterone in normal children and adolescents and in boys with delayed puberty. *Acta Paediatr Scand*. 1978;67:655-658.
26. Coviello AD, Kaplan B, Lakshman KM, Chen T, Singh AB, Bhasin S. Effects of graded doses of testosterone on erythropoiesis in healthy young and older men. *J Clin Endocrinol Metab*. 2008;93: 914-919.
27. Bachman E, Travison TG, Basaria S, et al. Testosterone induces erythrocytosis via increased erythropoietin and suppressed hepcidin: evidence for a new erythropoietin/hemoglobin set point. *J Gerontol A Biol Sci Med Sci*. 2014;69:725-735.
28. Celec P, Ostatnikova D, Hodosy J. On the effects of testosterone on brain behavioral functions. *Front Neurosci*. 2015;9:12.

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Exhibit F

OPEN ACCESS

How does hormone transition in transgender women change body composition, muscle strength and haemoglobin? Systematic review with a focus on the implications for sport participation

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ABSTRACT

Objectives We systemically reviewed the literature to assess how long-term testosterone suppressing gender-affirming hormone therapy influenced lean body mass (LBM), muscular area, muscular strength and haemoglobin (Hgb)/haematocrit (HCT).

Design Systematic review.

Data sources Four databases (BioMed Central, PubMed, Scopus and Web of Science) were searched in April 2020 for papers from 1999 to 2020.

Eligibility criteria for selecting studies Eligible studies were those that measured at least one of the variables of interest, included transwomen and were written in English.

Results Twenty-four studies were identified and reviewed. Transwomen experienced significant decreases in all parameters measured, with different time courses noted. After 4 months of hormone therapy, transwomen have Hgb/HCT levels equivalent to those of cisgender women. After 12 months of hormone therapy, significant decreases in measures of strength, LBM and muscle area are observed. The effects of longer duration therapy (36 months) in eliciting further decrements in these measures are unclear due to paucity of data. Notwithstanding, values for strength, LBM and muscle area in transwomen remain above those of cisgender women, even after 36 months of hormone therapy.

Conclusion In transwomen, hormone therapy rapidly reduces Hgb to levels seen in cisgender women. In contrast, hormone therapy decreases strength, LBM and muscle area, yet values remain above that observed in cisgender women, even after 36 months. These findings suggest that strength may be well preserved in transwomen during the first 3 years of hormone therapy.

INTRODUCTION

Currently the world of sport, from grassroots level to elite, is facing the challenge of how to include transgender people in sporting competitions. Regulations governing the participation of athletes from outside the sex/gender binary have existed since the 1940s.[1–4] Presently, World Athletics requires that transgender athletes[5] and athletes with differences of sexual development[6] have testosterone levels ≤5 nmol/L in order to be eligible for the female category. There has been heavy criticism of this, and previous, testosterone-based regulations.[7–9] Although no openly transgender athlete has competed in the Olympics to date, the increasing visibility of gender-diverse people in society[10] means that the sports administrators and legislators must create rules to accommodate athletes from outside the sex/gender binary.[11]

There are many quantifiable performance-related differences between male and female athletes. In contrast, the performance-related differences between transwomen who have received gender affirming hormone treatment (GAHT) and cisgender women are less clear. GAHT for transwomen consists of an antiandrogen agent plus the introduction of exogenous oestrogen,[12] with the goal of altering the hormonal milieu and, as a result, feminisation of the body.[13] To date, there have been no prospective studies investigating the changes in athletic performance in transgender athletes after hormonal transition. In non-athletic transgender populations, studies are commonly focused on clinical outcomes, such as bone health.[14] However, studies in non-athletic transwomen undergoing GAHT also report changes in lean body mass (LBM),[15] muscle cross-sectional area (CSA),[16] muscular strength[17] and haemoglobin (Hgb)[18] and/or haematocrit (HCT).[19] These parameters are of relevance to athletic performance.

In endurance sports, Hgb is of importance. Hgb is a protein carried by the red blood cells that is responsible for transporting oxygen from the lungs to peripheral tissues.[20] Low Hgb, or low HCT, the volume of red blood cells compared with total blood volume, can lead to a diminished supply of oxygen to the tissues, and therefore have a direct effect on endurance performance. Typical values for Hgb differ between males and females, with 'normal' values ranging between 131–179 g/L for men and 117–155 g/L for women.[21] HCT values are also higher in males (42%–52%) than females (37%–47%).[22] Testosterone exerts erythrogenic effects that results in increases in both HCT and Hgb.[23] Since GAHT significantly lowers testosterone levels in transgender women,[24] it is possible that they may experience reductions in HCT and Hgb, which would be anticipated to negatively affect endurance performance.

In sports demanding speed and power, muscular strength and the ability to generate high rates of force are recognised as key determinant in athletic success.[25] In cisgender males, increases in testosterone due to puberty promote muscular strength in association with increased muscle CSA, and increased lean muscle mass.[26] It has been hypothesised that muscle retains a long-term memory allowing it to perform tasks that it has undertaken many times previously and myonuclei retention is thought to play an important role in such muscle memory.[27] Myonuclei number is increased with training and with use of anabolic steroids.[28] However, detraining does not diminish the myonuclei number,[27] and it has been hypothesised that cessation of steroids may also not lead to reductions in myonuclei number.[28] Hence, it is possible that strength advantages gained when training in a high-testosterone environment may not be fully reversed by testosterone suppression.

Understanding both the physiological effects of GAHT on athletic performance, and the time course of these effects, is of importance to decision-makers and those undertaking policy reviews. While it is known that testosterone levels are markedly reduced in transgender women taking testosterone suppressing GAHT,[29] the effects of this hormonal change on physiology, and the time course in which these changes occur, are less clear. Individual studies provide crucial, primary research on the topic, but a systematic review is warranted to provide a robust summary of the available evidence. Because bone mineral density studies have already been subject to systematic review,[30 31] this review focuses on physiological changes induced by GAHT in transwomen that affect athletic performance; specifically, LBM, CSA, strength and Hgb/HCT.

Aim

The aim of this systematic review was to: (1) summarise the current state of knowledge as it relates to the changes, and the time course of these changes, in physiological parameters associated with athletic performance in non-athletic transwomen resulting from GAHT (suppression of testosterone and supplementation with oestrogen), and (2) consider the potential implications for the participation of transwomen in elite sport.

MATERIALS AND METHODS

Search strategy and selection criteria

This systematic review was conducted in line with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[32] Two electronic searches of four online databases (BioMed Central, PubMed, Scopus and Web of Science) were completed 15 months apart. The first was performed by BSK in January 2019 and the second by JH in April 2020. The two sets of search results were compared by GLW. The second search identified novel data from three additional studies using the same cohorts as three studies identified in the first search. The more recent search also identified three additional recent papers. Reference lists were also searched for additional citations pertinent to the review. The searches combined terms related to transwomen, GAHT, muscle and blood parameters (online supplemental table 1).

Study selection, quality assessment, and data extraction

Each study was initially categorised based on its design (eg, cohort, case–control) and examined for quality in line with the Effective Public Health Practise Project (EPHPP) tool.[33] This is a generic tool used to evaluate a variety of intervention study designs and is suitable for use in systematic reviews,[34] having content and construct validity.[35] Based on the EPHPP, six domains are evaluated: (1) selection bias; (2) study design; (3) confounders; (4) blinding; (5) data collection method; and (6) withdrawals/dropouts. Each domain is rated as strong (3 points), moderate (2 points) or weak (1 point), and domain scores are averaged to provide the overall mean rating. Based on the overall mean rating, studies are rated as weak (1.00–1.50), moderate (1.51–2.50) or strong (2.51–3.00).

For longitudinal studies, data were extracted to examine changes in LBM, CSA, strength and Hgb/HCT in transwomen taking GAHT. In cross-sectional studies, data in transwomen were compared with data from both cisgender men and cisgender women. The study authors were contacted if there were any questions regarding the presented data. In this regard, authors of the nine studies carried out by the European Network for the Investigation of Gender Incongruence (ENIGI) were contacted regarding potential overlapping participants[15 17 19 36–41] and another author was contacted to clarify graphical data content.[16]

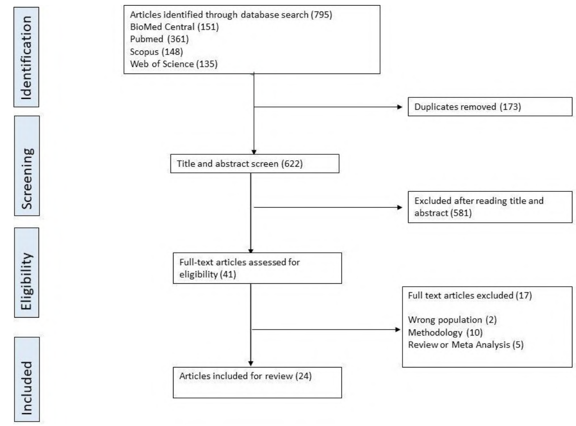

Figure 1 PRISMA flow chart illustrating search strategy. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

RESULTS

Search results

Figure 1 shows the search strategy following PRISMA guidelines. From an initial yield of 795 articles, 24 studies[15–19 36–54] were included in this review. The following information was extracted from each study: name of the first author, country, year of publication, number of transfemale participants, number of cisgender male and female participants (where applicable), duration of any follow-up, type of medical treatment, method of measurement, evaluation time, and results.

Quality assessment

Based on the mean EPHPP scores, all studies were categorised as moderate in quality. The individual scores are listed in the online supplemental table 2.

Study characteristics

A summary of the study characteristics is reported in table 1. The sample sizes of the studies varied from 12 to 249. Three large studies from the ENIGI group published in 2018 and 2019[15 17 19] contained much novel data, but also included many participants from previous studies making it impossible to accurately state the number of unique participants.

Study designs

Thirteen studies[15 17 19 36–40 42 43 46–48] utilised a follow-up study design comparing participants' measurements before initiating hormone transition (baseline) to several months after hormone transition. Two studies[41 51] used both follow-up and cross-sectional designs with cisgender controls. Six studies[18 45 50 52–54]

Table 1 Characteristics of reviewed studies

Author (year)	Study type	Country	Study quality rating	Participants (N) TW	CM	CW	HNTW	Age (years) Mean±SD med (min–max)	Timing (months post GAHT)	T (nmol/L) Baseline post GAHT	Measures LBM	CSA	MS	Hgb or HCT
Elbers *et al* (1999)[42]	Follow-up	Netherlands	Mod	20	–	–	–	26±6	Baseline 12	22 1.0	N	Y	N	N
Gooren and Bunck (2004)[43]	Follow-up	Netherlands	Mod	19	–	–	–	NR	Baseline 12 36	21.5 1.0 0.9	N	Y	N	Y
Mueller *et al* (2011)[44]	Prospective	Germany	Mod	84	–	–	–	36.3±11.3	Baseline 12 24	13.6 0.6 0.7	Y	N	N	N
Wierckx *et al* (2014)[45]	Follow-up	Norway and Belgium	Mod	53	–	–	–	31.7±14.8 19.3±2.4	Baseline 12	18.4 0.4	Y	N	N	Y
Gava *et al* (2016)[38]	Follow-up	Italy	Mod	40	–	–	–	32.9±9.4 29.4±10.2	Baseline 12	19.2 0.7	Y	N	N	N
Auer *et al* (2016)[46]	Follow-up	Belgium	Mod	20	–	–	–	NR	Baseline 12	20.5 2.0	N	N	Y	Y
Auer *et al* (2018)[40]	Follow-up	Belgium	Mod	45	–	–	–	34.8±1.4	Baseline 12	17.5 1.9	Y	N	N	N
Jarin *et al* (2017)[39]	Follow-up	USA	Mod	13	–	–	–	18 (14–25)	Baseline 6	13.6 6.9	N	N	N	Y
Defreyne *et al* (2018)[19]	Follow-up	Netherlands and Belgium	Mod	239	–	–	–	28.5 (16–65)	Baseline 3 6 24	17.4 0.7 0.6 0.6	N	N	N	Y
Vita *et al* (2018)[48]	Follow-up	Italy	Mod	21	–	–	–	25.2±7.0	Baseline 30	20.5 1.1	N	N	N	Y
Klaver *et al* (2018)[15]	Follow-up	Netherlands and Belgium	Mod	179	–	–	–	29.0 (18–66)	Baseline 12		Y	N	N	N
Olson-Kennedy *et al* (2018)[49]	Prospective	USA	Mod	23	–	–	–	18 (12–23)	Baseline 24	14.8 5.9	N	N	N	Y
Tack *et al* (2018)[36]	Follow-up	Belgium	Mod	21	–	–	–	16.3±1.2	Baseline 5–31	15.2 8.8	Y	Y	Y	N
Tack *et al* (2017)[47]	Follow-up	Belgium	Mod	21	–	–	–	16.3±1.2	Baseline 12–31	15.8 7.8	N	N	N	Y
Scharff *et al* (2019)[17]	Follow-up	Netherlands and Belgium	Mod	249	–	–	–	28 (23–40)	Baseline 12	18.3 0.8	N	N	Y	N
Wiik (2020)[16]	Prospective	Sweden	Mod	11	–	–	–	27±4	Baseline 4 12	18.0 0.5 0.5	N	Y	Y	Y
Van Caenegem *et al* (2014)[45]	Follow-up and cross-sectional	Belgium	Mod	49	49	–	–	33±12 30 (17–67) 33±12	Baseline 12 24 TW Baseline vs CM	19.0 0.5 0.5	Y	Y	Y	N
Haraldsen *et al* (2007)[51]	Follow-up and cross-sectional	Norway	Mod	12	77	–	–	29.3±7.8 33.9±9.3	Baseline 12 TW Baseline vs CM	16.8 6.8	Y	Y	N	N

Continued

Table 1 Continued

Author (year)	Study type	Country	Study quality rating	Participants (N) TW	CM	CW	HNTW	Age (years) Mean±SD med (min–max)	Timing (months post GAHT)	T (nmol/L) Baseline post GAHT	Measures LBM	CSA	MS	Hgb or HCT
SoRelle *et al* (2019)[52]	Cross-sectional	USA	Mod	133	–	–	87	33±12 31±12	TW>6 m vs HNTW	1.9 12.7	N	N	N	Y
Greene *et al* (2019)[18]	Cross-sectional	USA	Mod	93	–	–	–	35.1 (18–69)	TW>12 m vs CW ranges	1.4	N	N	N	Y
Roberts *et al* (2014)[53]	Cross-sectional	USA	Mod	55	20	20	–	46 (27–67) 58 (21–84) 56 (23–88)	TW>6 m vs CM TW>6 m vs CW		N	N	N	Y
Lapauw *et al* (2008)[54]	Cross-sectional	Belgium	Mod	23	20	–	–	41±7 40±7	TW>48 m vs CM	1.1 20.1	Y	Y	Y	Y
Jain *et al* (2019)[50]	Cross-sectional	USA	Mod	277	–	–	102	31±7.1 31±7.1	TW vs HNTW		N	N	N	Y
Sharula (2012)[37]	Cross-sectional	Japan	Mod	129	–	–	22	33.9±10.0 31.5±9.9	TW vs HNTW	2.5 20.5	N	N	N	Y

CM, cismen; CSA, cross-sectional area; CW, ciswomen; HCT, haematocrit; Hgb, haemoglobin; HNTW, hormone-naive transwomen; LBM, lean body mass; TW, transwomen.

used an exclusively cross-sectional design; three comparing transwomen on GAHT with cisgender controls[18 53 54] and three comparing transwomen on GAHT with hormone-naive transwomen.[45 50 52] Three studies[16 44 49] used a prospective method gathering data over 12–24 months. Aside from these three studies, data were extracted from medical charts (nine of which were from the same research group,[15 17 19 36–41]) posing a risk of selective data reporting and publication bias.

Medical treatments

Medical treatments for endocrine transition were varied, in line with the individualised approach advised by the WPATH Standards of Care.[55] Fourteen studies[15 17 19 36–43 46 48 54] used cyproterone acetate (50–100 mg daily) as an antiandrogen. In six studies[16 38 40 44 46 49] a form of gonadotropin-releasing hormone agonist was administered either to supress puberty or androgens. In four studies[18 49 50 52] spironolactone was used as an antiandrogen. Seventeen studies[15 17–19 36–39 41 44 45 47–50 52 53] used 2–4 mg/day of oral oestradiol valerate. Eleven studies[15–17 19 39 42 43 45 46 48 49] used transdermal 17-beta-oestradiol releasing 100 mcg/day. Four studies[16 18 47 49] used an injection of oestradiol valerate (10 mg/ampoule, every 1–4 months). Two studies[45 54] used 0.625–2.5 mg/day of conjugated equine oestrogen. Four studies,[42 43 51 54] all undertaken prior to 2010, used 25–50 mcg/day of ethinyl oestradiol. Ethinyl oestradiol was not used in any study after 2010, primarily due to increased risk of thrombogenesis.[56]

Based on the variability in drug regimens used, there is substantial heterogeneity in the hormone levels achieved. Although the transwomen in most of the studies achieved testosterone levels within the reference range for cisgender women, there were five studies[38 40 47 49 51] in which the transfemales had post-GAHT testosterone values greater than 5 nmol/L. Four of the five studies[38 40 47 49] were carried out on adolescent transfemales; two of the five studies[38 51] did not involve the use of an antiandrogen agent; one study[40] did not involve the use of any form of oestrogen. The high post-GAHT testosterone is a possible confounder, and potential physiological differences between adolescent and adult participants may also confound results.

Muscle mass and body fat changes

Table 2 summarises the studies reporting muscle mass and body fat. Eight studies[15 36 39–41 44 46 51] used a follow-up design to assess changes in LBM; seven studies assessed after 12 months,[15 36 39 41 44 46 51] and one[40] study reviewed patients who had been under treatment for 5–31 months. Seven of these studies,[15 36 39–41 44 51] including the large (n=179) ENIGI study,[15] and two studies[40 51] with high post-GAHT testosterone (~8 nmol/L), showed that total LBM was decreased by 3.0%–5.4% following hormone transition ($p<0.05$). The one study that failed to demonstrate significant changes in LBM[46] was not an outlier in any obvious way. The large ENIGI study[15] was the only study in which the limits of agreement would indicate a change in LBM at the 95% CI. All studies reported an increase in total body fat mass in transwomen after hormone transition. Three cross-sectional studies[41 51 54] compared transwomen with cisgender men. Two studies included hormone-naive transwomen.[41 51] These studies reported 6.4% and 8.0% lower LBM than in cisgender men and reductions of 4% in LBM in the transwomen with 12 months of GAHT. The third cross-sectional study compared transwomen who had undergone at least 48 months of GAHT with cisgender men[54] and reported 17% lower LBM in transwomen than in cisgender men.

Table 2 Changes in total LBM in kilograms

Longitudinal studies

Author (year)	Participants (N) TW	Baseline mean±SD (95% CI)	12 Months mean±SD (95% CI)	12–31 months mean±SD	% Change	P	T (nmol/L) Base-post GAHT
Mueller *et al* (2011)[11]	84	59.6 (54.6–64.6)	57.2 (54.0–64.1)		−4.0	<0.005	13.6–0.6
Wierckx *et al* (2014)[45]	40 (oral oestrogen) 12 (transdermal oestrogen)	56.0±7.5 62.6±9.3	53±8 59.7±8.1		−5.4 −4.6	<0.001 <0.05	18.0–0.4 19.7–0.5
Gava *et al* (2016)[38]	20 (cyproterone acetate) 20 (leuprolide acetate)	51.7±8.3 50.2±7.0	49.9±7.8 49.8±6.7		−3.5 −0.8	>0.05 >0.05	16.3–0.7 22.2–0.7
Auer *et al* (2018)[40]	45	59.5±8.7 (56.9–62.0)	57.5±12 (53.9–60.2)		−3.4	<0.001	17.5–1.9
Klaver *et al* (2018)[15]	179	57.2±8.3	55.5 (54.9–56.1)		−3.0	<0.001	
Tack *et al* (2018)[36]	21	47.0±6.4		44.8±6.3	−4.7	<0.01	15.2–8.8
Haraldsen *et al* (2007)[51]	12	54.4±6.2	52.2		−4.0	<0.001	16.8–8.6
Van Caenegem *et al* (2015)[41]	49	57.4±8.7	55.1±8.7		*−4.0*	<0.001	19.0–0.5

Cross-sectional studies

Author (year)	Participants (N) TW	Participants (N) CM	TW baseline mean±SD	TW 48 months mean±SD	CM mean±SD	% Difference	P	T (nmol/L) TW
Lapauw *et al* (2008)[54]	23	46		51.2±8.4	61.8±7.9	−17.2	<0.001	1.1
Haraldsen *et al* (2007)[51]	12	77	54.4±6.2		59.1±5.7	−8.0	<0.05	16.8
Van Caenegem *et al* (2015)[41]	49	49	57.4±8.7		61.3±6.8	−6.4	<0.05	19.0

Data are from dual energy X-ray absorptiometry scans.
CM, cismen; LBM, lean body mass; TW, transwomen.

CSA changes

Four follow-up studies[16 40–42] investigated the CSA either in the quadriceps, forearm or calf regions using MRI[16 42] or peripheral quantitative computed tomography (pQCT).[40 41] Of note, two of the studies measured the total CSA of the individual MRI[42] or pQCT[41] image while two studies measured the isolated muscle.[16 40] A decrease in CSA of 1.5%–11.7% was reported over periods ranging from 12 to 36 months. One of these studies[40] examined adolescent participants who only reached a final testosterone level of 8.8 nmol/L and exhibited forearm and calf CSA decreases of 4.1% and 8.9%, respectively. There were two studies[41 42] that assessed muscle CSA at both 12 months and at either 24 or 36 months. The first study[42] reported a 9.5% decrease in quadriceps CSA compared with baseline after 12 months and an 11.7% decrease in quadriceps CSA compared with baseline after 36 months. The second study[41] reported a 1.5% decrease in tibia CSA compared with baseline after 12 months and a 3.8% decrease compared with baseline after 24 months. The same study reported that compared with baseline, forearm CSA was decreased by 8.6% after 12 months, yet at 24 months was 4.4% lower than baseline, indicating that forearm CSA was 4.2% larger at 24 months than at 12 months. There was only one study[42] in which the limits of agreement indicated a change at the 95% CI. Two cross-sectional studies[41 54] compared transwomen with cisgender men. One study reported 9% smaller CSA in hormone-naive transwomen[41] than in cisgender men, with the transwomen undergoing a further 4% decrease in CSA with 24 months of GAHT. The transwomen in the second study had all undergone at least 48 months of GAHT[54] and had 24% smaller CSA than cisgender men. See table 3.

Muscular strength changes

Table 4 summarises the studies reporting muscular strength. Five longitudinal studies[16 17 37 40 41] investigated the muscular strength of transwomen. Four of the studies[17 37 40 41] measured hand grip strength in participants on the ENIGI study. The largest of the three (n=249) ENIGI studies[17] and one other study[41] found significant ($p<0.001$) reductions (4.3% and 7.1%, respectively) after 12 months on GAHT. Two ENIGI studies[37 40] found no significant strength differences, although one of these studies[40] was carried out on adolescents who failed to reach typical female testosterone levels (8.8 nmol/L after GAHT). The large ENIGI study[17] was the only study in which the limits of agreement would indicate a change in strength at the 95% CI. The fifth longitudinal study to assess strength measured upper leg strength using knee flexion and extension and found no significant difference after 12 months.[16] Two studies[41 54] used a cross-sectional design to compare the strength of transwomen to cisgender men. One study found 14% lower hand grip strength in hormone-naive transwomen than in cisgender men ($p<0.001$)[41] and a further 7% reduction in hand grip strength of the transwomen after 12 months of GAHT. The other study[54] found 24% lower hand grip and quadriceps strength in transwomen than in cisgender men after 48 months or more on GAHT ($p<0.001$).

Hgb and HCT changes

Nine studies[16 19 36–38 43 47–49] reported the levels of Hgb or HCT in transwomen before and after GAHT, from a minimum of three to a maximum of 36 months post hormone therapy. Eight of these studies,[16 19 36–38 43 48 49] including the large (n=239) ENIGI study,[19] found that hormone therapy led to a significant (4.6%–14.0%) decrease in Hgb/HCT ($p<0.01$), while one study found no significant difference after 6 months.[47] The mean age of participants in the latter study was 18 years and the range was 14–25 years. The participants also failed to reach typical female testosterone levels (after 6 months mean testosterone=6.9 nmol/L), while in six[16 19 36 37 43 48] of the eight other studies mean testosterone after GAHT was less than 2.0 nmol/L. The large ENIGI study[19] was the only study in which the limits of agreement would indicate a change in Hgb/HCT at the 95%

Table 3 Changes in muscle CSA

Longitudinal studies

Author (year)	Participants (N) TW	CSA region (units)	Baseline CSA mean±SD (95% CI)	Follow-up CSA mean±SD (95% CI)	Number of months of GAHT	% Change	P	T (nmol/L) Base-post GAHT
Elbers *et al* (1999)[42]	20	Thigh (cm²)	307±47	278±37 (269–287) 271±39	12 36	−9.5 −11.7	<0.001 <0.001	22.0–1.0 22.0–0.9
Wiik (2020)[16]	11	Quadriceps (mm²)	6193±679	5931±671 (5680– 6190)	12	−4.2	<0.05	18.0–0.5
Tack *et al* (2018)[36]	21	Forearm (mm²) Calf (mm²)	3275±541 4204±1282	3142±574 3828±478	12–31 12–31	−4.1 −8.9	<0.05 >0.05	15.2–8.8
Van Caenegem *et al* (2015)[41]	49	Forearm (mm²) Tibia (mm²)	3999±746 7742±1361	3664±783 3825±867 7623±1479 7448±1390	12 24 12 24	−8.6 −4.4 −1.5 −3.8	<0.001 <0.001 <0.01 <0.01	19.0–0.5 19.0–0.5

Cross-sectional studies

Author (year)	Participants (N)		CSA region (units)	TW mean±SD	CM mean±SD	Number of months of GAHT	% Difference	P	T (nmol/L) TW
	TW	CM							
Lapauw *et al* (2008)[54]	23	46	Forearm (mm²) Tibia (mm²)	3500±700 6600±1300	4600±700 8700±1100	48 48	−23.9 −24.1	<0.001 <0.001	1.1
Van Caenegem *et al* (2015)[41]	49	49	Forearm (mm²) Tibia (mm²)	3999±746 7742±1361	4512±579 8233±1498	Baseline Baseline	−11.4 −6.0	<0.001 <0.01	19.0

Data are from MRI or pQCT.
CM, cismen; CSA, cross-sectional area; TW, transwomen.

CI. Three cross-sectional studies[18 53 54] compared HCT in transwomen post GAHT with cisgender controls (table 5). Two studies found that transwomen on GAHT for 6 or 48 months had lower (10%) HCT than cisgender men[53 54] ($p<0.005$), while two studies found no difference between transwomen after 6 and 12 months of GAHT and cisgender women.[18 53] Three cross-sectional studies[45 50 52] found significant differences[45 50] ($p<0.05$) or large effect sizes[52] (Cohen's $d=1.0$) in HCT between transwomen after 6 months of GAHT and hormone-naive transwomen, and HCT decreases of 7.4%–10.9%. See table 5.

DISCUSSION

We summarise changes induced by GAHT in non-athletic transwomen in four characteristics strongly associated with athletic performance: LBM, muscle CSA, muscular strength, and Hgb/ HCT levels. Overall, the findings demonstrate a reduction in these parameters over time. However, the time course of these reductions was not consistent across the parameters assessed.

In keeping with the muscular anabolic effects of testosterone[57] and the mixed effects of oestrogens,[58] studies using dual energy X-ray absorptiometry report decreased LBM (0.8%–5.4%) in association

Table 4 Changes in strength measures

Longitudinal studies

Author (year)	Participants (N) TW	Strength measure (units)	Baseline mean±SD (95% CI)	12 months mean±SD (95% CI)	21–31 months Mean±SD	% Change	P	T (nmol/L) Base-post GAHT
Van Caenegem *et al* (2015)[41]	49	Hand grip (kg)	42±9	39±9		−7.1	<0.001	19.0–0.5
Auer *et al* (2016)[46]	20	Hand grip (kg)	41.7±7.8	41.9±7		0.5	>0.05	17.5–1.9
Tack *et al* (2018)[36]	21	Hand grip (kg)	33.8±8.1		34.3±5.6	1.5	>0.05	15.2–8.8
Scharff (2019)	249	Hand grip (kg)	41.8±8.9	40.0±8.9 (39.2– 40.8)		−4.3	<0.001	18.3–0.8
Wiik (2020)[16]	11	Knee extension (N-m) Knee flexion (N-m)	239.7±44.0 99.5±16.8	242.6±41.5 (230–252) 101.5±15.5 (92–109)		1.2 2.0	>0.05 >0.05	18.0–0.5

Cross-sectional studies

Author (year)	Participants (N)		Strength measure (units)	TW baseline mean±SD	TW 48 months mean±SD	CM mean±SD	% Difference	P	T (nmol/L) TW
	TW	CM							
Van Caenegem *et al* (2015)[41]	49	49	Hand grip (kg)	42±9		49±6	−14.3	<0.001	19.0
Lapauw *et al* (2008)[54]	23	46	Hand grip (kg) Knee extension (N-m)		41±8 150±49	53±8 200±44	−22.6 −25	<0.001 <0.001	1.1

CM, cismen; TW, transwomen.

Table 5 Changes in HCT and Hgb levels

Longitudinal studies

Author (year)	Participants (N) TW	Measure (units)	Baseline mean±SD (95% CI)	Follow-up mean±SD (95% CI)	Number of months	% Change	P	T (nmol/L) Base-post GAHT
Wierckx (2014)	40 (oral oestrogen) 12 (transdermal oestrogen)	HCT (%)	45±2.5 45.5±1.7	42±5.7 42.2±2.3	12 12	−7.0 −4.6	<0.01 <0.001	18.0–0.4 19.7–0.5
Auer *et al* (2016)[46]	20	HCT (%)	45.2±2.7	42.7±1.8	12	−5.5	<0.01	17.5–1.9
Jarin *et al* (2017)[39]	13	HCT (%)	43.8	42.3	6	−3.4	>0.05	13.6–6.9
Vita *et al* (2018)[48]	21	HCT (%)	44.8±2.9	40.1±2.6	6–30	−10.5	<0.001	20.5–1.1
Defreyne *et al* (2018)[19]	239	HCT (%)	45.0±2.5 (44.9–45.5)	41.0±3.1 (40.9– 41.7) 41.1±3.2 (40.5– 41.2) 40.7±3.2 (40.0– 40.8)	3 6 24	−8.9 −8.7 −9.6	<0.001 <0.001 <0.001	17.4–0.7 17.4–0.6 17.4–0.6
Tack *et al* (2017)[47]	21	HCT (%)	43.8±1.9	39.9±2.2	12–31	−8.9	<0.001	15.2–8.8
Gooren and Bunck (2004)[43]	19	Hgb (mmol/L)	9.3±0.7	8.0±0.7 8.1±0.6	12 36	−14.0 −12.9	<0.001 <0.001	21.5–1.0 21.5–0.9
Olson-Kennedy *et al* (2018)[49]	23	Hgb (g/dL)	153±11	140±12	12	−8.3	<0.001	14.8–5.9
Wiik (2020)[16]	9 10	Hgb (g/L)	148.3±10.1 150.3±9.1	132.7±9.1 133.3±9.0	4 12	−10.5 −11.7	<0.001 <0.001	18.0–0.5 18.0–0.5

Cross-sectional studies

Author (year)	Participants (N) TW	CM	CW	HNTW	Measure (units)	TW mean±SD or (range)	Control mean±SD or (range)	Number of months	% Difference	P	T (nmol/L) TW
Lapauw *et al* (2008)[54]	23	46			HCT (%)	41.2±2.3	45.3±2.3	>48	−9.1	<0.001	1.1
SoRelle *et al* (2019)[52]	105			73	HCT (%)	(35.9– 48.7)	(39.0– 50.6)	>6	–	d=1.0	1.9
Greene *et al* (2019)[18]	93				HCT (%)	(35–47)	(35.5– 46) CW	>12	–	>0.05	1.4
Roberts *et al* (2014)[53]	55	20	20		HCT (%)	(34.6–43.7)	(38.4– 45.7) CM (34.4– 41.9) CW	>6	– –	<0.01 >0.05	
Jain (2019)	182 (oestrogen) 95 (oestrogen +progesterone)			92	HCT (%)	42.5 40.9	45.9±2.0	>3	−7.4 −10.9	<0.05 <0.05	
Sharula (2012)[37]	129			22	HCT (%)	40.2±3.1	44.4±2.4	>3	−9.5	<0.001	2.5

CM, cismen; CW, ciswomen; HCT, haematocrit; Hgb, haemoglobin; HNTW, hormone-naive transwomen; TW, transwomen.

with GAHT. Twelve months of GAHT also decreased muscle CSA (1.5%–9.7%). However, a further 12 or 24 months of GAHT did not always elicit further decreases in muscle CSA. Strength loss with 12 months of GAHT also ranged from non-significant to 7%. Taking these strength parameter data collectively, and in consideration of cisgender women demonstrating 31% lower LBM,[59] 36%[60] lower hand-grip strength and 35%[61] lower knee extension strength than cisgender men, the small decrease in strength in transwomen after 12–36 months of GAHT suggests that transwomen likely retain a strength advantage over cisgender women. Whether longer duration of GAHT would yield further decrements in strength in transgender women is unknown.

In contrast to strength-related data, blood cell findings revealed a different time course of change. After 3–4 months on GAHT, the HCT[19] or Hgb[16] levels of transwomen matched those of cisgender women, with levels remaining stable within the 'normal' female range for studies lasting up to 36 months. Given the rapid fall in Hgb/HCT to 'normal' female levels with GAHT, it is possible that transfemale athletes experience impaired endurance performance in part due to reduced oxygen transport from the lungs to the working muscles.[62] This postulate is consistent with findings reported in one of the few studies conducted in athletic transwomen.[63] In this study, the race times of eight transfemale distance runners were compared at baseline and after one or more years of GAHT. After adjusting performance for age, the eight runners were not more competitive in the female category (after GAHT) than they had been in the male category (before GAHT). Given this, and that the changes in Hgb/HCT follow a different time course than strength changes, sport-specific regulations for transwomen in endurance ver strength sports may be needed.

Of interest, compared with cisgender men, hormone-naive transwomen demonstrate 6.4%–8.0% lower LBM,[41 51] 6.0%–11.4% lower muscle CSA and ~10%–14% lower handgrip strength.[17 41 60] This disparity is noteworthy given that hormone-naive transwomen and cisgender men have similar testosterone levels.[16 17 19 42] Explanations for this strength difference are unclear but may include transwomen actively refraining from building muscle and/or engaging in disordered eating[64] or simply not being athletically inclined, perhaps influenced by feelings of an unwelcome presence in sporting arenas.[65] Taken together, hormone-naive transwomen may not, on average, have the same athletic attributes as cisgender men. The need to move beyond simple comparisons of cisgender men and women to assess the sporting capabilities of transwomen is imperative.

This systematic review identified studies that assessed the changes in LBM, CSA, muscular strength and Hgb/HCT in non-athletic transgender women following GAHT. However, several limitations are noted. Although the data we present are meaningful, the effects of GAHT on these parameters, or indeed athletic performance in transgender people who engage in training and competition, remain unknown. The levels of physical activity of the transwomen compared with cisgender women in the studies were not reported. Other limitations include the studies being written in English only, and the research being conducted in Western countries, contributing to geographical bias. Furthermore, as with much research with transgender individuals, there is a sparse data risk[66] because of small sample sizes and short study durations, indicative of the relatively small population, difficulties with recruitment and high drop-out rates over time. Indeed, the overlap of participants in the ENIGI studies and the heterogenous methodology in the other studies precluded the possibility of meaningful meta-analysis. However, overall, the results across different study groups and methods (ie, longitudinal vs follow-up studies) are largely consistent, suggesting that the risk of selective reporting and publication bias are low and the data in the reviewed studies are reliable. This review only focused on binary transgender individuals; those who medically transition from their birth assigned gender to the opposite gender and did not consider non-binary individuals. Not only are there even more limited data on non-binary individuals, but also, for many, their affirmed gender expression does not require GAHT, thus there are no hormone-induced changes to observe which would be relevant to this review. That is not to say that non-binary inclusivity in sport is not an important issue, only that the central tenets are not focused on physiology.

As previously stated, a major limitation in this area of research is the absence of studies in transgender athletes. However, a very recent study reported changes in fitness levels of 29 transmen and 46 transwomen in the United States Air Force, from before and after 30 months of GAHT.[67] Enlisted Air Force members are required to engage in regular physical activity and to complete annual assessments of number of sit-ups and push-ups in 1 min, and 1.5 mile race time. Although not athletes per se, enlisted members could at least be considered exercise trained. The study reported that after 2 years on GAHT there were no significant differences between ciswomen and transwomen in the number of push-ups or sit-ups performed in 1 min. However, transwomen ran significantly faster during the 1.5 mile fitness test than ciswomen. These observations in trained transgender individuals are consistent with the findings of the current review in untrained transgender individuals, whereby 30 months of GAHT may be sufficient to attenuate some, but not all, influencing factors associated with muscular endurance and performance.

Overall, this review reports decreases in muscle strength, LBM and muscle CSA in response to 12–36 months, and decreases in Hbg after 3–4 months, of GAHT in transwomen. These findings may help to shape future studies with transgender athletes and provide data for valuable and rigorous research going forward. Sporting bodies wish to be inclusive to all athletes, and there is a critical desire and need for more research to be able to develop evidence-based policies around this topic. Given that the range of physical parameters important for success varies considerably between sports, and that the physiological effects of GAHT vary in their time course (eg, muscle vs blood), future research should be sport specific as well as athlete centric. Although a level playing field in sport is illusory, it is important that opportunities for women to engage in meaningful competition within the female category exist.[68] Whether transgender and cisgender women can engage in meaningful sport, even after GAHT, is a highly debated question. However, before this question can be answered with any certainty, the intricacies and complexity of factors that feed into the development of high-performance athletes warrant further investigation of attributes beyond those assessed herein.

Contributors GLW devised the study. BSK completed an initial search in 2019 with GLW and HMD. JH completed a second search in 2020 with GLW and EOD. All authors contributed to the manuscript.

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What is already known

- There is much debate on whether (and when) transwomen should be permitted to compete in the female category in sport.

What are the new findings

- Longitudinal and cross-sectional studies identify that hormone therapy in transwomen decreases muscle cross-sectional area, lean body mass, strength and haemogloblin levels, with noted differences in the time course of change.
- Haemoglobin levels decrease to those seen in cisgender women after 4 months of hormone therapy. In contrast, despite significant decreases in muscle cross-sectional area, lean body mass and strength after 12–36 months of hormone therapy, values remain higher than that in cisgender women.
- It is possible that transwomen competing in sports may retain strength advantages over cisgender women, even after 3 years of hormone therapy.

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REFERENCES

1 Ferguson-Smith MA, Ferris EA. Gender verification in sport: the need for change? *Br J Sports Med* 1991;25:17–20.
2 Simpson JL, Ljungqvist A, de la Chapelle A, *et al*. Gender verification in competitive sports. *Sports Med* 1993;16:305–15.
3 Ljungqvist A. Sex segregation and sport. *Br J Sports Med* 2018;52:3.
4 International Olympic Committee. IOC consensus meeting on sex reassignment and hyperandrogenism, 2015. Available: https://stillmed.olympic.org/Documents/Commissions_PDFfiles/Medical_commission/201511_ioc_consensus_meeting_on_sex_reassignment_and_hyperandrogenism-en.pdf
5 World Athletics. Eligibility regulations transgender regulation, 2019. Available: https://www.worldathletics.org/about-iaaf/documents/book-of-rules
6 World Athletics. Eligibility regulations for the female classification, 2019. Available: https://www.worldathletics.org/about-iaaf/documents/book-of-rules
7 Karkazis K, Carpenter M. Impossible "Choices": The Inherent Harms of Regulating Women's Testosterone in Sport. *J Bioeth Inq* 2018;15:579–87.
8 Hutcheon D. Hyperandrogenism in athletics: a review of Chand V. IAAF. law in sport, 2015. Available: https://www.lawinsport.com/topics/item/hyperandrogenism-in-athletics-a-review-of-chand-v iaaf
9 Karkazis K, Jordan-Young R, Davis G, *et al*. Out of bounds? A critique of the new policies on hyperandrogenism in elite female athletes. *Am J Bioeth* 2012;12:3–16.
10 Floyd MJ, Martin O, Eckloff KJ. A qualitative study of transgender individuals' experiences of healthcare including radiology. *Radiography* 2020;26:e38–44.

11 Buzuvis E. Challenging gender in Single-Sex spaces: lessons from a feminist Softball League. law and contemporary problems. *Sex in Sport* 2017;80.
12 Seal LJ. A review of the physical and metabolic effects of cross-sex hormonal therapy in the treatment of gender dysphoria. *Ann Clin Biochem* 2016;53:10–20.
13 T'Sjoen G, Arcelus J, Gooren L, *et al*. Endocrinology of transgender medicine. *Endocr Rev* 2019;40:97–117.
14 Wiepjes CM, de Jongh RT, de Blok CJ, *et al*. Bone safety during the first ten years of Gender-Affirming hormonal treatment in Transwomen and Transmen. *J Bone Miner Res* 2019;34:447–54.
15 Klaver M, de Blok CJM, Wiepjes CM, *et al*. Changes in regional body fat, lean body mass and body shape in trans persons using cross-sex hormonal therapy: results from a multicenter prospective study. *Eur J Endocrinol* 2018;178:163–71.
16 Wiik A, Lundberg TR, Rullman E, *et al*. Muscle strength, size, and composition following 12 months of Gender-affirming treatment in transgender individuals. *J Clin Endocrinol Metab* 2020;105:e805–13.
17 Scharff M, Wiepjes CM, Klaver M, *et al*. Change in grip strength in trans people and its association with lean body mass and bone density. *Endocr Connect* 2019;8:1020–8.
18 Greene DN, McPherson GW, Rongitsch J, *et al*. Hematology reference intervals for transgender adults on stable hormone therapy. *Clin Chim Acta* 2019;492:84–90.
19 Defreyne J, Vantomme B, Van Caenegem E, *et al*. Prospective evaluation of hematocrit in gender-affirming hormone treatment: results from European network for the investigation of gender incongruence. *Andrology* 2018;6:446–54.
20 Weed RI, Reed CF, Berg G. Is hemoglobin an essential structural component of human erythrocyte membranes? *J Clin Invest* 1963;42:581–8.
21 Otto JM, Montgomery HE, Richards T. Haemoglobin concentration and mass as determinants of exercise performance and of surgical outcome. *Extrem Physiol Med* 2013;2:33.
22 Cohen E, Kramer M, Shochat T, *et al*. Relationship between hematocrit levels and intraocular pressure in men and women: a population-based cross-sectional study. *Medicine* 2017;96:e8290.
23 Coviello AD, Kaplan B, Lakshman KM, *et al*. Effects of graded doses of testosterone on erythropoiesis in healthy young and older men. *J Clin Endocrinol Metab* 2008;93:914–9.
24 Weinand JD, Safer JD. Hormone therapy in transgender adults is safe with provider supervision; a review of hormone therapy sequelae for transgender individuals. *J Clin Transl Endocrinol* 2015;2:55–60.
25 Cronin J, Lawton T, Harris N, *et al*. A brief review of handgrip strength and sport performance. *J Strength Cond Res* 2017;31:3187–217.
26 Handelsman DJ. Sex differences in athletic performance emerge coinciding with the onset of male puberty. *Clin Endocrinol* 2017;87:68–72.
27 Bruusgaard JC, Johansen IB, Egner IM, *et al*. Myonuclei acquired by overload exercise precede hypertrophy and are not lost on detraining. *Proc Natl Acad Sci U S A* 2010;107:15111–6.
28 Kadi F, Eriksson A, Holmner S, *et al*. Effects of anabolic steroids on the muscle cells of strength-trained athletes. *Med Sci Sports Exerc* 1999;31:1528–34.
29 Hembree WC, Cohen-Kettenis PT, Gooren L, *et al*. Endocrine treatment of Gender-Dysphoric/Gender-Incongruent persons: an endocrine Society clinical practice guideline. *J Clin Endocrinol Metab* 2017;102:3869–903.
30 Delgado-Ruiz R, Swanson P, Romanos G. Systematic review of the long-term effects of transgender hormone therapy on bone markers and bone mineral density and their potential effects in implant therapy. *JCM* 2019;8:784.
31 Fighera TM, Ziegelmann PK, Rasia da Silva T, *et al*. Bone mass effects of Cross-Sex hormone therapy in transgender people: updated systematic review and meta-analysis. *J Endocr Soc* 2019;3:943–64.
32 Liberati A, Altman DG, Tetzlaff J, *et al*. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med* 2009;6:e1000100.
33 Armijo-Olivo S, Stiles CR, Hagen NA, *et al*. Assessment of study quality for systematic reviews: a comparison of the Cochrane collaboration risk of bias tool and the effective public health practice project quality assessment tool: methodological research. *J Eval Clin Pract* 2012;18:12–18.
34 Storebø OJ, Pedersen N, Ramstad E, *et al*. Methylphenidate for attention deficit hyperactivity disorder (ADHD) in children and adolescents - assessment of adverse events in non-randomised studies. *Cochrane Database Syst Rev* 2018;5:CD012069.
35 Thomas BH, Ciliska D, Dobbins M, *et al*. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews Evid Based Nurs* 2004;1:176–84.
36 Wierckx K, Van Caenegem E, Schreiner T, *et al*. Cross-sex hormone therapy in trans persons is safe and effective at short-time follow-up: results from the European network for the investigation of gender incongruence. *J Sex Med* 2014;11:1999–2011.
37 Auer MK, Cecil A, Roepke Y, *et al*. 12-Months metabolic changes among gender dysphoric individuals under cross-sex hormone treatment: a targeted metabolomics study. *Sci Rep* 2016;6:37005.
38 Tack LJW, Heyse R, Craen M, *et al*. Consecutive cyproterone acetate and estradiol treatment in Late-Pubertal transgender female adolescents. *J Sex Med* 2017;14:747–57.
39 Auer MK, Ebert T, Pietzner M, *et al*. Effects of sex hormone treatment on the metabolic syndrome in transgender individuals: focus on metabolic cytokines. *J Clin Endocrinol Metab* 2018;103:790–802.
40 Tack LJW, Craen M, Lapauw B, *et al*. Proandrogenic and antiandrogenic progestins in transgender youth: differential effects on body composition and bone metabolism. *J Clin Endocrinol Metab* 2018;103:2147–56.
41 Van Caenegem E, Wierckx K, Taes Y, *et al*. Preservation of volumetric bone density and geometry in trans women during cross-sex hormonal therapy: a prospective observational study. *Osteoporos Int* 2015;26:35–47.
42 Elbers JM, Asscheman H, Seidell JC, *et al*. Effects of sex steroid hormones on regional fat depots as assessed by magnetic resonance imaging in transsexuals. *Am J Physiol* 1999;276:E317–25.
43 Gooren LJG, Bunck MCM. Transsexuals and competitive sports. *Eur J Endocrinol* 2004;151:425–9.
44 Mueller A, Zollver H, Kronawitter D, *et al*. Body composition and bone mineral density in male-to-female transsexuals during cross-sex hormone therapy using gonadotrophin-releasing hormone agonist. *Exp Clin Endocrinol Diabetes* 2011;119:95–100.
45 Sharula, Chekir C, Emi Y, *et al*. Altered arterial stiffness in male-to-female transsexuals undergoing hormonal treatment. *J Obstet Gynaecol Res* 2012;38:932–40.
46 Gava G, Cerpolini S, Martelli V, *et al*. Cyproterone acetate vs leuprolide acetate in combination with transdermal oestradiol in transwomen: a comparison of safety and effectiveness. *Clin Endocrinol* 2016;85:239–46.
47 Jarin J, Pine-Twaddell E, Trotman G, *et al*. Cross-Sex hormones and metabolic parameters in adolescents with gender dysphoria. *Pediatrics* 2017;139:e20163173.
48 Vita R, Settineri S, Liotta M, *et al*. Changes in hormonal and metabolic parameters in transgender subjects on cross-sex hormone therapy: a cohort study. *Maturitas* 2018;107:92–6.
49 Olson-Kennedy J, Okonta V, Clark LF, *et al*. Physiologic response to Gender-Affirming hormones among transgender youth. *J Adolesc Health* 2018;62:397–401.
50 Jain J, Kwan D, Forcier M. Medroxyprogesterone acetate in Gender-Affirming therapy for Transwomen: results from a retrospective study. *J Clin Endocrinol Metab* 2019;104:5148–56.
51 Haraldsen IR, Haug E, Falch J, *et al*. Cross-sex pattern of bone mineral density in early onset gender identity disorder. *Horm Behav* 2007;52:334–43.
52 SoRelle JA, Jiao R, Gao E, *et al*. Impact of hormone therapy on laboratory values in transgender patients. *Clin Chem* 2019;65:170–9.
53 Roberts TK, Kraft CS, French D, *et al*. Interpreting laboratory results in transgender patients on hormone therapy. *Am J Med* 2014;127:159–62.
54 Lapauw B, Taes Y, Simoens S, *et al*. Body composition, volumetric and areal bone parameters in male-to-female transsexual persons. *Bone* 2008;43:1016–21.
55 Coleman E, Bockting W, Botzer M, *et al*. Standards of care for the health of transsexual, transgender, and Gender-Nonconforming people, version 7. *Int J Transgend* 2012;13:165–232.
56 Dragoman MV, Tepper NK, Fu R, *et al*. A systematic review and meta-analysis of venous thrombosis risk among users of combined oral contraception. *Int J Gynaecol Obstet* 2018;141:287–94.
57 Handelsman DJ. Performance Enhancing Hormone Doping in Sport. In: Feingold KR, Anawalt B, Boyce A, *et al*, eds. *Endotext*. South Dartmouth (MA): MDText.com, Inc, 2000.
58 Rosa-Caldwell ME, Greene NP. Muscle metabolism and atrophy: let's talk about sex. *Biol Sex Differ* 2019;10:43.
59 Lee DH, Keum N, Hu FB, *et al*. Development and validation of anthropometric prediction equations for lean body mass, fat mass and percent fat in adults using the National health and nutrition examination survey (NHANES) 1999-2006. *Br J Nutr* 2017;118:858–66.
60 Bohannon RW, Wang Y-C, Yen S-C, *et al*. Handgrip strength: a comparison of values obtained from the NHANES and NIH Toolbox studies. *Am J Occup Ther* 2019;73:7302205080p1–9.
61 Neder JA, Nery LE, Shinzato GT, *et al*. Reference values for concentric knee isokinetic strength and power in nonathletic men and women from 20 to 80 years old. *J Orthop Sports Phys Ther* 1999;29:116–26.
62 Mairbäurl H. Red blood cells in sports: effects of exercise and training on oxygen supply by red blood cells. *Front Physiol* 2013;4:332.
63 Harper J. Race times for transgender athletes. *Journal of Sporting Cultures and Identities* 2015;6:1–9.
64 Witcomb GL, Bouman WP, Brewin N, *et al*. Body image dissatisfaction and eating-related psychopathology in trans individuals: a matched control study. *Eur Eat Disord Rev* 2015;23:287–93.
65 Jones BA, Arcelus J, Bouman WP, *et al*. Barriers and facilitators of physical activity and sport participation among young transgender adults who are medically transitioning. *Int J Transgend* 2017;18:227–38.
66 Greenland S, Mansournia MA, Altman DG. Sparse data bias: a problem hiding in plain sight. *BMJ* 2016;352:i1981.
67 Roberts TA, Smalley J, Ahrendt D. Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organisations and legislators. *Br J Sports Med* 2020:bjsports-2020-102329.
68 Harper J, Martinez-Patino M-J, Pigozzi F, *et al*. Implications of a third gender for elite sports. *Curr Sports Med Rep* 2018;17:42–4.

Exhibit G

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REVIEW ARTICLE

Integrating Transwomen and Female Athletes with Differences of Sex Development (DSD) into Elite Competition: The FIMS 2021 Consensus Statement

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Abstract
Sport is historically designated by the binary categorization of male and female that conflicts with modern society. Sport's governing bodies should consider reviewing rules determining the eligibility of athletes in the female category as there may be lasting advantages of previously high testosterone concentrations for transwomen athletes and currently high testosterone concentrations in differences in sex development (DSD) athletes. The use of serum testosterone concentrations to regulate the inclusion of such athletes into the elite female category is currently the objective biomarker that is supported by most available scientific literature, but it has limitations due to the lack of sports performance data before, during or after testosterone suppression. Innovative research studies are needed to identify other biomarkers of testosterone sensitivity/responsiveness, including molecular tools to determine the functional status of androgen receptors. The scientific community also needs to conduct longitudinal studies with specific control groups to generate the biological and sports performance data for individual sports to inform the fair inclusion or exclusion of these athletes. Eligibility of each athlete to a sport-specific policy needs to be based on peer-reviewed scientific evidence made available to policymakers from all scientific communities. However, even the most evidence-based regulations are unlikely to eliminate all differences in performance between cisgender women with and without DSD and transwomen athletes. Any remaining advantage held by transwomen or DSD women could be considered as part of the athlete's unique makeup.

1 Introduction

Since antiquity, athletic and Olympic competitions have been separated according to the traditional binary concept of male/female to promote fairness and equity, as well as being divided by criteria such as weight, age, affiliation,

Extended author information available on the last page of the article

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Key Points

The use of testosterone concentration limits of 5 nmol/L in transwomen and DSD women athletes is a justifiable threshold based on the best available scientific evidence.

There is a distinct lack of sports performance data to inform and update sports policy for DSD women and transwomen athletes.

Fair integration or exclusion of transwomen and DSD women athletes needs to be based on peer-reviewed experimental sporting performance evidence when such evidence becomes available.

amateur or professional status, and level of competition [1]. The binary classification of male and female was based on different methods, including physical examination (1966), Barr bodies (1968), Y chromosome (1991), and sex-determining region Y (*SRY*) gene (1996) [2]. A female athlete, when suspected to be male, could have been classified as either male or female depending on the previous methodology applied. For example, an individual with androgen insensitivity syndrome, with a 46, XY karyotype, would be classified as a female in 1966 and as a male in 1968, whereas an individual with congenital adrenal hyperplasia with a 46, XX karyotype, would be classified as male in 1966 and as a female in 1968. These examples illustrate such methods were unreliable, discriminatory, not fit for purpose, and that the integration of athletes outside of the binary of male and female is not a new problem (Table 1).

Integrating athletes who previously experienced male puberty into elite female sport is far from straight forward and remains highly contentious. For this reason, the concept of "*athletic gender*" was recently proposed [3, 4] which involves designating athletes to a gender for sports performance only and not social identity using quantitative criteria based on performance [3]. This concept speaks to a "*start over*" notion put forward by Maayan Sudai [5], who proposes the introduction of a classification system based on physiological parameters for athletes, regardless of gender. This would be analogous to the classification system used to assess eligibility to compete in Paralympic events [5]; however, the application of this would be very difficult for

Table 1 Summary of what is already known in this area, and future considerations in integrating transwomen and DSD women into elite women's sport

What is already known	Future considerations
The binary classification of athletes fails to consider differences in sex development (DSD) women and transwomen athletes	The use of testosterone concentration limits of 5 nmol/L in transwomen and DSD women athletes is a justifiable threshold. This level could be refined for specific events with the emergence of new supporting evidence
Testosterone production and action are the primary factors used in determining differences in performance between cis men and cis women	Any treatment is a purely personal and private decision and no sports body should provide recommendations on treatment
Only observational data showing the sporting performance of transwomen and DSD athletes exist	Fair integration of transwomen and DSD women athletes into elite sport needs to be based on peer-reviewed experimental evidence
Recent additions in the scientific literature including original studies provide the necessary impetus for the development of more evidence-based integration of DSD women and transwomen into elite competition	Any safety risks to cisgender female athletes due to the inclusion of transwomen in female elite sport must be evidence-based to justify exclusion
	The assumption that the physiology of elite DSD women and transwomen athletes is the same as elite male athletes is an oversimplified view
	New innovative scientific approaches are needed to guide new sports-specific policy (e.g., quantifying bioactive testosterone and individual sensitivity to testosterone, the role of sex chromosomes in athletic performance, and the extent to which muscle memory is retained after prolonged high testosterone exposure)
	There is a distinct lack of sports performance data to inform and update sports policy, in part due to the lack of funding and lack of elite athletic participants in this research area
	The participation of transwomen and DSD women elite athletes in research will be hindered by their low numbers in elite competition. Recruitment for research may have to be targeted also at the sub-elite level with the specific requirement of being an athlete at higher than grassroots level
	The need to develop approaches to distinguish between predisposition to outstanding performances (e.g., haematological and anatomical features) and any unfair advantages held by transwomen or DSD women

sport's governing bodies due to its complexity and financial commitment to implement at all levels of sport.

The concept of athletic gender could help safeguard fair competition and prevent an unfair advantage, principles which underpin the true essence of sport [6], and would be in line with the fundamental principles of the Olympic Charter which emphasizes the need to respect the freedom and rights of athletes, as well as the importance of competing without any form of discrimination. The Olympic Charter states that "*The enjoyment of the rights and freedoms set forth in this Olympic Charter shall be secured without discrimination of any kind, such as race, colour, sex, sexual orientation, language, religion, political or other opinion, national or social origin, property, birth or other status*" [7] and importantly refers to sex and not gender. Sex is considered in Olympic sports only when it could determine the outcome of a competition. Some sports do not use a sex classification, e.g. shooting, sailing, or horse riding.

The terms "*sex*" and "*gender*" have different meanings and their overlap is conceptually complex. *Sex* refers to any individual's biology, such as anatomical or chromosomal differences, which are used to categorize an individual as male or female, whereas gender refers to socially constructed roles related to sex distinctions [8]. While gender identity is a self-defined social construct that shapes how an individual chooses to live, gender identity alone will not be enough to determine the appropriate sports category for each individual that allows fair competition, especially in the case of elite sport.

The current article aims to highlight the main issues to be considered surrounding the participation of female athletes with previously high testosterone concentrations (transwomen) and female athletes with naturally high testosterone concentrations [differences in sex development (DSD)] in elite female sport. The two cases, cisgender women athletes with DSD (DSD women, for short) and transwomen athletes, will be presented separately to enhance reader understanding, while future research considerations will be discussed together in Sect. 5, because the considerations for both groups of athletes are similar. It is important to note that the fluidity of gender identity does include non-binary and transmen athletes. However, in this article, the authors wish to focus on the integration of DSD women and transwomen athletes into the elite female category of sports. The reasoning for this is that transmen (birth-assigned female transitioned to male) athletes are perceived to not have the same magnitude of competitive advantage as transwomen or DSD women athletes when integrated into male elite sports [9] and that non-binary individuals are less likely to undertake gender-affirming treatment and are predominantly female sex assigned at birth [10], forgoing the effects of male puberty.

2 Methods

Here, we present the International Federation of Sports Medicine (FIMS) consensus on integrating DSD women and transwomen athletes into elite female sport based on identifying, selecting, and critically appraising the very limited relevant primary research. An added objective of this consensus was to provide a roadmap for future research direction. The review of the evidence was performed by the first and second author (BH and GL) using the following keywords: "transgender" or "transwomen", "intersex" or "DSD", "gender identity", "testosterone", "competition", and "sport". The first draft of the manuscript was written by the first and last authors (BH and YP). Of all 78 invited authors, 1 author declined the invitation and 7 authors elected to withdraw their names during one of the draft rounds. These names are not included on the authorship list above. All remaining 70 authors reviewed, commented on and approved the final draft. The drafting of the consensus statement was initiated by the last author (YP) via email for ease of verification and process during the unprecedented constraints due to the COVID-19 pandemic. Voting on the consensus statements was performed remotely using Google Forms (Google™, California, USA). The voting result was collated by the first author (BH) along with dissenting opinions and discussions which were manifested and reported in the manuscript. All statements received unanimous approval by all named authors except for the statement on the testosterone limit of 5 nmol/L, which received majority approval and the voting result is included in the article. The authors consider it essential to declare the extent of agreement, as well as dissenting views.

3 DSD Women Athletes

3.1 Background

DSD is a group of rare conditions involving genes, hormones and reproductive organs [11, 12]. This article will focus on the integration of DSD women athletes in the elite female category of sports who currently have high testosterone concentrations which the binary classification of sports fails to consider. The German Federal Parliament approved a law that came into effect in December 2018 that permits children with DSD born with ambiguous sexual anatomy who are not distinctly male or female to indicate a third gender category on their birth certificate [13]. This action follows a court ruling by the Federal Constitutional Court of Germany in October 2017 that ruled the existing regulations discriminated against people with DSD, the principle being that the gender identity of an individual must be protected as a fundamental human right [14].

The views of the Court of Arbitration for Sport (CAS) have evolved concerning legal sex being a factor to determine the eligibility of an athlete to compete in a male or female category. In the Dutee Chand vs. the Athletics Federation of India and the International Association of Athletics Federations (IAAF) arbitration tribunal in 2014, CAS stated in their decision that "*The distinction between male and female is a matter of legal recognition*" [15]. In contrast, in the Caster Semenya and Athletics South Africa vs. IAAF tribunal in 2018, CAS stated that "*a person's legal sex alone may not always constitute a fair and effective means of making that determination*" [16]. The Human Rights Council under the United Nations recently released a statement on discrimination against women in sport [17]. While not limited to discrimination concerning DSD women and androgen sensitivity, the position taken is that both member and non-member states of the United Nations should work in unison to recognize protected characteristics and eliminate discrimination.

3.2 The Challenge

Conditions such as DSD are rare and primarily of genetic origin [18] and are presented concomitantly with ambiguous genitalia at birth which can occur phenotypically in undervirilized genotypic males or virilized genotypic females. These features can result in individuals assigned female at birth possessing testosterone concentrations comparable to cisgender males and, therefore, much higher than non-DSD women, including those with polycystic ovary syndrome [19]. Hyperandrogenic 46, XY DSD female athletes in the 2011 IAAF World Championships were 140 times more prevalent (0.7% of athletes had testosterone concentrations of > 15.6 nmol/L [20]) compared to 0.005% [20, 21] reported in the general population [22, 23], which could be an indicator of performance advantage [20]. A possible indicator of fair integration of DSD women athletes into competitive sport would be a similar prevalence of DSD women and non-DSD women athletes in the championships as in the general population.

The DSD condition is a natural attribute as opposed to a doping issue, such as the misuse of anabolic steroids. However, observational data have shown a clear difference in performance in DSD women athletes depending on whether testosterone concentrations were suppressed or not. For example, there was an average performance reduction of approximately 5.7% in the best performances of three female distance runners who had their testosterone concentrations suppressed from 21–25 to 2 nmol/L over 2 years [23]. Although a notable finding, no firm conclusions can be reached due to the reliance on a small number of athletes. Within DSD women athletes, there are individuals with 46, XY karyotype, and androgen insensitivity, which can be either complete androgen insensitivity (CAIS) or partial androgen insensitivity (PAIS). Therefore, testosterone concentrations in such individuals will not have the same functional effect as those with normal androgen receptors. This complexity needs to be considered if testosterone concentration, either as a single parameter or more likely as one of several parameters, will evolve into a viable solution.

3.3 The Present Rulings in Elite Sport

Following an observational study by Bermon and Garnier describing the serum androgen levels of male and female athletes and their relationship to performance in track and field events [24], the eligibility regulations for the female classification were created and published by the IAAF (now World Athletics) in April 2018. Implementation of the policy was planned for November 2018 [25]. However, this study [24] and the subsequent regulations have been subject to much debate [26–30]. The IAAF regulations permitted female athletes with specific DSD's (i.e., testosterone concentrations ≥ 5 nmol/L and sufficient sensitivity to androgens) to compete in international competitions in the female category from 400 up to 1500 m if they reduced testosterone concentrations to < 5 nmol/L for at least 6 continuous months. These requirements needed to be maintained for the athlete to continue to be eligible for the female category of the events described in the regulation.

Considering a challenge brought by Caster Semenya against these regulations, the IAAF agreed to delay the implementation and await the decision from CAS. The panel's decision was released in May 2019, with the statement that the "*Panel has dismissed the requests for arbitration considering that the Claimants were unable to establish that the DSD Regulations were invalid*" [31]. Semenya appealed to Switzerland's Federal Supreme Court, which suspended the implementation of the eligibility regulation in June 2019. However, Semenya ultimately lost her appeal [32] in August 2020 and the eligibility regulations were reinstated with the court citing that "*fairness in sport is a legitimate concern and forms a central principle of sporting competition*" [33].

In addition to the media frenzy both for and against the inclusion of DSD women athletes in the female category of sports [34], editorials have been published sparking subsequent critiques and rebuttals in response [32, 35]. This fervour has also sparked academic and general community outrage at the IAAF ruling, which has been declared as discriminatory against Semenya. Idiosyncratically, the emotional and legal argument is that Semenya is being victimized and unfairly treated as a female athlete, yet her sex is not biologically clearly defined in the male/female binary definition. This case is an inevitable consequence of the antithesis between the binary concept of gender applied to sport and the new realm of gender fluidity, as illustrated by DSD women athletes.

World Athletics in their most recent version of the eligibility regulations for the female classification (athletes with DSD), state that not all DSD women athletes who wish to compete in the female classification should need to reduce their testosterone levels to < 5 nmol/L. They state that: "*A woman who has androgen insensitivity syndrome (AIS) is completely (CAIS) or partially (PAIS) insensitive to testosterone, thereby eliminating (CAIS) or reducing (PAIS) the physiological effect of that testosterone. An athlete with CAIS is not a Relevant Athlete. An athlete with PAIS will only be a Relevant Athlete if she is sufficiently androgen-sensitive for her elevated testosterone concentrations to have a material androgenising effect. The benefit of any doubt on this issue will be resolved in favour of the athlete*" [31].

4 Transwomen Athletes

4.1 Background

Transgender refers to a gender expression that is different from the sex that is assigned at birth. In this article, a specific focus will be placed on transwomen, assigned male at birth who have transitioned to female both socially and legally and have had previous exposure to high testosterone concentrations during puberty. Recently, a controversial bill (i.e., 2019 Tennessee SB2077) prohibiting the participation of transwomen athletes in school sports was introduced in the U.S. legislature. Should this bill pass into law, a burden would be placed on education providers to ensure pupils participate according to the biological sex indicated on their birth certificate. Additionally, the bill seeks to impose a civil penalty of US $10,000 as well as the revocation of public funds for any school that acts contrary to the bill [36].

In March 2020, a second similarly controversial bill (i.e., the 2020 State of Idaho HB500) known as the "*Fairness in Women's Sports Act*", was passed into state law making Idaho the first state to ban transwomen from participating in girls and women's sports [37]. The bill states that "*Athletic teams or sports designated for females, women, or girls shall not be open to students of the male sex*" [38] and that if a student's sex is disputed, "*a student may establish sex by presenting a signed physician's statement that shall indicate the student's sex solely on: (a) the student's internal and external reproductive anatomy; (b) the student's normal endogenously produced levels of testosterone; and (c) an analysis of the student's genetic makeup*" [38].

The bill received praise from the Senior Vice President of U.S. Legal Division, citing that "*Allowing males to compete in girls' sports destroys fair competition and women's athletic opportunities*" [39] but has drawn criticism given the Act conflicts with the right to privacy provision within the 4th Amendment to the American Constitution. Indeed, this has formed the basis of a claim brought by the American Civil Liberties Union against the State of Idaho regarding the legitimacy of the Act [40], alleging that the legislation could violate the federal law known as Title IX which prohibits sex discrimination, not gender discrimination, in educational institutions that receive federal financing [41]. This kind of legislation will inevitably result in tension between domestic law and international treaties developed to promote inclusivity and protect individuals from discrimination based on protected characteristics.

4.2 The Challenge

Although permitted by the IOC since 2004, no recognized transgender athlete has participated in the Olympic Games [42]. The main argument opposing the integration of transwomen athletes into the female category for future Olympics is the perceived sporting advantages that transwomen have over cisgender women, such as lever length or height advantages conferred by skeletal size and bone density despite testosterone reductions [43]. Prior athletic training with high testosterone concentrations may potentially result in advantages such as muscle memory [44], which may persist for some time post testosterone suppression. This is a concern for sports highly dependent on muscle mass, strength, and aerobic capacity. This will be expanded on in Sect. 5.5.

Despite these concerns, evidence on transwomen's sporting performance is scarce (Table 1) and in the case of aerobic performance, non-existent. Couple this with the data already showing that oxygen-carrying haemoglobin levels are reduced in transwomen to female norms levels [45], it is a sports performance proxy that is urgently needing investigation due to the importance of the cardiovascular system during aerobic exercise. Low testosterone concentrations have been reported in transwomen undergoing hormone replacement therapy (HRT) [46] and in a recent meta-analysis, HRT was found not to affect the motor coordination or visuospatial abilities of transwomen [47]. In a study of 50 non-athlete transwomen who had undergone gender-affirming surgery (GAS) coupled with HRT, a reduction in muscle mass and bone mineral density was reported together with an increase in fat mass following HRT initially and 1 year after GAS [48]. These data on non-athletic transwomen and non-sports performance measures make it difficult to suggest that the athletic capabilities of transwomen individuals undergoing HRT or GAS are comparable to those of cisgender women and because of this, the recording of data describing transwomen's sporting performance should be of the highest importance to sporting governing bodies and researchers.

While data on transwomen's athletic performance remain to be experimentally determined, a first retrospective study did evaluate the performances of eight non-elite transwoman masters athletes who had participated in running competitions, first as males and then as females [49]. Running performance was compared using a standard age grading methodology [age grade (%) = age standard × 100/race time] for comparing groups of athletes of any age and gender in track-and-field and distance running [49, 50]. Overall, the group of athletes obtained similar "age-graded" scores in both categories. However, the design of the study may limit its relevance given the small sample size, no reporting of testosterone levels, self-reported run times, no reporting of when the participants ran after their transition, the athletes were not elite, and the findings of this study have not been replicated.

A review paper by Hilton and Lundberg [43] addressed the integration of transwomen in the elite female category of sport. The authors concluded that anthropometric and muscle mass advantages are sustained in transwomen after 12 months of gender-affirming treatment based on studies showing the physiological changes caused by HRT in transwomen and chemical castration in men. Conversely, due to these studies being conducted in non-athletic transgender women, they also concluded that "*it is still uncertain how transgender women athletes, perhaps undergoing advanced training regimens to counteract the muscle loss during the therapy, would respond*" [43].

Despite the lack of direct sport-specific studies of transgender athletes in their review, Hilton and Lundberg raised safety as their primary concern and proposed that 12 months of testosterone suppression is insufficient to mitigate their safety concerns [43]. However, the main criticism of this review is the purely biological argument from an elite male versus elite female position, implying that transwomen athletes are the same as elite male athletes (Table 1). Data showing lower baseline isometric torque and muscle volume [51] in transwomen compared to cisgender males highlight the problematic nature of inferring that transwomen and cisgender males are the same, as this ignores the impact of gender-affirming treatments such as HRT and GAS and the psychological effects of gender dysphoria such as low self-esteem, anxiety and/or depression, and becoming socially isolated [52].

Recently, Roberts et al. [53], retrospectively reviewed pre- and post-HRT military fitness test results in transwomen individuals ($n = 46$) of the U.S. Air Force. These authors found that the push-up (31% more than their female counterparts) and sit-up (15% more than their female counterparts) advantages over ciswomen at baseline had been negated after 2 years, but not after 1 year. This finding agrees with previous studies that have shown that baseline muscular strength in transwomen is not significantly diminished after 1 year [51, 53] but is after 2 years of HRT [53]. Roberts et al. also found that running performance in the 1.5 mile run remained 12% faster on average in transwomen after 2 years of HRT [53]. These findings require replication in trained transwomen athletes, although they would suggest a different rate and extent of mitigation of the advantages held by transwomen given that the strength advantages, but not the cardiovascular advantages, of transwomen were mitigated after 2 years of HRT. These observations also question the required testosterone suppression time of 12 months for transwomen to be eligible to compete in women's sport, as most advantages over ciswomen were not negated after 12 months of HRT. How applicable these performance data are from both Harper [49] and Roberts et al. [53] in determining the extent of advantage remaining in transwomen athletes post-gender-affirming treatment remains to be determined. This will require longitudinal transgender athlete case-comparison studies that control for variations in hormonal exposure and involve numerous indices of performance (Table 1).

4.3 The Present Rulings in Elite Sport

The participation of transgender athletes in the Olympic Games was approved following the *2003 Stockholm Consensus on Sex Reassignment in Sports*, which recommended that transwomen athletes undergoing sex reassignment after puberty be eligible for competition 2 years post-gonadectomy, HRT, and legal recognition of assigned sex [42]. The IOC released one update of the recommendations in 2015 [54]. Most sports governing bodies adopted this policy, declaring the eligibility of transwomen athletes with serum testosterone concentrations < 10 nmol/L for at least 12 months before the first competition and throughout the competition period. There was also no requirement for surgical procedures for any anatomical changes. World Athletics [55], World Rowing [56] and Union Cycliste Internationale (UCI) [57] have all adopted the lower serum testosterone concentration limit of 5 nmol/L for transwomen athletes. Some would consider a 5 nmol/L limit high, as healthy premenopausal women typically have a testosterone concentration < 5 nmol/L (e.g., < 1.7 nmol/L) [19]). The support for the < 5 nmol/L limit (Table 1) for transwomen athletes emerges from a study where 24 healthy, physically active women aged 18–35 years underwent 10 weeks of testosterone treatment [22]. This study reported improved running time to exhaustion during an incremental maximal test on a treadmill by 21.17 s (8.5%) and an increase in lean body mass. However, the average testosterone concentrations of these participants did not exceed 5 nmol/L (from 0.9 ± 0.4 to 4.3 ± 2.8 nmol/L) [22], which is considerably below the 10 nmol/L threshold used by the IOC [54].

World Rugby became the first international sports governing body to ban the participation of transwomen in the elite female level of sport in October 2020. They state that "*Transgender women may not currently play women's rugby because of the size, force- and power producing advantages conferred by testosterone during puberty and adolescence, and the resultant player welfare risks this creates*" [58]. The policy, by its admission, is based on a "*hypothetical cross-over scenario in which a typical male tackler mass is involved in a tackle against a ball carrier with a typical female mass*" [58]. The policy itself speaks to the "common sense" view that transwomen athletes are larger and stronger than their cisgender peers, which mischaracterises transwomen athletes as elite male athletes (Table 1) and has been opposed by rugby unions such as the USA and Canada. England Rugby will also not implement the policy stating to the media that it "*believes further scientific evidence is required alongside detailed consideration of less restrictive measures in relation to the eligibility of transgender players*" [59]. World Rugby's ruling is a prominent polarising example of the need for sports-specific performance data for transwomen athletes.

5 Future Research Considerations

5.1 Testosterone as the Primary Biomarker for Eligibility

Despite being imperfect, serum testosterone concentrations are being considered as the primary biomarker to regulate the inclusion of athletes into the female category. At this time, it is the only method based on an objective biomarker supported by most available scientific literature (Table 1), while also accomplishing the integration of DSD women athletes and transwomen athletes into the female category of sports. This is consistent with the fundamental principles of the Olympic Charter and is an attempt to be fair to all participants by ensuring an equitable competitive environment. However, many unresolved issues need clarification before unreservedly adopting testosterone concentration, or any biomarkers, to define "*athletic gender*" [3]. Resolving these issues will require the scientific and sports medicine community to employ innovative research ideas [e.g., a combination of cell, animal, and human research paradigms (Table 1)] to generate the biological data needed to inform the inclusion or exclusion of transwomen and DSD women athletes in elite female sports.

Areas of research focus could include better methods for quantifying bioavailable testosterone, also known as free testosterone, as a potentially better alternative to total circulating testosterone as a criterion for participation in the female category of sports. Bioavailable testosterone is the testosterone that is taken up and used by the body's cells and could be measured in conjunction with an allowance for androgen insensitivity [3]. An increase in bioavailable testosterone over time seems to induce a greater increase in muscle mass and strength [60], although this finding has been recently disputed [61]. In contrast, when bioavailable testosterone was reduced to castrate levels in young men, isometric strength did not increase after resistance exercise training [62]. Assuming these findings are replicated and if extrapolated to elite DSD women athletes and transwomen athletes, they would imply that decreasing bioavailable testosterone concentrations would mitigate to some extent any previous sporting advantage due to the previously high testosterone concentrations. This is a particularly encouraging future avenue of research.

The role of testosterone in muscle anabolism (i.e., tissue growth, substrate restoration, and recovery) and catabolism (i.e., tissue breakdown and metabolic regulation) is well described [63] and, therefore, could be another avenue of research. The hypothesis is that the low testosterone concentrations induced in transwomen or DSD women will impact negatively on muscle performance and recovery. Therefore, it is essential that researchers replicate or determine the precise time frame, individual variability, and mechanism(s) of this drop off in strength with HRT in trained athletes.

5.2 Genetics

Another pertinent issue is genetic factors (i.e., sex chromosome composition) in influencing athletic performance. Boys and girls demonstrate differences in a range of physical characteristics, including body composition and skinfold thickness [64], height, and explosive strength, even before puberty [65], suggesting that sex chromosome composition plays a role in determining differences in adult athletic performance. Consistent with this, different populations of muscle cells may express different phenotypes of androgen sensitivity, raising the possibility that the muscle response to training may be different between men and women at the same testosterone concentrations. Animal model studies are a feasible option to examine the influences of sex chromosomes and pubertal hormones. For example, the four core genotypes mouse model which incorporates mice with four different combinations of gonads and sex chromosomes [66, 67], has helped identify the influence of sex chromosomes on physical traits, such as obesity and food intake [68, 69]. This model represents an ideal opportunity to study muscle function in the present context as the different combinations of gonads and sex chromosomes will result in different testosterone concentrations. This model may highlight the true effect of testosterone on muscle function.

5.3 Androgen Receptor Function

Elucidating further androgen receptor function is another relevant future avenue of research. Androgen receptors can be modulated by specific proteins called coregulators [70–72] or mediated via the activation of membrane-bound protein receptors to initiate intracellular signalling pathways [73], which can occur even in the presence of low levels of androgens [74]. Investigations into the non-genomic actions of the androgen receptor have been limited to in vitro studies [75, 76] rather than in vivo due to the lack of an appropriate animal model that can distinguish between genomic and non-genomic receptor actions [75]. Androgen receptor knockout mice such as DBD-ARKO [40], which has a deletion of the second zinc finger of the DNA-binding domain, has been created for such research purposes. Given the inherent challenges of human studies, investigators need to adopt similar creative approaches if they are to elucidate the role of androgen receptors in elite DSD women and transwomen athletes.

5.4 Athlete Health

It is important to note that the World Medical Association has urged physicians not to implement the World Athletics policy on classifying women athletes, arguing that the policy is not in line with medical ethics and could be harmful to the athlete [77]. This argument is an outdated approach to protect the privacy of patients. If the athlete is fully informed of the consequences of treatment and not coerced into undergoing treatment, the athlete has free choice to do so (Table 1), which is a fundamental human right [32]. However, when the sex of an athlete is challenged or uncertain, eligibility would need to be determined for women's events. Such a concept to request eligibility is currently being implemented by World Rowing [56]. The justification is that it is ethical and may be necessary for a medical doctor to assist an athlete in determining their eligibility for a sex-restricted event. This requirement is not about treatment and treatment choices, which are always private and not relevant to the sports community. This process is essential to ensure all athletes, including transwomen and DSD women athletes, can compete on an even playing field with cisgender athletes, and currently, as the best proxy, transgender athletes have to demonstrate testosterone concentrations in a similar range to those athletes they wish to compete against. The eligibility of DSD women athletes must not only follow the same principles based on testosterone concentrations, but also needs to consider testosterone receptor function.

The health of athletes should be the number one priority of any sport, and it is clear that World Rugby's new transwomen exclusion policy [58] has the health of athletes at the heart of its policy. However, such exclusion policies should be based on generally accepted scientific consensus, including results from studies conducted in transwomen athletes. The authors of the World Rugby guidelines may be correct in their assumptions using hypothetical modelling of elite male versus elite female athletes [58]; however, until relevant transwomen athletic performance data become available, there is just as much circumstantial evidence to support this policy by World Rugby as there is to oppose it. For example, a study of young untrained women with polycystic ovary syndrome found greater muscle mass did not equate to greater peak muscle force [78]. There is an urgent need, therefore, for well-designed longitudinal studies throughout a transwomen's transition that assesses at regular intervals the main indices of performance relevant to all sports. Such data will prove invaluable to directly evaluate the true safety risks inherent in transwomen playing in the elite female category of sport.

5.5 Muscle Memory

Muscle memory refers to the persistence of cellular phenotype related to previous testosterone exposure [79]. Research shows that in addition to hormone concentrations, the number of myonuclei can affect skeletal muscle training [79, 80]. Indeed, muscle cells have multiple nuclei and their number increases with muscle hypertrophy [81, 82]. In female mice, short-term treatment with testosterone increased both muscle fibre cross-sectional area (CSA) and myonuclei number [79]. After cessation of exposure, muscle fibre CSA reverted to that of the control arm, but the number of myonuclei remained 42% higher than controls for at least 3 months. These resident myonuclei facilitated enhanced muscle hypertrophy during 6-day resistance training overload (31% increase in the fibre CSA vs. 6% in controls); this increase remained 20% higher compared with controls after 14-day overload [79]. The number of myonuclei not only reflects the current size of the fibre, but also the history of the fibre. Current data might fit a "*peak pegging*" hypothesis, where the number of myonuclei found in the fibre represents the largest size the fibre has achieved, and new myonuclei are only added if the fibre grows beyond that size. However, this "*peak pegging*" hypothesis found in female mice does not transfer to young healthy, physically active women. Horwath et al. showed no change in the myonuclei content following a 10-week testosterone administration of 10 mg daily protocol [83] coupled with an interesting finding of a 31% increase in satellite cells associated with type II fibres in the testosterone group. Satellite cells exit quiescence by extrinsic mechanical stretch to the fibre, generating differentiated cells and self-renewing stem cells by asymmetric division

[84], meaning that the myofibres could feasibly repair more quickly with exogenous testosterone administration.

Testosterone has been shown to increase the myonuclear number in men in a dose-dependent manner alongside muscle fibre CSA being well correlated with the myonuclear number [81, 82]. Nevertheless, further data are needed to confirm the extent to which myonuclei are retained over time after human muscle fibres have been exposed to a high testosterone environment. If high numbers of myonuclei are confirmed to be retained in transwomen or DSD women athletes, these results could imply that an advantage of previously high testosterone concentrations remains even after testosterone suppression. The relevant question would remain whether this potential effect is relevant to regulations that seek to prohibit individuals who have this potential advantage from competition.

5.6 Previous Failings Present Opportunity

Finally, it is important to stress that the current physiological data are insufficient to adequately inform policy and result from both a distinct lack of research funding and a limited number of elite athletes available to participate in this research area. For eligibility to be determined in the fairest manner possible, more funding and subsequent research are required to allow specialists in biological sciences and sports medicine to conduct experiments to determine the best solutions for integrating DSD women and transwomen athletes into the elite level of female sport.

5.7 FIMS Consensus Statements for the Integration of DSD Women and Transwomen Athletes into Elite Female Sport

Although serum testosterone concentrations constitute an indicator of androgen production and availability, a reliable biological index of androgen action is still lacking. Promising new developments in sport and exercise science are destined to contribute to the fair inclusion of DSD women and transwomen athletes. A well-coordinated multidisciplinary international research approach should include well-designed, controlled studies on the effect of testosterone on training and sports performance. Providing scientific evidence to use a system of biology multi-omics adequately and ethically (i.e., genomics, transcriptomics, metabolomics, and proteomics) to generate the necessary data and downstream biomarkers will be needed to address all open issues. There must be a transparent roadmap for the scientific community to focus on the best possible outcome of such new research. The authors, therefore, propose the following FIMS consensus statements and roadmap to facilitate the integration of DSD women and transwomen athletes into elite female sport:

- The inclusion of a third category in elite sport is not currently plausible, as the numbers of elite DSD women and transwomen athletes are relatively small.
- The prevalence of transwomen athletes in elite competition is likely to increase in the future, due to the increased visibility of transgender individuals in society [85, 86], which in turn may drive more people to consider expressing their chosen gender identity [87]. Research into transwomen sporting performance is highly relevant for leading scientists, leading clinicians, sport's governing bodies, and the World Anti-Doping Agency and is already a priority for the IOC [88].
- Transwomen have the right to compete in sports. However, cisgender women have the right to compete in a protected category.
- Any inclusion or exclusion policies on DSD women and/or transwomen athletes should be free of any social and/or religious prejudice, bias, or discrimination and should be based solely on the governance of fair competition.
- As each sport can vary greatly in terms of physiological demands, we support the view held also by others [43] stating that individual sport's governing bodies should develop their own individual policies based on broader guidelines developed on the best available scientific evidence, determined experimentally from a variety of sources with a particular preference for studies on transwomen and DSD women athletes.
- With data showing reductions in haemoglobin following testosterone suppression [45], obtaining data on DSD women and transwomen athletes' cardiovascular performance, such as maximal oxygen uptake, should be a priority for researchers due to the importance of the cardiovascular system in numerous sports performance contexts.
- The use of serum testosterone concentrations as the primary biomarker to regulate the inclusion of athletes into male and female categories is currently the most justified solution as it is supported by the available scientific literature (Table 1) and should be implemented at the elite level, where there is an emphasis on performance enhancement.
- DSD women or transwomen athletes should be fully informed by medical personnel of the risks and consequences of testosterone suppression treatment and must never be coerced or forced into testosterone suppression. The athletes must be free to make the decision that is best for them (Table 1).
- No sport's governing body should provide recommendations on treatment; this should be done by medical personnel (Table 1).
- If DSD women and transwomen athletes choose not to have suppressed testosterone, as is their right, they cannot compete in the restricted female category with high

testosterone concentrations above the policy threshold. Instead, they should be offered the chance to compete in the male category.

- A testosterone concentration threshold of 5 nmol/L in DSD women and transwomen athletes should be used as a global recommendation for sport's governing bodies at this present time and may be modified as new evidence arises for an event or sport-specific concentrations (Table 1).
- The statement on the testosterone concentration threshold for transwomen and DSD women athletes was the only point of contention for the FIMS Panel. All 70 authors voted, of whom 87% were in favour of the 5 nmol/L threshold, 2% of authors were in favour of a threshold of 8 nmol/L, 2% were in favour of a threshold around the upper testosterone concentration of normal healthy females of 0.2–1.7 nmol/L [89], and 8% of authors were in favour of no change to the limit until further evidence was acquired. This large but not unanimous majority consensus highlights the area most in need of research, i.e., altered bioavailability of testosterone and performance indices in DSD women and transwomen athletes.
- New innovative avenues must be explored to guide improved, up to date policy (Table 1), for example, quantifying bioactive testosterone and individual sensitivity to testosterone, the role of sex chromosomes in athletic performance, the role of androgen receptors, and the extent to which muscle memory is retained after high testosterone exposure. In addition, identification of other biomarkers (e.g., metabolomics, proteomics) that may better differentiate individual sensitivity to testosterone is needed. Liquid chromatography–mass spectrometry is well accepted as the preferred technique for the analysis of testosterone [90, 91].
- The best available scientific methods, such as well-designed, controlled studies, must be utilised to acquire new scientific evidence on sporting performance measures to derive policies on DSD women and/or transwomen sporting participation. This should be on a sport-by-sport basis when the evidence arises, rather than the universal approach to sports regulations at present due to the lack of individual sports data.

5.8 Dissenting Opinions During Consensus Discussions

During the consensus discussions, there was a constructive debate on the testosterone limit in the elite category of female sports. One author agreed that the concentration of 5 nmol/L was a median value between the upper and lower ranges of female and male testosterone. However, the 5 nmol/L level adopted by World Athletics is based on the inference that there is a relationship between performance and testosterone concentrations and is meant to represent the value above which a performance advantage is no longer within the bounds of healthy cisgender females. This assumption is likely false due to the multifactorial nature of different sports. Although there is evidence to suggest that performance of female athletes with high testosterone levels may be enhanced, it is still a contentious issue that requires research before and after testosterone suppression to identify where the testosterone threshold should be set for such athletes, and the limit may have to follow a sport-by-sport evidenced basis instead of a holistic approach.

The authors also discussed the issue of athletes' health, which is timely given the announcement of World Rugby's transgender guideline which excludes transwomen players to safeguard cisgender female players at the international level. One author opposed the "one size does not fit all" notion of World Rugby's policy due to its assumption that all transwomen are larger in stature and heavier than their cisgender counterparts. This assumption is due to studies like Roberts et al. showing that transwomen are heavier when presented as a pre-treatment average [53]. However, some cisgender women athletes are taller than transwomen or have greater muscle mass than transwomen and anthropometric variation is a part of sport. If the modelling scenario in World Rugby's policy of a "*typical male tackler mass*" involved in a rugby tackle with a "*typical female tackler mass*" [58] is confirmed, an exclusion policy could be implemented on an individual basis and resolving all the practical challenges that this would entail. Safety in sport is of great importance and exclusion based on safety is a justifiable cause but exclusion needs to be evidenced-based and include some consideration of transwomen athletic performance metrics.

Another author strongly affirmed that all cut-offs for hormones that are out of normal ranges for age and/or gender are pathological, not physiological, and are associated with different side effects, some of them increasing health risks and some potentially useful at different levels for physiological performance. The author stated, "*that as sports physicians we have to decide if firstly, we protect athlete's health issues or social issues*" and that sport physicians should mimic society's physicians and be "*a cornerstone for athletes health*".

6 Conclusions

Ultimately, even the most evidence-based policies will not eliminate differences in sporting performance between athletes in the elite category of female sports. However, any advantage held by a person belonging to an athlete in this category could be considered part of the athlete's unique individuality. Whatever the solution, there is an urgent need for a well-coordinated multidisciplinary international research program, backed by appropriate research grant funding and athlete participation, to generate the evidence to inform future objective policy decisions. Such decisions should be based on the best available scientific evidence from the best available scientific practice and the decisions made will also require a firm political resolve to fairly integrate transwomen and DSD women athletes into elite female sport.

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References

1. Archives TN. Equality Act 2010. http://www.legislation.gov.uk/ukpga/2010/15/section/195. Accessed 4 Mar 2020.
2. Sánchez FJ, Martínez-Patiño MJ, Vilain E. The new policy on hyperandrogenism in elite female athletes is not about "sex testing." J Sex Res. 2013;50(2):112–5.
3. Harper J, Martinez-Patino M-J, Pigozzi F, Pitsiladis Y. Implications of a third gender for elite sports. Curr Sports Med Rep. 2018;17(2):42–4.
4. Harper J, Lima G, Kolliari-Turner A, Malinsky FR, Wang G, Martinez-Patino MJ, et al. The fluidity of gender and implications for the biology of inclusion for transgender and intersex athletes. Curr Sports Med Rep. 2018;17(12):467–72. https://doi.org/10.1249/JSR.0000000000000543.
5. Sudai M. The testosterone rule—constructing fairness in professional sport. J Law Biosci. 2017;4(1):181–93.
6. Jones BA, Arcelus J, Bouman WP, Haycraft E. Sport and transgender people: a systematic review of the literature relating to sport participation and competitive sport policies. Sports Med. 2017;47(4):701–16.
7. Committee IO. Olympic Charter. 2020. www.olympic.org/documents/olympic-charter. Accessed 15 Jun 2020.
8. Walker PL, Cook DC. Brief communication: gender and sex: vive la difference. Am J Phys Anthropol. 1998;106(2):255–9.
9. Vilain E, Betancurt JO, Bueno-Guerra N, Martinez-Patiño MJ. Transgender athletes in elite sport competitions. Transgender Athletes in Competitive Sport. Oxfordshire: Routledge; 2017.
10. Reisner SL, Hughto JM. Comparing the health of non-binary and binary transgender adults in a statewide non-probability sample. PLoS ONE. 2019;14(8):e0221583.
11. NHS. Differences in sex development. 2019. https://www.nhs.uk/conditions/differences-in-sex-development/. Accessed 15 Sep 2020.
12. Jung EJ, Im DH, Park YH, Byun JM, Kim YN, Jeong DH, et al. Female with 46. XY karyotype Obstet Gynecol Sci. 2017;60(4):378–82.
13. Court GFC. Act on amending the act on the civil status of persons (Personenstandsgesetz). In: Article 4 of the Act of 18.12.2018. 2018. http://www.gesetze-im-internet.de/englisch_gg/englisch_gg.pdf. BGBl. 2018 IS. 2369.
14. Court TFC. Order of the First Senate of 10th October. 2017. http://www.bverfg.de/e/rs20171010_1bvr201916en.html. Accessed 25 Jun 2020.
15. Sport CoAf. CAS 2014/A/3759 Dutee Chand v. Athletics Federation of India (AFI) & The International Association of Athletics Federations (IAAF). 2014. https://www.doping.nl/media/kb/3317/CAS%202014_A_3759%20Dutee%20Chand%20vs.%20AFI%20%26%20IAAF%20%28S%29.pdf. Accessed 26 Feb 2020.
16. Sport CoAf. CAS 2018/0/5794 Mokgadi Caster Semenya v. International Association of Athletics Federations and CAS 2018/0/5798 Athletics South Africa v. International Association of Athletics Federations. 2018. https://www.tas-cas.org/fileadmin/user_upload/CAS_Award_-_redacted_-_Semenya_ASA_IAAF.pdf. Accessed 26 Feb 2020.
17. Council UNHR. Promotion of the cultural rights of everyone and respect for cultural diversity. 2019. https://documents-dds-ny.un.org/doc/UNDOC/GEN/G19/098/67/PDF/G1909867.pdf?OpenElement. Accessed 19 April 2020.
18. Ellaithi M, Kamel A, Saber O, Hiort O. Consanguinity and disorders of sexual developments in the Sudan. Sudan JMS. 2011;6(4):267–70.
19. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocr Rev. 2018;39(5):803–29. https://doi.org/10.1210/er.2018-00020.
20. Bermon S, Garnier PY, Hirschberg AL, Robinson N, Giraud S, Nicoli R, et al. Serum androgen levels in elite female athletes. J Clin Endocrinol Metab. 2014;99(11):4328–35.
21. Morel Y, Rey R, Teinturier C, Nicolino M, Michel-Calemard L, Mowszowicz I, et al. Aetiological diagnosis of male sex ambiguity: a collaborative study. Eur J Pediatr. 2002;161(1):49–59.
22. Hirschberg AL, Knutsson JE, Helge T, Godhe M, Ekblom M, Bermon S, et al. Effects of moderately increased testosterone concentration on physical performance in young women: a double

blind, randomised, placebo controlled study. Br J Sports Med. 2019;54:599–604.
23. Bermon S. Androgens and athletic performance of elite female athletes. Curr Opin Endocrinol Diabetes Obes. 2017;24(3):246–51.
24. Bermon S, Garnier P-Y. Serum androgen levels and their relation to performance in track and field: mass spectrometry results from 2127 observations in male and female elite athletes. Br J Sports Med. 2017;51(17):1309–14.
25. Federations. IAoA. Eligibility Regulations for the Female Classification (Athletes with Differences of Sex Development). Version 1.0. 2018. www.iaaf.org/about-iaaf/documents/rules-regulations. Accessed 6 March 2020.
26. Pielke R, Tucker R, Boye E. Scientific integrity and the IAAF testosterone regulations. Int Sports Law J. 2019;19(1–2):18–26.
27. Menier A. Use of event-specific tertiles to analyse the relationship between serum androgens and athletic performance in women. Br J Sports Med. 2018;52(23):1540.
28. Koh B, Adair D, Elphick L. Not by gender, not by sex, but by testosterone saith the IAAF: International Athletics and the new female eligibility regulations. Law Sport J. Available at SSRN: https://ssrn.com/abstract=31846642018.
29. Bermon S, Hirschberg AL, Kowalski J, Eklund E. Serum androgen levels are positively correlated with athletic performance and competition results in elite female athletes. Br J Sports Med. 2018;52(23):1531–2.
30. Loland S. Caster Semenya, athlete classification, and fair equality of opportunity in sport. J Med Ethics. 2020;46(9):584–90.
31. Federations. IAoA. Eligibility Regulations for the female classification (athletes with differences of sex development). Version 2.0. 2019. www.iaaf.org/about-iaaf/documents/rules-regulations. Accessed 1 Jun 2020.
32. Hamilton BR, Martinez-Patiño MJ, Barrett J, Seal L, Tucker R, Papadopoulou T, et al. Response to the United Nations Human Rights Council's report on race and gender discrimination in sport: an expression of concern and a call to prioritise research. Sports Med. 2020. https://doi.org/10.1007/s40279-020-01380-y.
33. Court SFS. DSD Regulations: Caster Semenya's appeal against the decision of the Court of Arbitration for Sport dismissed. 2020. https://www.bger.ch/files/live/sites/bger/files/pdf/en/4A_248_2019_yyyy_mm_dd_T_e_18_18_10.pdf. Accessed 10 Oct 2020.
34. Johnson J, Sotherton K. Caster Semenya ruling: The case for and against IAAF's testosterone regulations. The Telegraph, Online. 2019. https://www.telegraph.co.uk/athletics/2019/05/02/caster-semenya-ruling-case-against-iaafs-testosterone-regulations/. Accessed 8 Apr 2020.
35. Tannenbaum C, Bekker S. Sex, gender, and sports. BMJ. 2019;364:l1120.
36. Committee TGAFR. Fiscal Note HB 1572—2077. 2020. http://www.capitol.tn.gov/Bills/111/Fiscal/HB1572.pdf. Accessed 1 Apr 2020.
37. Luevano A. Fairness In Women's Sports Act bans some transgender athletes. Local News 8 and KIDK Eyewitness News 3, Online 2020. https://localnews8.com/sports/2020/04/02/fairness-in-womens-sports-act-bans-some-transgender-athletes/. Accessed 15 Jun 2020.
38. Idaho TSo. Fairness in Women's Sports Act. 2020. https://legislature.idaho.gov/sessioninfo/billbookmark/?yr=2020&bn=H0500. Accessed 17 Apr 2020.
39. Freedom AD. Idaho governor signs Fairness for Women in Sports Act into law. 2020. http://www.adfmedia.org/News/PRDetail/10948. Accessed 17 Apr 2020.
40. Press A. Civil rights groups file suit against Idaho ban on trans athletes in women's sports. The Guardian. 2020. https://www.theguardian.com/sport/2020/apr/15/idaho-transgender-ban-womens-sports-lawsuit. Accessed 17 Apr 2020.
41. Minsberg T. 'Boys are boys and girls are girls': Idaho Is first state to bar some transgender athletes. The New York Times, Online. 2020. https://www.nytimes.com/2020/04/01/sports/transgender-idaho-ban-sports.html. Accessed 17 Apr 2020.
42. Cavanagh SL, Sykes H. Transsexual bodies at the Olympics: the international Olympic Committee's policy on transsexual athletes at the 2004 Athens Summer Games. Body Soc. 2006;12(3):75–102.
43. Hilton EN, Lundberg TR. Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage. Sports Med. 2020. https://doi.org/10.1007/s40279-020-01389-3.
44. Pitsiladis Y, Harper J, Betancurt JO, Martinez-Patino M-J, Parisi A, Wang G, et al. Beyond fairness: the biology of inclusion for transgender and intersex athletes. Curr Sports Med Rep. 2016;15(6):386–8.
45. Gooren LJ, Bunck MC. Transsexuals and competitive sports. Eur J Endocrinol. 2004;151(4):425–30.
46. Gooren LJ, Giltay EJ, Bunck MC. Long-term treatment of transsexuals with cross-sex hormones: extensive personal experience. J Clin Endocrinol Metab. 2008;93(1):19–25.
47. Karalexi MA, Georgakis MK, Dimitriou NG, Vichos T, Katsimpris A, Petridou ET, et al. Gender-affirming hormone treatment and cognitive function in transgender young adults: a systematic review and meta-analysis. Psychoneuroendocrinology. 2020;119:104721.
48. T'Sjoen G, Weyers S, Taes Y, Lapauw B, Toye K, Goemaere S, et al. Prevalence of low bone mass in relation to estrogen treatment and body composition in male-to-female transsexual persons. J Clin Densitom. 2009;12(3):306–13.
49. Harper J. Race times for transgender athletes. J Sport Cult Ident. 2015;6(1):1–9.
50. Grubb H. Models for comparing athletic performances. J R Stat Soc Ser D Stat. 1998;47(3):509–21.
51. Wiik A, Lundberg T, Rullman E, Andersson D, Holmberg M, Mandić M, et al. Muscle strength, size, and composition following 12 months of gender-affirming treatment in transgender individuals. J Clin Endocrinol. 2020;105(3):e805–13.
52. NHS. Gender dysphoria. The National Health Service. 2020. https://www.nhs.uk/conditions/gender-dysphoria/. Accessed 29 Jul 2020.
53. Roberts TA, Smalley J, Ahrendt D. Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organisations and legislators. Br J Sports Med. 2020. https://doi.org/10.1136/bjsports-2020-102329.
54. Commitee IO. Consensus Meeting on Sex Reassignment and Hyperandrogenism. 2015. https://stillmed.olympic.org/Documents/Commissions_PDFfiles/Medical_commission/2015-11_ioc_consensus_meeting_on_sex_reassignment_and_hyperandrogenism-en.pdf. Accessed 20 Feb 2020.
55. Athletics W. Eligibility Regulations Transgender Athletes. 2019. https://www.worldathletics.org/about-iaaf/documents/book-of-rules. Accessed 22 Oct 2020.
56. Rowing W. Rule 13 and Bye law to rule 13– Men's and Women's Events. 2020. www.worldrowing.com. Accessed 2 Dec 2020.
57. Internationale UC. Rule 13.5.028. 2020. https://www.uci.org/docs/default-source/rules-and-regulations/part-xiii---medical-rules---01.03.2020.pdf. Accessed 5 Dec 2020.
58. Rugby W. World Rugby Transgender Guideline. Online. 2020. https://playerwelfare.worldrugby.org/?documentid=231. Accessed 2 Nov 2020.
59. Ingle S. RFU clears trans women to keep playing domestic women's rugby in England. The Guardian. 2020. https://www.theguardian.com/sport/2020/oct/14/rfu-clears-trans-women-to-play-womens-rugby-at-all-levels-in-england?fbclid=IwAR359QKh

JiCxKr8a_u8yX1vGNN7opyvA52uJVykCfTR7B9ehb2EJvc8_kOM. Accessed 2 Nov 2020.
60. Rønnestad BR, Nygaard H, Raastad T. Physiological elevation of endogenous hormones results in superior strength training adaptation. Eur J Appl Physiol. 2011;111(9):2249–59.
61. Schwanbeck SR, Cornish SM, Barss T, Chilibeck PD. Effects of training with free weights versus machines on muscle mass, strength, free testosterone, and free cortisol levels. J Strength Cond Res. 2020;34(7):1851–9.
62. Kvorning T, Andersen M, Brixen K, Madsen K. Suppression of endogenous testosterone production attenuates the response to strength training: a randomized, placebo-controlled, and blinded intervention study. Am J Physiol Endocrinol Metab. 2006;291(6):E1325–32.
63. Kraemer WJ, Ratamess NA, Nindl BC. Recovery responses of testosterone, growth hormone, and IGF-1 after resistance exercise. J Appl Physiol. 2017;122(3):549–58.
64. Kelso A, Vogel K, Steinacker JM. Ultrasound measurements of subcutaneous adipose tissue thickness show sexual dimorphism in children of three to five years of age. Acta Paediatr. 2019;108(3):514–21.
65. Marta CC, Marinho DA, Barbosa TM, Izquierdo M, Marques MC. Physical fitness differences between prepubescent boys and girls. J Strength Cond Res. 2012;26(7):1756–66.
66. Arnold AP, Chen X. What does the "four core genotypes" mouse model tell us about sex differences in the brain and other tissues? Front Neuroendocrinol. 2009;30(1):1–9.
67. Burgoyne PS, Arnold AP. A primer on the use of mouse models for identifying direct sex chromosome effects that cause sex differences in non-gonadal tissues. Biol Sex Differ. 2016;7(1):68.
68. Chen X, McClusky R, Chen J, Beaven SW, Tontonoz P, Arnold AP, et al. The number of x chromosomes causes sex differences in adiposity in mice. PLoS Genet. 2012;8(5):e1002709.
69. Chen X, Wang L, Loh DH, Colwell CS, Taché Y, Reue K, et al. Sex differences in diurnal rhythms of food intake in mice caused by gonadal hormones and complement of sex chromosomes. Horm Behav. 2015;75:55–63.
70. Heinlein CA, Chang C. Androgen receptor (AR) coregulators: an overview. Endocr Rev. 2002;23(2):175–200.
71. Heemers HV, Tindall DJ. Androgen receptor (AR) coregulators: a diversity of functions converging on and regulating the AR transcriptional complex. Endocr Rev. 2007;28(7):778–808.
72. van de Wijngaart DJ, Dubbink HJ, van Royen ME, Trapman J, Jenster G. Androgen receptor coregulators: recruitment via the coactivator binding groove. Mol Cell Endocrinol. 2012;352(1–2):57–69.
73. Papakonstanti EA, Kampa M, Castanas E, Stournaras C. A rapid, nongenomic, signaling pathway regulates the actin reorganization induced by activation of membrane testosterone receptors. J Mol Endocrinol. 2003;17(5):870–81.
74. Lamont KR, Tindall DJ. Minireview: Alternative activation pathways for the androgen receptor in prostate cancer. Mol Endocrinol. 2011;25(6):897–907.
75. Davey RA, Grossmann M. Androgen receptor structure, function and biology: from bench to bedside. Clin Biochem Rev. 2016;37(1):3.
76. Heinlein CA, Chang C. The roles of androgen receptors and androgen-binding proteins in nongenomic androgen actions. J Mol Endocrinol. 2002;16(10):2181–7.
77. Association WM. World Medical Association urges physicians not to implement IAAF rules on classifying women athletes. 2020. https://www.wma.net/news-post/wma-urges-physicians-not-to-implement-iaaf-rules-on-classifying-women-athletes/. Accessed 8 Jul 2020.
78. Caliskan Guzelce E, Eyupoglu N, Torgutalp S, Aktoz F, Portakal O, Demirel H, et al. Is muscle mechanical function altered In polycystic ovary syndrome? J Endocr Soc. 2019;3(Supplement_1):MON-205.
79. Egner IM, Bruusgaard JC, Eftestøl E, Gundersen K. A cellular memory mechanism aids overload hypertrophy in muscle long after an episodic exposure to anabolic steroids. J Physiol. 2013;591(24):6221–30.
80. Bruusgaard JC, Johansen I, Egner I, Rana Z, Gundersen K. Myonuclei acquired by overload exercise precede hypertrophy and are not lost on detraining. Proc Natl Acad Sci USA. 2010;107(34):15111–6.
81. Sinha-Hikim I, Roth SM, Lee MI, Bhasin S. Testosterone-induced muscle hypertrophy is associated with an increase in satellite cell number in healthy, young men. Am J Physiol Endocrinol Metab. 2003;285(1):E197–205.
82. Sinha-Hikim I, Cornford M, Gaytan H, Lee ML, Bhasin S. Effects of testosterone supplementation on skeletal muscle fiber hypertrophy and satellite cells in community-dwelling older men. J Clin Endocrinol Metab. 2006;91(8):3024–33.
83. Horwath O, Apró W, Moberg M, Godhe M, Helge T, Ekblom M, et al. Fiber type-specific hypertrophy and increased capillarization in skeletal muscle following testosterone administration in young women. J Appl Physiol. 2020;128(5):1240–50.
84. Le Grand F, Rudnicki MA. Skeletal muscle satellite cells and adult myogenesis. Curr Opin Cell Biol. 2007;19(6):628–33.
85. Aitken M, Steensma TD, Blanchard R, VanderLaan DP, Wood H, Fuentes A, et al. Evidence for an altered sex ratio in clinic-referred adolescents with gender dysphoria. J Sex Med. 2015;12(3):756–63.
86. De Vries A, Kreukels B, T'sjoen G, Ålgars M, Mattila A. Increase of referrals to gender identity clinics: a European trend. Transgender Healthc Europe. Book of abstracts. 2015.
87. Bouman WP, de Vries AL, T'Sjoen G. Gender dysphoria and gender incongruence: an evolving inter-disciplinary field. Milton Park: Taylor & Francis; 2016.
88. Committee. IO. Call for Applications. 2019. https://www.olympic.org/news/2019-call-for-applications. Accessed 16 Apr 2020.
89. NHS. Testosterone. 2020. https://www.nbt.nhs.uk/severn-pathology/requesting/test-information/testosterone. Accessed 2 Aug 2020.
90. Stanczyk FZ, Clarke NJ. Advantages and challenges of mass spectrometry assays for steroid hormones. J Steroid Biochem Mol Bio. 2010;121(3–5):491–5.
91. Martínez-Escribano A, Maroto-García J, Ruiz-Galdón M, Barrios-Rodríguez R, Álvarez-Millán JJ, Cabezas-Sánchez P, et al. Measurement of serum testosterone in nondiabetic young obese men: comparison of direct immunoassay to liquid chromatography-tandem mass spectrometry. Biomolecules. 2020;10(12):1697.

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Exhibit H

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REVIEW ARTICLE

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Transgender Women in the Female Category of Sport: Perspectives on Testosterone Suppression and Performance Advantage

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Abstract
Males enjoy physical performance advantages over females within competitive sport. The sex-based segregation into male and female sporting categories does not account for transgender persons who experience incongruence between their biological sex and their experienced gender identity. Accordingly, the International Olympic Committee (IOC) determined criteria by which a transgender woman may be eligible to compete in the female category, requiring total serum testosterone levels to be suppressed below 10 nmol/L for at least 12 months prior to and during competition. Whether this regulation removes the male performance advantage has not been scrutinized. Here, we review how differences in biological characteristics between biological males and females affect sporting performance and assess whether evidence exists to support the assumption that testosterone suppression in transgender women removes the male performance advantage and thus delivers fair and safe competition. We report that the performance gap between males and females becomes significant at puberty and often amounts to 10–50% depending on sport. The performance gap is more pronounced in sporting activities relying on muscle mass and explosive strength, particularly in the upper body. Longitudinal studies examining the effects of testosterone suppression on muscle mass and strength in transgender women consistently show very modest changes, where the loss of lean body mass, muscle area and strength typically amounts to approximately 5% after 12 months of treatment. Thus, the muscular advantage enjoyed by transgender women is only minimally reduced when testosterone is suppressed. Sports organizations should consider this evidence when reassessing current policies regarding participation of transgender women in the female category of sport.

Key Points

Given that biological males experience a substantial performance advantage over females in most sports, there is currently a debate whether inclusion of transgender women in the female category of sports would compromise the objective of fair and safe competition.

Here, we report that current evidence shows the biological advantage, most notably in terms of muscle mass and strength, conferred by male puberty and thus enjoyed by most transgender women is only minimally reduced when testosterone is suppressed as per current sporting guidelines for transgender athletes.

This evidence is relevant for policies regarding participation of transgender women in the female category of sport.

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1 Introduction

Sporting performance is strongly influenced by a range of physiological factors, including muscle force and power-producing capacity, anthropometric characteristics, cardiorespiratory capacity and metabolic factors [1, 2]. Many of these physiological factors differ significantly between biological males and females as a result of genetic differences and androgen-directed development of secondary sex characteristics [3, 4]. This confers large sporting performance advantages on biological males over females [5].

When comparing athletes who compete directly against one another, such as elite or comparable levels of school-aged athletes, the physiological advantages conferred by biological sex appear, on assessment of performance data, insurmountable. Further, in sports where contact, collision or combat are important for gameplay, widely different physiological attributes may create safety and athlete welfare concerns, necessitating not only segregation of sport into male and female categories, but also, for example, into weight and age classes. Thus, to ensure that both men and women can enjoy sport in terms of fairness, safety and inclusivity, most sports are divided, in the first instance, into male and female categories.

Segregating sports by biological sex does not account for transgender persons who experience incongruence between their biological sex and their experienced gender identity, and whose legal sex may be different to that recorded at birth [6, 7]. More specifically, transgender women (observed at birth as biologically male but identifying as women) may, before or after cross-hormone treatment, wish to compete in the female category. This has raised concerns about fairness and safety within female competition, and the issue of how to fairly and safely accommodate transgender persons in sport has been subject to much discussion [6–13].

The current International Olympic Committee (IOC) policy [14] on transgender athletes states that "it is necessary to ensure insofar as possible that trans athletes are not excluded from the opportunity to participate in sporting competition". Yet the policy also states that "the overriding sporting objective is and remains the guarantee of fair competition". As these goals may be seen as conflicting if male performance advantages are carried through to competition in the female category, the IOC concludes that "restrictions on participation are appropriate to the extent that they are necessary and proportionate to the achievement of that objective".

Accordingly, the IOC determined criteria by which transgender women may be eligible to compete in the female category. These include a solemn declaration that her gender identity is female and the maintenance of total serum testosterone levels below 10 nmol/L for at least 12 months prior to competing and during competition [14]. Whilst the scientific basis for this testosterone threshold was not openly communicated by the IOC, it is surmised that the IOC believed this testosterone criterion sufficient to reduce the sporting advantages of biological males over females and deliver fair and safe competition within the female category.

Several studies have examined the effects of testosterone suppression on the changing biology, physiology and performance markers of transgender women. In this review, we aim to assess whether evidence exists to support the assumption that testosterone suppression in transgender women removes these advantages. To achieve this aim, we first review the differences in biological characteristics between biological males and females, and examine how those differences affect sporting performance. We then evaluate the studies that have measured elements of performance and physical capacity following testosterone suppression in untrained transgender women, and discuss the relevance of these findings to the supposition of fairness and safety (i.e. removal of the male performance advantage) as per current sporting guidelines.

2 The Biological Basis for Sporting Performance Advantages in Males

The physical divergence between males and females begins during early embryogenesis, when bipotential gonads are triggered to differentiate into testes or ovaries, the tissues that will produce sperm in males and ova in females, respectively [15]. Gonad differentiation into testes or ovaries determines, via the specific hormone milieu each generates, downstream in utero reproductive anatomy development [16], producing male or female body plans. We note that in rare instances, differences in sex development (DSDs) occur and the typical progression of male or female development is disrupted [17]. The categorisation of such athletes is beyond the scope of this review, and the impact of individual DSDs on sporting performance must be considered on their own merits.

In early childhood, prior to puberty, sporting participation prioritises team play and the development of fundamental motor and social skills, and is sometimes mixed sex. Athletic performance differences between males and females prior to puberty are often considered inconsequential or relatively small [18]. Nonetheless, pre-puberty performance differences are not unequivocally negligible, and could be mediated, to some extent, by genetic factors and/or activation of the hypothalamic–pituitary–gonadal axis during the neonatal period, sometimes referred to as "minipuberty". For example, some 6500 genes are differentially expressed between males and females [19] with an estimated 3000 sex-specific differences in skeletal muscle likely to influence composition and function beyond the effects of androgenisation [3], while increased testosterone during minipuberty in males aged 1–6 months may be correlated with higher growth velocity and an "imprinting effect" on BMI and bodyweight [20, 21]. An extensive review of fitness data from over 85,000 Australian children aged 9–17 years old showed that, compared with 9-year-old females, 9-year-old males were faster over short sprints (9.8%) and 1 mile (16.6%), could jump 9.5% further from a standing start (a test of explosive power), could complete 33% more push-ups in 30 s and had 13.8% stronger grip [22]. Male advantage of a similar magnitude was detected in a study of Greek children, where, compared with 6-year-old females, 6-year-old males completed 16.6% more shuttle runs in a given time and could jump 9.7% further from a standing position [23]. In terms of aerobic capacity, 6- to 7-year-old males have been shown to have a higher absolute and relative (to body mass) VO_{2max} than 6- to 7-year-old females [24]. Nonetheless, while some biological sex differences, probably genetic in origin, are measurable and affect performance pre-puberty, we consider the effect of androgenizing puberty more influential on performance, and have focused our analysis on musculoskeletal differences hereafter.

Secondary sex characteristics that develop during puberty have evolved under sexual selection pressures to improve reproductive fitness and thus generate anatomical divergence beyond the reproductive system, leading to adult body types that are measurably different between sexes. This phenomenon is known as sex dimorphism. During puberty, testes-derived testosterone levels increase 20-fold in males, but remain low in females, resulting in circulating testosterone concentrations at least 15 times higher in males than in females of any age [4, 25]. Testosterone in males induces changes in muscle mass, strength, anthropometric variables and hemoglobin levels [4], as part of the range of sexually dimorphic characteristics observed in humans.

Broadly, males are bigger and stronger than females. It follows that, within competitive sport, males enjoy significant performance advantages over females, predicated on the superior physical capacity developed during puberty in response to testosterone. Thus, the biological effects of elevated pubertal testosterone are primarily responsible for driving the divergence of athletic performances between males and females [4]. It is acknowledged that this divergence has been compounded historically by a lag in the cultural acceptance of, and financial provision for, females in sport that may have had implications for the rate of improvement in athletic performance in females. Yet, since the 1990s, the difference in performance records between males and females has been relatively stable, suggesting that biological differences created by androgenization explain most of the male advantage, and are insurmountable [5, 26, 27].

Table 1 outlines physical attributes that are major parameters underpinning the male performance advantage [28–38]. Males have: larger and denser muscle mass, and stiffer connective tissue, with associated capacity to exert greater muscular force more rapidly and efficiently; reduced fat mass, and different distribution of body fat and lean muscle mass, which increases power to weight ratios and upper to lower limb strength in sports where this may be a crucial determinant of success; longer and larger skeletal structure, which creates advantages in sports where levers influence force application, where longer limb/digit length is favorable, and where height, mass and proportions are directly responsible for performance capacity; superior cardiovascular and respiratory function, with larger blood and heart volumes, higher hemoglobin concentration, greater cross-sectional area of the trachea and lower oxygen cost of respiration [3, 4, 39, 40]. Of course, different sports select for different physiological characteristics—an advantage in one discipline may be neutral or even a disadvantage in another—but examination of a variety of record and performance metrics in any discipline reveals there are few sporting disciplines where males do not possess performance advantage over females as a result of the physiological characteristics affected by testosterone.

3 Sports Performance Differences Between Males and Females

3.1 An Overview of Elite Adult Athletes

A comparison of adult elite male and female achievements in sporting activities can quantify the extent of the male performance advantage. We searched publicly available sports federation databases and/or tournament/competition records to identify sporting metrics in various events and disciplines, and calculated the performance of males relative to females. Although not an exhaustive list, examples of performance gaps in a range of sports with various durations, physiological performance determinants, skill components and force requirements are shown in Fig. 1.

The smallest performance gaps were seen in rowing, swimming and running (11–13%), with low variation across individual events within each of those categories. The performance gap increases to an average of 16% in track cycling, with higher variation across events (from 9% in the 4000 m team pursuit to 24% in the flying 500 m time trial). The average performance gap is 18% in jumping events (long jump, high jump and triple jump). Performance differences larger than 20% are generally present when considering sports and activities that involve extensive upper body contributions. The gap between fastest recorded tennis serve

Table 1 Selected physical difference between untrained/moderately trained males and females. Female levels are set as the reference value

Variable	Magnitude of sex difference (%)	References
Body composition		
Lean body mass	45	Lee et al. [28]
Fat%	− 30	
Muscle mass		
Lower body	33	Janssen et al. [29]
Upper body	40	
Muscle strength		
Grip strength	57	Bohannon et al. [30]
Knee extension peak torque	54	Neder et al. [31]
Anthropometry and bone geometry		
Femur length	9.4	Jantz et al. [32]
Humerus length	12.0	Brinckmann et al. [33]
Radius length	14.6	
Pelvic width relative to pelvis height	− 6.1	
Tendon properties		
Force	83	Lepley et al. [34]
Stiffness	41	
VO_{2max}		
Absolute values	50	Pate et al. [35]
Relative values	25	
Respiratory function		
Pulmonary ventilation (maximal)	48	Åstrand et al. [36]
Cardiovascular function		
Left ventricular mass	31	Åstrand et al. [36]
Cardiac output (rest)	22	Best et al. [37]
Cardiac output (maximal)	30	Tong et al. [38]
Stroke volume (rest)	43	
Stroke volume (maximal)	34	
Hemoglobin concentration	11	

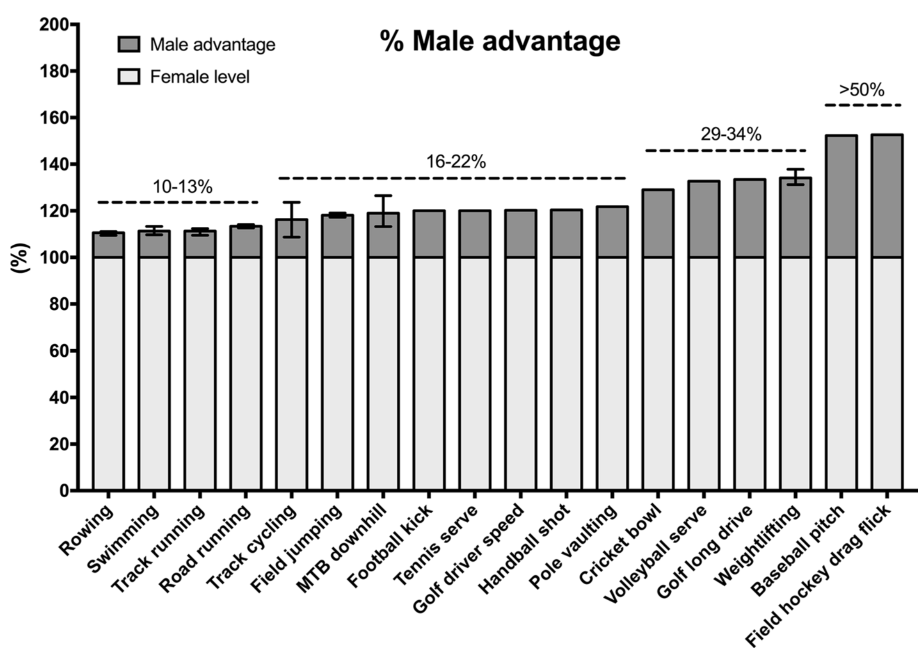

Fig. 1 The male performance advantage over females across various selected sporting disciplines. The female level is set to 100%. In sport events with multiple disciplines, the male value has been averaged across disciplines, and the error bars represent the range of the advantage. The metrics were compiled from publicly available sports federation databases and/or tournament/competition records. *MTB* mountain bike

is 20%, while the gaps between fastest recorded baseball pitches and field hockey drag flicks exceed 50%.

Sports performance relies to some degree on the magnitude, speed and repeatability of force application, and, with respect to the speed of force production (power), vertical jump performance is on average 33% greater in elite men than women, with differences ranging from 27.8% for endurance sports to in excess of 40% for precision and combat sports [41]. Because implement mass differs, direct comparisons are not possible in throwing events in track and field athletics. However, the performance gap is known to be substantial, and throwing represents the widest sex difference in motor performance from an early age [42]. In Olympic javelin throwers, this is manifested in differences in the peak linear velocities of the shoulder, wrist, elbow and hand, all of which are 13–21% higher for male athletes compared with females [43].

The increasing performance gap between males and females as upper body strength becomes more critical for performance is likely explained to a large extent by the observation that males have disproportionately greater strength in their upper compared to lower body, while females show the inverse [44, 45]. This different distribution of strength compounds the general advantage of increased muscle mass in upper body dominant disciplines. Males also have longer arms than females, which allows greater torque production from the arm lever when, for example, throwing a ball, punching or pushing.

3.2 Olympic Weightlifting

In Olympic weightlifting, where weight categories differ between males and females, the performance gap is between 31 and 37% across the range of competitive body weights between 1998 and 2020 (Fig. 1). It is important to note that at all weight categories below the top/open category, performances are produced within weight categories with an upper limit, where strength can be correlated with "fighting weight", and we focused our analysis of performance gaps in these categories.

To explore strength–mass relationships further, we compared Olympic weightlifting data between equivalent weight categories which, to some extent, limit athlete height, to examine the hypothesis that male performance advantage may be largely (or even wholly) mediated by increased height and lever-derived advantages (Table 2). Between 1998 and 2018, a 69 kg category was common to both males and females, with the male record holder (69 kg, 1.68 m) lifting a combined weight 30.1% heavier than the female record holder (69 kg, 1.64 m). Weight category changes in 2019 removed the common 69 kg category and created a common 55 kg category. The current male record holder (55 kg, 1.52 m) lifts 29.5% heavier than the female record holder (55 kg, 1.52 m). These comparisons demonstrate that males are approximately 30% stronger than females of equivalent stature and mass. However, importantly, male vs. female weightlifting performance gaps increase with increasing bodyweight. For example, in the top/open weight category of Olympic weightlifting, in the absence of weight (and associated height) limits, maximum male lifting strength exceeds female lifting strength by nearly 40%. This is further manifested in powerlifting, where the male record (total of squat, bench press and deadlift) is 65% higher than the female record in the open weight category of the World Open Classic Records. Further analysis of Olympic weightlifting data shows that the 55-kg male record holder is 6.5% stronger than the 69-kg female record holder (294 kg vs 276 kg), and that the 69-kg male record is 3.2% higher than the record held in the female open category by a 108-kg female (359 kg vs 348 kg). This Olympic weightlifting analysis reveals key differences between male and female strength capacity. It shows that, even after adjustment for mass, biological males are significantly stronger (30%) than females, and

Table 2 Olympic weightlifting data between equivalent male–female and top/open weight categories

	Sex	Weight (kg)	Height (m)	Combined record (kg)	Strength to weight ratio	Relative performance (%)
2019 record in the 55 kg weight-limited category						
Liao Qiuyun	F	55	1.52	227	4.13	
Om Yun-chol	M	55	1.52	294	5.35	29.5
1998–2018 record in the 69-kg weight-limited category						
Oxsana Slivenko	F	69	1.64	276	4.00	
Liao Hui	M	69	1.68	359	5.20	30.1
Comparative performances for top/open categories (all time heaviest combined lifts)						
Tatiana Kashirina	F	108	1.77	348	3.22	
Lasha Talakhadze	M	168	1.97	484	2.88	39.1

F female, *M* male

that females who are 60% heavier than males do not overcome these strength deficits.

3.3 Perspectives on Elite Athlete Performance Differences

Figure 1 illustrates the performance gap between adult elite males and adult elite females across various sporting disciplines and activities. The translation of these advantages, assessed as the performance difference between the very best males and very best females, are significant when extended and applied to larger populations. In running events, for example, where the male–female gap is approximately 11%, it follows that many thousands of males are faster than the very best females. For example, approximately 10,000 males have personal best times that are faster than the current Olympic 100 m female champion (World Athletics, personal communication, July 2019). This has also been described elsewhere [46, 47], and illustrates the true effect of an 11% typical difference on population comparisons between males and females. This is further apparent upon examination of selected junior male records, which surpass adult elite female performances by the age of 14–15 years (Table 3), demonstrating superior male athletic performance over elite females within a few years of the onset of puberty.

These data overwhelmingly confirm that testosterone-driven puberty, as the driving force of development of male secondary sex characteristics, underpins sporting advantages that are so large no female could reasonably hope to succeed without sex segregation in most sporting competitions. To ensure, in light of these analyses, that female athletes can be included in sporting competitions in a fair and safe manner, most sports have a female category the purpose of which is the protection of both fairness and, in some sports, safety/welfare of athletes who do not benefit from the physiological changes induced by male levels of testosterone from puberty onwards.

Table 3 Selected junior male records in comparison with adult elite female records

Event	Schoolboy male record	Elite female (adult) record
100 m	10.20 (age 15)	10.49
800 m	1:51.23 (age 14)	1:53.28
1500 m	3:48.37 (age 14)	3:50.07
Long jump	7.85 m (age 15)	7.52 m
Discus throw	77.68 m (age 15)	76.80 m

M meters

Time format: minutes:seconds.hundredths of a second

3.4 Performance Differences in Non-elite Individuals

The male performance advantages described above in athletic cohorts are similar in magnitude in untrained people. Even when expressed relative to fat-free weight, VO_{2max} is 12–15% higher in males than in females [48]. Records of lower-limb muscle strength reveal a consistent 50% difference in peak torque between males and females across the lifespan [31]. Hubal et al. [49] tested 342 women and 243 men for isometric (maximal voluntary contraction) and dynamic strength (one-repetition maximum; 1RM) of the elbow flexor muscles and performed magnetic resonance imaging (MRI) of the biceps brachii to determine cross-sectional area. The males had 57% greater muscle size, 109% greater isometric strength, and 89% greater 1RM strength than age-matched females. This reinforces the finding in athletic cohorts that sex differences in muscle size and strength are more pronounced in the upper body.

Recently, sexual dimorphism in arm force and power was investigated in a punch motion in moderately-trained individuals [50]. The power produced during a punch was 162% greater in males than in females, and the least powerful man produced more power than the most powerful woman. This highlights that sex differences in parameters such as mass, strength and speed may combine to produce even larger sex differences in sport-specific actions, which often are a product of how various physical capacities combine. For example, power production is the product of force and velocity, and momentum is defined as mass multiplied by velocity. The momentum and kinetic energy that can be transferred to another object, such as during a tackle or punch in collision and combat sports are, therefore, dictated by: the mass; force to accelerate that mass, and; resultant velocity attained by that mass. As there is a male advantage for each of these factors, the net result is likely synergistic in a sport-specific action, such as a tackle or a throw, that widely surpasses the sum of individual magnitudes of advantage in isolated fitness variables. Indeed, already at 17 years of age, the average male throws a ball further than 99% of 17-year-old females [51], despite no single variable (arm length, muscle mass etc.) reaching this numerical advantage. Similarly, punch power is 162% greater in men than women even though no single parameter that produces punching actions achieves this magnitude of difference [50].

4 Is the Male Performance Advantage Lost when Testosterone is Suppressed in Transgender Women?

The current IOC criteria for inclusion of transgender women in female sports categories require testosterone suppression below 10 nmol/L for 12 months prior to and during competition. Given the IOC's stated position that the "overriding sporting objective is and remains the guarantee of fair competition" [14], it is reasonable to assume that the rationale for this requirement is that it reduces the male performance advantages described previously to an acceptable degree, thus permitting fair and safe competition. To determine whether this medical intervention is sufficient to remove (or reduce) the male performance advantage, which we described above, we performed a systematic search of the scientific literature addressing anthropometric and muscle characteristics of transgender women. Search terms and filtering of peer-reviewed data are given in Supplementary Table S1.

4.1 Anthropometrics

Given its importance for the general health of the transgender population, there are multiple studies of bone health, and reviews of these data. To summarise, transgender women often have low baseline (pre-intervention) bone mineral density (BMD), attributed to low levels of physical activity, especially weight-bearing exercise, and low vitamin D levels [52, 53]. However, transgender women generally maintain bone mass over the course of at least 24 months of testosterone suppression. There may even be small but significant increases in BMD at the lumbar spine [54, 55]. Some retrieved studies present data pertaining to maintained BMD in transgender women after many years of testosterone suppression. One such study concluded that "BMD is preserved over a median of 12.5 years" [56]. In support, no increase in fracture rates was observed over 12 months of testosterone suppression [54]. Current advice, including that from the International Society for Clinical Densitometry, is that transgender women, in the absence of other risk factors, do not require monitoring of BMD [52, 57]. This is explicable under current standard treatment regimes, given the established positive effect of estrogen, rather than testosterone, on bone turnover in males [58].

Given the maintenance of BMD and the lack of a plausible biological mechanism by which testosterone suppression might affect skeletal measurements such as bone length and hip width, we conclude that height and skeletal parameters remain unaltered in transgender women, and that sporting advantage conferred by skeletal size and bone density would be retained despite testosterone reductions compliant with the IOC's current guidelines. This is of particular relevance to sports where height, limb length and handspan are key (e.g. basketball, volleyball, handball) and where high movement efficiency is advantageous. Male bone geometry and density may also provide protection against some sport-related injuries—for example, males have a lower incidence of knee injuries, often attributed to low quadriceps (Q) angle conferred by a narrow pelvic girdle [59, 60].

4.2 Muscle and Strength Metrics

As discussed earlier, muscle mass and strength are key parameters underpinning male performance advantages. Strength differences range between 30 and 100%, depending upon the cohort studied and the task used to assess strength. Thus, given the important contribution made by strength to performance, we sought studies that have assessed strength and muscle/lean body mass changes in transgender women after testosterone reduction. Studies retrieved in our literature search covered both longitudinal and cross-sectional analyses. Given the superior power of the former study type, we will focus on these.

The pioneer work by Gooren and colleagues, published in part in 1999 [61] and in full in 2004 [62], reported the effects of 1 and 3 years of testosterone suppression and estrogen supplementation in 19 transgender women (age 18–37 years). After the first year of therapy, testosterone levels were reduced to 1 nmol/L, well within typical female reference ranges, and remained low throughout the study course. As determined by MRI, thigh muscle area had decreased by − 9% from baseline measurement. After 3 years, thigh muscle area had decreased by a further − 3% from baseline measurement (total loss of − 12% over 3 years of treatment). However, when compared with the baseline measurement of thigh muscle area in transgender men (who are born female and experience female puberty), transgender women retained significantly higher thigh muscle size. The final thigh muscle area, after three years of testosterone suppression, was 13% larger in transwomen than in the transmen at baseline ($p < 0.05$). The authors concluded that testosterone suppression in transgender women does not reverse muscle size to female levels.

Including Gooren and Bunck [62], 12 longitudinal studies [53, 63–73] have examined the effects of testosterone suppression on lean body mass or muscle size in transgender women. The collective evidence from these studies suggests that 12 months, which is the most commonly examined intervention period, of testosterone suppression to female-typical reference levels results in a modest (approximately − 5%) loss of lean body mass or muscle size (Table 4). No

Table 4 Longitudinal studies of muscle and strength changes in adult transgender women undergoing cross-sex hormone therapy

Study	Participants (age)	Therapy	Confirmed serum testosterone levels	Muscle/strength data	Comparison with reference females
Polderman et al. [73]	*N* = 12 TW 18–36 yr (age range)	T suppression + E supplementation	< 2 nmol/L at 4 mo	*LBM* 4 mo − 2.2%	*LBM* 4 mo 16%
Gooren and Bunck [62]	*N* = 19 TW 26 ± 6 yr	T suppression + E supplementation	≤ 1 nmol/L at 1 and 3 yr	*Thigh area* 1 yr − 9% / 3 yr -12%	*Thigh area* 1 yr 16%/3 yr 13%
Haraldsen et al. [63]	*N* = 12 TW 29 ± 8 yr	E supplementation	< 10 nmol/L at 3 mo and 1 yr	*LBM* 3 mo/1 yr—small changes, unclear magnitude	
Mueller et al. [64]	*N* = 84 TW 36 ± 11 yr	T suppression + E supplementation	≤ 1 nmol/L at 1 and 2 yr	*LBM* 1 yr − 4%/2 yr − 7%	
Wierckx et al. [65]	*N* = 53 TW 31 ± 14 yr	T suppression + E supplementation	< 10 nmol/L at 1 yr	*LBM* 1 yr − 5%	*LBM* 1 yr 39%
Van Caenegem et al. [53] (and Van Caenegem et al. [76])	*N* = 49 TW 33 ± 14 yr	T suppression + E supplementation	≤ 1 nmol/L at 1 and 2 yr	*LBM* 1 yr − 4%/2 yr − 0.5% *Grip strength* 1 yr − 7%/2 yr − 9% *Calf area* 1 yr − 2%/2 yr − 4% *Forearm area* 1 yr − 8%/2 yr − 4%	*LBM* 1 yr 24%/2 yr 28% *Grip strength* 1 yr 26%/2 yr 23% *Calf area* 1 yr 16%/2 yr 13% *Forearm area* 1 yr 29%/2 yr 34%
Gava et al. [66]	*N* = 40 TW 31 ± 10 yr	T suppression + E supplementation	< 5 nmol/L at 6 mo and ≤ 1 nmol/L at 1 yr	*LBM* 1 yr − 2%	
Auer et al. [67]	*N* = 45 TW 35 ± 1 (SE) yr	T suppression + E supplementation	< 5 nmol/L at 1 yr	*LBM* 1 yr − 3%	*LBM* 1 yr 27%
Klaver et al. [68]	*N* = 179 TW 29 (range 18–66)	T suppression + E supplementation	≤ 1 nmol/L at 1 yr	*LBM 1 yr* Total − 3% Arm region − 6% Trunk region − 2% Android region 0% Gynoid region − 3% Leg region − 4%	*LBM 1 yr* Total 18% Arm region 28% Leg region 19%
Fighera et al. [69]	*N* = 46 TW 34 ± 10	E supplementation with or without T suppression	< 5 nmol/L at 3 mo ≤ 1 nmol/L at 31 mo	*ALM* 31 mo − 4% from the 3 mo visit	
Scharff et al. [70]	*N* = 249 TW 28 (inter quartile range 23–40)	T suppression + E supplementation	≤ 1 nmol/L at 1 yr	*Grip strength* 1 yr − 4%	*Grip strength* 1 yr 21%
Wiik et al. [71]	*N* = 11 TW 27 ± 4	T suppression + E supplementation	≤ 1 nmol/L at 4 mo and at 1 yr	*Thigh volume* 1 yr − 5% *Quad area* 1 yr − 4% *Knee extension strength* 1 yr 2% *Knee flexion strength* 1 yr 3%	*Thigh volume* 1 yr 33% *Quad area* 26% *Knee extension strength* 41% *Knee flexion strength* 33%

Studies reporting measures of lean mass, muscle volume, muscle area or strength are included. Muscle/strength data are calculated in reference to baseline cohort data and, where reported, reference female (or transgender men before treatment) cohort data. Tack et al. [72] was not included in the table since some of the participants had not completed full puberty at treatment initiation. van Caenegem et al. [76] reports reference female values measured in a separately-published, parallel cohort of transgender men

N number of participants, *TW* transgender women, *Yr* year, *Mo* month, *T* testosterone, *E* estrogen. ± Standard deviation (unless otherwise indicated in text), *LBM* lean body mass, *ALM* appendicular lean mass study has reported muscle loss exceeding the −12% found by Gooren and Bunck after 3 years of therapy. Notably, studies have found very consistent changes in lean body mass (using dual-energy X-ray absorptiometry) after 12 months of treatment, where the change has always been between −3 and −5% on average, with slightly greater reductions in the arm compared with the leg region [68]. Thus, given the large baseline differences in muscle mass between males and females (Table 1; approximately 40%), the reduction achieved by 12 months of testosterone suppression can reasonably be assessed as small relative to the initial superior mass. We, therefore, conclude that the muscle mass advantage males possess over females, and the performance implications thereof, are not removed by the currently studied durations (4 months, 1, 2 and 3 years) of testosterone suppression in transgender women. In sports where muscle mass is important for performance, inclusion is therefore only possible if a large imbalance in fairness, and potentially safety in some sports, is to be tolerated.

To provide more detailed information on not only gross body composition but also thigh muscle volume and contractile density, Wiik et al. [71] recently carried out a comprehensive battery of MRI and computed tomography (CT) examinations before and after 12 months of successful testosterone suppression and estrogen supplementation in 11 transgender women. Thigh volume (both anterior and posterior thigh) and quadriceps cross-sectional area decreased −4 and −5%, respectively, after the 12-month period, supporting previous results of modest effects of testosterone suppression on muscle mass (see Table 4). The more novel measure of radiological attenuation of the quadriceps muscle, a valid proxy of contractile density [74, 75], showed no significant change in transgender women after 12 months of treatment, whereas the parallel group of transgender men demonstrated a +6% increase in contractile density with testosterone supplementation.

As indicated earlier (e.g. Table 1), the difference in muscle strength between males and females is often more pronounced than the difference in muscle mass. Unfortunately, few studies have examined the effects of testosterone suppression on muscle strength or other proxies of performance in transgender individuals. The first such study was published online approximately 1 year prior to the release of the current IOC policy. In this study, as well as reporting changes in muscle size, van Caenegem et al. [53] reported that hand-grip strength was reduced from baseline measurements by −7% and −9% after 12 and 24 months, respectively, of cross-hormone treatment in transgender women. Comparison with data in a separately-published, parallel cohort of transgender men [76] demonstrated a retained hand-grip strength advantage after 2 years of 23% over female baseline measurements (a calculated average of baseline data obtained from control females and transgender men).

In a recent multicenter study [70], examination of 249 transgender women revealed a decrease of −4% in grip strength after 12 months of cross-hormone treatment, with no variation between different testosterone level, age or BMI tertiles (all transgender women studied were within female reference ranges for testosterone). Despite this modest reduction in strength, transgender women retained a 17% grip strength advantage over transgender men measured at baseline. The authors noted that handgrip strength in transgender women was in approximately the 25th percentile for males but was over the 90th percentile for females, both before and after hormone treatment. This emphasizes that the strength advantage for males over females is inherently large. In another study exploring handgrip strength, albeit in late puberty adolescents, Tack et al. noted no change in grip strength after hormonal treatment (average duration 11 months) of 21 transgender girls [72].

Although grip strength provides an excellent proxy measurement for general strength in a broad population, specific assessment within different muscle groups is more valuable in a sports-specific framework. Wiik et al., [71] having determined that thigh muscle mass reduces only modestly, and that no significant changes in contractile density occur with 12 months of testosterone suppression, provided, for the first time, data for isokinetic strength measurements of both knee extension and knee flexion. They reported that muscle strength after 12 months of testosterone suppression was comparable to baseline strength. As a result, transgender women remained about 50% stronger than both the group of transgender men at baseline and a reference group of females. The authors suggested that small neural learning effects during repeated testing may explain the apparent lack of small reductions in strength that had been measured in other studies [71].

These longitudinal data comprise a clear pattern of very modest to negligible changes in muscle mass and strength in transgender women suppressing testosterone for at least 12 months. Muscle mass and strength are key physical parameters that constitute a significant, if not majority, portion of the male performance advantage, most notably in those sports where upper body strength, overall strength, and muscle mass are crucial determinants of performance. Thus, our analysis strongly suggests that the reduction in testosterone levels required by many sports federation transgender policies is insufficient to remove or reduce the male advantage, in terms of muscle mass and strength, by any meaningful degree. The relatively consistent finding of a minor (approximately −5%) muscle loss after the first year of treatment is also in line with studies on androgen-deprivation therapy in males with prostate cancer, where the annual loss of lean body mass has been reported to range between −2 and −4% [77].

Although less powerful than longitudinal studies, we identified one major cross-sectional study that measured muscle mass and strength in transgender women. In this study, 23 transgender women and 46 healthy age- and height-matched control males were compared [78]. The transgender women were recruited at least 3 years after sex reassignment surgery, and the mean duration of cross-hormone treatment was 8 years. The results showed that transgender women had 17% less lean mass and 25% lower peak quadriceps muscle strength than the control males [78]. This cross-sectional comparison suggests that prolonged testosterone suppression, well beyond the time period mandated by sports federations substantially reduces muscle mass and strength in transgender women. However, the typical gap in lean mass and strength between males and females at baseline (Table 1) exceeds the reductions reported in this study [78]. The final average lean body mass of the transgender women was 51.2 kg, which puts them in the 90th percentile for women [79]. Similarly, the final grip strength was 41 kg, 25% higher than the female reference value [80]. Collectively, this implies a retained physical advantage even after 8 years of testosterone suppression. Furthermore, given that cohorts of transgender women often have slightly lower baseline measurements of muscle and strength than control males [53], and baseline measurements were unavailable for the transgender women of this cohort, the above calculations using control males reference values may be an overestimate of actual loss of muscle mass and strength, emphasizing both the need for caution when analyzing cross-sectional data in the absence of baseline assessment and the superior power of longitudinal studies quantifying within-subject changes.

4.3 Endurance Performance and Cardiovascular Parameters

No controlled longitudinal study has explored the effects of testosterone suppression on endurance-based performance. Sex differences in endurance performance are generally smaller than for events relying more on muscle mass and explosive strength. Using an age grading model designed to normalize times for masters/veteran categories, Harper [81] analyzed self-selected and self-reported race times for eight transgender women runners of various age categories who had, over an average 7 year period (range 1–29 years), competed in sub-elite middle and long distance races within both the male and female categories. The age-graded scores for these eight runners were the same in both categories, suggesting that cross-hormone treatment reduced running performance by approximately the size of the typical male advantage. However, factors affecting performances in the interim, including training and injury, were uncontrolled for periods of years to decades and there were uncertainties regarding which race times were self-reported vs. which race times were actually reported and verified, and factors such as standardization of race course and weather conditions were unaccounted for. Furthermore, one runner improved substantially post-transition, which was attributed to improved training [81]. This demonstrates that performance decrease after transition is not inevitable if training practices are improved. Unfortunately, no study to date has followed up these preliminary self-reports in a more controlled setting, so it is impossible to make any firm conclusions from this data set alone.

Circulating hemoglobin levels are androgen-dependent [82] and typically reported as 12% higher in males compared with females [4]. Hemoglobin levels appear to decrease by 11–14% with cross-hormone therapy in transgender women [62, 71], and indeed comparably sized reductions have been reported in athletes with DSDs where those athletes are sensitive to and been required to reduce testosterone [47, 83]. Oxygen-carrying capacity in transgender women is most likely reduced with testosterone suppression, with a concomitant performance penalty estimated at 2–5% for the female athletic population [83]. Furthermore, there is a robust relationship between hemoglobin mass and VO_{2max} [84, 85] and reduction in hemoglobin is generally associated with reduced aerobic capacity [86, 87]. However, hemoglobin mass is not the only parameter contributing to VO_{2max}, where central factors such as total blood volume, heart size and contractility, and peripheral factors such as capillary supply and mitochondrial content also plays a role in the final oxygen uptake [88]. Thus, while a reduction in hemoglobin is strongly predicted to impact aerobic capacity and reduce endurance performance in transgender women, it is unlikely to completely close the baseline gap in aerobic capacity between males and females.

The typical increase in body fat noted in transgender women [89, 90] may also be a disadvantage for sporting activities (e.g. running) where body weight (or fat distribution) presents a marginal disadvantage. Whether this body composition change negatively affects performance results in transgender women endurance athletes remains unknown. It is unclear to what extent the expected increase in body fat could be offset by nutritional and exercise countermeasures, as individual variation is likely to be present. For example, in the Wiik et al. study [71], 3 out of the 11 transgender women were completely resistant to the marked increase in total adipose tissue noted at the group level. This inter-individual response to treatment represents yet another challenge for sports governing bodies who most likely, given the many obstacles with case-by-case assessments, will form policies based on average effect sizes.

Altogether, the effects of testosterone suppression on performance markers for endurance athletes remain insufficiently explored. While the negative effect on hemoglobin concentration is well documented, the effects on VO_{2max}, left ventricular size, stroke volume, blood volume, cardiac output lactate threshold, and exercise economy, all of which are important determinants of endurance performance, remain unknown. However, given the plausible disadvantages with testosterone suppression mentioned in this section, together with the more marginal male advantage in endurance-based sports, the balance between inclusion and fairness is likely closer to equilibrium in weight-bearing endurance-based sports compared with strength-based sports where the male advantage is still substantial.

5 Discussion

The data presented here demonstrate that superior anthropometric, muscle mass and strength parameters achieved by males at puberty, and underpinning a considerable portion of the male performance advantage over females, are not removed by the current regimen of testosterone suppression permitting participation of transgender women in female sports categories. Rather, it appears that the male performance advantage remains substantial. Currently, there is no consensus on an acceptable degree of residual advantage held by transgender women that would be tolerable in the female category of sport. There is significant dispute over this issue, especially since the physiological determinants of performance vary across different sporting disciplines. However, given the IOC position that fair competition is the overriding sporting objective [14], any residual advantage carried by transgender women raises obvious concerns about fair and safe competition in the numerous sports where muscle mass, strength and power are key performance determinants.

5.1 Perspectives on Athletic Status of Transgender Women

Whilst available evidence is strong and convincing that strength, skeletal- and muscle-mass derived advantages will largely remain after cross-hormone therapy in transgender women, it is acknowledged that the findings presented here are from healthy adults with regular or even low physical activity levels [91], and not highly trained athletes. Thus, further research is required in athletic transgender populations.

However, despite the current absence of empirical evidence in athletic transgender women, it is possible to evaluate potential outcomes in athletic transgender women compared with untrained cohorts. The first possibility is that athletic transgender women will experience similar reductions (approximately −5%) in muscle mass and strength as untrained transgender women, and will thus retain significant advantages over a comparison group of females. As a result of higher baseline characteristics in these variables, the retained advantage may indeed be even larger. A second possibility is that by virtue of greater muscle mass and strength at baseline, pre-trained transgender women will experience larger relative decreases in muscle mass and strength if they converge with untrained transgender women, particularly if training is halted during transition. Finally, training before and during the period of testosterone suppression may attenuate the anticipated reductions, such that relative decreases in muscle mass and strength will be smaller or non-existent in transgender women who undergo training, compared to untrained (and non-training) controls.

It is well established that resistance training counteracts substantial muscle loss during atrophy conditions that are far more severe than testosterone suppression. For example, resistance exercise every third day during 90-days bed rest was sufficient to completely offset the 20% reduction in knee extensor muscle size noted in the resting control subjects [92]. More relevant to the question of transgender women, however, is to examine training effects in studies where testosterone has been suppressed in biological males. Kvorning et al. investigated, in a randomized placebo-controlled trial, how suppression of endogenous testosterone for 12 weeks influenced muscle hypertrophy and strength gains during a training program (3 days/week) that took place during the last 8 weeks of the 3-month suppression period [93]. Despite testosterone suppression to female levels of 2 nmol/L, there was a significant + 4% increase in leg lean mass and a + 2% increase in total lean body mass, and a measurable though insignificant increase in isometric knee extension strength. Moreover, in select exercises used during the training program, 10RM leg press and bench press increased + 32% and + 17%, respectively. While some of the training adaptations were lower than in the placebo group, this study demonstrates that training during a period of testosterone suppression not only counteracts muscle loss, but can actually increase muscle mass and strength.

Males with prostate cancer undergoing androgen deprivation therapy provide a second avenue to examine training effects during testosterone suppression. Testosterone levels are typically reduced to castrate levels, and the loss of lean mass has typically ranged between −2 and −4% per year [77], consistent with the findings described previously in transgender women. A recent meta-analysis concluded that exercise interventions including resistance exercise were generally effective for maintaining muscle mass and increasing muscle strength in prostate cancer patients undergoing androgen deprivation therapy [94]. It is important to emphasize that the efficacy of the different training programs may vary. For example, a 12-week training study of prostate cancer patients undergoing androgen deprivation therapy included drop-sets to combine heavy loads and high volume while eliciting near-maximal efforts in each set [95]. This strategy resulted in significantly increased lean body mass (+3%), thigh muscle volume (+6%), knee extensor 1RM strength (+28%) and leg press muscle endurance (+110%).

In addition to the described effects of training during testosterone suppression, the effect of training prior to testosterone suppression may also contribute to the attenuation of any muscle mass and strength losses, via a molecular mechanism referred to as 'muscle memory' [96]. Specifically, it has been suggested that myonuclei acquired by skeletal muscle cells during training are maintained during subsequent atrophy conditions [97]. Even though this model of muscle memory has been challenged recently [98], it may facilitate an improved training response upon retraining [99]. Mechanistically, the negative effects of testosterone suppression on muscle mass are likely related to reduced levels of resting protein synthesis [100], which, together with protein breakdown, determines the net protein balance of skeletal muscle. However, testosterone may not be required to elicit a robust muscle protein synthesis response to resistance exercise [100]. Indeed, relative increases in muscle mass in men and women from resistance training are comparable, despite marked differences in testosterone levels [101], and the acute rise in testosterone apparent during resistance exercise does not predict muscle hypertrophy nor strength gains [102]. This suggests that even though testosterone is important for muscle mass, especially during puberty, the maintenance of muscle mass through resistance training is not crucially dependent on circulating testosterone levels.

Thus, in well-controlled studies in biological males who train while undergoing testosterone reduction, training is protective of, and may even enhance, muscle mass and strength attributes. Considering transgender women athletes who train during testosterone suppression, it is plausible to conclude that any losses will be similar to or even smaller in magnitude than documented in the longitudinal studies described in this review. Furthermore, pre-trained transgender women are likely to have greater muscle mass at baseline than untrained transgender women; it is possible that even with the same, rather than smaller, relative decreases in muscle mass and strength, the magnitude of retained advantage will be greater. In contrast, if pre-trained transgender women undergo testosterone suppression while refraining from intense training, it appears likely that muscle mass and strength will be lost at either the same or greater rate than untrained individuals, although there is no rationale to expect a weaker endpoint state. The degree of change in athletic transgender women is influenced by the athlete's baseline resistance-training status, the efficacy of the implemented program and other factors such as genetic make-up and nutritional habits, but we argue that it is implausible that athletic transgender women would achieve final muscle mass and strength metrics that are on par with reference females at comparable athletic level.

5.2 The Focus on Muscle Mass and Strength

We acknowledge that changes in muscle mass are not always correlated in magnitude to changes in strength measurements because muscle mass (or total mass) is not the only contributor to strength [103]. Indeed, the importance of the nervous system, e.g. muscle agonist activation (recruitment and firing frequency) and antagonist co-activation, for muscle strength must be acknowledged [104]. In addition, factors such as fiber types, biomechanical levers, pennation angle, fascicle length and tendon/extracellular matrix composition may all influence the ability to develop muscular force [105]. While there is currently limited to no information on how these factors are influenced by testosterone suppression, the impact seems to be minute, given the modest changes noted in muscle strength during cross-hormone treatment.

It is possible that estrogen replacement may affect the sensitivity of muscle to anabolic signaling and have a protective effect on muscle mass [106] explaining, in part, the modest change in muscle mass with testosterone suppression and accompanying cross-hormone treatment. Indeed, this is supported by research conducted on estrogen replacement therapy in other targeted populations [107, 108] and in several different animal models, including mice after gonadectomy [109] and ovariectomy [110].

In terms of other performance proxies relevant to sports performance, there is no research evaluating the effects of transgender hormone treatment on factors such as agility, jumping or sprint performance, competition strength performance (e.g. bench press), or discipline-specific performance. Other factors that may impact sports performance, known to be affected by testosterone and some of them measurably different between males and females, include visuospatial abilities, aggressiveness, coordination and flexibility.

5.3 Testosterone-Based Criteria for Inclusion of Transgender Women in Female Sports

The appropriate testosterone limit for participation of transgender women in the female category has been a matter of debate recently, where sports federations such as World Athletics recently lowered the eligibility criterion of free circulating testosterone (measured by means of liquid chromatography coupled with mass spectrometry) to < 5 nmol/L. This was based, at least in part, on a thorough review by Handelsman et al. [4], where the authors concluded that, given the nonoverlapping distribution of circulating testosterone between males and females, and making an allowance for females with mild hyperandrogenism (e.g. with polycystic ovary syndrome), the appropriate testosterone limit should be 5 rather than 10 nmol/L.

From the longitudinal muscle mass/strength studies summarised here, however, it is apparent that most therapeutic interventions result in almost complete suppression of testosterone levels, certainly well below 5 nmol/L (Table 4). Thus, with regard to transgender women athletes, we question whether current circulating testosterone level cut-off can be a meaningful decisive factor, when in fact not even suppression down to around 1 nmol/L removes the anthropometric and muscle mass/strength advantage in any significant way.

In terms of duration of testosterone suppression, it may be argued that although 12 months of treatment is not sufficient to remove the male advantage, perhaps extending the time frame of suppression would generate greater parity with female metrics. However, based on the studies reviewed here, evidence is lacking that this would diminish the male advantage to a tolerable degree. On the contrary, it appears that the net loss of lean mass and grip strength is not substantially decreased at year 2 or 3 of cross-hormone treatment (Table 4), nor evident in cohorts after an average 8 years after transition. This indicates that a plateau or a new steady state is reached within the first or second year of treatment, a phenomenon also noted in transgender men, where the increase in muscle mass seems to stabilise between the first and the second year of testosterone treatment [111].

6 Conclusions

We have shown that under testosterone suppression regimes typically used in clinical settings, and which comfortably exceed the requirements of sports federations for inclusion of transgender women in female sports categories by reducing testosterone levels to well below the upper tolerated limit, evidence for loss of the male performance advantage, established by testosterone at puberty and translating in elite athletes to a 10–50% performance advantage, is lacking. Rather, the data show that strength, lean body mass, muscle size and bone density are only trivially affected. The reductions observed in muscle mass, size, and strength are very small compared to the baseline differences between males and females in these variables, and thus, there are major performance and safety implications in sports where these attributes are competitively significant. These data significantly undermine the delivery of fairness and safety presumed by the criteria set out in transgender inclusion policies, particularly given the stated prioritization of fairness as an overriding objective (for the IOC). If those policies are intended to preserve fairness, inclusion and the safety of biologically female athletes, sporting organizations may need to reassess their policies regarding inclusion of transgender women.

From a medical-ethical point of view, it may be questioned as to whether a requirement to lower testosterone below a certain level to ensure sporting participation can be justified at all. If the advantage persists to a large degree, as evidence suggests, then a stated objective of targeting a certain testosterone level to be eligible will not achieve its objective and may drive medical practice that an individual may not want or require, without achieving its intended benefit.

The research conducted so far has studied untrained transgender women. Thus, while this research is important to understand the isolated effects of testosterone suppression, it is still uncertain how transgender women athletes, perhaps undergoing advanced training regimens to counteract the muscle loss during the therapy, would respond. It is also important to recognize that performance in most sports may be influenced by factors outside muscle mass and strength, and the balance between inclusion, safety and fairness therefore differs between sports. While there is certainly a need for more focused research on this topic, including more comprehensive performance tests in transgender women athletes and studies on training capacity of transgender women undergoing hormone therapy, it is still important to recognize that the biological factors underpinning athletic performance are unequivocally established. It is, therefore, possible to make strong inferences and discuss potential performance implications despite the lack of direct sport-specific studies in athletes. Finally, since athlete safety could arguably be described as the immediate priority above considerations of fairness and inclusion, proper risk assessment should be conducted within respective sports that continue to include transgender women in the female category.

If transgender women are restricted within or excluded from the female category of sport, the important question is whether or not this exclusion (or conditional exclusion) is necessary and proportionate to the goal of ensuring fair, safe and meaningful competition. Regardless of what the future will bring in terms of revised transgender policies, it is clear that different sports differ vastly in terms of physiological determinants of success, which may create safety considerations and may alter the importance of retained performance advantages. Thus, we argue against universal guidelines for transgender athletes in sport and instead propose that each individual sports federation evaluate their own conditions for inclusivity, fairness and safety.

Compliance with Ethical Standards

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References

1. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: training considerations. Sport Med. 2018;48:765–85.
2. Coyle EF. Integration of the physiological factors determining endurance performance ability. Exerc Sport Sci Rev. 1995;23:25–63.
3. Haizlip KM, Harrison BC, Leinwand LA. Sex-based differences in skeletal muscle kinetics and fiber-type composition. Physiology. 2015;30(1):30–9.
4. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocr Rev. 2018;39(5):803–29.
5. Sandbakk Ø, Solli GS, Holmberg HC. Sex differences in world-record performance: the influence of sport discipline and competition duration. Int J Sports Physiol Perform. 2018;13(1):2–8.
6. Genel M. Transgender athletes: how can they be accommodated? Curr Sports Med Rep. 2017;16(1):12–3.
7. Coggon J, Hammond N, Holm S. Transsexuals in sport—fairness and freedom, regulation and law. Sport Ethics Philos. 2008;2(1):4–17.
8. Pitsiladis Y, Harper J, Betancurt JO, et al. Beyond fairness. Curr Sports Med Rep. 2016;15:386–8.
9. Reeser JC. Gender identity and sport: is the playing field level? Br J Sports Med. 2005;39(10):695–9.
10. Transgender Policy in Sport. A review of current policy and commentary of the challenges of policy creation. Curr Sports Med Rep. 2019;18(6):239–47.
11. Harper J, Martinez-Patino MJ, Pigozzi F, Pitsiladis Y. Implications of a third gender for elite sports. Curr Sports Med Rep. 2018;17(2):42–4.
12. Singh B, Singh K. The hermeneutics of participation of transgender athletes in sports—intensifying third force. Phys Cult Sport Stud Res. 2011;52(1):44–8.
13. Bianchi A. Transgender women in sport. J Philos Sport. 2017;44:229–42.
14. Harper J, Hirschberg AL, Jose M, et al. IOC consensus meeting on sex reassignment and hyperandrogenism. 2015. https://stillmed.olympic.org/Documents/Commissions_PDFfiles/Medical_commission/2015-11_ioc_consensus_meeting_on_sex_reassignment_and_hyperandrogenism-en.pdf. Accessed 28 Nov 2020
15. Carré GA, Greenfield A. The gonadal supporting cell lineage and mammalian sex determination: the differentiation of sertoli and granulosa cells. In: Piprek R, editor. Molecular mechanisms of cell differentiation in gonad development. Results and problems in cell differentiation, vol 58. Cham: Springer; 2016. p. 47–66.
16. Sobel V, Zhu YS, Imperato-McGinley J. Fetal hormones and sexual differentiation. Obstet Gynecol Clin N Am. 2004;31(4):837–xi.
17. Hughes IA. Disorders of sex development: a new definition and classification. Best Pract Res Clin Endocrinol Metab. 2008;22(1):119–34.
18. Tønnessen E, Svendsen IS, Olsen IC, et al. Performance development in adolescent track and field athletes according to age, sex and sport discipline. PLoS ONE. 2015;10(6):e0129014.
19. Gershoni M, Pietrokovski S. The landscape of sex-differential transcriptome and its consequent selection in human adults. BMC Biol. 2017;15(1):7.
20. Lanciotti L, Cofini M, Leonardi A, Penta L, Esposito S. Up-to-date review about minipuberty and overview on hypothalamic-pituitary-gonadal axis activation in fetal and neonatal life. Front Endocrinol. 2018;23(9):410.
21. Becker M, Hesse V. Minipuberty: why does it happen? Horm Res Paediatr. 2020;93(2):76–84.
22. Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985. Br J Sports Med. 2013;47(2):98–108.
23. Tambalis KD, Panagiotakos DB, Psarra G, et al. Physical fitness normative values for 6–18-year-old Greek boys and girls, using the empirical distribution and the lambda, mu, and sigma statistical method. Eur J Sport Sci. 2016;16(6):736–46.
24. Eiberg S, Hasselstrom H, Grønfeldt V, et al. Maximum oxygen uptake and objectively measured physical activity in Danish children 6–7 years of age: the Copenhagen school child intervention study. Br J Sports Med. 2005;39(10):725–30.
25. Bae YJ, Zeidler R, Baber R, et al. Reference intervals of nine steroid hormones over the life-span analyzed by LC-MS/MS: Effect of age, gender, puberty, and oral contraceptives. J Steroid Biochem Mol Biol. 2019;193:105409.
26. Thibault V, Guillaume M, Berthelot G, et al. Women and men in sport performance: the gender gap has not evolved since 1983. J Sport Sci Med. 2010;9(2):214–23.
27. Millard-Stafford M, Swanson AE, Wittbrodt MT. Nature versus nurture: have performance gaps between men and women reached an asymptote? Int J Sports Physiol Perform. 2018;13(4):530–5.
28. Lee DH, Keum N, Hu FB, et al. Development and validation of anthropometric prediction equations for lean body mass, fat mass and percent fat in adults using the National Health and Nutrition Examination Survey (NHANES) 1999–2006. Br J Nutr. 2017;118(10):858–66.
29. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. J Appl Physiol. 2000;89:81–8.
30. Bohannon RW, Wang YC, Yen SC, Grogan KA. Handgrip strength: a comparison of values obtained from the NHANES and NIH Toolbox studies. Am J Occup Ther. 2019;73(2):1–9.
31. Neder JA, Nery LE, Shinzato GT, et al. Reference values for concentric knee isokinetic strength and power in nonathletic men and women from 20 to 80 years old. J Orthop Sports Phys Ther. 1999;29:116–26.

32. Jantz LM, Jantz RL. Secular change in long bone length and proportion in the United States, 1800–1970. Am J Phys Anthropol. 1999;110(1):57–67.
33. Brinckmann P, Hoefert H, Jongen HT. Sex differences in the skeletal geometry of the human pelvis and hip joint. J Biomech. 1981;14(6):427–30.
34. Lepley AS, Joseph MF, Daigle NR, et al. Sex differences in mechanical properties of the Achilles tendon: longitudinal response to repetitive loading exercise. J Strength Cond Res. 2018;32(11):3070–9.
35. Pate RR, Kriska A. Physiological basis of the sex difference in cardiorespiratory endurance. Sports Med. 1984;1(2):87–9.
36. Astrand PO, Cuddy TE, Saltin B, Stenberg J. Cardiac output during submaximal and maximal work. J Appl Physiol. 1964;19:268–74.
37. Best SA, Okada Y, Galbreath MM, et al. Age and sex differences in muscle sympathetic nerve activity in relation to haemodynamics, blood volume and left ventricular size. Exp Physiol. 2014;99(6):839–48.
38. Tong E, Murphy WG, Kinsella A, et al. Capillary and venous haemoglobin levels in blood donors: a 42-month study of 36 258 paired samples. Vox Sang. 2010;98(4):547–53.
39. Dominelli PB, Molgat-Seon Y, Sheel AW. Sex differences in the pulmonary system influence the integrative response to exercise. Exerc Sport Sci Rev. 2019;47(3):142–50.
40. Wingate S. Cardiovascular anatomy and physiology in the female. Crit Care Nurs Clin N Am. 1997;9(4):447–52.
41. Haugen T, Breitschädel F, Wiig H, Seiler S. Countermovement jump height in national team athletes of various sports: a framework for practitioners and scientists. Int J Sports Physiol Perform. 2020 **(accessed 4 May 2020 from Researchgate)**
42. Thomas JR, French KE. Gender differences across age in motor performance a meta-analysis. Psychol Bull. 1985;98(2):260–82.
43. Antti M, Komi PV, Korjus T, et al. Body segment contributions to javelin throwing during final thrust phases. J Appl Biomech. 1994;10:166–77.
44. Lassek WD, Gaulin SJC. Costs and benefits of fat-free muscle mass in men: relationship to mating success, dietary requirements, and native immunity. Evol Hum Behav. 2009;20(5):322–8.
45. Stoll T, Huber E, Seifert B, et al. Maximal isometric muscle strength: normative values and gender-specific relation to age. Clin Rheumatol. 2000;19(2):105–11.
46. Coleman DL. Sex in sport. Law Contemp Probl. 2017;80:63–126.
47. CAS 2018/O/5794 Mokgadi Caster Semenya v. International Association of Athletics Federation. https://www.tas-cas.org/fileadmin/user_upload/CAS_Award_-_redacted_-_Semenya_ASA_IAAF.pdf. Accessed 28 Nov 2020
48. Sparling PB. A meta-analysis of studies comparing maximal oxygen uptake in men and women. Res Q Exerc Sport. 1980;51(3):542–52.
49. Hubal MJ, Gordish-Dressman H, Thompson PD, et al. Muscle size and strength gain after unilateral resistance training. Med Sci Sport Exerc. 2005;37(6):964–72.
50. Morris JS, Link J, Martin JC, Carrier DR. Sexual dimorphism in human arm power and force: implications for sexual selection on fighting ability. J Exp Biol. 2020;223(Pt 2):jeb212365.
51. Thomas JR, Thomas KT. Development of gender differences in physical activity. Quest. 1988;40(3):219–29.
52. Wiepjes CM, de Jongh RT, de Blok CJM, et al. Bone safety during the first ten years of gender-affirming hormonal treatment in transwomen and transmen. J Bone Miner Res. 2019;34(3):447–54.
53. Van Caenegem E, Wierckx K, Taes Y, et al. Preservation of volumetric bone density and geometry in trans women during cross-sex hormonal therapy: a prospective observational study. Osteoporos Int. 2015a;26(1):35–47.
54. Singh-Ospina N, Maraka S, Rodriguez-Gutierrez R, et al. Effect of sex steroids on the bone health of transgender individuals: a systematic review and meta-analysis. J Clin Endocrinol Metab. 2017;102(11):3904–13.
55. Fighera TM, Ziegelmann PK, da Silva TR, Spritzer PM. Bone mass effects of cross-sex hormone therapy in transgender people: updated systematic review and meta-analysis. J Endocr Soc. 2019;3(5):943–64.
56. Ruetsche AG, Kneubuehl R, Birkhaeuser MH, Lippuner K. Cortical and trabecular bone mineral density in transsexuals after long-term cross-sex hormonal treatment: a cross-sectional study. Osteoporos Int. 2005;16(7):791–8.
57. Rosen HN, Hamnvik OPR, Jaisamrarn U, et al. Bone densitometry in transgender and gender non-conforming (TGNC) individuals: 2019 ISCD official position. J Clin Densitom. 2019;22(4):544–53.
58. Khosla S, Melton LJ, Riggs BL. Estrogens and bone health in men. Calcif Tissue Int. 2001;69(4):189–92.
59. Sigward SM, Powers CM. The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. Clin Biomech. 2006;21(1):41–8.
60. Francis P, Whatman C, Sheerin K, et al. The proportion of lower limb running injuries by gender, anatomical location and specific pathology: a systematic review. J Sport Sci Med. 2019;18(1):21–31.
61. Elbers JM, Asscheman H, Seidell JC, Gooren LJ. Effects of sex steroid hormones on regional fat depots as assessed by magnetic resonance imaging in transsexuals. Am J Physiol. 1999;276(2):E317-25.
62. Gooren LJG, Bunck MCM. Transsexuals and competitive sports. Eur J Endocrinol. 2004;151(4):425–9.
63. Haraldsen IR, Haug E, Falch J, et al. Cross-sex pattern of bone mineral density in early onset gender identity disorder. Horm Behav. 2007;52(3):334–43.
64. Mueller A, Zollver H, Kronawitter D, et al. Body composition and bone mineral density in male-to-female transsexuals during cross-sex hormone therapy using gonadotrophin-releasing hormone agonist. Exp Clin Endocrinol Diabetes. 2011;119(2):95–100.
65. Wierckx K, Van Caenegem E, Schreiner T, et al. Cross-sex hormone therapy in trans persons is safe and effective at short-time follow-up: results from the European network for the investigation of gender incongruence. J Sex Med. 2014;11(8):1999–2011.
66. Gava G, Cerpolini S, Martelli V, et al. Cyproterone acetate vs leuprolide acetate in combination with transdermal oestradiol in transwomen: a comparison of safety and effectiveness. Clin Endocrinol (Oxf). 2016;85(2):239–46.
67. Auer MK, Ebert T, Pietzner M, et al. Effects of sex hormone treatment on the metabolic syndrome in transgender individuals: focus on metabolic cytokines. J Clin Endocrinol Metab. 2018;103(2):790–802.
68. Klaver M, De Blok CJM, Wiepjes CM, et al. Changes in regional body fat, lean body mass and body shape in trans persons using cross-sex hormonal therapy: results from a multicenter prospective study. Eur J Endocrinol. 2018;178(2):163–71.
69. Fighera TM, da Silva E, Lindenau JDR, Spritzer PM. Impact of cross-sex hormone therapy on bone mineral density and body composition in transwomen. Clin Endocrinol (Oxf). 2018;88(6):856–62.
70. Scharff M, Wiepjes CM, Klaver M, et al. Change in grip strength in trans people and its association with lean body mass and bone density. Endocr Connect. 2019;8:1020–8.
71. Wiik A, Lundberg TR, Rullman E, et al. Muscle strength, size, and composition following 12 months of gender-affirming

treatment in transgender individuals. J Clin Endocrinol Metab. 2020;105(3):247.
72. Tack LJW, Craen M, Lapauw B, et al. Proandrogenic and antiandrogenic progestins in transgender youth: differential effects on body composition and bone metabolism. J Clin Endocrinol Metab. 2018;103(6):2147–56.
73. Polderman KH, Gooren LJG, Asscheman H, et al. Induction of insulin resistance by androgens and estrogens. J Clin Endocrinol Metab. 1994;79(1):265–71.
74. Aubrey J, Esfandiari N, Baracos VE, et al. Measurement of skeletal muscle radiation attenuation and basis of its biological variation. Acta Physiol (Oxf). 2014;210(3):489–97.
75. Rasch A, Byström AH, Dalen N, Berg HE. Reduced muscle radiological density, cross-sectional area, and strength of major hip and knee muscles in 22 patients with hip osteoarthritis. Acta Orthop. 2007;78(4):505–10.
76. Van Caenegem E, Wierckx K, Taes Y, et al. Body composition, bone turnover, and bone mass in trans men during testosterone treatment: 1-year follow-up data from a prospective case-controlled study (ENIGI). Eur J Endocrinol. 2015b;172(2):163–71.
77. Storer TW, Miciek R, Travison TG. Muscle function, physical performance and body composition changes in men with prostate cancer undergoing androgen deprivation therapy. Asian J Androl. 2012;14(2):204–21.
78. Lapauw B, Taes Y, Simoens S, et al. Body composition, volumetric and areal bone parameters in male-to-female transsexual persons. Bone. 2008;43(6):1016–21.
79. Imboden MT, Swartz AM, Finch HW, et al. Reference standards for lean mass measures using GE dual energy x-ray absorptiometry in Caucasian adults. PLoS ONE. 2017;12(4):e0176161.
80. Bohannon RW, Peolsson A, Massy-Westropp N, et al. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiotherapy. 2006;92(1):11–5.
81. Harper J. Race times for transgender athletes. J Sport Cult Identities. 2015;6(1):1–9.
82. Coviello AD, Kaplan B, Lakshman KM, et al. Effects of graded doses of testosterone on erythropoiesis in healthy young and older men. J Clin Endocrinol Metab. 2008;93(3):914–9.
83. Bermon S. Androgens and athletic performance of elite female athletes. Curr Opin Endocrinol Diabetes Obes. 2017;24(3):246–51.
84. Joyner MJ. VO2MAX, blood doping, and erythropoietin. Br J Sports Med. 2003;37(3):190–1.
85. Ekblom B, Goldbarg AN, Gullbring B. Response to exercise after blood loss and reinfusion. J Appl Physiol. 1972;33(2):175–80.
86. Kanstrup IL, Ekblom B. Blood volume and hemoglobin concentration as determinants of maximal aerobic power. Med Sci Sports Exerc. 1984;16(3):256–62.
87. Otto JM, Montgomery HE, Richards T. Haemoglobin concentration and mass as determinants of exercise performance and of surgical outcome. Extrem Physiol Med. 2013;2(1):33.
88. Joyner MJ, Lundby C. Concepts about VO_{2max} and trainability are context dependent. Exerc Sport Sci Rev. 2018;46(3):138–43.
89. T'Sjoen G, Arcelus J, Gooren L, et al. Endocrinology of transgender medicine. Endocr Rev. 2018;40(1):97–117.
90. Klaver M, Dekker MJHJ, de Mutsert R, et al. Cross-sex hormone therapy in transgender persons affects total body weight, body fat and lean body mass: a meta-analysis. Andrologia. 2017. https://doi.org/10.1111/and.12660.
91. Muchicko MM, Lepp A, Barkley JE. Peer victimization, social support and leisure-time physical activity in transgender and cisgender individuals. Leis Loisir. 2014;3–4:295–308.
92. Alkner BA, Tesch PA. Knee extensor and plantar flexor muscle size and function following 90 days of bed rest with or without resistance exercise. Eur J Appl Physiol. 2004;93:294–305.
93. Kvorning T, Andersen M, Brixen K, Madsen K. Suppression of endogenous testosterone production attenuates the response to strength training: a randomized, placebo-controlled, and blinded intervention study. Am J Physiol Metab. 2006;291:E1325-32.
94. Chen Z, Zhang Y, Lu C, et al. Supervised physical training enhances muscle strength but not muscle mass in prostate cancer patients undergoing androgen deprivation therapy: a systematic review and meta-analysis. Front Physiol. 2019;10:843.
95. Hanson ED, Sheaff AK, Sood S, et al. Strength training induces muscle hypertrophy and functional gains in black prostate cancer patients despite androgen deprivation therapy. J Gerontol A Biol Sci Med Sci. 2013;68(4):490–8.
96. Gundersen K. Muscle memory and a new cellular model for muscle atrophy and hypertrophy. J Exp Biol. 2016;219:235–42.
97. Bruusgaard JC, Johansen IB, Egner IM, et al. Myonuclei acquired by overload exercise precede hypertrophy and are not lost on detraining. Proc Natl Acad Sci. 2010;107:15111–6.
98. Murach KA, Dungan CM, Dupont-Versteegden EE, et al. "Muscle Memory" not mediated by myonuclear number?: secondary analysis of human detraining data. J Appl Physiol. 2019;127(6):1814–6.
99. Staron RS, Leonardi MJ, Karapondo DL, et al. Strength and skeletal muscle adaptations in heavy-resistance-trained women after detraining and retraining. J Appl Physiol. 1991;70:631–40.
100. Hanson ED, Nelson AR, West DWD, et al. Attenuation of resting but not load-mediated protein synthesis in prostate cancer patients on androgen deprivation. J Clin Endocrinol Metab. 2017;102(3):1076–83.
101. Roberts BM, Nuckols G, Krieger JW. Sex differences in resistance training. J Strength Cond Res. 2020;34(5):1448–60.
102. Morton RW, Oikawa SY, Wavell CG, et al. Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men. J Appl Physiol. 2016;121:129–38.
103. Balshaw TG, Massey GJ, Maden-Wilkinson TM, et al. Changes in agonist neural drive, hypertrophy and pre-training strength all contribute to the individual strength gains after resistance training. Eur J Appl Physiol. 2017;117:631–40.
104. Balshaw TG, Massey GJ, Maden-Wilkinson TM, et al. Neural adaptations after 4 years vs. 12 weeks of resistance training vs. untrained. Scand J Med Sci Sports. 2018;29(3):348–59.
105. Maden-Wilkinson TM, Balshaw TG, Massey GJ, Folland JP. What makes long-term resistance-trained individuals so strong? A comparison of skeletal muscle morphology, architecture, and joint mechanics. J Appl Physiol. 2020;128:1000–11.
106. Chidi-Ogbolu N, Baar K. Effect of estrogen on musculoskeletal performance and injury risk. Front Physiol. 2019;9:1834.
107. Sørensen MB, Rosenfalck AM, Højgaard L, Ottesen B. Obesity and sarcopenia after menopause are reversed by sex hormone replacement therapy. Obes Res. 2001;9(10):622–6.
108. Greising SM, Baltgalvis KA, Lowe DA, Warren GL. Hormone therapy and skeletal muscle strength: a meta-analysis. J Gerontol A Biol Sci Med Sci. 2009;64(10):1071–81.
109. Svensson J, Movérare-Skrtic S, Windahl S, et al. Stimulation of both estrogen and androgen receptors maintains skeletal muscle mass in gonadectomized male mice but mainly via different pathways. J Mol Endocrinol. 2010;45(1):45–57.
110. Kitajima Y, Ono Y. Estrogens maintain skeletal muscle and satellite cell functions. J Endocrinol. 2016;229(3):267–75.
111. Elbers JMH, Asscheman H, Seidell JC, et al. Long-term testosterone administration increases visceral fat in female to male transsexuals. J Clin Endocrinol Metab. 1997;82(7):2044–7.

Exhibit I

PLOS | ONE

RESEARCH ARTICLE

Performance Development in Adolescent Track and Field Athletes According to Age, Sex and Sport Discipline

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Abstract

Introduction

Sex-specific differences that arise during puberty have a pronounced effect on the training process. However, the consequences this should have for goal-setting, planning and implementation of training for boys and girls of different ages remains poorly understood. The aim of this study was to quantify performance developments in athletic running and jumping disciplines in the age range 11-18 and identify progression differences as a function of age, discipline and sex.

Methods

The 100 all-time best Norwegian male and female 60-m, 800-m, long jump and high jump athletes in each age category from 11 to 18 years were analysed using mixed models with random intercept according to athlete.

Results

Male and female athletes perform almost equally in running and jumping events up to the age of 12. Beyond this age, males outperform females. Relative annual performance development in females gradually decreases throughout the analyzed age period. In males, annual relative performance development accelerates up to the age of 13 (for running events) or 14 (for jumping events) and then gradually declines when approaching 18 years of age. The relative improvement from age 11 to 18 was twice as high in jumping events compared to running events. For all of the analyzed disciplines, overall improvement rates were >50% higher for males than for females. The performance sex difference evolves from < 5% to 10-18% in all the analyzed disciplines from age 11 to 18 yr.

Conclusion

To the authors' knowledge, this is the first study to present absolute and relative annual performance developments in running and jumping events for competitive athletes from early

to late adolescence. These results allow coaches and athletes to set realistic goals and prescribe conditioning programs that take into account sex-specific differences in the rate of performance development at different stages of maturation.

Introduction

Running and jumping are fundamental motor skills in most sport disciplines. Such skills are developed throughout life via growth, maturation and training [1]. Males have consistently performed better in sports reliant on sprinting, jumping and endurance capacity [2–6]. As women have gradually been given the opportunity to compete on equal terms with men, the sex difference in performance has progressively narrowed before stabilizing in the 1980s [2,4,6]. Recent studies of world-class athletes indicate that the sex difference is 10–12% for running events [2,4,6] and ~19% for jumping events [6]. To date, no studies have documented when these sex differences arise. An understanding of the expected sex differences is important to allow coaches and athletes to set realistic goals and prescribe optimal conditioning programs that take into account sex-specific differences in the rate of performance development at different stages of maturation.

Sexual dimorphism during puberty is highly relevant for understanding sex-specific performance developments in sports. The initiation of the growth spurt in well-nourished girls occurs at about 9–10 yrs of age. Age at peak height velocity (PHV) and peak weight velocity (PWV) in girls is 11–12 and 12–13 yrs, respectively, with an average 7–9 cm and 6–9 kg annual increase [7,8,9]. The growth spurt and PHV in girls occurs approximately 2 years earlier than for boys. However, the magnitude of the growth spurt is typically greater in boys, as they on average gain 8–10 cm and 9–10 kg annually at PHV and PWV, respectively. Girls experience an escalation in fat mass compared to boys. Fat free mass (FFM) (also termed lean muscle mass) is nearly identical in males and females up to the age of 12–13 yrs. FFM plateaus in females at 15–16 years of age, but continues increasing in males up to the age of 19–20 yrs [7,8,9]. On average, boys and girls increase their FFM by 7.2 and 3.5 $kg \cdot year^{-1}$, respectively, during the interval near peak height velocity. Corresponding estimates for changes in absolute fat mass are 0.7 and 1.4 $kg \cdot year^{-1}$, while estimates for relative fatness are -0.5% and +0.9%$\cdot year^{-1}$ in boys and girls, respectively [8].

Previous cross-sectional studies of primarily non-competitive adolescents reveal that sex differences in physical capacities (assessed as $\dot{V}O_2$ peak or isometric strength in the majority of cases) are negligible prior to the onset of puberty [9–15]. During the adolescent growth spurt, however, marked sex differences develop. This can primarily be explained by hormone-dependent changes in body composition [8,16] and increased red blood cell mass in boys [16,17]. Despite such sex-specific differences having a pronounced effect on the training process, the consequences these dissimilarities should have for goal setting, planning and implementation of training for boys and girls of different ages, remains poorly understood. No published studies to date have investigated expected annual performance developments in running and jumping disciplines among competitive athletes, from the start through to the end of puberty.

Information regarding the realistic potential for development for a dedicated athlete from the start to the end of puberty is currently lacking in the research literature. Only longitudinal or mixed longitudinal data can provide adequate information regarding performance development during the adolescence growth spurt [14]. The Statistics Committee of the Norwegian Athletics Federation has, over several decades, recorded and systemized competition results from athletic events for all Norwegian athletes from the age of 11 years. This unique database provides the opportunity to investigate the long-term performance development of competitive athletes in sports which place high demands on endurance running, sprint running and jumping ability, from childhood up until the end of puberty. Hence, the purpose of this study was to quantify performance developments in athletic running and jumping disciplines in the age range 11–18 yr and identify possible progression differences as a function of age, discipline and sex.

Materials and Methods

Data sample

This study was conducted in accordance with the declaration of Helsinki. Since our data are based on publically available resources, no informed consent was obtained. This study was approved by the local ethics committee at the Norwegian University of Life Sciences.

The Norwegian Athletics Association annually publishes all-time best results categorized by sex, age and discipline [18]. Each record within these rankings documents performance, name, birth date, club, competition date and venue where the result was set. The database is restricted to the individual season best for each discipline. In the present study, the 100 all-time best male and female 60 m, 800 m, long jump and high jump athletes in each age category from 11 to 18 years were included for analysis. According to Norwegian track & field regulations, athletes are allowed to compete in these disciplines from the age of 11. Long distance disciplines were excluded from analyses as Norwegian athletes are not allowed to compete in such disciplines before the age of 15. Throwing and hurdling events were also excluded due to different competition regulation standards across age categories (i.e. weight of throwing implement, hurdle height, etc.). The included 100 all-time best lists contain data back to 1975. Only outdoor season data were included for 800 m, long jump and high jump, while 60 m included both indoor and outdoor data. However, 60 m results obtained without electronic timing were excluded. Only 60 m and long jump results obtained with legal wind speed ($\leq 2\ m{\cdot}s^{-1}$) were included. Overall, the sample consisted of results from 1373 male and 1149 female athletes and a total of 6400 individual results. The distribution of male/female athletes across the analyzed sports disciplines were 408/369 for 60 m, 414/379 for 800 m, 440/371 for long jump and 354/347 for high jump. About 15–20% of the athletes were in the 100 all-time best lists in more than one discipline.

Statistical analyses

The data were analyzed using mixed models with result as dependent variable and age as fixed explanatory variable with an athlete-specific random variable to account for within-athlete dependency. Separate analyses were performed by discipline and sex. We used estimated marginal means with 95% confidence limits (95% CIs) to produce plots of expected progression by gender and exercise. Descriptive statistics are presented as mean and standard deviation (SD) in addition to percent (%) for change. Effect magnitudes (based on Cohen's *d*) across categories were interpreted categorically as small (*d* from 0.2 to 0.6), moderate (*d* from 0.6 to 1.2) or large (*d* from 1.2 to 2.0) using the scale presented by Hopkins et al. [19]. All analyses were performed using SAS software version 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

60 m sprint

Table 1 and Fig 1 show that boys improve 0.3–0.5 s over 60 m sprint each year up to the age of 14 yr (very large to nearly perfect annual effect), 0.1–0.2 s annually from 14 to 17 yr (moderate

Table 1. Expected progressions in running and jumping performance for 11–18 yr old males and females.

Age *(yr)*	60 m		800 m		Long Jump		High Jump	
	Boys *Progression (s and %)*	**Girls *Progression (s and %)***	**Boys *Progression (s and %)***	**Girls *Progression (s and %)***	**Boys *Progression m (%)***	**Girls *Progression m (%)***	**Boys *Progression m (%)***	**Girls *Progression m (%)***
11–12	-0.35 (4.1)	-0.35 (4.0)	-6.4 (4.4)	-7.3 (4.8)	+0.35 (7.4)	+0.36 (7.9)	+0.11 (7.4)	+0.10 (7.2)
12–13	-0.48 (5.8)	-0.25 (2.9)	-8.7 (6.2)	-5.5 (3.8)	+0.43 (8.6)	+0.30 (6.0)	+0.12 (7.9)	+0.09 (6.3)
13–14	-0.29 (3.7)	-0.16 (2.0)	-5.9 (4.5)	-3.6 (2.6)	+0.50 (9.0)	+0.21 (4.1)	+0.13 (8.1)	+0.06 (3.6)
14–15	-0.10 (1.3)	-0.02 (0.2)	-5.2 (4.1)	-2.2 (1.6)	+0.34 (5.6)	+0.13 (2.4)	+0.08 (4.3)	+0.04 (2.4)
15–16	-0.17 (2.3)	-0.08 (1.0)	-3.2 (2.7)	-1.6 (1.2)	+0.28 (4.4)	+0.10 (1.8)	+0.07 (3.6)	+0.03 (1.8)
16–17	-0.10 (1.4)	-0.07 (0.8)	-2.3 (1.9)	-1.5 (1.2)	+0.19 (2.9)	+0.06 (1.1)	+0.05 (2.5)	+0.01 (0.6)
17–18	-0.05 (0.7)	-0.02 (0.2)	-1.5 (1.4)	-0.6 (0.4)	+0.17 (2.5)	+0.02 (0.4)	+0.04 (1.9)	+0.01 (0.5)

Data are mean (standard deviation) for top 100 Norwegian male and female performers in each discipline.

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to large annual effect), and 0.05 s from age 17 to 18 yr (moderate effect). Relative annual improvement peaks between 12 and 13 yr (5.8%; nearly perfect effect), and then gradually declines to 0.7% between age 17 and 18 yr (moderate effect). On average, boys improve their 60 m performance by 18% from age 11 to 18 yr (Fig 2). Girls improve 0.35 s over 60 m from age 11 to 12 yr (4%; very large effect) (Table 1 and Fig 1). Then, absolute and relative annual improvement gradually slows and almost plateaus between age 14 and 15 (0.02 s; 0.2%; trivial effect). From age 15 to 17, annual improvement increases somewhat to 0.07–0.08 s (~1%; moderate effect) before plateauing again between age 17 and 18 (0.02 s; 0.2%; trivial effect). In total, girls improve their 60-m performance by 11% from age 11 to 18 yr (Fig 2). Fig 3 (panel A)

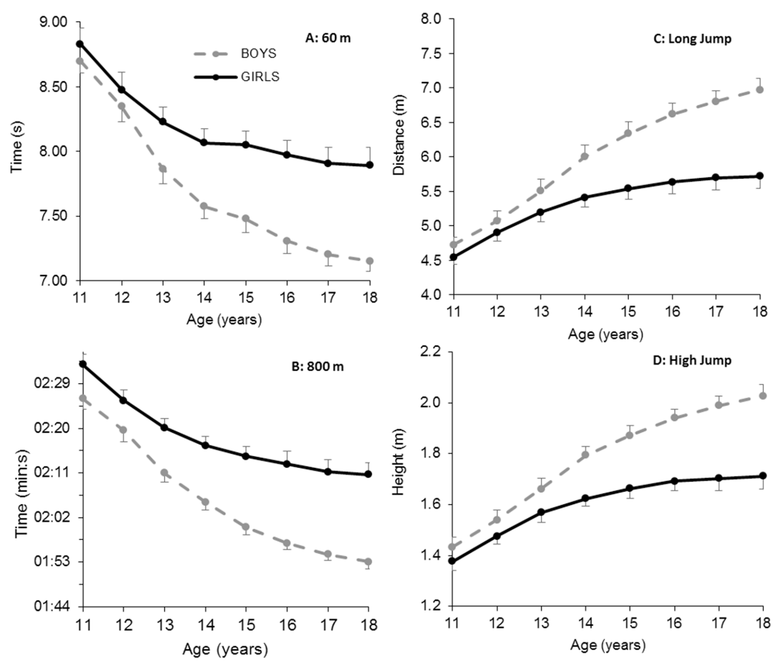

Fig 1. Performance development from age 11 to 18 in running and jumping disciplines. Data are mean ± SD for 60 m (panel A), 800 m (panel B) long jump (panel C) and high jump (panel D) for top 100 Norwegian male and female performers in each discipline.

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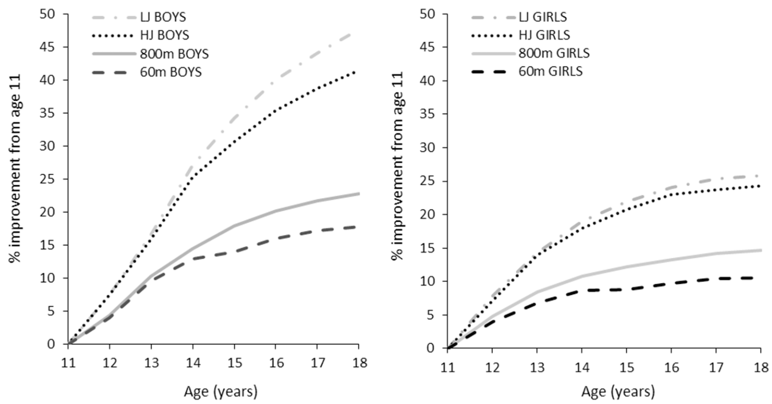

Fig 2. Percentage improvement in performance from age 11 to 18 in long jump, high jump, 60 m sprint and 800 m. Data are mean for top 100 Norwegian male (panel A) and female (panel B) performers in each discipline.

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shows that the sex difference for 60 m sprint evolves from 1.5% at age 11 to 10.3% at the age of 18. Table 2 presents sex ratio in performance at each age stage, and shows that the sex ratio for 60 m running performance develops from 0.99 at age 11 to 0.91 at age 18.

800 m

Table 1 and Fig 1 show that boys improve 6–9 s over 800 m each year up to age 14 yr (very large to nearly perfect annual effect). Relative annual improvement peaks between age 12 and 13 (6.2%; nearly perfect effect), then gradually decreases to 1.5 s between age 17 and 18 (1.4%; moderate effect). On average, boys enhance their 800-m performance by 23% from age 11 to 18 (Fig 2). For girls, both absolute and relative annual performance development gradually decreases across the analysed age stages. The improvement is slightly above 7 s between age 11 and 12 yr (4.8%: very large effect), decreasing to only 0.6 s from age 17 to 18 (0.4%; small effect) (Table 1 and Fig 1). Fig 2 shows that girls enhance their 800-m performance by 15% from age 11 to 18. The 800 m performance sex difference evolves from 4.8% at the age of 11 to 15.7% at the age of 18 (Fig 3, panel B). Table 2 shows that the sex ratio for 800 m running performance develops from 0.95 at age 11 to 0.86 at age 18.

Long jump

Table 1 and Fig 1 show that annual long jump improvement among boys gradually increases from 35 cm between age 11 and 12 yr (7.4%; very large effect) to 50 cm between age 13 and 14 (9%; very large effect). Both absolute and relative annual development then gradually falls to 17 cm between age 17 and 18 (2.5%; moderate effect). Fig 2 shows that boys, on average, improve their long jump performance by 48% from age 11 to 18 yr. For girls, both absolute and relative annual performance enhancement gradually falls from age 11 to 12 yr (36 cm; 7.9%; very large effect) until nearly plateauing between 17 and 18 yr (2 cm; 0.4%; trivial effect) (Table 1 and Fig 1). Overall, girls typically improve their long jump performance by 26% throughout the analysed age stages (Fig 2). The sex difference in long jump evolves from 3.6% at the age of 11 to 18% at the age of 18 (Fig 3, panel C). Table 2 shows that the sex ratio for long jump performance develops from 0.96 at age 11 to 0.82 at age 18.

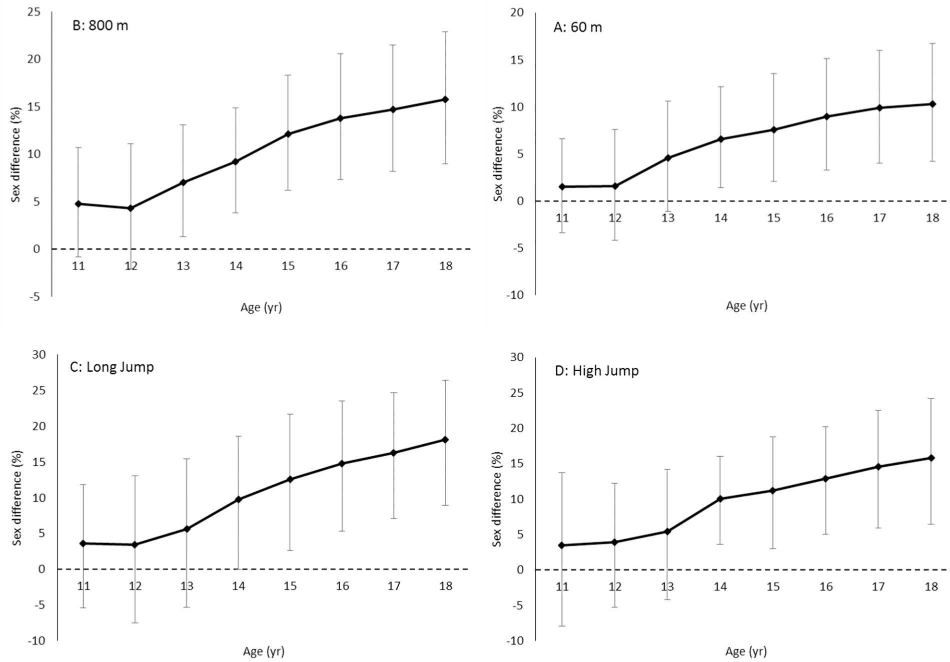

Fig 3. Sex difference (%) for performance in running and jumping disciplines from age 11 to 18. Data are mean and 95% CIs for 60 m (panel A), 800 m (panel B), long jump (panel C) and high jump (panel D) for top 100 Norwegian male and female performers in each discipline.

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High jump

Table 1and Fig 1 show that boys improve their high jump performance by 11–13 cm each year up to the age of 14 (7–8%; very large annual effects). Both absolute and relative annual improvement peaks between age 13 and 14 (13 cm; 8.1%; very large effect), then gradually decreases to 4 cm from age 17 to 18 (1.9%; moderate annual effect). Overall, boys improve their high jump performance by, on average, 41% from age 11 to 18 (Fig 2). For girls, both absolute and relative annual improvement decreases from 10 cm from age 11 to 12 yr (7.2%; very large effect) until it plateaus from age 16 (1 cm; ~0.5%; small annual effects) (Table 1 and Fig 1). Overall, girls typically improve their high jump performance by 24% from age 11 to 18 (Fig 2).

Table 2. Sex ratio in running and jumping performance for 11–18 yr old males and females.

	60 m	*800 m*	*Long Jump*	*High Jump*
11	0.99	0.95	0.96	0.97
12	0.98	0.96	0.97	0.96
13	0.96	0.93	0.94	0.95
14	0.94	0.92	0.90	0.90
15	0.93	0.89	0.87	0.89
16	0.92	0.88	0.85	0.87
17	0.91	0.87	0.84	0.85
18	0.91	0.86	0.82	0.84

Data are calculated from mean results of top 100 Norwegian male and female performers in each discipline.

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The sex difference in high jump performance evolves from 3.5% at the age of 11 to 16% at the age of 18 (Fig 3, panel D). Table 2 shows that the sex ratio for high jump performance develops from 0.97 at age 11 to 0.84 at age 18.

Discussion

To the authors' knowledge, this is the first study to present absolute and relative annual performance developments in running and jumping events for competitive athletes from early to late adolescence. Data from the 100 best performers in each age category from age 11 to 18 years show that male and female athletes perform almost equally up to the age of 12. Beyond this age, males outperform females. Relative annual performance development in females gradually decreases throughout the analyzed age period. In males, annual relative performance development accelerates up to the age of 13 (for running events) or 14 (for jumping events) and then gradually declines when approaching 18 years of age. The relative improvement from age 11 to 18 was twice as high in jumping events compared to running events. For all of the analyzed disciplines, overall improvement rates were >50% higher for males than for females.

Sexual dimorphism during puberty is central in understanding the sex- and discipline-specific performance developments observed in the current study. During puberty, boys begin to produce higher levels of circulating testosterone. This affects the production of muscle fibers through direct stimulation of protein synthesis [16,17]. Higher testosterone levels result in more muscle mass, which in turn facilitates greater power production and more advantageous ground reaction forces during running and jumping. Adolescent weight gain in boys is principally due to increased height (skeletal tissue) and muscle mass, while fat mass remains relatively stable [7,8,9]. In contrast, during puberty girls begin to produce higher levels of circulating estrogen and other female sex hormones [16]. Compared to their male counterparts, they experience a less pronounced growth spurt and a smaller increase in muscle mass, but a continuous increase in fat mass, thereby lowering the critical ratio between muscular power and total body mass. Fat free mass (FFM) in males and females is nearly identical up to 12–13 years of age. Subsequently, FFM plateaus in females at 15–16 years of age, but continues to increase in males up to 19–20 years of age [7,8,9]. On average, boys and girls increase their FFM by 7.2 and 3.5 $kg \cdot year^{-1}$, respectively, during the interval near peak height velocity. Corresponding estimates for changes in absolute fat mass are 0.7 and 1.4 $kg \cdot year^{-1}$, while estimates for body fat percentage are -0.5% and +0.9%$\cdot year^{-1}$ in boys and girls, respectively [8]. Moreover, increased red blood cell mass in boys at this time may contribute towards the widening sex difference for 800 m running [16,17]. Taking present and previous findings together, there appears to be a strong mechanistic connection between the observed sex-specific performance developments and hormone-dependent changes in body composition during puberty. Figs 1 and 2 are very consistent with the muscle mass proportion curve outlined by Malina et al. [8], where a sex difference break point at the age of 12 is clearly present. Beyond this age, males outperform females because maturation results in a shift in body composition. Our results are in line with previous investigations exploring physical capacities such as $\dot{V}O_{2\,peak}$ and isometric strength in non-competitive or non-specialized adolescents [8–12,20].

Fig 3 shows that performance development during puberty varies considerably according to sport discipline. Within the jumping disciplines, improvement rates were slightly higher for long jump compared to high jump. Within the running disciplines, the improvement rates were slightly higher for 800 m compared to 60 m. Magnitudes of improvement within sex in jumping events were twice as large as in running events throughout the analyzed age stages. Moreover, tables 1 and 2 show that the peak rate of improvement in boys is reached at a later stage in jumping events (13–14 years) compared to running events (12–13 years). From a motor learning perspective, running can be thought of as largely inherited, while jumping skills are to a larger degree affected by practice [21]. The relatively low performance progress in running exercises can possibly be explained, at least in part, by the fact that running is an innate movement typically developed naturally through growth and maturation from 1–2 years of age. A large part of the performance potential has thus already been exploited through natural play, growth and maturation. Jumping is also an innate movement, but not in the way in which long jump and high jump are executed in track and field athletics. These are performed with an approach speed from 7 to 12 $m{\cdot}s^{-1}$, and with the athlete required to handle forces of up 10 times their body weight [22,23]. It can therefore require many years of specific training to learn an optimal approach, take-off, flight- and landing technique. The relatively greater progress in jumping exercises can also be explained by growth and increased body height during puberty. The increase in body height means that the center of gravity will be higher, providing better mechanical conditions for performance in jumping events. Furthermore, Beunen & Malina [1] suggest that the plateau for some motor tasks occurs at a slightly older age. Previous studies of non-competitive adolescent boys indicate that peak gains in strength and power typically correspond with peak gains in body mass and muscle mass. Conversely, peak gains for running velocity and aerobic power typically occur at peak height velocity or slightly before [1,11,15] The adolescent performance spurt for running speed is likely related to growth of the lower extremities, as the legs experience maximum growth before trunk, neck and head [24].

The current results indicate that the sex difference evolves from $< 5\%$ to 10–18% in all the analyzed disciplines from age 11 to 18 yr. The gap widens considerably during early adolescence before gradually stabilizing when approaching the age of 18. This evolution is practically identical for the running and jumping disciplines. The observed sex differences at the age of 18 are in line with previous studies of world-class athletes where a sex difference of 10–12% for running events [2,4,6] and ~19% for jumping events [6] has been reported. To the authors' knowledge, this is the first study to document when these sex differences arise.

A limitation of the present study is the lack of maturity status data. Youths who are successful in sport may differ in maturity status compared with the general population. Even at a later age, early maturing boys continue to have an advantage in strength and power tasks, while the later maturing boys typically catch-up when it comes to speed tasks [25]. In girls, maturity-associated variation in performance is not consistent among tasks and from age to age [9,26]. Most samples of female adolescent athletes have mean or median ages at menarche within the normal range, with the exception of gymnasts, ballet dancers, figure skaters and divers, who tend to be later than those of athletes in other sports [1]. In Belgian male track athletes, all 15–16 year old athletes except one had a skeletal age in advance of chronologic age, while in corresponding 17–18 years old athletes, two-thirds had skeletal age equal to or in advance of that expected for chronologic age [27]. However, it is worth noting that regular training does not affect growth, the timing and magnitude of peak height velocity, and skeletal and sexual maturation in young athletes [28] and the pubertal progress of boys and girls active in sport is similar to the progress observed in boys or girls not active in sport.

Another limitation is that only a handful of the present athletes were top 100 performers in every age category from 11 to 18 years of age. One could argue that early maturing athletes are overrepresented in the younger age stages, while they are successively replaced with average or late maturing athletes who catch up or outperform the early maturers when approaching late adolescence. Thus, the present data might overestimate individual annual performance development. However, falling trends among early maturers, at least up until a point where they are no longer be within the top 100, are accounted for by the mixed models analysis. Furthermore, analysis of the small sample of athletes who were top 100 performers in every age category (2–6 athletes in each discipline) reveal similar performance development as our mixed model analysis. When interpreting the current data, it should also be recognized that there are some limitations associated with using ratios and percentage change values [29]. Since the slope of the relationship between the logarithmically transformed numerator and denominator deviated somewhat from one for some variables, these ratios may not scale accurately towards the extremes of each range. However, mixed model analyses were performed on absolute rather than ratio values. Furthermore, percentage change and ratio data are presented supplemental to absolute values, and should therefore facilitate rather than mislead interpretation.

Because of the physical changes that occur during puberty, the optimal training program for this age group likely differs somewhat between boys and girls. For example, for adolescent girls, increases in fat mass and reductions in relative strength often occur alongside reductions in coordination and neuromuscular control [30]. This may impair training tolerance and increase the risk of certain types of injury [31]. Hence it may be beneficial for female athletes to have a greater focus on neuromuscular training during this period [32]. From a practical perspective, the present results allow coaches and athletes to set realistic goals and prescribe conditioning programs that take into account sex-specific differences in the rate of performance development at different stages of maturation. Because hormone-dependent changes during puberty mean that adolescent boys and girls respond somewhat differently to exercise, it is important that training is tailored based on sex and the specific stage of growth and maturation.

Author Contributions

Conceived and designed the experiments: ET TH AG. Performed the experiments: ET TH ISS. Analyzed the data: TH ISS ICO. Contributed reagents/materials/analysis tools: ICO ISS. Wrote the paper: ET TH ISS AG ICO.

References

1. Beunen G, Malina RM. Growth, maturation and physical activity. In: Hebestreit H, and Bar-Or O, editors. The young athlete. Volume XIII of the encyclopaedia of sports medicine and IOC medical commission publication. Blackwell Publishing, 2008.
2. Cheuvront SN, Carter R, Deruisseau KC, Moffatt RJ. Running performance differences between men and women: an update. Sports Med. 2005; 35: 1017–24. PMID: 16336006
3. Nevill AM, Whyte G. Are there limits to running world records? Med Sci Sports Exerc. 2005; 37: 1785–8. PMID: 16260981
4. Seiler S, De Koning JJ, Foster C. The fall and rise of the gender difference in elite anaerobic performance 1952–2006. Med Sci Sports Exerc. 2007; 39: 534–40. PMID: 17473780
5. Berthelot G, Thibault V, Tafflet M, Escolano S, El Helou N, Jouven X et al. The citius end: world records progression announces the completion of a brief ultra-physiological quest. PLoS One. 2008; 3:e1552. doi: 10.1371/journal.pone.0001552 PMID: 18253499
6. Thibault V, Guillaume M, Berthelot G, Helou NE, Schaal K, Quinquis L, et al. Women and men in sport performance: The gender gap has not evolved since 1983. J Sports Sci Med. 2010; 9: 214–23 PMID: 24149688
7. Tanner JM, Whitehouse RH, Marubini E, Resele LF. The adolescent growth spurt of boys and girls of the Harpenden growth study. Ann Hum Biol. 1976; 3: 109–126. PMID: 1275435
8. Malina RM, Bouchard C, Beunen G. Human growth: Selected aspects of current research on well-nourished children. Annual Review of Anthropology 1988; 17:187–219.
9. Malina RM, Bouchard C, Bar-Or O. Growth, maturation and physical activity. 2nd ed. Champaign, IL: Human Kinetics; 2004.
10. Krahenbuhl GS, Skinner JS, Kohrt WM. Developmental aspects of maximal aerobic power in children. Exerc Sport Sci Rev. 1985; 13: 503–38. PMID: 3891374
11. Armstrong N, Welsman JR, Nevill AM, Kirby BJ. Modeling growth and maturation changes in peak oxygen uptake in 11–13 yr olds. J Appl Physiol. 1999; 87: 2230–2236. PMID: 10601172
12. Eisenmann JC, Malina RM. Age- and sex-associated variation in neuromuscular capacities of adolescent distance runners. J Sports Sci. 2003; 21: 551–557. PMID: 12848389

13. Malina RM, Woynarowska B, Bielicki T, Beunen G, Eweld D, Geithner CA, et al. Prospective and retrospective longitudinal studies of the growth, maturation, and fitness of Polish youth active in sport. Int J Sports Med. 1997; 18: 179–185. PMID: 9187971

14. Malina RM, Stawinska T, Ignasiak Z, Rozek K, Kochan K, Domaradzki J, Fugiel J. Sex differences in growth and performance of track and field athletes 11–15 years. J Hum Kin. 2010; 24: 79–85.

15. Geithner CA, Thomis MA, Eynde BV, Maes HHM, Loos RJF, Peeters M, Claessens ALM, Vlietinck R, Malina RM, Beunen GP. Growth in peak aerobic power during adolescence. Med Sci Sports Exerc. 2004; 36: 1616–1624. PMID: 15354046

16. Goswami B, Roy AS, Dalui R, Bandyopadhyay A. Impact of pubertal growth on physical fitness. Am J Sports Sci and Med. 2014; 2: 34–39.

17. Siervogel RM, Demerath EW, Schubert C, Remsberg KE, Chumlea WC, Sun S, et al. Puberty and body composition. Horm Res. 2003; 60: 36–45. PMID: 12955016

18. Norwegian Athletics Federation. All-time best statistics. Retrieved from: http://www.friidrett.no/stevner/statistikk1/alle%20tiders/Sider/Norgesbestegjennomalletider.aspx Updated Feb 1st, 2015.

19. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009; 41: 3–13. doi: 10.1249/MSS.0b013e31818cb278 PMID: 19092709

20. Valente-Dos-Santos J, Coelho-E-Silva MJ, Severino V, Duarte J, Martins RS, Figueiredo AJ et al. Longitudinal study of repeated sprint performance in youth soccer players of contrasting skeletal maturity status. J Sports Sci Med. 2012; 11: 371–9. PMID: 24149342

21. Schmidt RA, Wrisberg CA. Motor learning and performance: A situation based learning approach, 4th edition. Human Kinetics; 2008.

22. Lees A, Graham-Smith P, Fowler N. A biomechanical analysis of the last stride, touchdown, and takeoff characteristics of the men's long jump. J Appl Biomech. 1994; 10: 61–61.

23. Seyfarth A, Friedrichs A, Wank V, Blickhan R. Dynamics of the long jump. J Biomech. 1999; 32: 1259–1267. PMID: 10569704

24. Malina R. Top 10 research questions related to growth and maturation of relevance to physical activity, performance, and fitness. Res Quart Exerc Sport. 2014; 85: 157–173. PMID: 25098012

25. Beunen G, Ostyn M, Renson R, Simons J, Van Gerven D. Motor performance as related to chronological age and maturation. In: Shepard RJ. Lavallee H, editors. Physical fitness assessment: Principles, practice and application. C.C Thomas Springfield, IL, 1978: 229–236.

26. Little NG, Day JAP, Steinke L. Relationship of physical performance to maturation in perimenarcheal girls. Am J Hum Biol. 1997; 9: 163–171.

27. Malina RM, Beunen G, Wellens R, Claessens A. Skeletal maturity and body size of teenage Belgian track and field athletes. Ann Hum Biol. 1986; 13: 331–339. PMID: 3767306

28. Loucks AB, Vaitukaitis J, Cameron JL, Rogol AD, Skrinar G, Warren MP, et al. The reproductive system and exercise in women. Med Sci Sports Exerc. 1992: 24; 288–289.

29. Atkinson G, Batterham AM. The use of ratios and percentage changes in sports medicine: time for a rethink? *Int J Sports Med*. 2012; 33: 505–506. doi: 10.1055/s-0032-1316355 PMID: 22760546

30. Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. J Bone Joint Surg Am. 2004; 86-A: 1601–1608. PMID: 15292405

31. Tursz A, Crost M. Sports-related injuries in children. A study of their characteristics, frequency, and severity, with comparison to other types of accidental injuries. Am J Sports Med. 1986; 14: 294–299. PMID: 3728781

32. Myer GD, Ford KR, Hewett TE. Methodological approaches and rationale for training to prevent anterior cruciate ligament injuries in female athletes. Scand J Med Sci Sports. 2004; 14: 275–285. PMID: 15387801

Exhibit J

GLOBAL PARTNERS

WORLD RUGBY

Transgender Women Guidelines

Can transgender women play rugby?

- Transgender women who transitioned pre-puberty and have not experienced the biological effects of testosterone during puberty and adolescence can play women's rugby (subject to confirmation of medical treatment and the timing thereof)
- Transgender women who transitioned post-puberty and have experienced the biological effects of testosterone during puberty and adolescence cannot currently play women's rugby
- Transgender women can play mixed-gender non-contact rugby
- World rugby are committed to ongoing evaluation of the guidelines and will remain current on all published research that pertains to the biological and physiological implications of testosterone suppression, with a formal review of the Guideline every three years. In support of this, World Rugby will prioritise support for high quality research projects on transgender rugby players, as part of this commitment to evidence-based guidelines.

Why can't transgender women play women's rugby?

Effects of testosterone

Where reference is made to "females" and "males" to explain the effects of testosterone, the references are used to differentiate between "Biological Males" (tho

Testosterone is an androgenic-anabolic hormone whose functions include reproductive maturation, along with the genesis of male secondary sex characteristics. From puberty onwards, testosterone levels increase 20-fold in males, but remain low in females, resulting in circulating testosterone concentrations at least 15 times higher in males than in females of any age [1,2]. Among the biological changes initiated by testosterone and its derivatives are:

- Larger and denser lean muscle mass [3,4];
- Greater force-producing capacity of skeletal muscle [5,6];

- Longer, larger and denser skeletal structure [8,9];
- Changes to cardiovascular and respiratory function that include higher haemoglobin concentration, greater cross-sectional area of the trachea and lower oxygen cost of respiration (as described in [1,10-12]).

Collectively, these biological differences account for large sporting performance differences between males and females. These include gaps between 9% and 15% for running, swimming and jumping events [13], between 15% and 35% for functional tasks like kicking, throwing, bowling and weightlifting, and in excess of 50% for tasks that involve upper body force production [10], since the biological effects of testosterone creates disproportionately greater strength on their upper compared to lower body, while females show the inverse [14,15]. In weight-lifting events, for instance, even when matched for mass and stature, males lift approximately 30% more weight than females. Evaluated differently, males are able to lift weights similar to females who weigh 30% to 40% more than them [10]. Functional movements such as explosive jumping are similarly larger in elite males than females, with approximately 30% more power generated during a counter-movement jump [10].

The result of these biological differences is that males outperform females in all sporting activities where speed, size, power, strength, cardiorespiratory and anthropometric characteristics are crucial determinants of performance. This is true for many thousands of boys and men who have undergone a testosterone-induced puberty, with an effect large enough that 14 to 15-year old boys outperform the best female athletes in history in a range of running, jumping, throwing and strength events [13,16]. The size of these performance differences varies depending on the contributions made by each of the biological variables to performance, and indeed, some may be detrimental to performance in some events (mass during endurance running or cycling events, for example). Generally, however, there is no overlap in performance between males compared to females at all matched levels of competition from high school to the elite level. The performance disparity is illustrated by the observation that thousands of teenage boys and adult males are able to outperform the very best biological females every year [13].

Similar performance differences between males and females have been described in non athletically trained individuals. Males have muscle mass 30% to 40% greater than females [4], maximal cardiorespiratory capacities (VO2max) 25% to 50% greater than in females [17], cardiovascular parameters between 11% and 43% greater than in females, lower limb strength approximately 50% higher than in females across the lifespan, and upper body strength 50% to 100% higher than in age-matched females [6]. Even when elite females, trained in sports where grip strength is an important component of performance Uudo and handball), do not outperform untrained males in a grip strength task, with the very best female performance corresponding to approximately the 58 th percentile for males, and a 26% advantage for untrained males compared to typical elite females. Punching performance, a composite movement reliant on strength, power, co-ordination and mass, has been found to be 162% higher in males than in females [18], and 17-year old boys are able to throw a ball further than 99% of adult females [19].

Biological consideration for rugby union

The implications of biological and performance differences for rugby are two-fold. First, significant differences in strength, size, speed and power have potential consequences for the safety of participants in rugby, where much of the sport involves contacts in the form of tackles, rucks and mauls, as well as numerous periods of high force production during static contests for the ball, such as the scrum and ruck. Given the documented risk of injury in rugby from contact events in particular [20-24], the elevated possibility of all injuries, including serious accelerations. Since these factors contribute directly to injury risk, it is clear that large discrepancies create greater risks for smaller and slower players, particularly when size and speed exist in combination.

Given that the typical male player mass is 20% to 40% greater than typical women mass, that males have strength 40% to 80% greater (unadjusted for mass), and that men are 10% to 15% faster than women despite being heavier, the risk of injury created by large imbalances in mass and speed may be considered significant. To explore this, we assessed the range of masses of players at the international level and applied the findings to a biomechanical model to explore possible implications for injury risk should cross-over scenarios occur.

With respect to mass, we documented the range of sizes of elite men's and women's players from the 2011 Rugby World Cup up to the 2019 Rugby World Cup, finding:

- Typical (median) men's players are 41.1% heavier than typical women's players (103 kg vs 73 kg)
- Among forwards, the heaviest 1% of women players are smaller than the typical men's forward (109kg for women vs 112kg for men)
- The heaviest 1% of women's backs are smaller than typical men's backs (89kg vs 92kg)
- The lightest 1% of men's forwards are approximately equal in mass to the heaviest 10% of women's forwards, while the lightest 2% of men's backs are approximately equal to the heaviest 10% of women's backs
- Figure 1 below shows the frequency histograms for men's and women's players in forward and back positions

Figure 1: Frequency histograms of mass of forwards (left panel) and backs (right panel) in elite men's and women's rugby players. Dotted lines indicate the 50^{th} percentile, while dashed lines indicate the 98^{th} percentile for each group.

Implications for injury risk - head injury models

The differences observed between men and women with respects to mass may be combined with differences in speed to create a theoretical framework in which the inertial load and forces faced by smaller and slower player is significantly greater when in contact with a larger, faster player. this model is intended for illustrative purposes and demonstrates the impact of only one variable known to differ between biological exerted during contact would further increase the implications of the findings of this illustrative model, summarized below.

The representative figure below illustrates the concept of mass disparity as a risk of injury for ball carriers. It depicts the linear acceleration (A), angular acceleration (B), neck force (C) and neck moment (D) experienced by ball carriers of different masses when tackled by players with different masses. Using the known masses of international rugby player, the position of the average male (M50) and average female (F50) are plotted on each heat map. F90 shows the scenario where a tackler (T) corresponds to the 90th percentile for women's mass (see Figure 1) tackles a typical female mass ball carrier (BC). X indicates the hypothetical cross-over scenario in which a typical male tackler mass is involved in a tackle against a ball carrier with a typical female mass.

Figure 2. Graphical representations of linear acceleration (A), angular acceleration (B), neck force (C) and neck moment (D) for ball carriers of different masses during tackles by tacklers with different masses. Mso and Fso show the modelled situation when typical/median players tackle one another for men and women, respectively. F90 represents a female ball-carrier with typical mass against a tackler in the heaviest 10% of women's body mass. X denotes the cross-over situation that would hypothetically occur for a tackler at the men's median mass tackling a typical female ball carrier

The modelling shows that a tackle involving players with typical or average mass produces slightly greater accelerations and forces in men (Mso) than in women (Fso). This is a function of the higher mass of men's players. Head and neck kinematic and kinetic variables increase significantly when the heaviest 10% of women's body mass is used for the tackler against a typical ball carrier (F90), but this extreme "within female-bodied" scenario produces smaller kinetic and kinematic outcomes than if the hypothetical cross-over scenario were to occur, where an average male-bodied player is the tackler and the average female-bodied player the ball carrier **(X).** The magnitude of the increase in neck forces, moments and accelerations for the ball carrier is between 20% and 30% for typical cross-over scenario compared to the typical female vs female scenario, and is 10% greater for the male-bodied vs female-bodied crossover scenario than a tackle where the heaviest 10% of women are matched against typical women's mass (F90).

Were the cross-over to occur in a heavier male-bodied player (for example, the heaviest 10% of male-bodied players), the increase in neck load and head acceleration for the ball carrier approaches 50% compared to the typical tackle scenario in women's rugby. The magnitude of these extreme head accelerations and neck forces are not seen in women and are created by cross-over of male-bodied players to women's

The magnitude of the known risk factors for head injury are thus predicted by the size of the disparity in mass between players involved in the tackle. The addition of speed as a biomechanical variable further increases these disparities, which is relevant given that male players weighing 103kg (the median for men) would be expected to run between 10% and 15% faster than typical female players (mass 73kg), and thus considerably faster than female players who are heavier than the median (eg females at the 90th percentile, Fig 1). This would further compound the disparity created.

Next, it is important to also consider that these models do not account for the ability of players to actively exert force at high rates during tackles. This would be a function of power and strength, which are similarly known to be 30% to 80% greater in biological males than females. When these active applications of force during contact are added to the mass and speed characteristics illustrated and described above, the resultant neck and head forces and accelerations will increase even further, such that the illustrative model shown above depicts the smallest possible risk increase for typical players involved in a tackle as a result of mass alone. The addition of speed and force disparities will increase the magnitude of these risk factors beyond the 20% to 30% we illustrate above.

The implication of these increases is complex to quantify but would result in increased injury risk for the player experiencing the elevated risk outcomes (force and acceleration). This is because head injuries occur when forces and accelerations on the head and neck reach a threshold necessary to cause injury, and which is unique to each tackle situation. A tackle situation that typically produces risk factors within 20% of this threshold would, in the circumstance of a typical male-bodied vs typical female-bodied player illustrated above, be sufficiently increased to cause an injury. The higher risk scenario involving heavier male bodied players would further increase injury likelihood, since all tackle situations that normally produce kinetic and kinematic variables within 40% to 50% of an injury threshold would now exceed it, a scenario unseen in women's rugby. The addition of strength and speed as described, further increases the risk, such that a number of tackles that currently lie beneath the threshold for injury would now exceed it, causing head injury.

Finally, it must also be considered that the ability to withstand or tolerate forces on the head and neck are required to avoid brain injury. This is the reason neck strength is critical in injury prevention. Since the strength disparities between males and females is so large, including a 50% lower neck isometric strength in females, the reduced ability of female players to tolerate or withstand the forces in tackles is a further risk factor for injury, including head injury as described above, but relevant to all injuries where the rapid application of force or load are responsible for injury.

Implications for injury risk - scrum forces

The implication of greater mass and force-producing ability in males can be seen in forces measured during scrums in both elite and community level rugby. Research on the forces applied during scrums shows that at the elite level, males produce approximately twice the peak force of females in the scrum. Even at the community level, where peak force is 30% lower than in the elite game, males produce approximately 40% greater peak force during scrums than elite females. Given that force producing and receiving ability is likely to be significantly lower in female community players, the implication is that men's community level rugby scrums will be considerably more forceful than women's community level scrums.

applied must be withstood by a direct opponent. This is an illustration of how mismatches in strength and size are directly responsible for forces that result in injury.

Testosterone as a predictor of performance

It must be noted that the actual testosterone level, measurable in the body, is not a strong predictor of performance within men and within women [27-29]. This is because performance is multifactorial, and testosterone's androgenzing effects contribute to, but do not solely influence the biology and resultant performance outcomes within a group who are able to utilize it. The biological basis for male vs female differences is thus the result of testosterone, but it does not necessarily follow that within men and within women, the hormone is a predictor of performance.

Further, differences in the sensitivity to testosterone between individuals mean that a given level of testosterone is not a sensitive or specific predictor of performance within each group (males and females). This is in part because most males have elevated levels and some degree of sensitivity, while the level in females is significantly lower and rarely exceeds even the very low end of the male range [1]. Therefore, in two homogenous groups that are matched for either the presence or absence of a given variable (males and females for the presence or absence of testosterone, in this case), the predictive value of that variable within a group is greatly diminished, the same way that V02max is a significant predictor of running or cycling performance across the whole population, but not within a group of elite marathon runners or cyclists, who are already relatively homogenous for that characteristics [30]. Similarly, height is clearly advantageous for professional basketball, but within the National Basketball Association (NBA), where height has already been selected for and participants are in the extreme upper end of the overall population for that characteristic [31], it becomes a poorer predictor of performance.

However, when the same question -does testosterone predict performance across humans of both sexes - is asked of binary categories (males vs females in sport, rather than within males or females), then the predictive power of testosterone is strong, because "high testosterone" during adulthood is a very reliable indicator that the androgenizing effects of testosterone have occurred earlier during life. When understood and assessed this way, testosterone is necessary for peak performance (since the top performers within humans are all male), but it is not sufficient to attain it. It is here that the almost perfect sensitivity of biological sex emerges, since in a ranking list of the top thousand performances in most sport, every year, every single one will be biologically male.

Summary

In summary, across all performance levels and ages after puberty, testosterone is primarily (though not exclusively) responsible for very large typical differences in the biology of males and females, and consequently, performances between the sexes. These are summarized in Figure 3 below, which combines the biological differences between males and females with their performance implications, and is reproduced from a recent article currently in review [10].

Figure 3: Summary comparison of biological (left table) and performance (right figure) differences between males and females for a range of biological variables and physical activities/events. Reproduced from Hilton & Lundberg [10]

Given that the women's category exists to ensure protection, safety and equality for those who do not benefit from the biological advantage created by these biological performance attributes, the relevant and **crucial question is whether the suppression of testosterone for a period of 12 months, currently required for transgender women participation in women's sport, is sufficient to remove the biological differences summarized above?**

Effects of suppression of testosterone

Current policies regulating the inclusion of transgender women in sport are based on the premise that reducing testosterone to levels found in biological females is sufficient to remove many of the biologically-based performance advantages described above. However, peer-reviewed evidence suggests that this is not the case, and particularly that the reduction in total mass, muscle mass, and strength variables of transgender women may not be sufficient in order to remove the differences between males and females, and thus assure other participants of safety or fairness in competition.

Based on the available evidence provided by studies where testosterone is reduced, the biological variables that confer sporting performance advantages and create risks as described previously appear to be only minimally affected. Indeed, most studies assessing mass, muscle mass and/or strength suggest that the reductions in these variables range between 5% and 10% (as described by Hilton & Lundberg [10]). Given that the typical male vs female advantage ranges from 30% to 100%, these reductions are small and the biological differences relevant to sport are largely retained.

For instance, bone mass is typically maintained in transgender women over the course of at least 24 months of testosterone suppression, with some evidence even indicating small but significant increases in bone mineral density at the lumbar spine [32-34]. Height and other skeletal measurements such as bone length and hip width have also not been shown to change with testosterone suppression, and nor is there any plausible biological mechanism by which this might occur, and so sporting advantages due to skeletal differences between males and females appear unlikely to change with testosterone reduction.

With respects to strength, **1** year of testosterone suppression and oestrogen supplementation has been found to reduce thigh muscle area by 9% compared to baseline measurement [35]. After 3 years, a further reduction of 3% from baseline measurement occurred [36]. The total loss of 12% over three years of treatment meant that transgender women retained significantly higher thigh muscle size ($p<0.05$) than the baseline measurement of thigh muscle area in transgender men (who are born female and experience female puberty), leading to a conclusion that testosterone suppression in transgender women does not reverse muscle size to female levels [36].

levels results in a comparatively modest loss of lean body mass (LBM) or muscle size, with consistent changes between 3% and 5% reduction in LBM after 1 year of treatment (as summarized from source research studies by Hilton & Lundberg [10]).

Muscle force-producing capability is reduced after testosterone suppression, though as appears to be the case for muscle/lean mass, these reductions are considerably smaller in magnitude that the initial male-vs-female differences in these variables. For instance, hand-grip strength was reduced by 7% and 9% after **1** and 2 years, respectively, of cross hormone treatment in transgender women [39], and by 4% in 249 transwomen after 1 year of gender-affirming treatment, with no variation between different testosterone levels, age or BMI tertiles [45]. Transgender women retained a 17% grip-strength advantage over transgender men at baseline measurement, with a similarly large, retained advantage when compared to normative data from a reference or comparison group of biological females.

Most recently, Wiik et al found that isokinetic knee extension and flexion strength were not significantly reduced in 11 transgender women after 12 months of testosterone suppression, with a retained advantage of 50% compared to a reference group of biological females and the group of transgender men at baseline [41]. This absence of a reduction in strength occurred in conjunction with a 4% to 5% reduction in thigh volume, and no difference in the contractile density of the muscle, which suggests that the reduction of testosterone for a period of a year had no effect on the force-producing capacity per unit of cross sectional area [41], a variable that is known to be higher in males than females.

In conclusion, longitudinal research studies that have documented changes in lean mass, muscle mass/area and strength show consistently that small decreases occur as a result of testosterone suppression, with a resultant relatively large retained advantage in these variables compared to a group of biological females.

Conclusion

Testosterone exerts significant biological effects on biological males during puberty and adolescence. This creates large differences in strength, mass, speed, power, and endurance capacity. In turn, these create player welfare concerns and performance inequality in rugby, given the importance of physical contact and strength in the sport. Longitudinal research studies on the effect of reducing testosterone to female levels for periods of 12 months or more do not support the contention that variables such as mass, lean mass and strength are altered meaningfully in comparison to the original male-female differences in these variables. The lowering of testosterone removes only a small proportion of the documented biological differences, with large, retained advantages in these physiological attributes, with the safety and performance implications described previously. There is currently no basis with which safety and fairness can be assured to biologically female rugby players should they encounter contact situations with players whose biologically male advantages persist to a large degree.

While there is overlap in variables such as mass, strength, speed and the resultant kinetic and kinematic forces we have modelled to explore the risk factors, the situation where a typical player with male characteristics tackles a typical player with female characteristics increases the magnitude of known risk factors for head injuries by between 20% and 30%. In the event of smaller female players being exposed to that risk, or of larger male players acting as opponents, the risk factors increase significantly, and may reach levels twice as large, at the extremes. The basis for regulation is the typical scenario, though risk mitigation must be mindful of the potential for worst-case scenarios that may arise. Both are deemed unacceptably high, because they would result in a number of tackle situations that currently lie beneath a threshold required to cause injury increasing to exceed that threshold.

GLOBAL PARTNERS

Assessment of research limitations and implications

It is acknowledged that the published studies currently available on testosterone suppression and physiological changes (compiled and described in Hilton and Lundberg, 2020 and reviewed individually in the proposed policy document) have been conducted in untrained transgender women. This invites questions over the validity and generalizability of the studies to a sports-playing population.

This is a valid question, and it is acknowledged that research is required to fully address questions arising out of this limitation. World Rugby is committed to supporting high quality research proposals in this area, should they be submitted as part of World Rugby's Research programme.

However, this limitation can also be assessed within an understanding of the physiological implications of trained compared to untrained individuals undergoing testosterone suppression. The application of insights from complementary studies leads to a conclusion that the available research is in fact sufficient to arrive at firm conclusions about safety, performance and retained advantages, and thus the recognized limitations are not sufficient to refrain from drawing a conclusion on the likely implications of the transgender research for athletes.

In assessing this issue, two primary questions may be asked:

1. How would training undertaken during the process of testosterone suppression affect the changes observed in muscle and lean body mass, and strength variables, compared to studies done in individuals who do not perform training?
2. How would training prior to a period of testosterone suppression influence:
1. The baseline or pre-suppression measures for muscle mass and strength in transgender women, and thus the differences in these variables compared to a reference or control group of biological women (cisgender women)?
2. The likely "end-point" for muscle and lean body mass as well as strength after the testosterone suppression for a period of at least twelve months, once again compared to a reference or comparison group of cisgender women?

Both these questions can be answered by exploring complementary research studies. At present, there is evidence that:

Training during the intervention to lower testosterone levels can reduce, eliminate, and even reverse any losses in muscle and lean body mass, muscle volume, and muscle strength. This is supported by evidence from various study models in which biological males reduce testosterone to within the female range, and are able to maintain or even increase these physiological variables through training [46-48].

> The implication is that any performance decline as a result of androgen deprivation is minimized or eliminated, and so the studies cited in support of the World Rugby Guideline, while conducted on non-training individuals, establish the minimum possible retained advantage for trans women. That is, they establish that in the absence of training during testosterone suppression, an advantage is retained compared to cisgender women. That advantage is either the same, or very plausibly increased as a result of training.

assertion that trans women are weaker, less muscular and thus more similar to biological females at baseline, within a sporting context, since the transgender woman being considered by World Rugby is much more likely to be trained (or will train once transition begins, as described above).

> Further, once the period of testosterone suppression begins, then the degree to which muscle mass and strength decreases may be either the same or relatively greater in the trained trans women as a result of this higher baseline. Even if the relative loss of muscle mass and strength are higher than in untrained trans women, it is inconceivable, and even physiologically impossible, that a pre-trained athletic trans woman is going to lose so much muscle mass and strength that they end at a point where they are less muscular/lean and weaker than a theoretically untrained (and even 'self-starved') transgender woman.
>
> Therefore, if research on untrained trans women establishes that the retained advantage in muscle mass and strength is corresponds to a value of X percent, this is the smallest possible remaining advantage for a pre-trained trans woman. The effect of training can only be to increase this value or to achieve the same value of X percent retained advantage, but it cannot reduce it further, unless one argues that a trained trans woman will lose so much lean mass and strength that they end up weaker and less muscular than a completely non-athletic individual.

Finally, it is relevant that studies comparing untrained biological males and highly trained females, males retain an advantage despite the training status of biological females. For instance, in a study on grip strength, the strongest elite athletically trained females in sports where grip strength is a performance advantage Uudo and handball) are only as strong as untrained biological males at the 58th percentile, with a 26% difference in strength between typical elite females and typical untrained males [49]. Similarly, Morrow & Hosler (1981) found that untrained college-aged males were more than twice as strong as trained female basketball and volleyball players in a bench press task, with the top 5% strongest trained females equal in strength to the weakest 14% of untrained males This establishes that pre-trained biological females can increase strength beyond that of untrained females, but still do not compare to untrained biological males.

The implication is also that since even typical untrained biological males have a large strength advantage compared to elite and trained females, studies that have documented only small reductions in strength and thus persistence of strength advantages with androgen deprivation in untrained biological males (as in Kvorning et al [46], Chen et al [47] and in studies on transgender women cited herein) should be considered relevant for establishing the smallest possible retained advantage that would exist in the absence of training. As described above, and in studies where training is conducted while testosterone is suppressed [46-48], the advantage will only remain this size or increase.

Finally, it is also recognized that not all sports are affected similarly by the variables we have weighted as crucial for rugby (size, strength, speed, power). Indeed, in some sports, excess mass may be disadvantageous, and thus the model for retained advantage and persistent risk may present differently for different physical activities.

In conclusion, with those recognized limitations, World Rugby is committed to supporting research that may in future establish that biological differences between those to whom testosterone confers significant physiological and performance advantages and those to whom it does not are removed sufficiently to enable participation of transgender women in women's rugby. At the present time, however, based on

The referenced research used to support this position can be viewed **here**.

Conclusion - Testosterone, Welfare and Performance

Having considered all of the currently available information, the working group determined that the best evidence **currently** available means that those who experienced the biological effects of testosterone during puberty and adolescence cannot safely or fairly compete in women's rugby. That means that currently, transgender women may not compete in women's rugby.

World Rugby is committed to encouraging transgender people to remain involved with rugby and is currently funding research to continue to review any evidence that may emerge to enable the participation of transgender women in women's rugby. Details of the research currently underway, along with details of how to apply for research funding for those who may be interested, is available **here**.

How do I stay involved in rugby if I can no longer play in the category that I want to?

World Rugby acknowledges that the introduction of this Guideline will mean that some players can no longer play in the category that they want to. It is possible that will change in the future and World Rugby is funding research to try to find out if there are ways to allow that safely and fairly (see **here** for details). In the meantime, there are many other ways to stay involved with rugby:

- Other forms of the game: Many forms of non-contact Rugby exist such as: Tag; Touch; Flag etc all have open
- Coaching: Coaching can be hugely rewarding and can provide players with life lessons, engender a love for the sport and provide an enjoyable vehicle for World Rugby and its member Unions offer several courses for coaches of children, adolescents, and adults. All courses are open to any participant.
- Refereeing: For many people who may not be able to play, refereeing is a viable alternative to stay close to the game. World Rugby and its member Unions offer several introductory courses and a pathway exists in all Unions for fast-tracking talented
- Administration: All clubs rely on volunteer administrators. As individuals enter the latter stages of the long-term participant model, then administration becomes a realistic outlet for many. A number of Unions have dedicated support resources for individuals who wish to pursue this path of staying involved.

World Rugby is currently exploring the possibility of an "open category" of rugby in which any player could play, regardless of gender identity. World Rugby has committed to exploring this option with its Unions, Associations, International Rugby Players, and trans advocate groups including Gendered Intelligence and International Gay Rugby.

What if I have concerns about safety or fairness relating to someone I am playing with or against?

It is important to note that many people do not meet cultural or local norms or stereotypes related to the expression of gender identity. All players and Unions ought to take care to consider this when raising any concerns about another player. In the event that a player or Union has a genuine concern about safety or fairness in relation to another player, the concern should be dealt with as follows:

determines that the concerns are not frivolous or vexatious, the CMO should contact the World Rugby CMO setting out the basis for the

3. The World Rugby CMO will engage with the CMO of the Union of the player about whom the concerns have been raised, ensuring confidentiality for the player and involved team-mates and opponents throughout the

4. The World Rugby CMO and the relevant player's CMO will discuss the situation and agree on the most appropriate actions, based on the specific circumstances

5. In some circumstances, such appropriate actions may include a recommendation that a standardised endocrinological assessment be performed [Appendix].

6. For the avoidance of doubt, no player should or would be forced to undergo any medical or other assessment. It is a player's responsibility to decide on whether he or she wishes to proceed with any assessment. However, it should be noted that deciding not to participate in an assessment, having been requested to do so, may have consequences in terms of the player's eligibility to participate in the category of competition that is consistent with his/her/their gender identity, since it may not be possible to determine whether issues of safety or fairness arise without such assessment.

Exhibit K

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RESEARCH HIGHLIGHT

The significance of testosterone for fair participation of the female sex in competitive sports

Louis Gooren

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Sex segregation in competitive sports is regarded as fair. Before puberty, boys and girls hardly differ in height, muscle and bone mass. Pubertal testosterone exposure leads to an ultimate average greater height in men of 12–15 centimeters, larger bones, greater muscle mass, increased strength and higher hemoglobin levels. Post-pubertal androgen ablation reverses, at least in part, previous anabolic effects of testosterone on muscle,[1] bone mineral density and hemoglobin, but the bones remain longer and have a wider diameter. As testosterone administration produces a dose-dependent increase in muscle mass and maximal voluntary strength,[2,3] exogenous androgens are banned as performance-enhancing drugs.[4] Men with testosterone deficiency are allowed to receive testosterone replacements which do not raise blood testosterone levels above the normal male range.[5,6]

A recent paper highlights the historical case of a Dutch female athlete (1926–2007) outperforming most of her competitors in the years 1948–1950.[7] DNA analysis revealed that she was 46,XX/46,XY mosaic, with equal numbers of both genetic cell types. While having breasts, she also had a degree of facial hairiness pointing to an excess of circulating testosterone, likely produced by the presence of Leydig cell in her gonads on the basis of her XX/XY mosaicism. On the basis of this case, the authors have also given attention to the societal context of sports women becoming involved in a (public) discussion about their sex which is an intrusion into their privacy. The authors advocate that matters of sex of participants in competitive sports should be settled before athletes enter the arena, and this will be elaborated below.

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Prior to the year 2000, genotyping was the means of determining sex for competition in sports. Chromosomal sex alone is not a particularly adequate indicator for the purpose of ensuring fair competition, however. In humans, there is no solid evidence that the pattern of sex chromosomes has a direct effect on muscle mass and strength. Rather, the influence is indirect through determination of the nature of the embryonic gonadal anlagen (testes or ovaries), the hormonal products of these (testosterone and estradiol) and the quantitative relationship between those products. In sports, previous and present exposure to androgens is a reasonable criterion for reducing unfair competition, for both women and men. So, previous and present exposure to testosterone should be the determinant of fair competition between men and between women, also separating the two sexes. Changes in fat-free mass, muscle size, strength and power appear to be associated with testosterone dose and achieved concentrations.[8]

An issue is the participation in competitive sports of people with errors of sexual differentiation and also of transsexuals treated with cross-sex hormones (i.e., female-to-male transsexuals receiving doses of testosterone similar in magnitude as men receiving testosterone replacement). With regard to the effects of testosterone in transsexuals, the dividing line is whether sex (re)assignment has taken place before or after hormonal puberty. Before puberty, there are no significant differences in body composition between girls and boys, so, in this context only post-pubertal sex reassignment is relevant.

It has been demonstrated in the rat that genetic configuration and gonadal status have no known significant effect on sensitivity to the biological action of sex steroids.[9] Effects of testosterone in puberty and thereafter are certainly in part reversible but there is no definitive information on the extent of this. It is unknown whether or for how long earlier effects of androgen exposure carry over after androgen ablation.[10] In a study comparing muscle surface areas between male-to-female transsexuals and female-to-male transsexuals, we noted a significant difference in the average, but there was also a considerable overlap between the two groups before any hormonal intervention had taken place. In spite of muscle surface area reduction induced by androgen deprivation, after 1 year the mean muscle surface area in male-to-female transsexuals remained significantly greater than in untreated female-to-male transsexuals; again, an almost complete overlap was noted between the two groups. Testosterone administration to female-to-male transsexuals increased muscle surface areas significantly, producing a large overlap with untreated male-to-female transsexuals but with a significantly lower mean.[10] Effects of cross-sex hormones on insulin-like growth factor and hemoglobin levels paralleled changes in muscle surface area.[10]

Another group of interest is subjects with disorders of sexual differentiation and other subjects with a higher-than-normal endogenous production of androgenic–anabolic hormones (such as congenital virilizing adrenal hyperplasia and polycystic ovarian syndrome). There are studies reporting a higher lean body mass and bone mass in women with polycystic ovarian syndrome,[11–13] but whether this translates into better performance in sports is unknown.

For transsexual people, the International Olympic Committee has drawn a necessarily arbitrary but reasonable line with regard to participation of sex-reassigned transsexuals: sex reassignment must have taken place at least 2 years earlier. In support of this decision, in the abovementioned study, we found that changes in muscle surface area were not greater after 3 years of cross-sex hormone administration than after 1 year.[10] Hormone treatment must be appropriate for the reassigned sex (no overdosing of testosterone in female-to-male transsexuals), and the reassigned sex must be legally recognized. The International Olympic Committee policy is not binding for other sports organizations. Very recently (1 May 2011), the International Association of Athletics Federations (IAAF) has adopted revised guidelines for the participation in sports of athletes who have undergone sex reassignment. Reassigned transsexuals must notify the IAAF of their status if they wish to compete with others. This will be dealt with confidentially for the protection of the privacy of the person, thus avoiding public debate on the sex of the participant. The person in question will be examined by an Expert Medical Panel of the IAAF assessing the period of time since the sex reassignment, the athlete's androgen levels and the nature, duration and results of any treatment following sex reassignment. The results will be reported to the IAAF which will grant permission if the medical assessment does not provide indications of unfair advantage over other female competitors.

For subjects with hyperandrogenism, on 12 April 2011, the IAAF announced the adoption of new rules and regulations governing the eligibility of females with hyperandrogenism to participate in women's competition, which equally have come into force on 1 May 2011 (http://www.iaaf.org/aboutiaaf/news/newsid=59746.html). The approach is similar to that of transsexuals. Athletes with a hyperandrogenic disorder report to the IAAF and will undergo an assessment by the Expert Medical Panel. The IAAF is of the opinion that elevated androgen levels originating from congenital virilizing adrenal hyperplasia or polycystic ovarian syndrome or similar conditions are no ground for exclusion even though the associated hyperandrogenism may provide some advantages to the athlete. For the time being, the upper limit of acceptable serum testosterone levels is a level that is clearly at the lower limit of the normal male range (10 nmol l^{-1}). This position was adopted because there is no consensus on the upper range of serum testosterone levels in women,[14] also in view of the problems with accurate measurements, metabolites, circadian rhythm and binding proteins etcetera of serum testosterone.[15] The present upper limit of acceptable serum testosterone levels seems a compromise of a committee that had to come up with formal rules generally applicable to a population of female athletes. It might very well be that future medical research solves the problems of determining one's androgen status more accurately and that a stricter consensus can be reached what constitutes hyperandrogenism in women. If so, it is likely that the upper limit of acceptable androgen levels for female athletes will be lowered. Most practicing physicians will start diagnostic work-up of hyperandrogenism if serum testosterone exceeds 3–5 nmol l^{-1}.

Eventually, it is illusionary to arrive at 100% fairness in competition on the basis of serum testosterone levels. First of all, there are the well-known methodological difficulties of measuring serum testosterone levels reliably.[15] Second, serum testosterone levels provide an indicator of the strength of the androgen signal, but have limited predictive value of the biological effects of testosterone which are codetermined by properties of the androgen receptor.[16] This is exemplified in people with abnormalities of the androgen receptor who have high circulating serum androgen levels, but androgen action is impaired due to genetically determined abnormalities of the molecular properties of the androgen receptor (androgen insensitivity syndrome). It seems further appropriate to place the effects of testosterone in the perspective of naturally occurring and imponderable differences in sporting capability between members of the same sex. Unfair competition should be prevented as much as possible, and the above measures of the IAAF are the best possible at present, but ultimately Nature is unfair in her endowments of talents for all walks of life, including sports.

1 Mauras N, Hayes V, Welch S, Rini A, Helgeson K *et al.* Testosterone deficiency in young men: marked alterations in whole body protein kinetics, strength, and adiposity. *J Clin Endocrinol Metab* 1998; **83**: 1886–92.
2 Storer TW, Magliano L, Woodhouse L, Lee ML, Dzekov C *et al.* Testosterone dose-dependently increases maximal voluntary strength and leg power, but does not affect fatigability or specific tension. *J Clin Endocrinol Metab* 2003; **88**: 1478–85.
3 Choong K, Lakshman KM, Bhasin S. The physiological and pharmacological basis for the ergogenic effects of androgens in elite sports. *Asian J Androl* 2008; **10**: 351–63.
4 Handelsman DJ, Heather A. Androgen abuse in sports. *Asian J Androl* 2008; **10**: 403–15.
5 Handelsman DJ, Gooren LJ. Hormones and sport: physiology, pharmacology and forensic science. *Asian J Androl* 2008; **10**: 348–50.
6 Gooren LJ, Behre HM. Testosterone treatment of hypogonadal men participating in competitive sports. *Andrologia* 2008; **40**: 195–9.
7 Ballantyne KN, Kayser M, Grootegoed JA. Sex and gender issues in competitive sports: investigation of a historical case leads to a new viewpoint. *Br J Sports Med*; e-pub ahead of print 3 May 2011 ; doi: 10.1136/bjsm.2010.082552.
8 Bhasin S, Woodhouse L, Casaburi R, Singh AB, Bhasin D *et al.* Testosterone dose-response relationships in healthy young men. *Am J Physiol Endocrinol Metab* 2001; **281**: E1172–81.
9 Bentvelsen FM, Brinkmann AO, van der Schoot P, van der Linden JE, van der Kwast TH *et al.* Developmental pattern and regulation by androgens of androgen receptor expression in the urogenital tract of the rat. *Mol Cell Endocrinol* 1995; **113**: 245–53.
10 Gooren LJ, Bunck MC. Transsexuals and competitive sports. *Eur J Endocrinol* 2004; **151**: 425–9.
11 Notelovitz M. Androgen effects on bone and muscle. *Fertil Steril* 2002; **77** (Suppl 4): S34–41.
12 Douchi T, Oki T, Yamasaki H, Kuwahata R, Nakae M *et al.* Relationship of androgens to muscle size and bone mineral density in women with polycystic ovary syndrome. *Obstet Gynecol* 2001; **98**: 445–9.
13 Carmina E, Guastella E, Longo RA, Rini GB, Lobo RA. Correlates of increased lean muscle mass in women with polycystic ovary syndrome. *Eur J Endocrinol* 2009; **161**: 583–9.
14 Revised 2003 consensus on diagnostic criteria and long-term health risks related to polycystic ovary syndrome (PCOS). *Hum Reprod* 2004; **19**: 41–7.
15 Bhasin S, Zhang A, Coviello A, Jasuja R, Ulloor J *et al.* The impact of assay quality and reference ranges on clinical decision making in the diagnosis of androgen disorders. *Steroids* 2008; **73**: 1311–7.
16 Zitzmann M. Pharmacogenetics of testosterone replacement therapy. *Pharmacogenomics* 2009; **10**: 1341–9.

Exhibit L

Chapter 2

Armstrong N, McManus AM (eds): The Elite Young Athlete.
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Physiology of Elite Young Female Athletes

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Abstract

The participation of girls in elite sport has increased exponentially over the past 30 years. Despite these increases a tradition for recruiting boys for exercise studies persists and our knowledge of the physiologic response to exercise in girls remains limited. Girls' physiology varies with age and maturation and is underpinned by a divergent hormonal milieu which begins early in foetal life. Sexual dimorphism underlies much of the physiologic response to exercise, and becomes most acute during adolescence when boys become taller, heavier, less fat and are more muscular than girls. Young girl athletes are not simply smaller, less muscular boys. The widening sex disparity in responses to exercise during puberty cannot always be accounted for by size. The woeful number of studies on girls and our prior inability to non-invasively study the complexity of the cellular metabolic response to exercise means an integrative understanding of girls' physiological responses to exercise remains elusive. Success in elite sport requires intense training, which for a long time was thought to cause disruption to normal growth and maturation. It would appear that exercise training, without other predisposing factors, is unlikely to cause aberrations to either growth or maturation. Nevertheless, there is clear evidence of a boundary between healthy and unhealthy levels of exertion when coupled with caloric limitation. Sports in which intense training is combined with the need for leanness may predispose girls to increased risk of skeletal and reproductive health problems, and ensuring risk is minimised should be a priority.

The young female athlete is unique. She stands out from her peers, who show declining levels of physical activity from early puberty [1]. In comparison to boys, she remains under-represented in competitive sport [2]. This persists to Olympic level competition with 1,704 fewer women competing at the 2008 Beijing Olympics than men [3]. Moreover, there are fewer scientific data on physiologic issues associated with exercise in girls than in boys. Traditionally, boys have been recruited for exercise studies and a search of key databases shows that this persists with comparatively fewer articles investigating physiologic responses to exercise in girls. This preference for recruiting boys reflects social constraints which can be traced back to Victorian values surrounding women, exercise and health [4]. Central to the issue of women's involvement in sport was biology, bolstered by the idea that a woman's structural and functional ability was unable to tolerate strenuous exercise, presenting considerable risk to her reproductive health. Indeed, whether or not chronic training causes less than optimal structural and functional alterations in girls remains the topic of lively debate [5–8].

Sexual dimorphism does indeed underlie much of the physiological response to acute and chronic exercise, and although a myriad of factors have been shown to influence the development of sport performance [9], structural and functional capacity represent a significant contribution to the gender differences notable. Figure 1

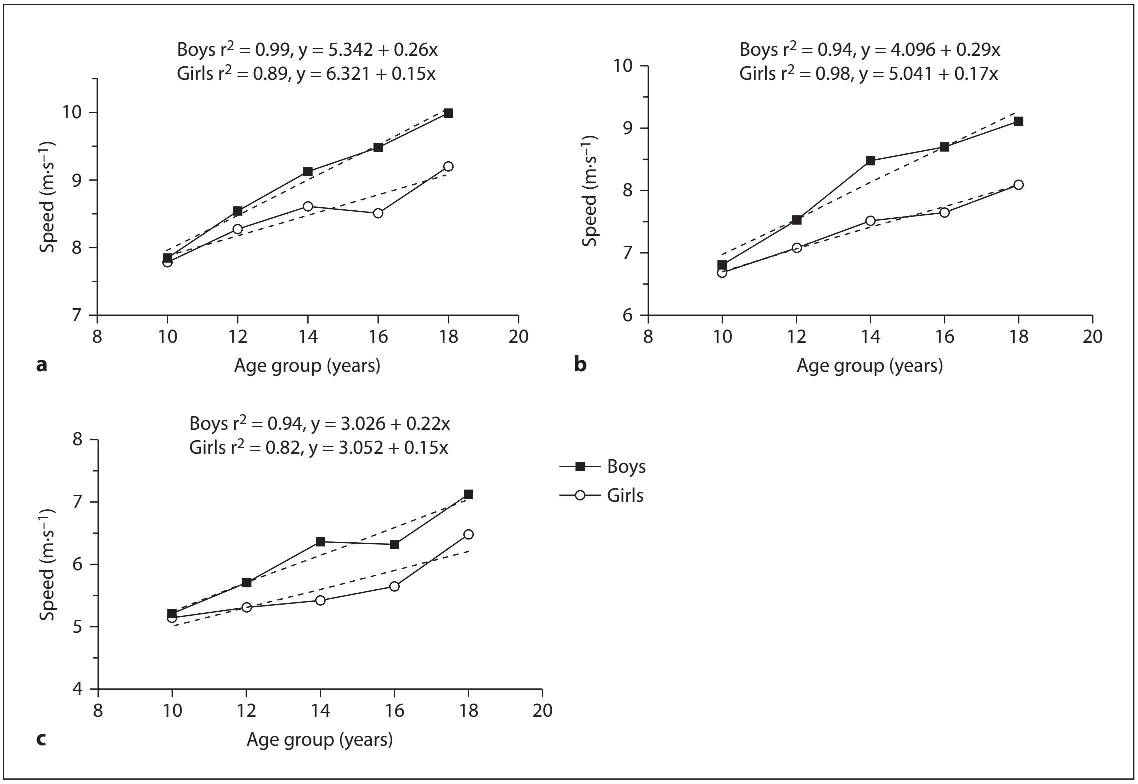

Fig. 1. Average running speed from North American age-group track and field records and world junior records over 100m (**a**), 400m (**b**) and 1,500m (**c**) for girls and boys.

illustrates the average running speed over 100, 400 and 1,500 m for girls and boys competing in age-group track and field championships in North America and world junior records [10, 11]. Analyses of these data show that regardless of distance, average running speed increases with age in both girls and boys (r^2 >0.82 for all distances). Prior to 11 years of age differences in average speed are minimal, thereafter disparity becomes more pronounced with boys 8–15% faster than girls from 13 years of age onwards. This is consistent with the 9–15% advantage in speed adult men have over women across a wide range of distances from 100 m to 200 km [12]. When the slopes of the regression lines were compared between the sexes by age, these were significantly different for 100 and 400 m with the rate of improvement greater in the boys than the girls (see fig. 1). The rate of improvement in running speed over 1,500 m was similar between boys and girls with a pooled slope of 0.19. That an interaction between distance, speed developmental trajectories and sex exists suggests intriguing physiological mechanisms.

A key question to be addressed is whether the superior performances of boys relate to qualitative discrepancies in functional capacity or alternatively, they are simply a function of the increased body size and disparate body composition that accompanies adolescent growth and maturation. Appropriate adjustment for differences in body size and composition dampen many apparent physiological differences [13, 14]; however, young girl athletes are not simply smaller, less muscular boys. Girls' physiology varies with age and is underpinned by a divergent hormonal milieu which begins early in foetal life. There is evidence that in the two-cell stage of embryonic development, long before visual gonadal differentiation, the sex-determining region of the Y chromosome has already been transcribed [15]. Testosterone secretion commences at about 3 months in the male foetus, the absence of which in the female foetus allows maturation of the female reproductive organs, and by birth subtle differences in cardiac function and body composition already exist [16, 17]. The accentuated hormonal adjustments which occur during adolescence result in differential development and a widening sex disparity in many physiological responses to exercise, some of which cannot be accounted for by size.

The primary focus of this chapter is on physiologic issues that are associated with exercise in girls; but to illustrate sexual dimorphism, comparisons will be made with boys where relevant. The chapter begins with a brief overview of growth and maturation in girls, including a discussion of issues related to body composition and size. This is followed by a focus on the acute responses to sustained aerobic exercise, as well as short-duration high-intensity exercise in girls. The possible physiological mechanisms that underlie these responses, such as sex differences in pulmonary, cardiac, and peripheral function, as well as cellular metabolism are discussed. The chapter concludes with consideration of the contention that intensive training poses a substantial threat to the development and health of young girls.

Growth and Maturation

Growth hormone (GH), insulin-like growth factor I (IGF-I), the sex steroids and insulin are all potent anabolic hormones. Their complex interactions enable linear growth, bone mineralization, increases in muscle and metabolic adaptations during childhood and adolescence and much of this hormonal mélange is sex dependent [18]. For example, the physiological effects of the sex steroids testosterone and oestrogen differ markedly, with evidence that combined testosterone and GH administration causes increases in IGF-I concentrations, resulting in enhanced anabolism, greater increases in fat free mass and higher whole body protein synthesis in boys [19]. Oestrogen administration, on the other hand, has been shown to have no effect on whole body protein synthesis in girls [19]. Sex dimorphic growth and development is most pronounced during adolescence, which forms the primary focus of the following sections.

Stature and body mass follow a double-sigmoid growth pattern in girls and boys, with rapid gains in infancy, slower yearly gains of about 5–6 cm in stature and 2.25–2.75 kg in body mass through childhood, and a second rapid gain in adolescence [20]. Girls usually begin adolescent growth before boys and progress at a faster rate than boys [21, 22]. At the peak of the adolescent growth spurt, girls gain approximately 8–9 cm in a year in stature. Boys only gain about 3 cm more in stature during the adolescent growth spurt, but are about 11–13 cm taller by adulthood because of their extra pre-adolescent growth [23]. From onset to completion, adolescent growth in stature lasts about 4–4.5 years in girls, until rising levels of oestrogen induce epiphyseal fusion marking an end to the growth in stature, usually around a skeletal age of 15 years [18, 21]. Peak body mass velocity is in lag by some 4–6 months with peak height velocity and total body mass gains of 16 kg are usual during the adolescent growth spurt in girls [24].

Other body proportions such as sitting height, leg length, biacromial and bicristal breadths follow a similar growth pattern to stature. Leg length and sitting height differ little between girls and boys during childhood [23]. At the onset of adolescence rapid growth in leg length precedes trunk growth. Boys surpass girls in leg length by about 12 years of age and in sitting height around

14 years of age. Yet, the ratio of sitting height to stature is higher in girls than boys through adolescence indicating relatively shorter legs in girls for the same stature. Girls have a marginally wider bicristal breadth than boys from late childhood to late adolescence, when boys catch-up [23]. In contrast, boys experience much more dramatic increases in biacromial breadth compared to girls [23]. When bicristal breadth is expressed as a ratio of biacromial breadth (hip-to-shoulder ratio), in comparison to boys values are higher in girls from early childhood, with bicristal breadth approximately 72–73% of biacromial breath, remaining quite stable through adolescence. In boys a decline in this ratio is noted from about 70% at 11 years of age, to 65% by 16 years of age, which is an outcome of the disproportionately faster growth of biacromial breadth [23]. Interestingly, although stature as well as mass-to-stature ratio differ between girls involved in different competitive sports, minimal differences in other proportions such as arm span and seated height have been reported [25, 26]. Greater mass-to-stature ratios can confer performance benefit in some sports such as throwing events; however, the combined effect of broader hips and shorter legs that usually accompany a greater mass-for-stature and characterize early maturation in girls, is generally disadvantageous. Although data are sparse, young female athletes in running events or gymnastics are generally more likely to be characterized by longer legs, lower hip-to-shoulder ratios and lower mass-for-stature.

Assessment of maturity stage is vital but poses considerable challenge. Skeletal age is the biological marker of choice, but is hindered by ethical constraints related to ionizing radiation exposure. The timing and tempo of sexual maturation in girls has most commonly been described using the visual descriptive stages of secondary sexual characteristics. These were first documented by Reynolds and Wines [27], and then further refined by J.M. Tanner and are better known as Tanner stages [28]. There is a large normal variation in the timing and tempo of sexual maturation in girls, as well as clearly documented sex differences. Like linear growth, girls normally begin sexual maturation before boys and progress toward full maturity at a faster tempo than boys [22].

A recent large-scale longitudinal study of Caucasian and African-American children suggests that the average girl begins breast development at 9.8 years, whilst the average boy begins genital development at about 10.3 years [21]. Pubic hair growth usually occurs around 10.2 years in girls and around 11.3 years in boys. The onset of the initial stages of sexual maturity in these American girls is somewhat earlier than previously published data for European girls, for whom breast budding was reported to occur at about 10.5 years and Tanner Stage two for pubic hair at 10.8 years [28, 29]. This discrepancy probably reflects the different racial mix of the groups, in addition to a possible secular trend for a declining age of onset of maturation [30].

Asynchronous maturation of secondary sex characteristics in girls is common and has been defined as a difference of at least 4 months between breast and pubic hair development. About 51–66% of girls follow an asynchronous maturation pattern [21, 31]. Most (about 70%) follow a thelarchal pathway, with breast development beginning prior to pubic hair growth (adrenarche). Asynchrony usually persists into Tanner stage 3, the onset of which is on average 11.3 years for breast development, with pubic hair stage three occurring some 2 months later [31]. As the latter stages of sexual maturity are attained, development becomes more synchronous. A minority of girls (approximately 30%) follow an adrenarchal asynchronous pathway, in which pubic hair development precedes breast development. Thelarchal asynchrony is believed to result from initial advanced stimulation of gonadotropin and oestrogen, thereby enabling earlier breast development. The converse is true of adrenarchal asynchrony, where the advanced production of testosterone and adrenal hormones promotes earlier pubic hair growth. Age of onset of menses usually occurs during Tanner stage three for breast development. For those girls following the thelarchal pathway, menses occurs at an earlier age, around 12.6 years. Those following the adrenarchal pathway usually begin menses around 13.1 years [21, 31]. Lower oestrogen levels are noted in girls following an adrenarchal maturation pathway which persists throughout adolescence. This affords a body composition advantage, characterized by a lower sum of skinfolds, percent body fat and waist-to-hip ratio [31]. Girls involved in intensive training are generally characterized by lower percent body fat, but there is little evidence to suggest that they preferentially follow an asynchronous adrenarchal pathway [32].

The presence of asynchronous sexual maturation has implications when comparing young athletes with non-athletes, as well as making comparisons between girls and boys. Whether alignment is on the basis of a single marker (e.g. pubic hair development), the creation of a composite score for both pubic hair and breast development, or on differing secondary sex characteristics (such as genitalia and breast development), the assumption is that the timing of the appearance of a particular characteristic, as well as the tempo, is homogeneous. This is clearly not always the case, and it has been suggested that alignment of sexual maturation to other biological or somatic markers of maturation (e.g. age at menarche or peak height velocity) is more appropriate [33]. Menarchal age is convenient if retrospective, otherwise, like peak height velocity, a prospective research design is necessary. Assessment of maturational stage continues to present a real methodological challenge to paediatric exercise physiologists.

Body Composition and Size

Fat

Small sex differences in fat mass and percent body fat are evident from mid-childhood, with levels rising substantially in girls during adolescence. Body fat gains by the end of puberty usually result in 26–31% body fat in the average adolescent girl [34, 35]. Young athletes are generally leaner than the average non-athletic girl, but this is dependent on the chosen sport. Values as low as 14.3% have been reported for 15-year-old rhythmic gymnasts, with gymnasts generally showing lower body fat than other athletes [34]. Body fat values from 21 to 25% have been reported for dancers, distance runners and cross-country skiers from the ages of 10–17 years [36–39]. Higher values have been reported for 13- to 17-year-old high-school athletes competing in lacrosse, soccer, softball, swimming, track and field and volleyball (mean 27.4 ± 0.7%) [40].

Sex steroids are major determinants of body fat distribution, with the increases in body fat generally subcutaneous and in the gluteal and femoral regions in girls. Fat mass, combined with a smaller leg length-to-stature ratio, lowers the centre of gravity in girls, thereby affording better balance. However, fat mass is also negatively related to heat dissipation, which may prove disadvantageous in girls during endurance events in hot environmental conditions [41].

Fat tissue has relatively uniform properties throughout life, with negligible water content and a tissue density of 0.9007 $kg \bullet l^{-1}$ [42]. Recent reference data from Wells et al. [42] have shown that in comparison lean tissue shows sex-specific chemical maturation, with decreases in water content and increases in density with increasing age. These new data have implications for the assessment of body fat since previous reference data extrapolated rather than directly assessed age specific tissue densities and hydration. Wells et al.'s [42] work provides the first comprehensive empirical data set for lean tissue properties for 4- to 23-year-old boys and girls, with lean tissue density values in girls of 1.0905 $kg \bullet l^{-1}$ at 8–9 years, rising to 1.1021 $kg \bullet l^{-1}$ at 16–17 years. Lean tissue hydration values declined with age from 75.2% at 8–9 years to 73.7% at 16–17 years in girls. Importantly, this study has shown that these new values differ from previously simulated values. The lean tissue density values of Wells et al. [42] were consistently higher, whilst the hydration data were consistently lower than those reported by Lohman [43]. Comparisons of % fat calculated from densitometry with the Lohman [43] formula led to a between-study error of –1 to 2.5% fat in the average girl. Wells et al. [42] provide important new reference values for the assessment of body fat by both hydrometry (total body water, bioelectrical impedance) and densitometry which should ensure greater clarity in future analyses.

Muscle

At birth, boys tend to have a greater lean mass than girls. This difference remains small but detectable throughout childhood with about a 10% greater lean mass in boys than girls prior to puberty [17]. The sharp increase in muscle mass disparity between the sexes during puberty indicates a primary role of the gonadal steroidal hormones. Muscle mass in girls increases from about 25 kg at 10 years of age to about 45 kg by 18 years of age [42]. Reported values for 15- to 17-year-old female athletes are not dissimilar, ranging from 42 to 53 kg [23]. These gains in muscle tissue represent an increase of about 5% in muscle mass. The relative contribution of muscle mass to total body mass usually declines once consideration is given to the relative contribution of fat mass. In comparison, the androgen-mediated growth of muscle in boys results in muscle mass reaching about 55% of total body mass at maturity [44]. The greater overall skeletal muscle mass in adolescent boys creates a potential cascade of functional differences apparent in adults such as differing muscle fibre size, activities of metabolic enzymes, lipid content and oxidation, relative expression of myosin isoforms, and fatigability [45–50]. Maturation of these features remains poorly understood.

The use of ultrasonography and magnetic resonance imaging (MRI) are providing insight into changes in muscle architecture with growth. A recent study using ultrasonography demonstrated that muscle thickness (a marker of physiological cross-sectional area) and pennation angle were correlated with age from 4 to 10 years in both sexes [51]. Findings from MRI studies have shown similarly that muscle cross-sectional area increases with age from childhood through adolescence, and more so in boys than girls [52]. Pennation angle on the other hand has not been found to differ between the sexes [51]. Whilst muscle cross-sectional area and pennation angle are related to age, this has not been shown in muscle fibre length [51]. Muscle fibre length has been found to have high inter- and intra-individual variation, which may reflect a greater malleability in response to external stimuli such as the extent and intensity of exercise [51].

Morphological change in the muscle impacts upon function. Maximal strength, for example, is dependent on the specific joint angle (force-length relationship), contraction type, muscle cross-sectional area and velocity. The length of the muscle fibre is proportional to the absolute maximum contraction velocity, whilst the pennation angle dictates the proportion of force transmitted to the tendon. Muscle strength, expressed as torque, increases with age in children, but gains are greater in boys. This has been presumed to be an outcome of the greater muscle cross-sectional area [53]. Alternatively, there may be intrinsic sex differences in the fibre composition and fatigue characteristics of skeletal muscle that materialize during adolescence that also influence the ability to increase torque.

In adults, several studies have reported higher glycolytic enzyme activity and lower oxidative enzyme activity in men compared to women, supporting the contention that men have a lower proportion of type I fibres [50, 54]. Data on muscle fibre typing in children are limited because of the invasive nature of the biopsy methodology, but there is evidence to show that differentiation of fibre type occurs during the first few years of life. About 10% of skeletal muscle fibres remain undifferentiated up until puberty, with no sex difference notable in the percentage of type I fibres (slow-twitch oxidative fibres) during childhood [55]. By adolescence females have a lower % of type I muscle fibres than males [45, 56] and the type II muscle fibres of young men are bigger than their type I fibres, something not evident in young women [56, 58].

Although boys gain more in strength than girls during adolescence, elite girl athletes are stronger than their less athletic peers. For example, average quadriceps and biceps isometric strength was reported to be 22% greater in elite gymnasts and swimmers and 18% greater in tennis players compared to less athletic school children [59]. Interestingly this study found no differences in strength between sports in the girls, even when co-varied for body mass. The relationship between strength and body mass, or strength-to-mass ratio, has been seen as an important predictor of sport performance particularly in gymnastics, middle- and long-distance running. Indeed, elite adult women runners such as Yvonne Murray and Greta Waitz were 17–18% below the average body mass for their stature at the peak of their running careers, which suggests relative strength was high. The work of Bencke et al. [60] has shown that 11-year-old girl gymnasts were the smallest, lightest and possessed the highest explosive strength compared to other athletes, suggesting high relative strength confers advantage in some sports in girls.

Bone

Bone characteristics differ little between boys and girls prior to puberty, but then follow two sex-divergent growth paths. During the adolescent growth spurt boys experience increases predominantly in bone diameter and cortical thickness due to periosteal apposition [17]. Girls on the other hand experience increases in cortical thickness, a decrease in medullary diameter, and little increase in periosteal diameter as a result of oestrogen inhibition of periosteal apposition [17, 61]. It should be noted that bone accretion and endocortical features appear to be site specific with data showing endocortical resorption at the mid-femur and proximal tibia in girls through puberty, but no endocortical resorption at the radial diaphysis [62, 63].

During puberty**,** bone mineral content (BMC) accrual rate is in lag with muscle accrual rate, suggesting that muscle enlargement, and concomitant increases in muscle force, are important for bone development [64]. Indeed, the 'functional muscle-bone unit' hypothesis suggests muscle force is a primary determinant of bone mass, structure and strength [65]. Young female runners and gymnasts have been shown to have elevated bone mass and enlarged bone size at specific sites such as the radius and lumbar spine in gymnasts [66] and the femur in runners [67], reflecting the specific mechanical-loading patterns these sports require. This has led some to conclude that muscular force alone explains the impact loading effect on bone [68–70]. On the contrary, recent research has shown that bone mass, size and strength increases in the upper extremity in gymnasts are independent of maturation, stature and muscle cross-sectional area and substantiates the hypothesis that other non-muscular loading factors may also account for skeletal adaptations [71, 72].

Puberty is the most favourable period for augmented bone mineralization, with about one quarter of adult bone being laid down. Bone mineral accrual is sex and maturity dependent and appears to be enhanced by oestrogen. It is clear that the early pubertal and pre-menarchal years are particularly important for young girls in terms of optimizing their bone mineralization and weight-bearing exercise plays a key complementary role in this process [73].

Body Size Considerations

By the time the adolescent growth spurt is complete the body size, shape and composition of boys and girls is different. Boys have become taller, have longer legs, broader shoulders, are heavier, and have less fat and more muscle than girls. The effect of these discrepancies on performance is substantial, and it is important in understanding girls' physiologic responses to exercise that we are able to effectively partition the impact of size from function. Traditionally in exercise physiology this has been achieved by expressing the physiological measure of interest (y) as a ratio of an appropriate marker of body size (x) to give the ratio y/x. Tanner suggested in 1949 that the use of such ratio standards to scale physiological measurements to size was 'theoretically fallacious and unless in exceptional circumstances, misleading' [74]. Yet this has largely been ignored with much of the comparison between men and women, or boys and girls based on ratio standards [75, 76]. An implicit assumption with the ratio standard is that the relationship is linear and the y intercept is zero. Additionally, ratio standards should only be used when the coefficient of variation (V) for body size (x), divided by the coefficient of variation (V) for the physiological variable (y), equals the Pearson product moment correlation coefficient (r) for the two variables, expressed by the equation $V_x/V_y = rx,y$. These assumptions are rarely met and the outcome is scaling distortion, which may have obscured our understanding of the physiologic responses of girls [77].

Theoretically, morphological and physiological variables are scaled according to the general allometric equation $y = ax^b$, where y is the morphological or physiological variable of interest, x is the chosen size denominator, b is the scaling exponent and a is the constant [78]. When this equation is solved the resultant power function ratio (y/x^b) is derived. Various studies have shown that with careful consideration of the denominator, alternative approaches, such as the allometric power function ratio or more complex multilevel modelling of longitudinal data, are more appropriate than ratio scaling when comparisons of various physiological outcomes between individuals of differing body size are sought [79, 80]. These alternatives should, wherever possible, be utilised.

Acute Responses to Aerobic Exercise

Peak oxygen uptake (peak $\dot{V}O_2$), the highest $\dot{V}O_2$ elicited during an exercise test to exhaustion in children, is well-established as the best single measure of aerobic fitness [81]. In comparison to boys, girls are characterised with a smaller absolute peak $\dot{V}O_2$. Predicted values range from 1.5 to 2.2 litres $\bullet$ min^{-1} in 10- to 16-year-old girls and are lower than boys by 11, 19, 23 and 27% at ages 10, 12, 14 and 16 years of age, respectively [82]. Peak $\dot{V}O_2$ is strongly correlated with body size and composition and thus, much of the divergence in values reflects this. When expressed as a ratio standard with body mass ($ml \bullet kg^{-1} \bullet min^{-1}$), peak $\dot{V}O_2$ shows a progressive decline in girls from 13 years of age, with values dropping from approximately 45 to 35 $ml \bullet kg^{-1} \bullet min^{-1}$ [83]. In contrast, mass-related peak $\dot{V}O_2$ in young female runners has been found to be relatively constant with values of 56.3, 57.1, 56.9 and 54.3 $ml \bullet kg^{-1} \cdot min^{-1}$ at ages 10, 12, 14 and 16 years, respectively [84]. Likewise, peak $\dot{V}O_2$ has been shown to be fairly stable between 11 and 16 years of age in elite girl swimmers and tennis players [85], with values of 51–52 $ml \bullet kg^{-1} \bullet min^{-1}$ and 47–49 $ml \bullet kg^{-1} \bullet min^{-1}$, respectively. When multilevel modelling was used to account for mass, stature and biological age, the elite girl swimmers and tennis players showed increases in peak $\dot{V}O_2$ until late puberty when increases became non-significant [85]. Similarly, in the less athletic population when more appropriate allometric adjustment is used to partition size effects in body mass and stature, peak $\dot{V}O_2$ has been found to increase significantly from 11 to 13 years in girls, and then remain constant with no decline into adulthood evident [81].

Dramatic pubertal changes in muscle, fat and mass contribute to the widening of the sex difference in peak $\dot{V}O_2$. When a marker of body fat was included in a multilevel regression model which incorporated body mass, stature and age, the sex difference in peak $\dot{V}O_2$ was reduced, but the greater increase in boys' peak $\dot{V}O_2$ with growth compared to girls was still not fully explained [83]. Equally, longitudinal data have shown that even when differences in body mass and fat mass are controlled for allometrically, girls utilise less oxygen than boys during submaximal exercise, and this becomes more pronounced with age [86]. Understanding the physiologic mechanisms that underlie these size-independent sex differences in peak and submaximal $\dot{V}O_2$ requires consideration of the coordinated systems response, which includes pulmonary, cardiac and peripheral adjustments to the demands in muscular energy. A discussion of key features of each follows.

Pulmonary

It was generally assumed that because exercise training exerts little influence on lung structure or function that the lungs exert minimal influence on oxygen transport. However, there is evidence that lung function adaptation does occur as a consequence of exercise training in girls [87]. Moreover recent investigation of sex differences in pulmonary structure and function in adults has shown considerable effects on gas exchange and the integrated ventilatory response during exercise, in particular exercise-induced arterial hypoxia [88]. There are well-documented sex differences in anatomical aspects of the pulmonary system which occur during lung growth [89]. The consequence of sex dependent pubertal thoracic growth is a larger thoracic width in boys. When coupled with a greater muscle mass for generating lower lung function, boys have approximately 25% greater lung volumes than girls who are matched for stature [89]. By adult life, in addition to the smaller lung volumes, stature and age independent lower resting diffusion capacity (corrected for haemoglobin), lower maximal expiratory flow rates [90], and a greater occurrence of exercise-induced hypoxia has been shown in women [91]. Equally, there is also evidence that when matched for size and aerobic power women do not have reduced diffusion capacity or impaired ventilation perfusion during exercise [92].

In children, like adults, exercise pulmonary gas exchange depends on pulmonary ventilation ($\dot{V}_E$) and at maximal work rates high rates of ventilation are usual. Maximal values of 49–95 litres • min^{-1} have been recorded for girls between the ages of 9 and 16 years [93] and there is a consistent sex difference with values somewhat higher in boys (58–105 litres • min^{-1}) for the same age span. It should be noted that cross-study comparisons are difficult given the dependence of ventilation on the protocol and data such as these need to be interpreted cautiously. Maximum ventilation remains higher in boys, whether controlled for body size using a ratio standard or allometric adjustment with either stature and/or body mass [94, 95]. Thus, the higher peak $\dot{V}O_2$ in boys is indeed supported by a higher $\dot{V}_E$.

During exercise, an expiratory flow limitation is apparent in adult women but not men, resulting in a greater oxygen cost of breathing and the onset of arterial desaturation [88, 96]. Recent evidence has provided a comparison between pre-pubertal boys and girls and found no difference in the occurrence or severity of expiratory flow limitation between girls and boys and no changes in arterial saturation during exercise to maximum [97]. Others have found little evidence of exercise induced arterial hypoxaemia in pre-pubertal girls, or lower ventilatory efficiency at maximum [98, 99]. When Armstrong et al. [94] compared ventilatory parameters during submaximal exercise at the same absolute intensities they noted that girls demonstrated higher ventilatory equivalents for oxygen and carbon dioxide, i.e. poorer ventilatory efficiency in comparison to boys. However, when they compared submaximal ventilatory efficiency during the same relative exercise intensities, values were remarkably similar between the sexes. This suggests that differences apparent at absolute submaximal exercise intensities simply reflect the higher relative percentage of maximum that girls are working at and do not denote true inefficiency.

There is little evidence that prior to puberty pulmonary structure or function limits oxygen uptake, however, considerable evidence has shown pulmonary function influences gas exchange in adult women, suggesting that maturational adjustments occur. At present however, there is little evidence to substantiate this.

Blood Volume and Haemoglobin

Assessment of blood volume in children and adolescents is complex and the variability in techniques means there are considerable discrepancies between studies. There are conflicting results regarding changes in blood volume with age. Some have shown that blood volume per unit body mass increases with age [100], others have found no change [101], whilst others report decreasing blood volume with age [102]. Likewise, data on sex differences in blood volume between girls and boys are mixed. When normalised using a ratio standard with body mass, differences between girls and boys were apparent from about 6 years of age, with values lower in the girls [103]. In contrast, when normalised using a ratio standard for lean body mass, sex differences are no longer apparent for pre-pubertal children, or at any maturational stage [103].

In boys, haemoglobin rises through adolescence to about 152 $g \bullet l^{-1}$ by 16 years of age [104]. Girls, on the other hand, usually demonstrate a plateau in haemoglobin concentration with values of about 137 $g \bullet l^{-1}$ by 16 years of age [104]. Highly trained adolescent female athletes also show lower haemoglobin concentration values compared to trained boys, with about a 7% difference [105]. Fully saturated, 1 g of haemoglobin carries 1.34 ml of oxygen, and one would presume that the smaller increase in haemoglobin in girls would result in a reduced oxygen carrying capacity in comparison to boys. However, it has been shown that haemoglobin concentration is not a significant predictor of peak $\dot{V}O_2$ in 11- to 17-year-olds once body size and composition and maturation have been controlled for [83].

Cardiac and Vascular Considerations

There are clear differences in cardiac function at rest and during exercise between girls and boys, with differences apparent even prior to puberty. The electrical conduction system is influenced by sex steroid hormones, with girls normally having higher resting heart rates than boys – somewhere in the magnitude of 90 beats per minute at around 10–12 years of age [106]. This is thought to relate to intrinsic differences in the sinus node pacemaker [107], a difference notable at birth with newborn boys displaying lower baseline heart rates than girls [16]. The higher resting heart rate in girls is often explained as an artefact of differences in cardiac dimensions, and indeed the ratio of heart mass to body mass has been found to be higher in boys than girls at birth, remaining so through adolescence [106]. Heart volume has also been found to be greater in boys with values of 342 and 403 ml for pre-pubertal girls and boys, respectively, and of 466 and 561 ml for pubertal girls and boys, respectively [108]. When adjusted for body mass these differences were found to persist through puberty (female 10.0 $ml \bullet kg^{-1}$; male 10.8 $ml \bullet kg^{-1}$). Inconsistencies in the findings, however, are present and others have found no differences in either left ventricular mass [109] or heart volume [110].

Echocardiographic studies that have shown greater left ventricular mass in boys compared

Table 1. Oxygen uptake, stroke index, cardiac index and arteriovenous oxygen difference at maximal cycle ergometer exercise

Reference	Sex	n	Age (years)	SI ($ml \cdot m^{-2}$)	HR (bpm)	CI ($litres \cdot min^{-1} \cdot m^{-2}$)	a-v O_2 difference ($ml \cdot 100\ ml^{-1}$)	Peak $\dot{V}O_2$ ($litres \cdot min^{-1} \cdot kg^{-1}$)	Peak $\dot{V}O_2$ ($litres \cdot min^{-1}$)
Cumming [111]	F	29	11.8±3.1	46±3†	174±11	8.61±8.1†	–	–	–
	M	31	12.6±3.5	56±13	170±17	10.1± 1.8	–	–	–
Rowland et al. [112]	F	24	11.7±0.5	55±9†	198±9	10.9±1.7†	12.3±1.9	40.4±5.8†	1.84±31
	M	25	12.0±0.4	62±9	199±11	12.3±2.2	12.2±1.7	47.1±6.1	1.98±28
Obert et al. [113] Pre-training experimental group	F	7	10.66±0.3	47±7†	204±5	9.4±1.4†	13.2±1.6	40.9±8.9†	–
	M	9	10.66±0.5	52±8	199±9	10.5±1.8	13.0±2.1	44.1±6.1	–
Pre-training control group	F	10	10.41±0.3	46±6†	202±7	9.4±1.2†	13.1±2.8†	42.4±5.6†	–
	M	9	10.5±0.3	49±5	202±7	9.7±0.8	15.6±1.5	51.5±6.3	–
Winsley et al. [114]	F	9	10.2±0.3	45±6	192±11	8.7±1.1	12.6±1.6†	–	1.23±.08†
	M	9	10.1±0.5	47±8	195±11	8.9±1.4	14.8±2.1	–	1.41±.18

SI = Stroke index; HR = heart rate; CI = cardiac index; a-v O_2 difference = arterio-venous oxygen difference; $\dot{V}O_2$ = oxygen uptake. † Significant differences noted.

to girls have suggested that the reduced cardiac mass in girls may be associated with reduced contractility, reduced pre-load or increased afterload [106]. All of these could result in a reduced stroke index (SI) and therefore reduced cardiac index (CI). Cardiac index has generally been found to be higher in boys than girls at maximal exercise (table 1) and in the absence of sex differences in maximal heart rate, it would appear that SI most likely accounts for this difference. Absolute maximal SI index has been reported to be between 7 and 13% less in girls than boys. When corrected for body fat, this difference was reduced to 5.2% [112], but remained nonetheless. Interestingly, the lower maximal SI index apparent in girls has not always been found to relate to left ventricular dimensions, which suggests sex differences may instead relate to other factors such as the peripheral pump, systemic vascular resistance or differing adrenergic responses [113, 115].

Evidence of cardiac re-modelling following training has provided some insight into the role systemic vascular resistance may play in SI differences between boys and girls [113]. Following 13 weeks of training, both pre-pubertal boys and girls increased LV end-diastolic diameter and left ventricular mass. However, only LV end-diastolic diameter was related to percent increase in SI. Percent increase in SI was also inversely related to systemic vascular resistance, suggestive of vascular adaptations in response to high-intensity training. Of note, the decrease in systemic vascular resistance was greater in the boys than the girls, which may account for the greater increase in maximal SI in the boys.

The vasoregulatory capacity of the arterial and arteriolar vessels manipulates peripheral resistance. When blood is effectively distributed to the working muscle, peripheral resistance is reduced, which unloads the heart improving the capacity of the heart to increase SI. This is achieved by improving the flow of blood to and through the muscle and both the vasculature and skeletal muscle pump are involved. Interestingly, no sex differences in arterial compliance have been noted in pre- and early-pubertal children [116], although the beneficial role of oestrogen in vasodilation is well established and female advantage in arterial compliance is apparent in adults [117].

The skeletal muscle pump utilises the rhythmic muscle contractions to empty the venous vessels, aiding blood muscle hyperaemia and venous return. There is scant information on the skeletal muscle pump in children, but evidence in boys suggests, like adults, the skeletal muscle pump is associated with improved CI [118, 119]. In Rowland et al.'s [119] study, arteriovenous oxygen (a-v O_2) difference, a composite index of the haematological components of oxygen delivery, remained constant during unloaded exercise suggesting the increases in muscle oxygen supply were met by the increasing blood volume. Conversely, as exercise intensity increased with loading, a-v O_2 difference increased indicating decreased effectiveness of the muscle pump in satisfying the metabolic demands of the working muscle.

Whilst some studies have found no differences in estimated a-v O_2 difference at maximal or submaximal intensities between pre-pubertal girls and boys [112, 120], there are conflicting findings. Data recently published from a thoracic impedance measure of peak CI and MRI markers of cardiac size [114] demonstrated that pre-pubertal boys had a 16.7% higher a-v O_2 difference than girls. This was the only distinguishing factor to explain the significantly higher peak $\dot{V}O_2$ in the boys compared to the girls and unlike other studies no difference in either CI or SI were apparent at maximal exercise. It is interesting to note that a-v O_2 difference was 16% lower in the girls of the control group (table 1) in the study of Obert et al. [113]. These findings are intriguing, but confirmatory studies are needed to help understand the inconsistencies in the extant data.

Muscle Cellular Metabolism during Moderate Intensity Exercise

Characterizing muscle metabolism during exercise is extremely challenging and for a long time hampered by the need for invasive measurement of enzymatic activity. ^{31}P magnetic resonance spectroscopy (MRS) has enabled the study of high energy phosphates non-invasively in human skeletal muscle. This technique can provide an estimation of skeletal muscle metabolic activity via examination of creatine phosphate (PCr), inorganic phosphate (P_i) and intracellular pH, and has been validated in both adults and children [121, 122]. There remain methodological challenges in the paediatric population, which have been outlined by Armstrong and Fawkner [123], but the data available are providing fascinating insight into cellular metabolic processes.

Children, like adults show high correspondence between MRS determined muscle phosphocreatine (PCr) activity and the pulmonary oxygen uptake ($p\dot{V}O_2$) kinetic response [124, 125]. This implies that $p\dot{V}O_2$ kinetics also provide a marker of energy utilization at the muscular level, one which may prove very useful in understanding the interplay between cardiopulmonary and metabolic processes during exercise. More comprehensive descriptions of oxygen uptake kinetic assessments have been provided elsewhere [126] and only the salient issues related to girls' responses are summarized here. The $p\dot{V}O_2$ kinetic response is tri-phasic, but only phases II and III pertain to muscle oxygen uptake kinetics. During moderate intensity exercise, the phase II $p\dot{V}O_2$ kinetic response involves an exponential increase in oxygen uptake toward steady state, which signifies increases in muscle $\dot{V}O_2$. The primary response is described by a time constant (τ), representing the time taken (s) to achieve 63% of the change in $p\dot{V}O_2$. The attainment of a steady state denotes phase III. At higher workloads, i.e. those above the maximal lactate steady state, the $p\dot{V}O_2$ kinetic response alters, with phase III showing a delayed increase, eventually resulting in a $p\dot{V}O_2$ value higher than predicted on the basis of exercise intensity. This 'slow component' represents an increasing inefficiency in energy turnover and negatively correlates with increases in $\dot{V}O_2$ per unit increases in work, suggesting fatigue. To ensure confidence in the kinetic parameters estimated, the level of measurement rigour needed is high [126]. Few of the available oxygen uptake kinetics studies with children provide this and as such information on girls is very limited.

There is little evidence of a sex difference in $p\dot{V}O_2$ kinetic responses during moderate intensity exercise in children [127]. Neither have sex differences been found in boys and girls for MRS determined pH, P_i to PCr ratio (P_i/PCr) or PCr kinetic time constant at either the onset or offset of moderate intensity exercise [128]. In contrast, a study of the kinetic responses to high-intensity exercise found sex differences [129]. Results showed phase II $p\dot{V}O_2$ kinetics were approximately 20% slower in pre-pubertal girls compared to boys and the relative contribution of the $p\dot{V}O_2$ slow component to the end exercise $p\dot{V}O_2$ in the girls was about 30% greater. This is suggestive of a lower tolerance of fatigue in the girls, but the mechanisms underlying this response are not yet understood. One hypothesis suggests that these differences reflect a difference between boys and girls in the energetic profiles of the recruited muscles.

Barker et al. [130] have explored high-intensity exercise responses of the quadriceps muscle using MRS in children, but showed in accord with the $p\dot{V}O_2$ kinetic work, that girls responded with a greater anaerobic metabolic contribution than boys. These findings were partly attributed to the inequalities in maturity status, with relatively immature boys compared to the girls. Maturation of the cellular anaerobic response was noted in the girls in this study, who progressed from a response that was attenuated prior to puberty, but adult-like with ensuing maturation. This was not apparent in the boys, most likely an artefact of the narrow age range of the boys (9–12 years). Generally, high-intensity work requires the recruitment of fast twitch muscle fibres that are faster and larger, with a greater glycolytic and lower oxidative capacity. As discussed earlier, there is evidence of sex differences in muscle fibre type and size which vary with age and maturation, and clearly comparison of cellular metabolism during high-intensity exercise in girls and boys who are more closely aligned in terms of maturation is something which deserves further enquiry.

To summarise, there are differences between boys and girls in the aerobic responses to exercise which cannot be accounted for solely by size. Ventilatory parameters do not appear to influence peak $\dot{V}O_2$ in pre-pubertal children, however, there is scant information on the maturation of ventilatory responses in girls. It has been suggested that peripheral factors may be more important in defining aerobic fitness than cardiac function [131], but these are poorly understood in children and in particular in girls.

Acute Responses to High-Intensity Exercise

Most sports require short-duration bursts of high-intensity effort, which are supported by high muscle energy turnover. The direct examination of muscular energetics during short-duration high-intensity exercise is complex and instead investigations have largely concentrated on mechanical output markers of short duration exercise performance. The most commonly employed tests are the Wingate cycle ergometer test (WAnT) and cycle ergometer force-velocity tests, both eliciting markers of leg power. Wingate test values for leg peak power in girls aged 11–16 years have ranged from 260 to 542 W [132–136], whilst comparable values between 250 and 555 W have been recorded using force-velocity tests in similarly aged girls [137–140]. Mean power values from the Wingate test have ranged from 228 to 341 W in 11- to 16-year-old girls [132, 136]. It is interesting to note that neither peak nor mean power appear to be unusually high in young girls who are engaged in elite tennis, swimming or gymnastics training [141]. Higher values have been recorded for elite handball players and elite sprinters [133, 141], which could not be fully explained by age and body composition; however, when comparison was made with published values for less athletic girls, peak and mean power for these elite girl athletes were not substantially different.

Longitudinal data have shown that leg peak power increases with age in both boys and girls, but the increases in boys are greater than in girls. In a study of 7- to 18-year-olds, peak power was shown to increase by 273% in girls from 7 to 16 years of age, and then to plateau [142]. In comparison, boys showed increases of 375% over this period with no plateau at 16 years. Armstrong et al. [132] examined changes in leg peak power from 12 to 17 years of age and noted increases of 66% in girls, whilst boys increased peak power by 120% over the same period. The increases noted by Armstrong et al. [132] are similar in magnitude to those of Martin et al. [142] when the same age range is considered. Similar age-related increases in mean power have been noted, again with increases in boys almost double those of girls between the ages of 12 and 17 years [132]. Sex differences in peak leg power do not appear to emerge until about 14 years of age [141], whilst mean power is greater in boys than girls from about 13 years of age [132]. Clearly age is an important predictor of short-term power in young people. The influence of stature and mass as predictors of peak and mean power have also been established [132, 143], highlighting the need to consider both body mass and composition when assessing short-term power. De Ste Croix and colleagues [143] have shown that in addition to the effects of body mass, sum of skinfolds and age, MRI determined thigh muscle volume exerts considerable influence on young people's short-term power output. Furthermore, De Ste Croix and colleagues [143] have shown using multi-level modelling that in addition to the effects of body mass, sum of skinfolds and age, MRI-determined thigh muscle volume has a significant impact on young people's short-term power output during cycling.

There are very few data on skeletal muscle metabolism during short-duration high-intensity exercise in girls. A MRS study of pH and P_i/PCr ratio during supramaximal plantar flexion exercise in pre-pubertal and pubertal girls found that the maturational differences in pH and P_i/PCr values were not statistically significant [144]. The authors concluded that glycolytic metabolism was not maturity dependent; rather, it was dependent on muscle cross-sectional area. A more recent study of the PCr kinetics and intracellular pH response during high-intensity exercise also showed a non significant sex difference in pH. It is worthy of note that in both studies [144, 145] there was considerable variability within small samples which may be masking biological significance. Wilcox et al. [145] did demonstrate that the PCr cost per watt was higher in the girls compared to the boys [145]. These findings suggest lower efficiency in the girls compared to the boys, which may be an outcome of differences in muscle fibre type, muscle activation patterns or leg vasodilatory response. However, this study failed to demonstrate that the differences in the slow component of the PCr response between children and adults were statistically significant, raising doubt that age-related change in muscle fibre recruitment substantially influences skeletal muscle metabolism during high-intensity exercise.

Does Intensive Training Pose a Threat to the Development and Health of Young Girls?

Growth

Many young athletes begin formal training before 10 years of age, with young elite gymnasts, swimmers and tennis players entering their respective sport between the ages of 6 and 7.5 years [146]. In a number of countries young girls are recruited into specialised sport schools as young as 5 years of age [147]. These elite young athletes train intensively all year round, for many hours, with weekly training volumes of 24 h not being unusual [148]. Whether intensive training such as this distorts normal growth and maturation remains a topic of much debate [7, 149].

Evidence of reduced or delayed growth in some young athletes, such as gymnasts, has been suggested to be a direct outcome of the intensive training these youngsters have endured [5, 50, 151]. Counter-argument contends that growth reductions or delay in young athletes simply reflect their late maturation [136, 152–154]. The Training of Young Athletes (TOYA) study found that elite young female swimmers and tennis players were generally taller than the general population throughout the growth period (close to the 75th percentile for stature), whilst gymnasts were generally smaller (below the 50th percentile for stature) from 10 to 17 years of age [146]. What was noteworthy was that by 18 years of age, the gymnasts were above the 50th percentile for stature and when aligned by biological age (years from attainment of menarche), gymnasts, swimmers and tennis players showed no significant differences in height. The catch-up growth noted in the gymnasts was indicative of late maturation and apparent in girls who are not involved in competitive training, but who mature late. Both the fathers and mothers of gymnasts have been found to be significantly shorter than the parents of other athletes and genetic predisposition for stature has been not only been shown to be preserved, but often exceeded [146, 155]. Combined, this evidence indicates that the tendency for short stature in gymnasts is not, as argued by some [151], evidence of a training-induced alteration in growth, but more likely a reflection of a genetic predisposition for later development and short stature.

Reproductive Health

Menstrual dysfunction in young athletes has also been interpreted as evidence that intensive training in young girls is harmful to reproductive health [156]. Menstrual dysfunction includes delayed menarche (onset after 16 years), luteal phase defects, oligomenorrhea and amenorrhea (table 2). Several studies have concluded that female gymnasts, swimmers and ballet dancers have delayed menarche. De Ridder et al. [29] observed that, in comparison to a control group of girls matched for maturation and fatness, girls involved in competitive gymnastics exhibited delayed menarche. An early hypothesis suggested that because these young girls had low levels of body fat they did not attain a critical level of body fat (22%) necessary for menstruation. The wide variability noted in body fat at menarche [35] has provided proof that a threshold of 22% body fat is incorrect. Additionally, there is sufficient experimental evidence in women to show that it is not body fat but caloric deprivation that affects reproductive health [157].

Genetic predisposition for late menarche in athletes has also been explored. When age of menarche in a group of elite gymnasts was correlated with maternal menarchal age, it was, on average, in lag by 0.81 years [158]. This lag was double that noted for elite swimmers and triple that for elite tennis players. These data suggest that despite a genetic predisposition for delayed menarche, this does not fully explain the extent of the delay, signalling that training may indeed delay menarche in gymnasts. However, Baxter-Jones et al. [158] went on to show that when the time period between menarchal age and retirement from the sport were

Table 2. Components of the female athlete triad, diagnosis and prevention

Component of the triad	Diagnosis	Warning signs	Prevention
Energy availability [160]	Energy availability is defined as energy intake minus exercise energy expenditure, with a threshold of 30 $kcal \cdot kg^{-1}$ $LBM \cdot day^{-1}$.	Low body mass (>85% of ideal body mass for stature). Fatigue.	Monitor dietary intake. Monitor training volume. Focus on healthy eating and caloric balance. Educate youngsters about nutritional fads. Reinforce message that body mass is only one aspect of good performance. Educational information on nutrition and energy expenditure, e.g. http://kidshealth.org/teen/food/sports/triad.html
Eating disorders [173]	*Anorexia nervosa* Refusal to maintain body mass over a minimally normal mass for age and stature. Intense fear of gaining mass or becoming fat. Disturbed body image. Secondary amenorrhea. *Bulimia nervosa* Recurrent episodes of binge eating (eating a large amount of food in a discrete period of time and lacking control over eating during the episode). Recurrent inappropriate compensatory behaviour such as self-induced vomiting, laxatives or excessive exercise. The binge-eating and purging behaviours occur at least twice a week for 3 months.	*Anorexia* Dramatic loss in body mass. Preoccupation with food, calories and body mass. Wears baggy clothes. Fine, downy facial hair. Mood swings. Avoidance of food-related social activities. *Bulimia* Noticeable loss in body mass. Excessive worry over weight. Bathroom visits after eating. Depression. Strict dieting followed by binging. Dental erosion.	Promote healthy body image. Removal of body mass/fat monitoring by coaches. Provide opportunities for developing self-coping strategies. Deemphasize body mass and thinness. Provide opportunities for nutritional counselling.
Menstrual dysfunction [174]	Oligomenorrhea – irregular menses (length between cycles >35 days). Primary amenorrhea – absence of menstruation by 15 years in girls with secondary sexual characteristics. Secondary amenorrhea- absence of menstrual cycles for 3 cycles after onset of menses.	Irregular or absent menstrual cycle.	Ask athletes to keep a training diary and include monitoring of menstrual cycle. Help girls understand that secondary amenorrhea is not normal. Provide education on reproductive health and the link between menstruation and bone health. Provide dietary education and help girls understand the link between diet and reproductive health.

Table 2. Continued

Component of the triad	Diagnosis	Warning signs	Prevention
	Luteal phase dysfunction – shortened secretory phase of the menstrual cycle, typically less than 10 days.		
Low bone mineral density [175]	If comparison with age, gender, stature and race specific Z-scores yields values ≤2.0 this is classified as a low bone mineral density for chronological age. Osteoporosis is diagnosed if low BMD for chronological age is accompanied by one or more of the following fracture histories: long bone fracture of the lower extremities; vertebral compression fracture and two or more long–bone fractures of the upper extremities.	Secondary amenorrhea. Stress fracture. History of fractures.	Provide educational information on osteoporosis. Provide information on nutrition for bone health, particularly focusing on calcium-rich foods. Monitor diet and provide opportunities for nutritional counselling.

considered, 92% of the girls began menarche prior to retiring. The authors concluded that training was therefore unlikely to cause the delay in menarche noted in the gymnasts, instead there was simply a chronological age difference in the timing of events. It would appear that exercise training, without other predisposing factors, is unlikely to be the cause of menstrual dysfunction.

The Female Athlete Triad

The female athlete triad was established in the early 1990s as a syndrome of three separate, but inter-related conditions, namely menstrual dysfunction, disordered eating and premature osteoporosis [159]. An updated position statement from the American College of Sports Medicine (ACSM) has revised the definition of the triad as the presence of one or more of (1) low energy availability (with or without eating disorders), (2) amenorrhea, and (3) osteoporosis (table 2) [160]. Prevalence estimates of components of the female triad are very dependent on the athletic group studied, with higher rates in sports where low body mass is the norm. For instance, 25% of young women in endurance, weight class or aesthetic sports had clinical eating disorders, compared to 9% of the general population [161]. Secondary amenorrhea has been reported to be as high as 69% in dancers and less than 1% in the general population [162, 163]. Osteoporosis has been found in about 13% of female athletes, although this is not too different from the normal population [164] and in pre-menopausal women low bone mineral density for age is a more appropriate marker than osteoporosis.

Much of the available data on the female triad is on college-age or young adult athletes, with few reports targeting adolescents. Two key studies of high school athletes have shown a considerable number of girls present with components of the female triad. In a study of 170 13- to 18-year-olds, 18% had disordered eating, 24% had oligomenorrhea or amenorrhea and 22% had low bone mass for their age based on WHO diagnostic criteria [165]. A higher rate of occurrence of low energy availability (55%) was noted in a study of 80 similarly aged young athletes, with 16% diagnosed with amenorrhea and using the same WHO diagnostic criteria, 16% presented with low bone mineral density [166]. The existence of the female athlete triad in these young girls is particularly worrying given this is a time when substantial amounts of bone should be accrued.

Energy deficiency appears to be particularly harmful when combined with excessive exercise, and leads to reduced oestrogen levels, athletic amenorrhea and bone demineralisation. Loucks et al. [167] have shown that there is an energy availability threshold of 20–25 $kcal \bullet kg^{-1}$ $LBM \bullet day^{-1}$, below which skeletal and reproductive health is compromised. This group conducted a number of studies in which women underwent energy availability manipulations, decreasing energy availability from 45 to 20 $kcal \bullet kg^{-1}$ $LBM \bullet day^{-1}$ or from 45 to 10 $kcal \bullet kg^{-1}$ $LBM \bullet day^{-1}$. These reductions caused blunting of LH pulsatility [168] and a de-linking of bone resorption and formation [169]. The existence of an energy availability threshold may help to explain why not all athletes develop athletic amenorrhea even when following the same training programme and provides a useful marker for nutritional health.

Recent conjecture that the triad is a ‘myth’ [8] has caused intense debate [164, 170, 171]. This contention stems from a number of criticisms, including flaws in the epidemiological evidence, assumptions that low energy availability implies disordered eating and a lack of experimental evidence in athletes. Much of the epidemiological evidence of the prevalence of the female triad is for individual components of the triad, rather than for the synchronous appearance of all three which, it has been argued, over-inflates the extent of the problems. When occurrence of all three components is examined, prevalence falls dramatically [172]. On the other hand, the definition of the female athlete triad states explicitly that presence of one component is sufficient for diagnosis and the revised guidelines provided by the ACSM, have removed disordered eating and replaced it with energy availability, accepting that low energy availability does not equate to a pathological eating disorder [160].

Definitive conclusions on whether elite participation causes aberrations to skeletal and reproductive health are not possible. Nevertheless, there is clear evidence of a boundary between healthy and unhealthy levels of exertion when coupled with caloric limitation. Exposure to excessive training and caloric limitation causes abnormality in skeletal and reproductive function and regardless of the magnitude of the problem, young girl athletes deserve protection. Protection likely entails athlete education, coach recognition of the triad and the monitoring of both training volume and nutritional health in young elite girls. Table 2 provides an overview of the components of the triad, with possible prevention strategies for young athletes, coaches and parents.

Conclusions

Girls have differential growth and development in comparison to boys, resulting in substantial differences in body size and composition. Whilst stronger and leaner than many of her non-athletic peers, the smaller stature, shorter legs, lower muscularity and greater relative fatness of the elite girl athlete means she is not as strong, nor as fast as her male counterpart. Some discordant responses to exercise are not solely explained by body size and/or composition and there is evidence of underlying qualitative differences which require further clarification.

A young girl's involvement in elite sport predisposes her to increased risk of skeletal and reproductive health problems, particularly in sports where intense training is coupled with the need for leanness. Ensuring girls involved in elite training are in an environment which optimises their athletic potential while minimising risk is a priority. This entails sufficient knowledge of the physiologic responses to exercise in girls, as well as thorough understanding of the female triad disorder, its aetiology and prevention. Despite the burgeoning literature in the field of paediatric exercise physiology, an integrative understanding of girls' physiological responses to exercise remains elusive. Traditional technologies have proved inadequate in providing a detailed understanding of the complexity of the cellular metabolic response to exercise and this is compounded by the need to separate qualitative changes from changes which are an artefact of a growing, maturing body. More recent application of non-invasive imaging techniques and breath-by-breath gas analysis is facilitating a more integrated understanding of the responses to exercise, but the number of studies to date with girls is woefully small. In addition, more needs to be learnt about the female triad and its antecedents in younger girls. The dearth of information on girls and emergence and availability of new technologies provides plenty of scope for future studies in paediatric exercise physiology.

References

1 Armstrong N, Welsman JR, Kirby BJ: Longitudinal changes in 11–13-year-olds' physical activity. Acta Paediatr 2000;89:775–780.

2 Women's Sport and Fitness Foundation: Participation. Factsheet November 2009:http://www.wsff.org.uk/documents/Participation_factsheet_November_09.pdf

3 Women's Sport and Fitness Foundation: WSSF viewpoint – women and the Olympics. Factsheet July 2009:http://www.wsff.org.uk/documents/Women_and_the_Olympics.pdf

4 Vertinsky P: The Eternally Wounded Woman: Women, Doctors and Exercise in the Late Nineteenth Century. Chicago, University of Illinois Press, 1994.

5 Theintz G, Howald H, Weiss U, Sizonenko P: Evidence for a reduction of growth potential in adolescent female gymnasts. J Pediatr 1993;122:306–313.

6 Damsgaard R, Bencke J, Matthiesen G, Petersen J, Müller J: Is prepubertal growth adversely affected by sport? Med Sci Sports Exerc 2000;32:1698–1703.

7 Baxter-Jones ADG, Maffulli N, Mirwald RL: Does elite competition inhibit growth and delay maturation in some gymnasts? Probably not. Pediatr Exerc Sci 2003;15:373–382.

8 DiPietro L, Stachenfeld NS: The myth of the female athlete triad. Br J Sports Med 2006;40:490–493.

9 McManus AM, Armstrong N: The elite child athlete; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 489–502.

10 USA Track and Field Age Group Records. http://www.dyestat.com/rivals/227840.html#GIRLS

11 World Junior Records http://www.iaaf.org/statistics/index.html

12 Coast JR, Blevins JS, Wilson BA: Do gender differences in running performance disappear with distance? Can J Appl Physiol 2004;29:139–145.

13 George K, Sharma S, Batterham A, Whyte G, McKenna W: Allometric analysis of the association between cardiac dimensions and body size variables in 464 junior athletes. Clin Sci 2001;100:47–54.

14 Nevill AM, Holder RL: Scaling, normalizing, and per ratio standards: an allometric modeling approach. J Appl Physiol 1995;79:1027–1031.

15 Ao A, Erickson RP, Winston RML, Handysiade A: Transcription of paternal Y-linked genes in the human zygote as early as the pro-nucleate stage. Zygote 1994;2:281–287.

16 Turgeon JL, Carr MC, Maki PM, Mendelsohn ME, Wise PM: Complex actions of sex steroids in adipose tissue, the cardiovascular system and brain: insights from basic science and clinical studies. Endocr Rev 2006;27:575–605.

17 Wells JCK: Sexual dimorphism of body composition. Best Pract Res Clin Endocrinol Metab 2007;21:415–430.

18 Rogol A, Clark P, Roemmich J: Growth and pubertal development in children and adolescents: effects of diet and physical activity. Am J Clin Nutr 2000;72:S521–S528.

19 Mauras N: Growth hormone and testosterone: effects on whole body metabolism and skeletal muscle in adolescence. Horm Res 2006;66:42–48.

20 Baxter-Jones ADG: Growth and maturation; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 157–168.

21 Susman EJ, Houts RM, Steinberg L, Belsky J, Cauffman E, Dehart G, Friedman SL, Roisman GI, Halpern-Felsher BL, Eunice Kennedy Shriver NICHD Early Child Care Research Network: Longitudinal development of secondary sexual characteristics in girls and boys between ages 9 1/2 and 15 1/2 years. Arch Pediatr Adolesc Med 2010; 164:166–173.
22 Sherar LB, Baxter-Jones AD, Mirwald RL: Limitations to the use of secondary sex characteristics for gender comparisons. Ann Hum Biol 2004;31:586–593.
23 Malina RM, Bouchard C, Bar-Or O (eds): Growth, Maturation and Physical Activity. Champaign, Human Kinetics, 2004, pp 39–81.
24 Sinclair D, Dangerfield P: Human Growth after Birth, ed 6. Oxford, Oxford University Press, 1988.
25 Claessons AL, Veer FM, Stijnen V, Lefevre J, Maes H, Steens G, Beunen G: Anthropometric characteristics of outstanding male and female gymnasts. J Sports Sci 1991;9:53–74.
26 Damsgaard R, Bencke J, Matthiesen G, Petersen J, Müller J: Body proportions, body composition and pubertal development of children in competitive sports. Scand J Med Sci Sports 2001;11:54–60.
27 Reynolds EL, Wines JV: Individual differences in physical changes associated with adolescence in girls. Am J Dis Child 1948;75:329–350.
28 Tanner JM: Growth at Adolescence, ed 2. Oxford, Blackwell Scientific Publications, 1962.
29 de Ridder C, Thijssen J, Bruning P, Van den Brande J, Zonderland M, Erich W: Body fat mass, body fat distribution, and pubertal development: a longitudinal study of physical and hormonal sexual maturation of girls. J Clin Endocrinol Metab 1992;75:442–446.
30 Kaplowitz P: Pubertal development in girls: secular trends. Curr Opin Obstet Gynecol 2006;18:487–491.
31 Biro FM, Lucky AW, Simbartl LA, Barton BA, Daniels SR, Striegel-Moore R, Kronsberg SS, Morrison JA: Pubertal maturation in girls and the relationship to anthropometric changes: pathways through puberty. J Pediatr 2003;142: 643–646.
32 Malina R: Physical growth and biological maturation of young athletes. Exerc Sport Sci Rev 1994;22:389–434.
33 Baxter-Jones ADG, Eisenmann JC, Sherar LB: Controlling for maturation in pediatric exercise science. Pediatr Exerc Sci 2005;17:18–30.
34 Klentrou P, Plyley M: Onset of puberty, menstrual frequency, and body fat in elite rhythmic gymnasts compared with normal controls. Br J Sports Med 2003; 37:490–494.
35 Sherar LB, Baxter-Jones AD, Mirwald RL: The relationship between body composition and onset of menarche. Ann Hum Biol 2007;34:673–677.
36 Matthews BL, Bennell KL, McKay HA, Khan KM, Baxter-Jones AD, Mirwald RL, Wark JD: The influence of dance training on growth and maturation of young females: a mixed longitudinal study. Ann Hum Biol 2006;33:342–356.
37 Barrack MT, Rauh MJ, Nichols JF: Cross-sectional evidence of suppressed bone mineral accrual among female adolescent runners. J Bone Min Res 2010;25:1850–1857.
38 Rusko H, Rahkila P, Karvinen E: Anaerobic threshold, skeletal muscle enzymes and fibre composition in young female cross-country skiers. Act Physiol Scand 1980;108:263–268.
39 Thorland WG, Johnson GO, Fagot TG, Tharp GD, Hammer RW: Body composition and somatotype characteristics of Junior Olympic athletes. Med Sci Sports Exerc 1981;13:332–338.
40 Malina RM: Regional body composition: age, sex and ethnic variation; in Roche AF, Heysnfield SB, Lohman TG (eds): Human Body Composition. Champaign, Human Kinetics, 1996, pp 217–255.
41 Falk B, Dotan R: Temperature regulation and elite young athletes; in Armstrong N, McManus AM (eds): The Elite Young Athlete. Med Sports Sci. Basel, Karger, 2011, vol 56, pp 126–149.
42 Wells JCK, Williams JE, Chomtho S, Darch T, Grijalva-Eternod C, Kennedy K, Haroun D, Wilson C, Cole TJ, Fewtrll MS: Pediatric reference data for lean tissue properties: density and hydration from age 5 to 20 y. Am J Clin Nutr 2010;91:610–618.
43 Lohman TG: Assessment of body composition in children. Pediatr Exerc Sci 1989;1:19–30.
44 Rogol AD: Growth at puberty: interaction of androgens and growth hormone. Med Sci Sports Exerc 1994;26:767–770.
45 Simoneau JA, Bouchard C: Human variation in skeletal muscle fibre-type proportion and enzyme activities. Am J Physiol 1989;257:E567–E572.
46 Staron RS, Hagerman FC, Hilida RS, Murray TF, Hostler DP, Crill MT, Ragg KE, Toma K: Fiber type composition of the vastus lateralis muscle of young men and women. J Histochem Cytochem 2002;48:623–629.
47 Schrauwen-Hinderling VB, Hesslink MKC, Schrauwen P, Kooi ME: Intramyocellular lipid content in human skeletal muscle. Obesity 2006;14:357–367.
48 Roepstorff C, Steffenson CH, Madsen M, Stallknecht B, Kanstrup L, Richter RA, Riens B: Gender differences in substrate utilization during submaximal exercise in endurance-trained subjects. Am J Physiol Endocrinol Metab 2002;282: E435–E447.
49 Hunter SK, Enoka RM: Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. J Appl Physiol 2001;91:2686–2694.
50 Jaworowski Å, Porter MM, Holmbäck AM, Downham D, Lexell J: Enzyme activities in the tibialis anterior muscle of young moderately active men and women: relationship with body composition, muscle cross-sectional area and fibre type composition. Acta Physiol Scand 2002;176:215–225.
51 Legerlotz K, Smith HK, Hing WA: Variation and reliability of ultrasonographic quantification of the architecture of the medial gastrocnemius muscle in young children. Clin Physiol Funct Imaging 2010;30:198–205.
52 De Ste Croix MBA, Armstrong N, Welsman JR, Sharp P: Longitudinal changes in isokinetic leg strength in 10–14 year olds. Ann Hum Biol 2002;29:50–62.
53 O'Brien TD, Reeves ND, Baltzopoulos V, Jones DA, Maganaris CN: In vivo measurements of muscle specific tension in adults and children. Exp Physiol 2009;95:202–210.
54 Nygaard E: Skeletal muscle fibre characteristics in young women. Acta Physiol Scand 1981;112:299–304.
55 Vogler C, Bove KE: Morphology of skeletal muscle in children. Arch Path Lab Med 1985;109:238–242.

56 Glenmark B, Hedberg G, Jansson E: Changes in muscle fibre type from adolescence to adulthood in women and men. Acta Physiol Scand 1992;146:251–259.
57 Glenmark B, Hedberg G, Kaijster L, Jansson E: Muscle strength from adolescence to adulthood: relationship to muscle fibre types. Eur J Appl Physiol Occup Physiol 1994;68:9–19.
58 Lexell J: Human aging, muscle mass, and fibre type composition. J Gerontol 1995; 50:11–16.
59 Maffulli N, King JB, Helms P: Training in elite young athletes (the training of young athletes (TOYA study): injuries, flexibility and isometric strength. Br J Sport Med 1994;28:123–136.
60 Bencke J, Damsgaard R, Saekmose A, Jørgensen P, Jørgensen K, Klausen K: Anaerobic power and muscle strength characteristics of 11 years old elite and non-elite boys and girls from gymnastics, team handball, tennis and swimming. Scand J Med Sci Sports 2002;12: 171–178.
61 Schoenau E: Bone mass increase in puberty: what makes it happen? Horm Res 2006;65(Suppl 2):2–10.
62 Kontulainen SA, Macdonald HM, McKay HA: Change in cortical bone density and its distribution differs between boys and girls during puberty. J Clin Endocrinol Metab 2006;91:2555–2561.
63 Högler W, Blimkie CJ, Cowell CT, Kemp AF, Briody J, Wiebe P, Farpour-Lambert N, Duncan CS, Woodhead HJ: A comparison of bone geometry and cortical density at the mid-femur between prepuberty and young adulthood using magnetic resonance imaging. Bone 2003;33:771–778.
64 Schoenau E, Neu MC, Manz F: Muscle mass during childhood: relationship to skeletal development. J Musculoskelet Neuronal Interact 2004;4:105–108.
65 Schoenau E: From mechanostat theory to development of the 'Functional Muscle-Bone-Unit'. J Musculoskelet Neuronal Interact 2005;5:232–238.
66 Ward KA, Roberts SA, Adams JE, Mughal MZ: Bone geometry and density in the skeleton of pre-pubertal gymnasts and school children. Bone 2005;36: 1012–1018.
67 Duncan CS, Blimkie CJR, Cowell CT, Burke ST, Briody JN, Howman-Giles R: Bone mineral density in adolescent female athletes: relationship to exercise type and muscle strength. Med Sci Sports Exerc 2002;34:286–294.
68 Haapasalo H, Kontulainen S, Sievanen H, Kannus P, Jarvinene M, Vuori I: Exercise-induced bone gain is due to enlargement in bone size without a change in volumetric bone density: a peripheral quantitative computed tomography study of the upper arms of male tennis players. Bone 2000;27:351–357.
69 Duncan CS, Blimkie CJR, Kemp A, Higgs W, Cowell CT, Woodhead H, Briody JN, Howman-Giles R: Mid-femur geometry and biomechanical properties in 15- to 18-yr-old female athletes. Med Sci Sports Exerc 2002;34:673–681.
70 Högler W, Blimkie CJR, Cowell CT, Inglis, Rauch F, Kemp AF, Wiebe P, Duncan CS, Farpour-Lambert N, Woodhead HJ: Sex-specific developmental changes in muscle size and bone geometry at the femoral shaft. Bone 2008;42:982–989.
71 Dowthwaite JN, Kanaley JA, Spadaro JA, Hickman RM, Scerpella TA: Muscle indices do not fully account for enhanced upper extremity bone mass and strength in gymnasts. J Musculoskelet Neuronal Interact 2009;9:2–14.
72 Daly RM, Saxon L, Turner CH, Robling AG, Bass SL: The relationship between muscle size and bone geometry during growth and in response to exercise. Bone 2004;34:281–287.
73 Bailey DA, Martin AD: Physical activity and skeletal health in adolescents. Pediatr Exerc Sci 1996;6:330–347.
74 Tanner JM: Fallacy of per-weight and per-surface area standards and their relation to spurious correlation. J Appl Physiol 1949;2:1–15.
75 Guenette A, Sheel AW: Exercise-induced arterial hypoxaemia in active young women. Appl Physiol Nutr 2007;32: 1263–1273.
76 Mota J, Guerra S, Leandro C, Pinto A, Ribeiro JC, Duarte JA: Association of maturation, sex, and body fat in cardiorespiratory fitness. Am J Human Biol 2002;14:707–712.
77 Armstrong N, Welsman JR: Aerobic fitness; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 97–108.
78 Nevill AM, Bate S, Holder RL: Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. Year Book Phys Anthropol 2005;48:141–153.
79 Tolfrey K, Barker A, Thom JM, Morse CI, Narici MV, Batterham AM: Scaling of maximal oxygen uptake by lower leg muscle volume in boys and men. J Appl Physiol 2006;100:1851–1856.
80 Rowland T, Goff D, Martel L, Ferrone L, Kline G: Normalization of maximal cardiovascular variables for body size in premenarchal girls. Pediatr Cardiol 2000;21:429–432.
81 Armstrong N, McManus AM, Welsman JR: Aerobic fitness; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 269–282.
82 Armstrong N, Welsman JR: Young People and Physical Activity. Oxford, Oxford University Press, 1997.
83 Armstrong N, Welsman JR: Peak oxygen uptake in relation to growth and maturation in 11- to 17-year-old humans. Eur J Appl Physiol 2001;85:546–551.
84 Eisenmann JC, Pivarnik JM, Malina RM: Scaling peak $\dot{V}O_2$ to body mass in young male and female distance runners. J Appl Physiol 2001;90:2172–2180.
85 Baxter-Jones A, Goldstein H, Helms P: The development of aerobic power in young athletes. J Appl Physiol 1993;75: 1160–1167.
86 Welsman JR, Armstrong N: Longitudinal changes in submaximal oxygen uptake in 11- to 13-year-olds. J Sports Sci 2000; 18:183–189.
87 Courteix D, Obert P, Lecoq AM, Guenon P, Kock G: Effect of intensive swimming training on lung volumes, airway resistances and on the maximal expiratory flow-volume relationship in prepubertal girls. Eur J Appl Physiol 1997;76:264–269.
88 Sheel AW, Richards JC, Foster GE, Guenette JA: Sex differences in respiratory exercise physiology. Sports Med 2004;34:567–579.
89 Boezen HM, Jansen DF, Postma DS: Sex and gender differences in lung development and their clinical significance. Clin Chest Med 2004;25:237–245.
90 Harms CA: Does gender affect pulmonary function and exercise capacity? Respir Physiol Neurobiol 2006;151:124–131.

91 Guenette A, Sheel AW: Exercise-induced arterial hypoxaemia in active young women. Appl Physiol Nutr 2007;32: 1263–1273.
92 Olfert IM, Balouch J, Kleinsasser A, Knapp A, Wagner H, Wagner PD, Hopkins SR: Does gender affect human pulmonary gas exchange during exercise? J Physiol 2004;557:529–541.
93 Fawkner SG, Armstrong N: Pulmonary function; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 243–254.
94 Armstrong N, Kirby BJ, McManus AM, Welsman JR: Prepubescents' ventilatory responses to exercise with reference to sex and body size. Chest 1997;112:1554–1560.
95 Rowland TW, Cunningham LN: Development of ventilatory responses to exercise in normal white children. Chest 1997;111:327–332.
96 Hopkins SR, Harms CA: Gender and pulmonary gas exchange during exercise. Exerc Sport Sci Rev 2004;32:50–56.
97 Swain KE, Rosenkranz SK, Beckman B, Harms CA: Expiratory flow limitation during exercise in prepubescent boys and girls: prevalence and implications. J Appl Physiol 2010;108:1267–1274.
98 Laursen PB, Tsang GCK, Smith GJ, van Velzen MV, Ignatova BB, Sprules EB, Chu KS, Coutts KD, McKenzie DC: Incidence of exercise-induced arterial hypoxemia in prepubescent females. Pediatr Pulmonol 2002;34:37–41.
99 Guerro L, Naranjo J, Carranza MD: Influence of gender on ventilatory efficiency during exercise in young children. J Sports Sci 2008;26:1455–1457.
100 Karlberg P, Lind J: Studies of the total amount of hemoglobin and the blood volume in children. 1. Determination of total hemoglobin and blood volume in normal children. Acta Paediatr Scand 1955;44:17–34.
101 Sukarochana K, Parenzan L, Thakurdas N, Kiesewetter WB: Red cell mass determinations in infancy and childhood, with the use of radioactive chromium. J Pediatr 1961;59:903–908.
102 Linderkamp O, Versmold HT, Riegel KP, Betke K: Estimation and prediction of blood volume in infants and children. Eur J Pediatr 1977;125:227–234.
103 Raes A, Van Aken S, Craen M, Donckerwolcke R, Walle JV: A reference frame for blood volume in children and adolescents. BMC Pediatrics 2006;6:3.
104 Dallman PR, Siimes MA: Percentile curves for hemoglobin and red cell volume in infancy and childhood. Pediatrics 1979;94:26–31.
105 Boyadjiev N, Taralov Z: Red blood cell variables in highly trained pubescent athletes: a comparative analysis. Br J Sports Med 2000;34:200–204.
106 Rowland TW: Developmental Exercise Physiology. Champaign, Human Kinetics, 1996, pp 117–140.
107 Larsen JA, Kadish AH: Effects of gender on cardiac arrhythmias. J Cardiovasc Electrophysiol 1998;9:655–664.
108 Wirth A, Trager E, Scheele K, Mayer D, Diehm K, Reischle K, Weicker H: Cardiopulmonary adjustment and metabolic response to maximal and submaximal physical exercise of boys and girls at different stages of maturity. Eur J Appl Physiol 1978;39:29–39.
109 Telford RD, McDonal IG, Ellis LB, Chennells MH, Sandstrom ER, Fuller PJ: Echocardiographic dimensions in trained and untrained 12-year-old-boys and girls. J Sports Sci 1988;6:49–57.
110 Thoren CAR, Asano K: Functional capacity and cardiac function in 10-year-old-boys and girls with high and low running performance; in Ilmarinen J, Valimaki I (eds): Children and Sport: Pediatric Work Physiology. Berlin, Springer, 1984 pp 182–188.
111 Cumming GR: Hemodynamics of supine bicycle exercise in 'normal' children. Am Heart J 1977;93:617–622.
112 Rowland TW, Goff D, Martel L, Ferrone L: Influence of cardiac functional capacity on gender differences in maximal oxygen uptake in children. Chest 2000; 117:629–635.
113 Obert P, Mandigout S, Nottin S, Vinet A, N'Guyen L, Lecoq A: Cardiovascular responses to endurance training in children: effect of gender. Eur J Clin Invest 2003;33:199–208.
114 Winsley RJ, Fulfold J, Roberts AC, Welsman JR, Armstrong N: Sex differences in peak oxygen uptake in prepubertal children. J Sci Med Sport 2009;12: 647–651.
115 Gutin B, Owens S, Trieber F, Mensah G: Exercise hemodynamics and left ventricular parameters in children; in Armstrong N, Kirby B, Welsman J (eds): Children and Exercise. Part XIX. London, E & FN Spon, 1997, pp 460–464.
116 Osika W, Dangardt F, Montgomery SM, Volkmann R, Li MG, Friberg P: Sex differences in peripheral artery intima, media and intima media thickness in children and adolescents. Atherosclerosis 2009;203:172–177.
117 Gavin KM, Seals DR, Silver AE, Moreau KL: Vascular endothelial estrogen receptor alpha is modulated by estrogen status and related to endothelial function and endothelial nitric oxide synthase in healthy women. J Clin Endocrinol Metab 2009;94:3513–3520.
118 Nadland IH, Walloc L, Toska K: Effect of the leg muscle pump on the rise in muscle perfusion during muscle work in humans. Eur J Appl Physiol 2009;105: 829–841.
119 Rowland T, Lisowski R: Hemodynamic responses to increasing cycle cadence in 11-year old boys: role of the skeletal muscle pump. Int J Sports Med 2001;22: 405–409.
120 Armstrong N, Welsman JR: Cardiovascular responses to submaximal treadmill running in 11 to 13 year olds. Acta Paediatr 2002;91:125–131.
121 Constantin-Theodosiu D, Greenhaff PL, McIntyre DB, Round JM, Jones DA: Anaerobic energy production in human skeletal muscle in intense contraction: a comparison of ^{31}P magnetic resonance spectroscopy and biochemical techniques. Exp Physiol 1997;82:592–601.
122 Barker A, Welsman J, Welford D, Fulford J, Williams C, Armstrong N: Reliability of ^{31}P magnetic resonance spectroscopy during an exhaustive exercise test in children. Eur J Appl Physiol 2006;98: 556–565.
123 Armstrong N, Fawkner SG: Exercise metabolism; in Armstrong N, van Mechelen W (eds): Paediatric Exercise Science and Medicine, ed 2. Oxford, Oxford University Press, 2008, pp 213–226.
124 Jones AM, Poole DC: Oxygen uptake dynamics: from muscle to mouth-an introduction to the symposium. Med Sci Sports Exerc 2005;37:1542–1550.
125 Barker AR, Welsman JR, Fulford J, Welford D, Williams CA, Armstrong N: Muscle phosphocreatine and pulmonary oxygen uptake kinetics in children at the onset and offset of moderate intensity exercise. Eur J Appl Physiol 2008;102: 727–738.
126 Fawkner SG, Armstrong N: Oxygen uptake kinetic response to exercise in children. Sports Med 2003;33:651–669.

127 Fawkner SG, Armstrong N, Potter CR, Welsman JR: Oxygen uptake kinetics in children and adults after the onset of moderate-intensity exercise. J Sports Sci 2002;20:319–326.
128 Barker AR, Welsman JR, Fulford J, Welford D, Armstrong N: Muscle phosphocreatine kinetics in children and adults at the onset and offset of moderate-intensity exercise. J Appl Physiol 2008;105:446–456.
129 Fawkner SG, Armstrong N: Longitudinal changes in the kinetic response to heavy intensity exercise. J Appl Physiol 2004; 97:460–466.
130 Barker AR, Welsman JR, Fulford J, Welford D, Armstrong N: Quadriceps muscle energetic during incremental exercise in children and adults. Med Sci Sports Exerc 2011;42:1303–1313.
131 Rowland TW: Circulatory responses to exercise: are we misleading Fick? Chest 2005;127:1023–1030.
132 Armstrong N, Welsman JR, Williams CA, Kirby BJ: Longitudinal changes in young people's short-term power output. Med Sci Sports Exerc 2000;32:1140–1145.
133 Thorland WG, Johnson GO, Cisar CJ, Housh TJ, Tharp GD: Strength and anaerobic responses of elite young female sprint and distance runners. Med Sci Sports Exerc 1987;19:56–61.
134 Blimkie CJ, Roche P, Bar-Or O: The anaerobic power ratio in adolescent boys and girls; in Rutenfranz J, Mocellin R, Klimt F (eds): Children and Exercise XII. International Series on Sport Science. Champaign, Human Kinetics, 1986, pp 31–37.
135 Palgi Y, Gutin B, Young J, Alejandro D: Physiological and anthropometric factors underlying endurance performance in children. Int J Sports Med 1984;5:67–73.
136 Bar-Or O: Pediatric Sports Medicine for the Practitioner (Comprehensive Manual in Pediatrics). New York, Springer, 1983.
137 Doré E, Bedu M, França NM, Van Praagh E: Anaerobic cycling performance characteristics in prepubescent, adolescent and young adult females. Eur J Appl Physiol 2001;84:476–481.
138 Aucouturier J, Lazaar N, Doré E, Meyer M, Ratel S, Duché P: Cycling peak power in obese and lean 6–8 year-old girls and boys. Appl Physiol Nutr Metab 2007;32: 367–371.
139 Van Praagh E: Development of anaerobic function during childhood and adolescence. Pediatr Exerc Sci 1990;2:336–348.
140 Williams CA, Armstrong N: Optimised peak power output of adolescent children during maximal sprint pedalling; in Ring FJ (ed): Children in Sport. Proc 1st Bath Sports Medicine Conference. Bath, University of Bath, 1995, pp 40–44.
141 Bencke J, Damsgaard R, Saekmose A, Jørgensen P, Jørgensen K, Klausen K: Anaerobic power and muscle strength characteristics of 11 years old elite and non-elite boys and girls from gymnastics, team handball, tennis and swimming. Scand J Med Sci Sports 2002;12: 171–178.
142 Martin RJF, Doré E, Twisk J, Van Praagh E, Hautier CA, Bedu M: Longitudinal changes of maximal short-term peak power in girls and boys during growth. Med Sci Sports Exerc 2004;36:498–503.
143 De Ste Croix MBA, Armstrong N, Chia MYH, Welsman JR, Parsons G, Sharpe P: Changes in short-term power output in 10- to 12-year-olds. J Sport Sci 2001;19: 141–148.
144 Peterson SR, Gaul CA, Stanton MM, Hanstock CC: Skeletal muscle metabolism during short-term, high-intensity exercise in prepubertal and pubertal girls. J Appl Physiol 1999;87:2151–2156.
145 Wilcocks RJ, Williams CA, Barker AR, Fulford J, Armstrong N: Age- and sex-related differences in muscle phosphocreatine and oxygenation kinetics during high-intensity exercise in adolescents and adults. NMR Biomed 2010; 3:569–577.
146 Erlandson MC, Sherar LB, Mirwald RL, Maffulli N, Baxter-Jones AD: Growth and maturation of adolescent female gymnasts, swimmers, and tennis players. Med Sci Sports Exerc 2008;40:34–42.
147 Hong F: Innocence lost: child athletes in China. Sport Society 2004;7:338–354.
148 Lang M: Surveillance and conformity in competitive youth swimming. Sport Educ Society 2010;15:19–37.
149 Caine D, Bass S, Daly R: Does elite competition inhibit growth and delay maturation in some gymnasts? Quite possibly. Pediatr Exerc Sci 2003;15:360–372.
150 Klentrou P, Plyley M: Onset of puberty, menstrual frequency, and body fat in elite rhythmic gymnasts compared with normal controls. Br J Sports Med 2003;37:490–494.
151 Bass S, Bradney G, Pearce E, Hendrich E, Inge K, Stuckey S, Lo SK, Seeman E: Short stature and delayed puberty in gymnasts: influence of selection bias on leg length and the duration of training on trunk length. J Pediatr 2000;1136: 149–155.
152 Georgopoulos N, Markou K, Theodoropoulou A, Paraskevopoulou P, Varaki L, Kazantzi Z, Leglise M, Vagenakis AG: Growth and pubertal development in elite female rhythmic gymnasts. J Clin Endocrinol Metab 1999;84:4525–4530.
153 Georgopoulos NA, Markou KB, Theodoropoulou A, Vagenakis GA, Benardot D, Leglise M, Dikmopoulos JCA, Vagenakis AP: Height velocity and skeletal maturation in elite female rhythmic gymnasts. J Clin Endocrinol Metab 2001;86:5159–5164.
154 Theodoropoulou A, Markou KB, Vagenakis GA, Benardot D, Leglise M, Kourounis G, Vagenakis AP, Georgopoulos NA: Delayed but normally progressed puberty is more pronounced in artistic compared with rhythmic elite gymnasts due to the intensity of training. J Clin Endocrinol Metab 2005; 90:6022–6027.
155 Baxter-Jones ADG, Helms PJ: Effects of training at a young age: a review of the Training of Young Athletes (TOYA) Study. Pediatr Exerc Sci 1996;8:310–327.
156 Constantini NW, Warren MP: Menstrual dysfunction in swimmers: a distinct entity. J Clin Endocrinol Metab 1995;80: 2740–2744.
157 Loucks AB: Energy availability, not body fatness, regulates reproductive function in women. Exerc Sport Sci Rev 2003;31: 144–148.
158 Baxter-Jones ADG, Helms P, Baines-Preece J, Preece M: Menarche in intensively training gymnasts, swimmers and tennis players. Ann Hum Biol 1994;21: 407–415.
159 Otis CL, Drinkwater B, Johnson M, Loucks A, Wilmore J: American College of Sports Medicine position stand: the female athlete triad. Med Sci Sports Exerc 1997;29:i–ix.
160 Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP, American College of Sports Medicine: American College of Sports Medicine position stand: the female athlete triad. Med Sci Sports Exerc 2007;39: 1867–1882.

161 Sundgot-Borgen J, Torstveit MK: Prevalence of eating disorders in elite athletes is higher than in the general population. Clin J Sport Med 2004;14: 25–32.

162 Abraham SF, Beumont PJ, Fraser IS, Llewellyn-Jones D: Body weight, exercise and menstrual status among ballet dancers in training. Br J Obstet Gynaecol 1982;89:507–510.

163 Chumlea WC, Schubert CM, Roche AF, Kulin HE, Lee PA, Himes JH, Sun SS: Age at menarche and racial comparisons in US girls. Pediatrics 2003;111:110–113.

164 Beals, KA, Meyer NL: Female athlete triad update. Clin Sports Med 2007;26: 69–89.

165 Nichols JF, Rauh MJ, Lawson MJ, Ming JI, Barkai HS: Prevalence of the female athlete triad syndrome among high school athletes. Arch Pediatr Adoesc Med 2006;160:137–142.

166 Hoch AZ, Pajewski NM, Moraski L, Carrera GF, Wilson CR, Hoffmann RG, Schimke JE, Gutterman DD: Prevalence of the female athlete triad in high school athletes and sedentary students. Clin J Sport Med 2009;19:421–428.

167 Loucks AB, Heath EM: Induction of low T_3 syndrome in exercising women occurs at a threshold of energy availability. Am J Physiol 1994;226:R817–R823.

168 Loucks AB, Thurma JA: Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. J Clin Endocrinol Metab 2003;88:297–311.

169 Ihle R, Loucks AB: Dose-response relationships between energy availability and bone turnover in young exercising women. J Bone Miner Res 2004;19: 1231–1240.

170 Loucks AB: Refutation of 'the myth of the female athlete triad'. Br J Sports Med 2007;41:55–57.

171 De Souza MJ, Vescovi JD, Willijmas NI, Van Heest JL, Warren MP: Correction of misinterpretation and misrepresentations of the female athlete triad. Br J Sports Med 2007;41:58–59.

172 Klungland-Torstveig M, Sundgot-Borgen J: The female athlete triad exists in both elite athletes and controls. Med Sci Sports Exerc 2005;37:1449–1459.

173 American Psychiatric Association: Eating disorders; in First M (ed): Diagnostic and Statistical Manual of Mental Disorders, ed 4. Washington, American Psychiatric Publishing, 1994 pp 539–550.

174 Practice Committee of the American Society for Reproductive Medicine: Current evaluation of amenorrhea. Fertil Steril 2004;82:266–272.

175 Bianchi ML, Baim S, Bishop NJ, Gordon CM, Hans DB, Langman CB, Leonard MB, Kalkwarf HJ: Official positions of the International Society for Clinical Densitometry (ISCD) on DXA evaluation in children and adolescents. Pediatr Nephrol 2010;25:37–47.

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Exhibit M

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Ethnic and sex differences in body fat and visceral and subcutaneous adiposity in children and adolescents

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Abstract

Body fat and the specific depot where adipose tissue (AT) is stored can contribute to cardiometabolic health risks in children and adolescents. Imaging procedures including magnetic resonance imaging and computed tomography allow for the exploration of individual and group differences in pediatric adiposity. This review examines the variation in pediatric total body fat (TBF), visceral AT (VAT) and subcutaneous AT (SAT) due to age, sex, maturational status and ethnicity. TBF, VAT and SAT typically increase as a child ages, though different trends emerge. Girls tend to accumulate more TBF and SAT during and after puberty, depositing fat preferentially in the gynoid and extremity regions. In contrast, pubertal and postpubertal boys tend to deposit more fat in the abdominal region, particularly in the VAT depot. Sexual maturation significantly influences TBF, VAT and SAT. Ethnic differences in TBF are mixed. VAT tends to be higher in white and Hispanic youth, whereas SAT is typically higher in African American youth. Asian youth typically have less gynoid fat but more VAT than whites. Obesity per se may attenuate sex and ethnic differences. Particular health risks are associated with high amounts of TBF, VAT and SAT, including insulin resistance, hepatic steatosis, metabolic syndrome and hypertension. These risks are affected by genetic, biological and lifestyle factors including physical activity, nutrition and stress. Synthesizing evidence is difficult as there is no consistent methodology or definition to estimate and define depot-specific adiposity, and many analyses compare SAT and VAT without controlling for TBF. Future research should include longitudinal examinations of adiposity changes over time in representative samples of youth to make generalizations to the entire pediatric population and examine variation in organ-specific body fat.

Keywords

pediatric; body fat; visceral adipose tissue; subcutaneous adipose tissue; ethnic differences; sex differences

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

INTRODUCTION

Pediatric obesity contributes to physical and emotional health problems during childhood[1] and leads to future co-morbidities and premature mortality in adulthood.[2] Health consequences associated with obesity differ based on where adipose tissue (AT) is stored, for instance subcutaneously between the skin and muscle versus internally, such as within the chest, abdomen and pelvis (visceral AT (VAT)) or within and between muscles (nonvisceral AT).[3] Recent advances in body composition imaging allow for the examination of specific depots of AT in the pediatric population, providing sufficient precision to evaluate individual and group differences. Although the terms body fat and AT are often used interchangeably, fat specifically refers to lipids in the form of triglycerides, located mostly in AT though also present in other tissues of the body.[3] Dual-energy X-ray absorptiometry (DXA) is the method most commonly used to quantify total body fat (TBF) *in vivo*.

AT is loose connective tissue replete with adipocytes.[3] Its chief functions are energy storage, thermal insulation and mechanical cushioning. AT is composed of 80% fat but also includes protein, minerals and water.[4] Total AT is subdivided into subcutaneous AT (SAT) and internal AT (IAT).[3] The major contributor to IAT is VAT, which is located beneath the abdominal muscles and is particularly linked to poor cardiometabolic outcomes in youth.[5,6] To measure total AT as well as AT stored in specific organs and regions, the gold standards are magnetic resonance imaging (MRI) and computed tomography (CT). MRI is favored for the measurement of AT in children because, unlike CT, it uses a magnet and does not emit radiation.[7] We primarily focus on the depots of VAT and SAT, yet because the literature contains variation in the definitions used for each internal compartment,[3] we include IAT and intra-abdominal AT (IAAT) when VAT is not reported. IAT includes all AT other than SAT,[3] and IAAT includes AT within both the abdomen and pelvic region.[8]

Recent technological advances in biomedical imaging have transformed our understanding of pediatric obesity phenotypes in recent years. Thus, the purpose of this paper is to review the current status of our understanding about the extent of human variation observed in adiposity across the pediatric age range. Our focus is on the contributions of age, sex, maturation and ethnicity to variation in TBF, VAT and SAT. Further, we provide evidence of the link between adiposity and health outcomes where possible. Finally, we also discuss potential mechanisms including biological, lifestyle and environmental influences, challenges to measuring children's adiposity, and future research directions. Studies were preferentially included if the methodology employed MRI, CT or DXA. Studies using non-imaging techniques, such as anthropometry, hydrodensitometry or bioelectrical impedance methods, were included where image-based evidence was sparse.

INFLUENCE OF AGE

Total body fat

TBF accumulates as a child ages,[9] although inter-individual variation is evident as early as the third trimester of gestation. For example, MRI examination of 27 fetuses at 38–41 weeks of gestation demonstrated a range of 11.8–25%BF.[10] Thirteen of these babies born to mothers with poorly controlled diabetes had higher birth weight and higher %BF (average of 27.4%) compared with the normal group, revealing early maternal influences on TBF.[10]

TBF also varies considerably during infancy: for instance, %BF estimated by MRI ranged from 13.3 to 22.6% in a group of eight white infants measured within 36 h of delivery.[11] Estimates from total body electrical conductivity demonstrated a sharp increase in %BF during the first 6 months of life and a slow decline thereafter in 423 healthy white infants (aged 14–379 days).[12]

After the first year of life, absolute TBF typically declines or stabilizes until 6 years of age.[13,14] A DXA study of the first 24 months of life found that %BF increased between 15 days and 6 months then decreased thereafter, although TBF increased with age.[15] At about 6 years of age, an ‘adiposity rebound’ occurs where TBF increases throughout the rest of childhood and into adolescence.[16] This rebound was confirmed in a growth curve analysis of CT scans that documented an average 2.0±0.9 kg per year increase in TBF throughout childhood between ages 8 and 13, adjusted for ethnicity, sex and baseline age.[17] When adjusted for total lean tissue mass, the increase in TBF remained significant at 1.9±0.8 kg per year, indicating that TBF accumulated faster than the growth of lean tissue.[17]

During the peripubertal and postpubertal periods, TBF tends to fluctuate within and among individuals. Trajectories established for 678 US children between the ages of 8 and 18 years, based on 12 observations over 4 years, revealed that TBF decreased as males aged, whereas TBF increased or remained constant in females.[18] The increase in TBF co-occurred with increases in body mass index (BMI) and abdominal circumference in both males and females. In a DXA study of 112 white girls tracked from ages 11 to 18 years, TBF gained was B6 kg.[19] Increase in %BF occurred between ages 11 and 12 and after age 16, whereas %BF decreased between 13.5 and 16 years.[19]

In an underwater weighing study, girls increased from 6.4 to 16.3 kg TBF and from 20 to 26%BF between the ages of 8 and 20, increasing constantly across the age range.[9] TBF growth was less consistent for boys and was inversely related to the increase in fat-free mass.[9] The increase of TBF persisted until about age 16 in girls and age 18 in boys, at which point it typically stabilized.[20] Similarly, in a sample of 8269 5–18-year-old children from the US National Health and Nutrition Examination Survey (NHANES), %BF based on skinfold thicknesses peaked at age 11 in boys but increased throughout childhood and adolescence for girls, resulting in a 1.5 times greater %BF in girls versus boys by age 18.[21]

Visceral adipose tissue

Young children deposit less than 10% of their AT in the IAAT depot, as observed in 12–14-year-olds.[8] Within the first month of life, IAT accounted for 10% of TBF in eight infants (within 36 h of delivery), yet most was deposited in the pelvis and limbs, not in the abdomen.[11] In fact, VAT was on average 0.03±0.01 l that comprised 33% of total IAT and just 0.7% of total body weight.[11] However, IAT may act as a protective fat layer in early infancy: 10 growth-restricted infants who had lower TBF, total SAT and abdominal SAT, still had similar levels of IAT compared with 25 normal weight newborns.[22] Similarly, VAT was higher in 2–6-year-old children born small-for-gestational age compared with normal weight babies.[23] High levels of VAT can persist for several years: by age 6 years, VAT in small-for-gestational age babies was on average 50% higher than normal birth weight children.[24]

VAT increases with age throughout childhood (ages 5–17) and into adulthood.[25] In African American prepubertal 4–10-year-old children, the rate of change of IAAT was 4.3±1.6 cm^2 per year over 2 years.[26] A longitudinal study of 138 white and African American children aged 8 years at baseline and followed for 3–5 years found that VAT grew on average 11.6±2.9 cm^2 per year, and after adjusting for abdominal SAT the growth rate remained significant at 5.2±2.2 cm^2 per year.[17] However, as age increased, the growth in VAT slowed down.[17]

Age contributed 7.3% to the variance in VAT in 7–16-year-old white and Hispanic youth.[27] Over a 2-year period in 11–13-year-olds, boys increased IAT by 69% and increased from 0.31 to 0.39 in abdominal IAT-to-SAT ratio.[28] Girls increased 48% in IAT with a reduction in abdominal IAT-to-SAT ratio from 0.39 to 0.35.[28] One cross-sectional study adjusted for total AT and ethnicity, and demonstrated a decline in VAT as females went through adolescence, in contrast to males where VAT grew larger after age 12.[25]

In summary, VAT is present at birth and increases throughout childhood and adolescence, independent of growth in TBF or SAT. VAT growth appears constant throughout prepubertal ages (4–10 years)[26] but group differences in VAT growth emerge during the peripubertal and postpubertal ages.[27]

Subcutaneous adipose tissue

SAT increases as children age,[25] and age contributed 11% of the variance in SAT in a sample of 7–16-year-old Hispanic and white children.[27] In the first year of life, SAT composes the majority of TBF, varying between 89.0 to 92.3% of TBF [29] and 15.9 to 27.8% of total body weight.[11] Abdominal SAT is slightly lower, averaging 0.11±0.06 l in eight white newborn infants but still accounting for 12.2% of total body weight.[11] Annual observations over 3–5 years in 138 children (age 8.1±1.6 years) demonstrated that abdominal SAT grew 32.6±10.7 cm^2 per year.[17] Once adjusted for TBF, however, the growth rate was no longer significant. The authors conjecture that SAT is deposited in other areas than abdominally during this period in childhood.[17]

INFLUENCE OF SEX

Total body fat

Cross-sectional and longitudinal studies indicate that girls have more TBF than boys throughout childhood and adolescence (Table 1). This has been demonstrated in a longitudinal underwater weighing study in 8–20-year-olds[9] and in DXA cross-sectional studies of 7–17-year-olds in the US[30,31] and 6–18-year-olds in China,[32] among others. A cross-sectional study of 265 4–26-year-olds revealed that DXA-measured %BF was higher in females compared with males at all ages, and %BF increased for females throughout this period but not for males.[33] A contributing factor to sex differences in TBF is the higher amount of extremity BF in girls, as demonstrated in US children and adolescents aged 5–18 years.[34,35] Girls also have higher %BF by age 5, and this sex difference continues to increase until 18 years of age.[36] One exception is a study of 194 boys and 96 girls aged 6–15 years, in which CT-measured %BF was not different among girls and boys, though this was in a sample of obese children where sex differences may be attenuated.[37]

Sex differences in body fat emerge at specific developmental periods. At infancy, there is little documented sex difference in TBF. Female infants tend to have 50 g more DXA-derived TBF at birth than male infants, yet this 1.5% difference is within the coefficient of variation, and thus may not be detected in small sample sizes.[11] For instance, there were no sex differences in TBF in a cohort of eight white infants.[11] However, male infants tend to be longer in stature and have more lean mass during the first year of life,[38] which may contribute to sex differences in %BF.

Little MRI or CT data are available on sex differences during early childhood. A multi-component study calculating TBF from water, potassium and bone content found that TBF did not differ by sex during 0 to 24 months, except at 6 and 9 months at which point girls had higher %BF than boys.[15] In prepubertal children, girls typically have more TBF than boys. A CT study of 43 boys and 58 girls in the US aged approximately 7 years demonstrated that girls had more TBF.[26] African American 4–10-year-old girls had higher TBF and %BF (measured by DXA) than boys,[39] and Italian 3–11-year-old girls had more TBF than boys based on estimated fat mass from skinfold measurements.[40] However, not all studies demonstrate sex differences in TBF before puberty. A multi-year longitudinal study of American boys and girls aged 8.1±1.6 years found similar TBF.[17] There were no significant sex differences for TBF measured by bioelectrical resistance in a study of 4 boys and 12 girls aged 6.4±1.2 years in the US.[41] A study of 129 African American and white 10–12-year-olds indicated no difference in TBF measured by DXA across sexes, though boys had a bimodal distribution of TBF whereas girls' TBF was skewed to higher values.[42] Additionally, there were no sex differences in total abdominal fat measured by CT in 31 6–7-year-olds in the Netherlands.[43] Not controlling for other influences like age, maturational status and obesity status may account for the contradictory findings on sex differences, particularly in studies with small sample sizes.

During the pubertal period, females develop more TBF and fat deposited in the arms and legs, whereas males develop more total lean and muscle mass.[38] In a group of 678 children aged 8, 11 and 14 years, BMI and waist circumference (WC) increased similarly for both sexes, yet TBF increased in females and decreased in males.[18] In contrast, one study demonstrated no sex differences in TBF in a study of 160 US girls and boys aged 12–13 years.[44] Throughout adolescence after puberty, boys continue to primarily increase lean mass with little increase in TBF, as opposed to girls who tend to gain substantial TBF but little lean mass.[38] This sex divergence was also demonstrated in skinfold measurements collected in a representative sample of 5–18-year-olds in the US: girls increased in %BF throughout childhood and adolescence, whereas boys %BF peaked at age 11 and declined thereafter.[21]

Visceral adipose tissue

Findings related to sex differences in children and adolescents VAT are mixed. Many studies indicate males have more VAT than females throughout the ages of 5–25,[5,25,44,45] while others indicate no sex differences in VAT after adjustment for abdominal SAT in 4–10-year-olds.[26] Sex explained 1.8% of the variance in VAT in a study of 497 7–16-year-old prepubertal and pubertal boys and girls, and there was no sex difference in the abdominal VAT-to-SAT ratio.[27] However, boys had more VAT than girls in an MRI study of 12–13-year-old children, and the magnitude of the difference increased as WC increased.[44]

During childhood before puberty, boys may accumulate more VAT than girls. This was demonstrated in a study of 138 US girls and boys (mean age 8.1±1.6 years and followed for 3–5 years) in which VAT was higher in boys than in girls,[17] as well as in 290 Japanese children aged 6–15 years.[37] Despite similar %BF in 64 7–11-year-old obese boys and girls, boys had more VAT.[5] A study of 138 Hispanic and African American youth aged 13–25 showed that MRI-measured VAT was higher in boys than in girls.[45] Whereas IAT increased in peripubertal boys over a 2-year period (baseline mean 13 years old), the same decreased in girls.[28] In contrast, a CT study of prepubertal boys and girls (mean 13 years old) showed that IAAT was the same.[30]

During puberty, boys develop a more android shape by depositing more fat in the abdomen, whereas girls develop more TBF in general but deposit it in the hips and limbs forming a gynoid shape.[46] Boys' abdominal fat increases independently of total AT,[38] which was demonstrated in Australian 5–35-year-old males who had more abdominal fat than girls regardless of TBF.[47] In a US study (n = 160) of 12-year-olds, pubertal boys had higher VAT, WC, BMI and waist–hip ratio, even though pubertal girls had higher %BF.[44] VAT remained similar across the ages of 5–12 years, yet males had more VAT between 12 and 17 years, which marked pubertal onset for most.[25] DXA-derived waist fat and trunk fat adjusted for extremity fat was higher in boys than girls for those in late puberty in a sample of 5–29-year-olds, even though girls had more extremity and hip fat and more %BF.[48] Although 6–16-year-olds in Japan had no sex differences in VAT, older adolescent boys aged 16–20 had more VAT than their female counterparts.[49] Importantly, obesity increases android fat distribution in both sexes, thereby decreasing sex differences in body shape.[38]

Some studies demonstrate that girls have higher VAT than boys during adolescence. In a study of 160 12–14-year-olds, despite similar WC, girls had more IAAT compared with boys;[8] girls also were more sexually mature and had higher BMI and WC. Female adolescents aged ∼13–14 years had more VAT than males,[50] and also had higher BMIs. There was no sex difference in IAT (measured at the L4 lumbar level) in 16 obese adolescents (baseline age 12.8±1.4 years) measured over a 5-year period during pubertal attainment.[51] However, none of these studies controlled for TBF, and the fact that girls tend to have higher TBF may be driving the sex difference in these studies. More research is needed to elucidate reliable sex differences in VAT, and controlling for TBF is an important consideration.

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Subcutaneous adipose tissue

SAT appears to be similar across sex before puberty. A study of 4 boys and 12 girls aged 6.4±1.2 years in the US showed no significant sex difference in abdominal SAT measured by skinfold thickness.[41] Similarly, abdominal SAT was the same in ~8-year-olds boys and girls in US,[17] in 6–7-year-olds in the Netherlands[43] and in 6–15-year-olds in Japan.[37] In contrast, 4–10-year-old girls had higher CT-measured abdominal SAT than boys,[26] African American 4–10-year-old girls had higher abdominal SAT measured by CT,[39] 8-year-old prepubertal girls had more abdominal SAT than boys in a US study using CT,[30] and girls had more whole-body SAT than boys in a sample of 147 5–17-year-old Caucasian, African American, Hispanic and Asian children.[25]

After puberty girls tend to accumulate more SAT than boys, as demonstrated in a 2-year study of 11–13-year-olds where girls increased abdominal SAT by 78% versus a 19% increase in boys.[28] Additionally, girls had more SAT in a CT study of 11–20-year-old Japanese adolescents,[49] and girls had more abdominal SAT in a sample of British 12–14-year-olds.[8] Whole-body SAT was also higher in pubertal adolescent girls in an MRI study of 5–17-year-olds in the US.[25] An exception was found in boys and girls with similar SAT in a CT study of 12–13-year-olds[44] and in a study of 138 US girls and boys aged 13–25;[45] however, neither analysis controlled for TBF.

INFLUENCE OF MATURATIONAL STATUS

Total body fat

Puberty involves simultaneous hormonal, biological and behavioral changes centered on sexual maturation, including the development of primary and secondary sexual characteristics.[52] Sexual maturation influences TBF accumulation. Whereas boys decrease in gynoid body fat in late puberty compared with early prepuberty, girls accumulate more gynoid body fat.[35] For instance, girls who are more sexually mature have more TBF than those less mature, whereas it is the opposite for boys.[53] In a DXA study of 920 5–18-year-old children grouped into pre-, early- and late-puberty based on breast or genitalia and pubic hair development, gynoid BF was lower in late pubertal compared with prepubertal boys, but there were no differences across pubertal stage for girls.[35] Skeletal maturation is also related to TBF, where rapidly maturing girls had more TBF and %BF than intermediate maturing girls, and rapidly maturing boys assessed from 8 to 20 years of age had higher TBF and %BF compared with slowly maturing boys.[9]

Visceral adipose tissue

Pubertal status explained 12.4% of the variance in VAT in a study of 7–16-year-olds.[27] In fact, failing to control for children and adolescents pubertal stage may contribute to inconsistencies in VAT comparisons across studies.[25] Obesity status may also alter the effects of puberty on VAT: in normal weight children, IAT typically decreases during puberty, whereas IAT typically stabilizes in obese children.[51] A longitudinal study of 16 obese male and female adolescents aged 12.8±1.4 years indicated that over a 4-year period, during which puberty was completed, IAT did not change, nor did relative body weight.[51]

Some results indicate that pubertal status did not significantly predict VAT in 5–17-year-olds, although chronological age did.[25] Children aged 7.7±1.6 years who remained prepubertal gained a similar amount of IAT (4.6 (SD 2.1) cm^2 per year) compared with those who began puberty (5.6 (SD 2.1) cm^2 per year).[26] In 10–15-year-old normal weight and obese youth, there was no difference in abdominal SAT-to-IAT ratio by pubertal status.[54] IAT remained constant over the 4 years (under 130 cm^2) though there was a 15–100 cm^2 range in individual variation of IAT.[54] Yet an MRI study of 170 British peripubertal 12–14-year-old youth demonstrated that pubertal status explained 3.7% of the variance in IAAT and was significantly related to IAAT in boys but not girls.[8] Pubertal status did not, however, significantly relate to the abdominal IAAT-SAT ratio in girls or boys.

During pubertal onset and directly following puberty, children and adolescents typically have low amounts of VAT compared with SAT. For instance, in one MRI study of 170 British 12–14-year-olds, less than 10% of total abdominal fat was IAAT.[8] Whereas fat distribution was consistent in pre- versus late-pubertal girls aged 5–18 years, boys gained more of an android fat distribution late in puberty.[35] Differences in VAT occurring in late puberty may be predominantly due to boys accumulation of VAT during this period versus smaller VAT growth in girls.[55]

Subcutaneous adipose tissue

Pubertal status contributed to 18.6% of the variance in abdominal SAT in a study of 497 7–16-year-old white and Hispanic children.[27] SAT appears to be relatively stable during puberty, as demonstrated in 170 12–14-year-olds in which there was no effect of pubertal status on abdominal SAT.[8] However, one study demonstrated an increase in abdominal SAT during and after puberty in 16 obese male and female adolescents over a 4-year period during pubertal onset from approximately age 12 through age 16.[51] Yet age, not pubertal status, significantly predicted SAT in a full-body MRI scan of 5–17-year-olds.[25]

INFLUENCE OF ETHNICITY

Total body fat

Ethnicity is a significant correlate of %BF, independent of BMI, sex, sexual maturation and distribution of fat, as demonstrated in a study of 201 white and African American 7–17-year-olds.[31] Ethnic differences are evident in TBF and fat patterning in children (Table 2). For instance, Asian 8–10-year-olds varied in TBF depending on country of origin and a marginal trend persisted in girls once adjusted for age and BMI.[56] White youth typically have more %BF than African American youth at any given BMI as observed in a sample of 7–17-year-olds;[31] however, the population of African American 2–17-year-old children experienced a steeper rise in the prevalence of obesity measured by BMI based on a 30-year period of successive cross-sectional data.[57] In a bioelectrical impedance study of white and African American 9–19-year-old girls, white girls had higher %BF between ages 9 and 12, whereas African American girls had a higher %BF at older ages.[58] These differences are attributed to minor fluctuations of %BF in girls between the ages of 9 and 12 years, followed by a steeper incline in %BF in African American girls after age 12 that eclipsed white girls' %BF.

In a DXA study of 920 children, Asian girls had less gynoid fat compared with white and African American girls throughout pre-, early and late puberty during the ages of 5–18, and Asian boys had less gynoid fat during early and late puberty.[35] Similarly, Asian boys and girls had less extremity and gynoid fat compared with whites, whereas gynoid fat was similar between Asian and African American boys.[35]

Some studies indicate no ethnic differences in TBF: in a sample of 36 white and 65 African American prepubertal 4–10-year-old children, there were no ethnic differences in TBF or %BF despite differences in IAAT and abdominal SAT.[26] In a sample of 40 African American and white 7–10-year-old girls, there was no difference in DXA-measured TBF or %BF calculated by bioelectric impedance, although white girls had more fat deposited in the arm and chest.[59] Similarly, a sample of 40 African American and white 8–18-year-old overweight adolescent boys demonstrated no difference in MRI-measured total AT, even though African Americans had more whole-body SAT and less VAT.[60] One study demonstrated higher TBF in African Americans than whites at approximately age 8.[17] Obesity status may attenuate racial differences in TBF, demonstrated in a study of 55 obese adolescents (mean age 14–15 years) in which TBF and %BF did not differ among white, African American or Hispanic ethnic groups.[61]

Visceral adipose tissue

Racial/ethnic differences in VAT appear as early as infancy: in a comparison of 69 healthy Asian Indian and white European infants within 2 weeks of birth, Asian Indians had more VAT, despite having lower body mass, smaller head circumference and length, and less non-abdominal superficial SAT compared with the white Europeans.[62] In fact, ethnicity is a significant predictor of IAAT and can be used in a regression equation along with skinfold thickness to predict IAAT when DXA data are absent.[63]

Similarly, white youth have more VAT than African American youth at a given BMI.[64] In a study of 55 obese adolescents aged ~13 years, MRI-measured VAT was higher in white and Hispanic obese adolescents compared with African American obese adolescents,[61] and in a multi-ethnic sample of 118 obese adolescents aged 13–15, African Americans were less likely to be in the middle or upper tertile of VAT compared with white and Hispanic adolescents.[65] Despite similar total AT, 11–18-year-old overweight white boys had 50% more VAT than similarly aged overweight African American boys.[60] White children also accumulate IAAT relative to abdominal SAT at a 26% higher rate compared with African American children aged 4–10, demonstrated by a steeper regression line for IAAT to abdominal SAT in white compared with African American obese and non-obese children.[26] In a 3–5-year longitudinal study beginning at approximately age 8, white children had a steeper growth in VAT, growing on average 1.9±0.8 cm^2 per year in VAT more than African Americans did, with no ethnic difference in abdominal SAT or TBF growth.[17] A study of 20 African American and 20 white 7–10-year-old normal weight girls matched for BMI, bone age, chronological age, breast stage and socio-economic status, found that white girls had higher MRI-measured VAT and higher waist-to-thigh ratio compared with African

American girls.[59] For a given waist-to-height ratio, in a sample of 12-year-olds, white boys had more VAT and higher WC than African American boys, but there was no difference for girls.[44]

There were ethnic differences between 407 Hispanic and white 5–18-year-olds where Hispanics had higher VAT amounts than whites, but after correcting for abdominal SAT and BMI there was no difference in VAT.[27] Moreover, ethnicity explained just 2.1% of the variance in VAT and 5.9% of the variance in abdominal SAT.

Racial differences in VAT may be attenuated in obese children and adolescents. For instance, one study of 36 obese African American and white 6–18-year-olds found that CT-measured VAT did not differ by ethnicity after adjustment for age and pubertal stage.[66]

Subcutaneous adipose tissue

Although white youth tend to have higher WC on average, African American youth often have higher abdominal SAT and this accumulates faster at higher levels of WC.[44] African American 7–11-year-olds had more abdominal SAT and TBF than white youth, despite no ethnic difference in %BF or VAT.[5] Also, 11–18-year-old African American overweight boys had more whole-body SAT and specifically more leg and thigh SAT compared with overweight white boys, despite having similar total AT.[60] However, abdominal SAT did not differ by ethnicity in a study of 36 obese African American and white 6–18-year-olds,[66] and abdominal SAT was higher in white girls compared with African American girls in a 7–10-year-old sample matched for age, BMI, breast stage and socioeconomic status.[59] Ethnic differences are also seen at the beginning of life: in a study of 69 infants under 2 weeks old, Asian Indian infants had more deep abdominal SAT and superficial abdominal SAT than white European infants, even with lower body mass.[62]

HEALTH RISKS

The importance of where AT is stored and ensuing health risks was made evident in a comparison study of 28 obese adolescents on average 13 years old, of which half were insulin resistant and half were insulin sensitive.[67] Despite pairs being matched for age, sex, pubertal stage and body composition, obese insulin-resistant adolescents had higher VAT, indicating that VAT in particular was related to early formation of insulin resistance. One study of 118 obese adolescents demonstrated that as VAT increased, abdominal SAT decreased.[68] Interestingly, this adiposity profile of high VAT and low abdominal SAT had hepatic steatosis, insulin resistance and increased risk for metabolic syndrome. In a group of 14 obese adolescent girls aged 10–16, VAT but not BMI or waist–hip ratio highly correlated with cardiovascular risk factors including basal insulin, triglycerides and HDL cholesterol.[69]

Ultrasonography-measured VAT in 192 6–15-year-old obese children demonstrated that VAT (maximum preperitoneal fat thickness) was related to elevated systolic blood pressure, regardless of family history of hypertension.[70] MRI-measured VAT was related to adverse markers of insulin resistance syndrome in 81 obese African American and white 13–16-year-olds, independent of cardiovascular fitness.[71] In fact, VAT was a more powerful predictor than %BF (measured by DXA) for lipoproteins. An early review of the literature determined that IAAT was related to fasting insulin, insulin secretion and sensitivity, triglyceride and cholesterol concentrations.[72] However, DXA-measured TBF was related to insulin sensitivity.

Sex influences

Sex differences in fat distribution may lead to different health outcomes. For instance, a study of 920 healthy US 5–18-year-olds revealed a relationship between trunk fat and higher fasting blood pressure in boys but not in girls.[34] This relationship remained in boys (African American, Asian, white) across all pubertal stages. Intra-abdominal obesity may only adversely influence blood pressure in males, whereas the metabolic and inflammatory responses to excess adiposity may be similar in boys and girls.[6] Obesity may attenuate sex differences in obesity-related health outcomes: in a separate study of children aged ∼11 years-old, there was no difference in insulin resistance in obese boys and girls with similar TBF, %BF, abdominal SAT and VAT.[66]

Maturational status

Pubertal status may affect the relationship between AT and health outcomes. In children aged ∼12 years whose amount of IAT remained constant across multiple measurements, IAT was related to insulin glucose metabolism after puberty only, but there was no relationship between IAT and insulin or glucose before puberty.[51] In peri- and postpubertal adolescents aged 10–15, IAT was significantly related to insulin and HDL cholesterol, demonstrating that adolescents past puberty have similar IAT-risk factor relationships as adults do.[54]

Ethnicity

The relationship between adiposity and metabolic risk may differ between African American and white youth.[64] Despite a lower VAT, African American 7–12-year-old youth tend to have higher risk for diabetes compared with white youth, as well as lower insulin sensitivity.[73] Glucose and insulin were correlated with abdominal SAT in African American girls only, and glucose/insulin were not correlated with VAT in either African American or white girls aged 7–10.[59] One study of 36 obese African American and white 6–18-year-olds found that VAT and abdominal SAT did not differ by ethnicity, nor did insulin levels or insulin resistance.[66] Further studies should investigate racial differences in how various adipose depots confer health risk.[59]

POTENTIAL MECHANISMS

It is important to discover the underlying mechanisms for the observed group differences in total and regional adiposity in children and adolescents, particularly to design clinical and public health interventions to prevent the accumulation of excess adiposity.

Biological and genetic factors

Genetic factors explain a significant proportion of the variance in total and depot-specific body fat.[74,75] However, the degree to which observed sex or ethnic differences in adiposity are explained by genetic differences is not well understood. The relative contributions of genes versus the environment to the total phenotypic variance in BMI may differ between white and African American children;[76] however, little research exists on the differential effects of specific genetic markers for obesity in different ethnic groups in childhood.[77] The determination of genetic influences on obesity in different ethnic groups is a research priority.

Pubertal changes including insulin-sensitivity change,[53] hormonal and endocrine factors,[46] and sex steroid hormones like estrogen[38] relate to body composition changes. Body composition may differ based on growth spurts and peak height velocity.[78] The earlier that the adiposity rebound occurs in a child's life, the more likely that child is to become overweight.[16]

Current level of adiposity may determine the location of subsequent adiposity accumulation: differences between obese and non-obese children are predominantly found in the abdominal SAT compartment, although obese children also have more IAAT.[79] The difference in SAT by adiposity status may be from continued expansion of the SAT depot compared to a plateau of IAT, as demonstrated in obese 12-year-old adolescents over a 4-year longitudinal study.[51] Obesity also attenuates group differences in adiposity and fat. Ethnic differences between obese white and black 6–18-year-olds were only found for the SAT depot but not for VAT,[66] and no ethnic differences were observed in TBF or %BF in obese 13–14-year-olds.[61] One explanation may be that obesity promotes central fat distribution in an android pattern regardless of sex, ethnicity or maturational status.[38] Further research should examine how obesity status diminishes group differences that are otherwise apparent in non-obese children.

Behavior and lifestyle factors

Though the literature is sparse, lifestyle factors including physical activity and nutrition may impact TBF and depot-specific adiposity,[55] and there may be group differences that influence these daily behaviors. In a study of 42 8-year-old children, after controlling for TBF, higher amounts of physical activity measured by accelerometry was related to lower VAT, but not SAT.[80] VAT measured by MRI was inversely related to aerobic fitness measured by peak VO_2 consumption during a treadmill test in 30 male and 22 female adolescents aged ~13.[50] A sedentary lifestyle may promote excess adipose accumulation. For instance, screen-time including watching television or movies predicted an increase in %BF measured by DXA in 661 healthy African American and white 14–18-year-olds.[81]

Nutrition also affects AT accumulation, though the relationships between dietary intake and depot-specific adiposity in children is not well studied.[55] Increased energy intake from protein predicted higher %BF in a sample of white and African American 14–18-year-old adolescents, but increased fat consumption predicted higher %BF in whites only and not in African Americans.[81] Interestingly, once energy intake was controlled for in regression analyses, there was no longer a significant relationship between vigorous physical activity and %BF.[81]

Stress may also be related to abdominal fat.[82,83] Insulin and cortisol may promote lipid growth.[47] A cross-sectional study of 23 female peripubertal Hispanic girls aged 8–11-years-old demonstrated that school-related life events were related to higher VAT and abdominal SAT for girls who had high cortisol awakening response, but not for those with lower cortisol levels.[82] This stress may derive from environmental factors, particularly socio-economic status, which is inversely related to TBF in children.[84]

CHALLENGES AND FUTURE DIRECTIONS

Childhood and adolescence is a time of rapid growth, and maturational status is difficult to quantify in children and adolescents because pubertal stage, biological development, skeletal growth and somatic growth increase at different rates for different children and vary by chronological age[78] and pubertal stage.[55] Most studies are limited to cross-sectional analyses, and longitudinal analyses of the maturation of AT across the pediatric age range and pubertal stages of development are needed.[55] AT can change quickly and dramatically, and even though the total mass of AT may remain constant, the distribution of the fat may change particularly in puberty.[85] These developmental changes demonstrate the need for whole-body MRI measured by multiple slices so that fat lost at one site may be detected as fat gained at another site.[85]

Owing to the cost and resources required, most imaging studies published to date are typically limited by small sample sizes that are not necessarily representative of populations.[55] Population-based data on depot-specific AT in children and adolescents is virtually nonexistent; thus efforts should be made to include imaging methods in large-scale studies. Further, an urgent research priority is to determine the best anthropometric measurements of total and depot-specific body fat in children, such that better measures can be incorporated into epidemiological studies.[8]

Choosing the best protocols for current imaging instruments remains an urgent need, particularly in the pediatric population. Reliability and validity across imaging measures of adiposity should be established. Errors related to slice gap and number must be overcome, and methodologies need to maximize accuracy while minimizing the burden to the participant. The measurement methodology including instrument and measurement site may alter results, particularly considering group differences in fat patterning. For example, the L4–L5 intervertebral region of the spine is predominantly used in MRI studies to measure abdominal adiposity, but it is unknown if this slice provides the most accurate estimate of abdominal adiposity in children. A single MRI slice may not adequately provide a reference standard to measure total abdominal adiposity, meaning that multiple slices are needed. Ethnic-specific MRI measurement sites of VAT have been recommended in adolescents to best predict total VAT and risk for the metabolic syndrome.[86] Understanding which specific depots and regions of fat yield the most harm is necessary to tailor physical activity and weight-reduction efforts.

Moving beyond the study of IAT and VAT to examine organ-specific fat deposits, such as liver fat and intramyocellular lipid content, warrants further research. Ectopic fat deposition in organs and other tissues may better explain ethnic differences in health risks.[87] Among obese adolescents, African Americans did not have sufficient liver fat to be detected, whereas white and Hispanic adolescents had over twice as much liver fat as considered normal.[61] Hispanic adolescents had higher liver fat and intramyocellular lipid content than both African American and white adolescents, even at similar weight and age. Moreover, ethnicity contributed 10% of the difference in liver fat and intramyocellular lipid, independent of age, gender or %BF.[61] Interestingly, in a multi-ethnic sample of 118 obese adolescents, at higher levels of VAT adolescents had less %BF and SAT and more hepatic fat, indicating that the excess amount of AT was being deposited in the visceral area, particularly in the liver.[65]

CONCLUSIONS

TBF and depot-specific AT influence cardiometabolic health risks in children and adolescents. Understanding the age, sex, maturational status and ethnic differences in TBF, VAT and SAT can improve prevention and treatment efforts, particularly if health risks are linked to these group differences. Future research should examine longitudinal changes of adiposity over time in representative samples of youth in order to generalize to the entire pediatric population.

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REFERENCES

1. Krebs NF, Jacobson MS. Academy of Pediatrics Committee on Nutrition. Prevention of pediatric overweight and obesity. Pediatrics. 2003; 112:424–430. [PubMed: 12897303]
2. Reilly JJ, Kelly J. Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: Systematic review. Int J Obes. 2011; 35:891–898.
3. Shen W, Wang Z, Punyanita M, Lei J, Sinav A, Kral JG, et al. Adipose tissue quantification by imaging methods: a proposed classification. Obesity. 2003; 11:5–16.
4. Snyder, WM.; Cook, MJ.; Nasset, ES.; Karhausen, LR.; Howells, GP.; Tipson, IH. Report of the Task Group on the Reference Man. Oxford: Paergamon Press; 1984.
5. Owens S, Gutin B, Ferguson M, Allison J, Karp W, Le NA. Visceral adipose tissue and cardiovascular risk factors in obese children. J Pediatrics. 1998; 133:41–45.
6. Syme C, Abrahamowicz M, Leonard GT, Perron M, Pitoit A, Qui X, et al. Intra-abdominal adiposity and individual components of the metabolic syndrome in adolescence: sex differences and underlying mechanisms. Arch Pediatrics Adolescent Med. 2008; 162:453–461.
7. Sopher, A.; Shen, W.; Pietrobelli, A. Pediatric body composition methods. In: Heymsfield, SB.; Lohman, TG.; Wang, Z.; Going, SB., editors. Human Body Composition. 2nd edn. Champaign, IL: Human Kinetics; 2005.
8. Benfield LL, Fox KR, Peters DM, Blake H, Rogers I, Grant C, et al. Magnetic resonance imaging of abdominal adiposity in a large cohort of British children. Int J Obes. 2008; 32:91–99.
9. Guo SS, Chumlea WC, Roche AF, Siervogel RM. Age- and maturity-related changes in body composition during adolescence into adulthood: The Fels Longitudinal Study. Int J Obes. 1997; 21:1167–1175.
10. Deans HE, Smith FW, Lloyd DJ, Law AN, Sutherland HW. Fetal fat measurement by magnetic resonance imaging. Br J Radiol. 1989; 62:603–607. [PubMed: 2758247]
11. Harrington TAM, Thomas EL, Modi N, Frost G, Coutts GA, Bell JD. Fast and reproducible method for the direct quantitation of adipose tissue in newborn infants. Lipids. 2002; 37:95–100. [PubMed: 11878317]

12. De Bruin NC, van Velthoven KAM, de Ridder M, Stijnen T, Juttmann RE, Degenhart HJ, et al. Standards for total body fat and fat-free mass in infants. Arch Dis Child. 1996; 74:386–399. [PubMed: 8669953]
13. Ellis KJ, Abrams SA, Wong WW. Body composition of a young, multiethnic female population. Am J Clin Nutr. 1997; 65:724–731. [PubMed: 9062521]
14. Ellis KJ. Body composition of a young, multiethnic male population. Am J Clin Nutr. 1997; 66:1323–1331. [PubMed: 9394682]
15. Butte NF, Hopkinson JM, Wong WW, Smith EO, Ellis KJ. Body composition during the first 2 years of life: an updated reference. Pediatric Research. 2000; 47:578–585. [PubMed: 10813580]
16. Freedman DS, Kettel Khan L, Serdula MK, Srinivasan SR, Berenson GS. BMI rebound, childhood height and obesity among adults: the Bogalusa Heart Study. Int J Obes. 2001; 25:543–549.
17. Huang TTK, Johnson MS, Figueroa-Colon R, Dwyer JH, Goran MI. Growth of visceral fat, subcutaneous abdominal fat, and total body fat in children. Obesity Res. 2001; 9:283–289.
18. Dai S, Labarthe DR, Grunbaum JA, Harrist RB, Mueller WH. Longitudinal analysis of changes in indices of obesity from age 8 years to age 18 years: Project HeartBeat! Am J Epidemiol. 2002; 156:720–729. [PubMed: 12370160]
19. Lloyd T, Chinchilli VM, Eggli DF, Rollings N, Kulin HE. Body composition development of adolescent white females: The Penn State Young Women's Health Study. Arch Pediatr Adolesc Med. 1998; 152:998–1002. [PubMed: 9790610]
20. Rolland-Cachera MF, Cole TJ, Sempe M, Tichet J, Rossignol C, Charraud A. Body mass index variations: Centiles from birth to 87 years. Eur J Clin Nutr. 1991; 45:13–21. [PubMed: 1855495]
21. Laurson KR, Eisenmann JC, Welk GJ. Body fat percentile curves for U.S. children and adolescents. Am J Preventive Med. 2011; 41(Suppl 2):S87–S92.
22. Harrington TAM, Thomas EL, Frost G, Modi N, Bell JD. Distribution of adipose tissue in the newborn. Pediatric Res. 2004; 55:437–441.
23. Ibáñez L, Lopez-Bermejo A, Suárez L, Marcos MV, Díaz M, de Zegher F. Visceral adiposity without overweight in children born small for gestational age. J Clin Endocrinol Metab. 2008; 93:2079–2083. [PubMed: 18334595]
24. Ibáñez L, Suárez L, Lopez-Bermejo A, Díaz M, Valls C, de Zegher F. Early development of visceral fat excess after spontaneou catch-up growth in children with low birth weight. J Clin Endocrinol Metab. 2008; 93:925–928. [PubMed: 18089700]
25. Shen W, Punyanitya M, Silva AM, Chen J, Gallagher D, Sardinha LB, et al. Sexual dimorphism of adipose tissue distribution across the lifespan: a cross-sectional whole-body magnetic resonance imaging study. Nutr Metab. 2009; 6:17.
26. Goran M, Nagy T, Treuth M, Trowbridge C, Dezenberg C, McGloin A, et al. Visceral fat in white and African American prepubertal children. Am J Clin Nutr. 1997; 65:1703–1708. [PubMed: 9174463]
27. Brambilla P, Bedogni G, Moreno LA, Goran MI, Gutin B, Fox KR, et al. Cross-validation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. Int J Obes. 2006; 30:23–30.
28. Fox KR, Peters DM, Sharpe P, Bell M. Assessment of abdominal fat development in young adolescents using magnetic resonance imaging. Int J Obes Relat Metab Disord. 2000; 24:1653–1659. [PubMed: 11126220]
29. Olhager E, Thomas KA, Wigstrom L, Forsum E. Description and evaluation of a method based on magnetic resonance imaging to estimate adipose tissue volume and total body fat in infants. Pediatr Res. 1998; 44:572–577. [PubMed: 9773848]
30. Herd S, Gower B, Dashti N, Goran M. Body fat, fat distribution and serum lipids, lipoproteins and apolipoproteins in African-American and Caucasian-American prepubertal children. Int J Obes. 2001; 25:198–204.
31. Daniels S, Khoury P, Morrison J. The utility of body mass index as a measure of body fatness in children and adolescents: differences by race and gender. Pediatrics. 1997; 99:804–807. [PubMed: 9164773]

32. Wang H, Story RE, Venners SA, Wang B, Yang J, Li Z, et al. Patterns and interrelationships of body-fat measures among rural Chinese children aged 6 to 18 years. Pediatrics. 2007; e120:e194–e101.

33. Ogle G, Allen J, Humphries I, Lu PW, Briody JN, Morley K, et al. Body-composition assessment by dual-energy X-ray absorptiometry in subjects aged 4–26 y. Am J Clin Nutr. 1995; 61:746–753. [PubMed: 7702015]

34. He Q, Horlick M, Thornton J, Wang J, Pierson RN Jr. Heshka S, et al. Sex and race differences in fat distribution among Asian, African-American, and Caucasian prepubertal children. J Clin Endocrinol Metab. 2002; 87:2164–2170. [PubMed: 11994359]

35. He Q, Horlick M, Thornton J, Wang J, Pierson RN, Heshka S, et al. Sex-specific fat distribution is not linear across pubertal groups in a multiethnic study. Obes Res. 2004; 12:725–733. [PubMed: 15090643]

36. Shaw NJ, Crabtree NJ, Kibirige MS, Fordham JN. Ethnic and gender differences in body fat in British schoolchildren as measured by DXA. Arch Dis Child. 2007; 92:872–875. [PubMed: 17522163]

37. Asayama K, Hayashibe H, Endo A, Okada T, Hara M, Masuda H, et al. Threshold values of visceral fat and waist girth in Japanese obese children. Pediatrics Int. 2005; 47:498–504.

38. Wells JCK. Sexual dimorphism of body composition. Best Practice Res Clin Endo-crinol Metab. 2007; 21:415–430.

39. Ku CY, Gower BA, Nagy TR, Goran MI. Relationship between dietary fat, body fat, and serum lipid profile in prepubertal children. Obes Res. 1998; 6:400–407. [PubMed: 9845229]

40. Maffeis C, Pietrobelli A, Grezzani A, Provera S, Tato L. Waist circumference and cardiovascular risk factors in prepubertal children. Obesity Res. 2001; 9:179–187.

41. Goran MI, Kaskoun MC, Shuman WP. Intra-abdominal adipose tissue in young children. Int J Obes. 1995; 19:279–283.

42. Bray GA, DeLany JP, Harsha DW, Volaufova J, Champagne CC. Evaluation of body fat in fatter and leaner 10-y-old African American and white children: the Baton Rouge Children's Study. Am J Clin Nutr. 2001; 73:687–702. [PubMed: 11273842]

43. Liem ET, Rolfe EDL, L'Abée C, Sauer PJJ, Ong KK, Stolk RP. Measuring abdominal adiposity in 6 to 7-year-old children. Eur J Clin Nutr. 2009; 63:835–841. [PubMed: 19127281]

44. Lee S, Kuk JL, Hannon TS, Arslanian SA. Race and gender differences in the relationships between anthropometrics and abdominal fat in youth. Obesity. 2008; 16:1066–1071. [PubMed: 18356853]

45. Le KA, Ventura EE, Fisher JQ, Davis JN, Weigensberg MJ, Punyanitya M, et al. Ethnic differences in pancreatic fat accumulation and its relationship withother fat depots and inflammatory markers. Diabetes Care. 2011; 34:485–490. [PubMed: 21270204]

46. Loomba-Albrecht LA, Styne DM. Effect of puberty on body composition. Curr Opin Endocrinol Diabetes Obesity. 2009; 16:10–15.

47. Cowell CT, Briody J, Lloyd-Jones S, Smith C, Moore B, Howman-Giles R. Fat distribution in children and adolescents - the influence of sex and hormones. Hormone Res Pediatrics. 1997; 48(Suppl 5):93–100.

48. Taylor RW, Grant AM, Williams SM, Goulding A. Sex differences in regional body fat distribution from pre- to postpuberty. Obesity. 2010; 18:1410–1416. [PubMed: 19893501]

49. Satake E, Nakagawa Y, Kubota A, Saegusa H, Sano S-i Ohzeki T. Age and sex differences in fat distribution in non-obese Japanese children. J Pediatric Endocrinol Metab. 2010; 23:873–878.

50. Winsley R, Armstrong N, Middlebrooke A, Ramos-Ibanez N, Williams C. Aerobic fitness and visceral adipose tissue in children. Acta Paediatrica. 2006; 95:1435–1438. [PubMed: 17062473]

51. Brambilla P, Manzoni P, Agostini G, Beccaria L, Ruotolo G, Sironi S, et al. Persisting obesity starting before puberty is associated with stable intraabdominal fat during adolescence. Int J Obes. 1999; 23:299–303.

52. Kirchengast S, Angelika G. Body composition characteristics during puberty in girls and boys from Eastern Austria. Int J of Anthropology. 2003; 18:139–151.

53. Travers SH, Jeffers BW, Bloch CA, Hill JO, Eckel RH. Gender and Tanner stage differences in body composition and insulin sensitivity in early pubertal children. J Clin Endocr Metab. 1995; 80:172–178. [PubMed: 7829608]

54. Brambilla P, Manzoni P, Sironi S, Del Maschio A, di Natale B, Chiumello G. Peripheral and abdominal adiposity in childhood obesity. Int J Obes Relat Metab Disord. 1994; 18:795–800. [PubMed: 7894517]

55. Suliga E. Visceral adipose tissue in children and adolescents: a review. Nutrition Res Rev. 2009; 22:137–147. [PubMed: 19737436]

56. Liu A, Byrne N, Kagawa M, Ma G, Kijboonchoo K, Nasreddine L, et al. Ethnic differences in body fat distribution among Asian pre-pubertal children: a cross-sectional multicenter study. BMC Public Health. 2011; 11:500. [PubMed: 21703012]

57. Freedman DS, Khan LK, Serdula MK, Ogden CL, Dietz WH. Racial and ethnic differences in secular trends for childhood BMI, weight, and height. Obesity. 2006; 14:301–308. [PubMed: 16571857]

58. Morrison JA, Barton BA, Obarzanek E, Crawford PB, Guo SS, Schreiber GB. Racial differences in the sums of skinfolds and percentage of body fat estimated from impedance in black and white girls, 9 to 19 years of age: The National Heart, Lung, and Blood Institute Growth and Health Study. Obesity Res. 2001; 9:297–305.

59. Yanovski JA, Yanovski SZ, Filmer KM, Hubbard VS, Avila N, Lewis B, et al. Differences in body composition of black and white girls. Am J Clin Nutr. 1996; 64:833–839. [PubMed: 8942404]

60. Lee S, Kim Y, Kuk JL, Boada FE, Arslanian S. Whole-body MRI and ethnic differences in adipose tissue and skeletal muscle distribution in overweight black and white adolescent boys. J Obesity. 2011; 2011:159373.

61. Liska D, Dufour S, Zern TL, Taksali S, Cali AMG, Dziura J, et al. Interethnic differences in muscle, liver and abdominal fat partitioning in obese adolescents. PLoS One. 2007; 2:e569. [PubMed: 17593968]

62. Modi N, Thomas EL, Uthaya SN, Umranikar S, Bell JD, Yajnik C. Whole body magnetic resonance imaging of healthy newborn infants demonstrates increased central adiposity in Asian Indians. Pediatr Res. 2009; 65:584–587. [PubMed: 19190541]

63. Goran M, Gower BA, Treuth MS, Nagy TR. Prediction of intra-abdominal and subcutaneous abdominal adipose tissue in healthy pre-pubertal children. Int J Obes. 1998; 22:549–558.

64. Bacha F, Saad R, Gungor N, Janosky J, Arslanian SA. Obesity, regional fat distribution, and Syndrome X in obese black versus white adolescents: race differential in diabetogenic and atherogenic risk factors. J Clin Endocrinol Metab. 2003; 88:2534–2540. [PubMed: 12788850]

65. Taksali SE, Caprio S, Dziura J, Dufour S, Cali AMG, Goodman TR, et al. High visceral and low abdominal subcutaneous fat stores in the obese adolescent: a determinant of an adverse metabolic phenotype. Diabetes. 2007; 57:367–371. [PubMed: 17977954]

66. Tershakovec AM, Kuppler KM, Zemel BS, Katz L, Weinzimer S, Harty MP, et al. Body composition and metabolic factors in obese children and adolescents. Int J Obes. 2003; 27:19–24.

67. Weiss R, Taksali SE, Dufour S, Yeckel CW, Papademetris X, Cline G, et al. The "obese insulin-sensitive" adolescent: importance of adiponectin and lipid partitioning. J Clin Endocrinol Metabolism. 2005; 90:3731–3737.

68. Cali AM, Caprio S. Ectopic fat deposition and the metabolic syndrome in obese children and adolescents. Hormone Res Pediatrics. 2009; 71(Suppl 1):2–7.

69. Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: Importance of the intraabdominal fat depot. Am J Clin Nutr. 1996; 64:12–17. [PubMed: 8669407]

70. Nishina M, Kikuchi T, Yamazaki H, Kameda K, Hiura M, Uchiyama M. Relationship among systolic blood pressure, serum insulin and leptin, and visceral fat accumulation in obese children. Hypertens Res. 2003; 26:281–288. [PubMed: 12733695]

71. Owens S, Gutin B, Barbeau P, Litaker M, Allison J, Humphries M, et al. Visceral adipose tissue and markers of the insulin resistance syndrome in obese black and white teenagers. Obesity Res. 2000; 8:287–293.

72. Goran MI, Gower BA. Relation between visceral fat and disease risk in children and adolescents. Am J Clin Nutr. 1999; 70:149S–1565.

73. Goran MI, Bergman RN, Gower BA. Influence of total vs. visceral fat on insulin action and secretion in African American and White children. Obesity Res. 2001; 9:423–431.

74. Comuzzie AG, Higgins PB, Voruganti S, Cole S. Cutting the fat: the genetic dissection of body weight. Prog Mol Biol Transl Sci. 2010; 94:197–212. [PubMed: 21036326]

75. Katzmarzyk PT, Perusse L, Bouchard C. Genetics of abdominal visceral fat levels. Am J Hum Biol. 1999; 11:225–235. [PubMed: 11533946]

76. Katzmarzyk PT, Mahaney MC, Blangero J, Quek JJ, Malina RM. Potential effects of ethnicity in genetic and environmental sources of variability in the stature, mass, and body mass index of children. Hum Biol. 1999; 71:977–987. [PubMed: 10592687]

77. Klimentidis YC, Chen G-B, Lopez-Alarcon M, Harris JJ, Duarte CW, Fernandez JR. Associations of obesity genes with obesity-related outcomes in multiethnic children. Arch Med Res. 2011; 42:509–514. [PubMed: 22051089]

78. Malina RM, Koziel S, Bielicki T. Variation in subcutaneous adipose tissue distribution associated with age, sex, maturation. Am J Hum Biol. 1999; 11:189–200. [PubMed: 11533943]

79. Fox KR, Peters DM, Armstrong N, Sharpe P, Bell M. Abdominal fat deposition in 11-year-old children. Int J Obes Relat Metab Disord. 1993; 17:11–16. [PubMed: 8383635]

80. Saelens BE, Seeley RJ, van Schaick K, Donnelly LF, O'Brien KJ. Visceral abdominal fat is correlated with whole-body fat and physical activity among 8-y-old children at risk of obesity. Am J Clin Nutr. 2007; 85:46–53. [PubMed: 17209176]

81. Stallmann-Jorgensen IS, Gutin B, Hatfield-Laube JL, Humphries MC, Johnson MH, Barbeau P. General and visceral adiposity in black and white adolescents and their relation with reported physical activity and diet. Int J Obes. 2007; 31:622–629.

82. Donoho CJ, Weigensberg MJ, Emken BA, Hsu J-W, Spruijt-Metz D. Stress and abdominal fat: preliminary evidence of moderation by the cortisol awakening response in Hispanic peripubertal girls. Obesity. 2010; 19:946–952. [PubMed: 21127479]

83. Kyrou I, Chrousos GP, Tsigos C. Stress visceral obesity, and metabolic complications. Ann NY Acad Sci. 2006; 1083:77–110. [PubMed: 17148735]

84. Rizzo NS, Ruiz JR, Hurtig-Wennlof A, Kwak L, Sjostrom M. Socioeconomic status and its association with objectively-measured total physical activity and body fat in children: The European Youth Heart Study. Int J Body Composit Res. 2010; 8:93–98.

85. Shen W, Liu H, Punyanitya M, Chen J, Heymsfield SB. Pediatric obesity pheno-typing by magnetic resonance methods. Curr Opin Clin Nutr Metab Care. 2005; 8:595–601. [PubMed: 16205458]

86. Lee S, Kuk JL, Kim Y, Arslanian S. Measurement site of visceral adipose tissue and prediction of metabolic syndrome in youth. Pediatr Diabetes. 2011; 12(pt2):250–257. [PubMed: 21129140]

87. D'Adamo E, Northrup V, Weiss R, Santoro N, Pierpont B, Savoye M, et al. Ethnic differences in lipoprotein subclasses in obese adolescents: importance of liver and intraabdominal fat accretion. Am J Clin Nutr. 2010; 92:500–508. [PubMed: 20573788]

88. Deurenberg P, Deurenberg-Yap M, Foo LF, Schmidt G, Wang J. Differences in body composition between Singapore Chinese, Beijing Chinese and Dutch children. Eur J Clin Nutr. 2003; 57:405–409. [PubMed: 12627175]

89. Gower BA, Nagy TR, Trowbridge CA, Dezenberg C, Goran MI. Fat distribution and insulin response in prepubertal African American and white children. Am J Clin Nutr. 1998; 67:821–827. [PubMed: 9583837]

90. Wong WW, Hergenroeder AC, Stuff JE, Butte NF, Smith EOB, Ellis KJ. Evaluating body fat in girls and female adolescents: advantages and disadvantages of dual-energy X-ray absorptiometry. Am J Clin Nutr. 2002; 76:384–389. [PubMed: 12145011]

Table 1

Sex differences in TBF and depot-specific adiposity in children and adolescents

Reference	*Country*	n *(boys, girls)*	*Age (y)*	*Instrument*	*TBF*	*VAT*	*Abdominal SAT*
47	Australia	169, 166	4–35	DXA	%BF: G>B		
31	US	100, 92	7–17	DXA	NS		
26	US	43, 58	7.7 ± 1.6	CT, DXA	G>B	IAAT: G>B	G>B
39	US	30, 36	4–10	CT, DXA	G>B		G> B
5	US	21, 43	7–11	MRI, DXA	NS	B>G	NS
51	US	8, 8	12.8 ± 1.4	MRI		IAT: NS	
71	US	26, 54	13–16	MRI, DXA	%BF: NS	NS	
42	US	65, 64	10–12	DXA	NS		
30	US	58, 43	AA: 8.3±1.4	CT, DXA	G>B	NS	G>B
			W: 8.6±1.2				
17	US	47, 91	8.1 ± 1.6	CT, DXA	NS	B>G	NS
			3–5 years longitudinal				
11	US	4, 4	<1.5 days	MRI	NS	NS	NS
88	Singapore, Beijing, the Netherlands	75, 75	7–12	DXA	NS		
66	US	15, 21	11.8 ± 0.5	CT, DXA	NS	NS	NS
37	Japan	194, 96	6–15	CT		B>G	NS
32	China	1328, 1165	6–18	DXA	G>B		
8	UK	74, 96	13.4 ±0.4	MRI		IAAT: G>B	G>B
			13.5 ±0.5				
44	US	84, 76	~12–13	CT, DXA	NS	B>G	NS
43	The Netherlands	14, 17	6–7	CT, DXA	NS	NS	NS
25	US	88, 59	5–17	MRI		NS (<12y)	G>B
						B>G (>12y)	
49	Japan	73, 57	6–20	CT		B>G (16–20 years)	G>B (11–20 years)
48	US	518, 491	5–29	DXA	G>B		
45	US	40, 98	13–25	MRI, DXA	%BF: G>B	B>G	NS

Abbreviations: %BF, percent body fat; B>G, boys significantly higher than girls; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; G>B, girls significantly higher than boys; IAT, internal adipose tissue; IAAT, intra-abdominal adipose tissue; MRI, magnetic resonance imaging; NS, no significant difference between sexes; SAT, subcutaneous adipose tissue; TBF, total body fat; VAT, visceral adipose tissue.

Table 2

Ethnic differences in TBF and depot-specific adiposity in children and adolescents

Reference	*Country: ethnic groups*	**n**	*Age (y)*	*Instrument*	*TBF*	*VAT*	*Abdominal SAT*
59	US girls: AA, W	40	7–10	MRI, DXA	NS	W>AA	W>AA
31	US: AA, W	192	7–17	DXA	NS		
13	US girls: AA, Hisp, W	313	3–18	DXA	Hisp>W		
14	US boys: AA, Hisp, W	297	3–18	DXA	Hisp>W Hisp>AA W>AA		
26	US	101	7.7 ± 1.6	CT, DXA	NS	W>AA	W>AA
89	US: AA, W	73	5–10	CT, DXA	NS	NS	NS
39	US: AA, W	66	4–10	CT	NS	IAAT: W>AA	NS
5	US: AA, W	64	7–11	MRI, DXA	AA>W	NS	AA>W
71	US: AA, W	81	13–16	MRI, DXA	%BF: NS	W>AA	
42	US: AA, W	129	10–12	DXA	NS		
73	US: AA, W	119	8–11	CT, DXA	NS	NS	NS
30	US: AA, W	101	AA: 8.3±1.4 W: 8.6±1.2	CT, DXA	NS	W>AA (adj. TBF)	W>AA (adj. TBF)
17	US: AA, W	138	8.1±1.6 Longitudinal	CT, DXA	AA>W	NS	NS
90	US girls: AA, AsA, Hisp, W	141	13.0 ± 1.9	DXA	NS		
64	US: AA, W	50	AA: 13.4±0.3 W: 13.3±0.4	CT, DXA	NS	W>AA	NS
61	US: AA, Hisp, W	55 obese	AA: 14.7±2.73 Hisp: 15.2±2.4 W: 14.6±1.84	MRI, DXA	NS	W and Hisp>AA	NS
44	US: AA, W	160	~12–13	CT, DXA	NS	NS	NS
45	US: AA, Hisp	138	13–25	MRI	%BF: Hisp>AA	Hisp>AA	NS
60	US: AA, W	40	11–18	MRI		W>AA	NS whole body: AA>W

Abbreviations: %BF, percent body fat; AA, African American; adj. TBF, analyses were adjusted for total body fat; AsA, Asian American; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; Hisp, Hispanic American, IAAT, intra-abdominal adipose tissue; MRI, magnetic resonance imaging; NS, no significant difference between ethnic groups; SAT, subcutaneous adipose tissue; TBF, total body fat; VAT, visceral adipose tissue; W, white.

Exhibit N

Re-Affirming the Value of the Sports Exception to Title IX's General Non-Discrimination Rule

DORIANE LAMBELET COLEMAN* MICHAEL J. JOYNER** DONNA LOPIANO***

It all grew from the power of an idea.[1]

INTRODUCTION

In just two years, we will celebrate Title IX's fiftieth anniversary. The statute was designed to address pervasive sex inequality in educational settings, including in admissions and programming, and in benefits and treatment. Although sex equality in education-based sport was not an original focus of Title IX's proponents, it became an integral part of the project from the date of its enactment in 1972. Indeed, by the time the statute was in effect re-enacted in 1988, Title IX had become synonymous with sport.[2]

Title IX's structure reflects a hybrid approach to sex equality. That is, the statute consists of a sex-blind non-discrimination rule, and its regulations contain a set of limited, sex-affirmative exceptions. Thus, the statutory text provides in relevant part that

> [n]o person in the United States shall, on the basis of sex, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any education program or activity receiving Federal financial assistance.[3]

And the exceptions permit schools to take sex into account to address imbalances in admissions, academic programming, and sport.[4] Because these

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1. Cary McTighe Musil, *The Triumph of Title IX*, MS. MAG., Fall 2007, at 42, https://www.feminist.org/education/TriumphsOfTitleIX.pdf (quoting Professor David Sadker, whose groundbreaking work with his wife Professor Myra Sadker on gender bias and educational equity helped to support the development and eventual success of Title IX).

2. *See generally* EQUAL PLAY: TITLE IX AND SOCIAL CHANGE (Nancy Hogshead-Makar & Andrew Zimbalist eds., 2007). *See also infra* notes 38–78 and accompanying text (setting out the history of Title IX).

3. 20 U.S.C. § 1681 (2018).

4. 34 C.F.R. § 106 (2019); 34 C.F.R. §§ 106.41(a)–(b) (2019) (containing the general non-discrimination provision and the sports exception to that provision).

original regulations were specifically required by Congress,[5] they have traditionally been accorded heightened deference by the courts and are tightly woven into Title IX's legal fabric.[6]

This regulatory approach was designed to and has yielded extraordinary results for women and girls, and for society more generally. The pre- and post-Title IX narrative is well worn at this point: "Title IX has successfully changed the lives of girls and of women educators, protecting their rights, broadening their horizons and setting them up for success in later stages of their education and careers."[7] Still, coming almost two centuries after Mary Wollstonecraft's original argument for educating women, its recency still surprises.[8]

There is this, for example, from *The Harvard Crimson* on November 15, 1968, three years before Title IX became law:

> Yale President Kingman Brewster announced yesterday that Yale will become coeducational in September 1969. The announcement came shortly after the Yale faculty approved with only one dissenting vote a plan to admit 250 freshman women plus 250 upperclass women by transfer. Eventually 1500 women will be admitted in addition to the 4000 male students . . . The faculty first approved under-graduate coeducation at Yale in 1962, after women graduate students had been admitted for several years. The administration considered establishing an independent coordinate college for women, similar to Radcliffe, two years ago. Later, Vassar was invited to consider affiliating with Yale, but its trustees declined to abandon Poughkeepsie for New Haven.[9]

This last bit of regional disrespect was righted in *The New York Times* which, a month later, reported that "[a] Radcliffe dormitory at Harvard is applying as a unit for admission to Yale next year . . . to end the frustrations of semi-

5. Pursuant to a now-defunct process, the regulations were presented by Secretary Weinberger to President Ford for his signature in May 1975, and then to Congress on June 4, 1975. From that date, Congress had 45 days to review and approve or disapprove them. Letter from Caspar Weinberger, Sec'y of the Dep't of Health, Education, & Welfare, to the President (Feb. 28, 1975), at A-1–2 [hereinafter Letter from Casper Weinberger] (delivering and explaining HEW's final regulation), (on file with the Gerald R. Ford Presidential Library). Had Congress failed to act, the regulations would have become valid by default. *Id.* In its review period, senators and congressmen opposed to Title IX in its entirety or as applied to sport presented a series of resolutions rejecting the regulations, but ultimately, on July 21, the regulations were approved. *See History of Title IX*, WOMEN'S SPORTS FOUND. (Aug. 13, 2019), https://www.womenssportsfoundation.org/advocate/title-ix-issues/history-title-ix/history-title-ix/. We detail this history, including the still-active practice of according the regulations heightened deference, *infra* at notes 40–69 and accompanying text.,

6. *See, e.g.*, McCormick ex rel. McCormick v. Sch. Dist. of Mamaroneck, 370 F.3d 275, 286 (2d Cir. 2004) (summarizing the legislative history of Title IX and noting this heightened deference point). *See also infra* notes 65–69 and accompanying text (further discussing the modern legal basis for heightened deference in this context).

7. *See* Jennifer Hahn, *Schoolgirl Dreams*, MS. MAG., Fall 2007, at 46.

8. MARY WOLLSTONECRAFT, A VINDICATION OF THE RIGHTS OF WOMAN (1792).

9. *Yale Will Admit Women in 1969; May Have Coeducational Housing,* HARV. CRIMSON (Nov. 15, 1968), https://www.thecrimson.com/article/1968/11/15/yale-will-admit-women-in-1969/ [hereinafter *Yale Will Admit Women in 1969*].

coeducation."[10] The utter lack of seriousness with which the matter was discussed among otherwise respectable people and institutions belied its significance for women. But it appears to have been in line with the administration's rationale for the policy change, which was reported more-or-less consistently by the rival schools' newspapers. According to *The Crimson*, President Brewster denied that a "student-sponsored Coed Week [which] brought women students from throughout the northeast for academic and social activity . . . had a direct effect on his decision, but his proposal to the faculty praised the organizers of the week and their guests for providing Yale with 'uncommon excitement.'"[11] The *Yale Daily News* noted that "the decision to have women in 1969 was based not on Yale's seeing her mission as the education of both sexes, but on fears that Yale cannot continue to attract the nation's top males to a non-coeducated campus."[12]

In this context, Title IX was very much an "idea revolution."[13] It sought to force colleges and universities to matriculate, educate, and graduate female students not to service men and their institutional needs, but on an equal basis with their male students. It required them to see women as they saw men: as students and as alumni without regard to their sex; and to own sex equality in all respects as one of their own institutional goals.

The transition wasn't always smooth, but with some notable exceptions, mostly today colleges and universities have fully embraced these ideas. Indeed, as we write this almost fifty years later, although their numbers are still disproportionately low in STEM fields and in leadership positions in the professional ranks, women have become the majority of college graduates.[14] As a result, they are an increasingly important part of the work force and the economy.[15] Title IX was not singularly responsible for these developments, of course, but the statute's role in the larger societal project that is sex equality, and specifically the empowerment of women and girls, is widely recognized and celebrated.[16]

This narrative is generally mirrored in the context of education-based sport. High schools, colleges, and universities understand that the education of women

10. *A Timeline of Women at Yale*, YALE U., https://celebratewomen.yale.edu/sites/default/files/files/Timeline-of-Women-at-Yale.pdf (last visited Dec. 1, 2019) (quoting N.Y. TIMES). This is not an isolated example of the sexism on display in the paper in that period. *See also, e.g*, Faith A. Seidenberg, *The Federal Bar v. The Ale House Bar: Women and Public Accommodations*, 5 VAL. U. L. REV. 318, 324–25 (1971) (noting that "The New York Times, in reporting the . . . story [of *Seidenberg v. McSorleys' Old Ale House, Inc*., 317 F. Supp. 593 (S.D.N.Y. 1970) (holding that bar violated Equal Protection Clause when it refused to admit women as patrons)], said, 'There was, perhaps a trace of wistfulness in the ruling [that] the sawdust-floored haven was just another "public place" that must admit any customer who comes in, even a woman.'" N.Y. TIMES, June 26, 1970, at 1.).

11. *Yale Will Admit Women in 1969*, *supra* note 9.

12. *A Timeline of Women at Yale*, *supra* note 10.

13. Musil, *supra* note 1, at 42 (quoting Professor Sadker).

14. Dani Matias, *New Report Says Women Will Soon Be Majority of College-Educated U.S. Workers*, NPR (June 20, 2019), https://www.npr.org/2019/06/20/734408574/new-report-says-college-educated-women-will-soon-make-up-majority-of-u-s-labor-f.

15. *Id*.

16. *See, e.g.*, Hogshead-Makar & Zimbalist, *supra* note 2.

and girls includes providing them with opportunities both to participate and to compete that are on par with those that are provided to boys and men. As is the case in STEM, the numbers are not equal, and schools often struggle to achieve their regulatory obligations.[17] Still, "[s]ince the enactment of Title IX, women's participation in sport has grown exponentially."[18] In high school, girls' participation numbers have grown from 294,000 in 1971–72 to more than 3.4 million in 2018-19.[19] In college, women's numbers have grown from 30,000[20] in 1972 to more than 288,000[21] in 2017–18. Women and girls today have the opportunity only boys and men had in the previous period to reap the widely recognized and highly valued benefits of being physically strong, of being on teams and developing the myriad skills associated with competitive sport, of attending college on athletic scholarships, and of high-end competitive experiences.[22] Again, although Title IX is not singularly responsible for these developments, it is generally credited with a central role in this aspect of the empowerment project.[23]

There is an important difference between the two stories, however. Where there has been a clear and steady upward trajectory for women and girls in academics, especially outside of STEM, in athletics the momentum has always been mixed, and it has been a constant battle to gain and to retain ground.[24] Among other things, the "fate" of women's sports "has always been tied to the larger political climate."[25] Because of this, and because of the recency in historical time of the broader commitment to sex equality, it is important for those who are devoted to the idea to remain attuned to shifts in that climate.

The earliest and most persistent political opponents of women's sports came from the broader football community and from men's sport more generally.[26] Whatever they thought about women's equality in theory, they were clear that it

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17. *See* Gerald Gurney, Donna Lopiano & Andrew Zimbalist, *Chapter 6: A Continuing Disgrace: Discrimination Based on Gender, Race, Ethnicity, and Disability*, *in* UNWINDING MADNESS: WHAT WENT WRONG WITH COLLEGE SPORTS AND HOW TO FIX IT (2017).

18. *This Day in History: Title IX Enacted*, HISTORY (July 28, 2019), https://www.history.com/this-day-in-history/title-ix-enacted [hereinafter *This Day in History*].

19. *2018-19 High School Athletics Participation Survey*, NAT'L FED'N OF STATE HIGH SCH. ASS'NS 50, 54 (2019), https://www.nfhs.org/sports-resource-content/high-school-participation-survey-archive/.

20. *This Day in History*, *supra* note 18.

21. *The Equity in Athletics Data Analysis Cutting Tool*, OFFICE OF POSTSECONDARY EDUC., U.S. DEP'T OF EDUC., http://ope.ed.gov/athletics (last visited Feb. 29, 2020).

22. See *infra* notes 128–147 and accompanying text (detailing this point).

23. *See, e.g.*, *This Day in History*, *supra* note 18.

24. This aspect of the story is routinely emphasized in Title IX retrospectives. *See, e.g.*, Hogshead-Makar & Zimbalist, *supra* note 2, at 5–6 (summarizing "the struggle for gender equity in athletics").

25. SUSAN WARE, TITLE IX: A BRIEF HISTORY WITH DOCUMENTS, 13 (2007). Interestingly, the explanations for the relative weakness of sport and STEM may be similar or the same, i.e., a lack of commitment on the part of original stakeholders to seeing females succeeding in those areas in particular, together with related sex-linked stereotypes and cultural norms. The numbers and experiences are better in medical school and medicine, which our co-author Michael Joyner suggests may be related to the higher likelihood of predictability, promotion, and success in that STEM field.

26. *See* Hogshead-Makar & Zimbalist, *supra* note 2; *infra* note 41 and accompanying text.

should not come at the expense of existing men's programs. In addition to resisting the threshold assumption that Title IX should apply to sport, they have specifically resisted the integration of teams, the inclusion of men's revenue producing sports in spending comparisons, and the reallocation of spending from men's programs to fund women's programs. Throughout, the underlying premise has been that men's sport produces higher value social goods and thus should not be diminished in an effort to achieve different goods that are of lesser or questionable value.

The most recent political challenge has come from the identity movement and affiliated advocacy groups whose goal has been to secure much needed protections for people who are transgender. To that end, movement advocates have pushed for policy reforms that would grow the circumstances in which law is sex-blind. Where sex remains a basis for classification, they have worked to ensure that people who are transgender are included in spaces and programming consistent with their gender identity.[27]

The merits of both approaches are clear to us in contexts where sex does not actually matter. But in sport, where sex and the sex-linked physical traits associated with the male and female body are outcome determinative, the effects of the proposed reforms would be revolutionary: they would require either the dismantling of Title IX's existing sex-segregated architecture and thus of the female category, or the unconditional inclusion of males who identify as females in girls and women's sport.[28] While the latter is less obviously existential than the former, both would signal that policymakers were abandoning the original commitment to sex equality in this setting.

There is no question about this, as the goal is expressed, unambiguously, in the public statements of movement advocates; for example, in this one from a set of prominent civil rights organizations dedicated to ensuring, among other things, that Title IX evolves to disallow any distinctions on the basis of sex as "sex" is normally defined:

> [W]e support laws and policies that protect transgender people from discrimination, including in participation in sports, and reject the suggestion that cisgender [sex typical] women and girls benefit from the exclusion of women and girls who happen to be transgender.[29]

27. Doriane Lambelet Coleman, *Sex in Sport*, 80 LAW & CONTEMP. PROBS 63, 102–111 (2017).

28. We understand that language and word choices are fraught in this discussion. We explain our approach and vocabulary immediately below, at and around notes 31–37. The bottom line is that our goal is to communicate to a broad audience in a highly contested space, including about what sex is and how it is relevant. To do this well, we can't adopt an unfamiliar or unclear lexicon, or one that assumes a particular political outcome since this paper is in part about what that outcome should be. We know this will make some readers uncomfortable, but we hope that this explanation will help. We intend no disrespect.

29. *Statement of Women's Rights and Gender Justice Organizations in Support of Full and Equal Access to Participation in Athletics for Transgender People*, NAT. WOMEN'S LAW CTR. (Apr. 10, 2019), https://nwlc.org/wp-content/uploads/2019/04/Womens-Groups-Sign-on-Letter-Trans-Sports-4.9.19.pdf [hereinafter *Statement of Women's Rights and Gender Justice Organizations*].

The underlying premise of those who support this move to elide the relevant physical differences between females on the one hand, and males who identify as women and girls on the other, is that reconceiving of sex as gender identity—or privileging gender identity over sex—will produce the highest value overall.[30]

The goals of this paper are to provide the legal, factual, and normative background necessary to evaluate the merits of this most recent challenge to the sports exception to Title IX's general nondiscrimination rule, and then to present the case for re-affirming the exception in a form that is appropriate for this next period of its history. It proceeds in three parts as follows: Part I describes the legal history of Title IX's sports exception, its goals, and the current state of the legal doctrine. Part II explains its scientific basis and rationale. Part III sets out the best case for and against affirming the commitment to sex equality in education-based sport, and then presents our argument for resolving the collision of interests at issue. The paper concludes that the original "idea revolution" continues to do important work and should not be abandoned, including in the sports space where equality requires not only recognizing but also celebrating physical sex differences. Including trans people within this design is difficult by definition, but because they are also entitled to dignity and respect, policymakers should accept the challenge.

* * *

Standardizing vocabulary is critical to communication among the different groups concerned with this topic. Many do not use the same words and phrases, and even if they do, they often use them differently. Most difficult are those instances when a word or term that is important to one group for descriptive or political reasons is politically anathema or even painful to another. Because capturing and controlling language is part of movement strategy, solving the latter impasse is especially complicated. We have attempted to standardize our use of the language in a way that avoids unnecessary harm or discomfort, but to the extent we cannot always do this, we intend no disrespect. Our goal is to communicate to a broad audience using standard terms, not to demean.[31]

Most importantly, given current debates, we do not work from the assumption that sex is or includes gender identity. Whether "sex" in law includes or is distinct from "gender identity" is at issue in both the debates about H.R. 5, The Equality Act (2019),[32] and in the Title VII case currently pending in the United

30. *See, e.g., id.* (arguing that it is good for all women that transgender women and girls are included in the category "women" including in athletics competition on the basis that there are no cognizable differences among transwomen and females that are not "driven by stereotypes and fear . . . nondiscrimination protections for transgender people—including women and girls who are transgender—are not at odds with women's equality or well-being, but advance them"). For an analysis of this claim from our perspective, i.e., from a different feminism, see *infra* notes 184–193 and accompanying text.

31. For a set of up-to-date working definitions from medicine and endocrinology, see Joshua D. Safer & Vin Tangpricha, *Care of Transgender Persons*, 381 NEW ENG. J. MED. 2451, 2451–60 (2019).

32. Earlier versions of H.R. 5 distinguished "sex" from "gender identity" where the current bill defines "sex" to include "gender identity." *See* Equality Act, H.R. 5, 116th Cong. (2019). This drafting move is based in evolving views in the advocacy and biosciences communities about how gender

States Supreme Court.[33] The related question whether gender identity is biologically based and, if so, whether it should be considered an aspect or characteristic of biological sex is the subject of ongoing consideration by relevant experts in the scientific community.[34] For now, however, both remain contested claims in a context in which "sex" is otherwise understood to be the word we use to denote the individual's biological and reproductive classification as male or female.[35] Because this paper is precisely about whether policy should be reformed so that sex in this standard sense comes to be replaced by or to include gender identity in the context of education-based sport, it is necessary for us clearly to distinguish the operative terms. Again, we intend no disrespect.

Sex – Biological sex. "Either of the two divisions, designated female and male, by which most organisms are classified on the basis of their reproductive organs and functions."[36] The cluster of sex-linked traits—i.e., chromosomal, gonadal, endocrinological (hormonal), and phenotypic characteristics—commonly used to establish and denote sex. Primary and secondary sex characteristics. Although they are terms of art and commonly used in science and medicine, "biological sex" and "biological (fe)male" may be hurtful to those who are triggered by references to sexed bodies. Because sport relies on the biological distinction between males and females to justify separate sex sport, however, we need to use the terms in their scientific sense and to consider their substance in this discussion.[37] Again, we intend no disrespect.

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identity is appropriately characterized and also how best to craft a political path to full equality and inclusion.

33. Equal Emp't Opportunity Comm'n v. R.G. & G.R. Harris Funeral Homes Inc., 884 F.3d 560 (6th Cir. 2018).

34. *See* Safer & Tangpricha, *supra* note 31, at 2451–52 (addressing this point). For a summary description of some of the ongoing work on "brain sex" more generally, see also Coleman, *Sex in Sport*, *supra* note 27, at 75–77.

35. *See, e.g.*, R (on the Application of Miller) v. College of Policing & Chief Constable of Humberside, [2020] EWHC 225 (Admin) [225], ¶ 267 (Eng.) (decision out of the United Kingdom's High Court of Justice, addressing this contested issue and the expert witness statement of Professor Kathleen Stock on the point that "For many English speakers, 'woman' is strictly synonymous with 'biologically female['] and 'man' with 'biologically male'.").

36. *Sex*, AM. HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE (5th ed. 2020).

37. One of our co-authors, Michael Joyner, is a biomedical researcher who, in the 2000s, was admonished in the peer review process to use the phrase "sex differences" and not "gender differences" when describing biological phenomenon. This insistence is increasingly routine in the biomedical setting where the study of sex differences is now well established and producing important value both in the basic sciences and in applications in personalized medicine. For example, there is a journal dedicated to the subject, see BIOLOGY OF SEX DIFFERENCES, https://bsd.biomedcentral.com/about/ (last visited Feb. 15, 2020); and the federal government routinely emphasizes this focus in its own work and in the distribution of research funding. *See, e.g.*, U.S. FOOD & DRUG ADMIN., *Understanding Sex Differences at FDA* (Apr. 12, 2019), https://www.fda.gov/science-research/womens-health-research/understanding-sex-differences-fda. This focus is in part the result of the report from the NAT'L. ACAD. OF SCI. INST. OF MED., EXPLORING THE BIOLOGICAL CONTRIBUTIONS TO HUMAN HEALTH: DOES SEX MATTER? (2001) [hereinafter EXPLORING THE BIOLOGICAL CONTRIBUTIONS], http://www.nationalacademies.org/hmd/~/ media/Files/Report%20Files/2003/Exploring-theBiological-

Female—An individual whose sex is female, i.e., who has ovaries not testes and a natural estrogenic not androgenic endocrine system. A person's designation as "female" may not correspond with their gender identity (in the case of a trans person) or their sex recorded at birth (in the case of some intersex persons).

Male—A person whose sex is male, i.e., who has testes not ovaries and a natural androgenic not estrogenic endocrine system. A person's designation as "male" may not correspond with their gender identity (in the case of a trans person) or their sex recorded at birth (in the case of some intersex persons).

Sex stereotype—An assumption (which may be evidence-based or not) or a generalization (which may have a factual basis) about the aptitudes, preferences, and capacities of males and females based on their biological sex.

Gender—Social and cultural expression of masculine or feminine behavior. Often used differently as a synonym for biological sex.

Gender identity—A person's deeply held internal sense of themselves as male, female, both, neither, or fluid, and which can be different from their biological sex or their sex recorded at birth.

Trans—Transgender—Gender incongruent—The word or term used to describe a person whose gender identity is different from their biological sex or their sex recorded at birth.

Trans(gender) woman/girl or man/boy—A person who is trans(gender) who identifies as a woman/girl or man/boy.

I. THE LEGAL HISTORY, MISSION, AND CURRENT DOCTRINE

Title IX was developed to secure equality for women and girls in federally funded educational settings. It filled the gap that was left by Title VII of the 1964 Civil Rights Act, which protects against sex discrimination in employment but excludes educational settings otherwise, and by Title VI, which prohibits federally funded programs from discriminating on the basis of race, color, and national origin, but not on the basis of sex. Because of this gap, there was no federal statutory remedy to address the educational disparities women and girls experienced in relation to boys and men before Title IX. There was also no effective constitutional remedy to address laws that supported sex discrimination, as the

Contributions-to-Human-Health-Does-Sex-Matter/DoesSexMatter8pager.pdf (explaining the difference between sex and gender (identity), reporting on the extensive physiological processes and medical contexts in which "sex matters", and because of this indicating, among other things, the need for researchers to address "the inconsistent and often confusing use of the terms "sex" and "gender" in the scientific literature and popular press").

United States Supreme Court had yet to subject them to more than rational basis scrutiny.[38]

As described in the Introduction, the architects of Title IX settled on a hybrid approach to achieving sex equality in education. They paired a general, sex-blind non-discrimination rule with a set of limited, sex-affirmative exceptions, which allow educational institutions to take sex into account where doing so is necessary to address particular imbalances, i.e., in admissions, in programming, and in sport. In sport, at least, if an institution can meet its sex equality obligations using a sex-blind approach—without taking sex into account—it need not use these sex-affirmative tools; they are formally permissive not mandatory. But they become mandatory in effect if these obligations are not or cannot be met otherwise.[39]

Assurances that sports teams would be sex segregated were material to Title IX's passage and to congressional approval of its implementing regulations.[40] For

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38. *See* Craig v. Boren, 429 U.S. 190 (1976) (holding for the first time that sex discrimination was subject to heightened, i.e., intermediate, scrutiny under the Constitution's Equal Protection Clause).

39. As it concerns sports, this requirement is clear in the statute's legislative history, in the original 1975 regulations, and in the original 1979 Policy Interpretation. *See* Regulations of the Department of Education, Nondiscrimination on the Basis of Sex in Education Programs or Activities Receiving Federal Financial Assistance, 34 C.F.R. §106.12 (regulations governing athletics); Title IX of the Education Amendments of 1972; The Policy Interpretation: Title IX and Intercollegiate Athletics, 44 Fed. Reg. 71,419 (Dec. 11, 1979) (again making clear the requirement of parity of competitive opportunities). For example, the 1979 Policy Interpretation provides, *inter alia*, as follows:

> 4. Application of the Policy—Selection of Sports.
>
> In the selection of sports, the regulation does not require institutions to integrate their teams nor to provide exactly the same choice of sports to men and women. However, where an institution sponsors a team in a particular sport for members of one sex, it may be required either to permit the excluded sex to try out for the team or to sponsor a separate team for the previously excluded sex.
>
> a. Contact Sports—Effective accommodation means that if an institution sponsors a team for members of one sex in a contact sport, it must do so for members of the other sex under the following circumstances:
>
> (1) The opportunities for members of the excluded sex have historically been limited; and
>
> (2) There is sufficient interest and ability among the members of the excluded sex to sustain a viable team and a reasonable expectation of intercollegiate competition for that team.
>
> b. Non-Contact Sports—Effective accommodation means that if an institution sponsors a team for members of one sex in a non-contact sport, it must do so for members of the other sex under the following circumstances:
>
> (1) The opportunities for members of the excluded sex have historically been limited;
>
> (2) There is sufficient interest and ability among the members of the excluded sex to sustain a viable team and a reasonable expectation of intercollegiate competition for that team; and
>
> (3) Members of the excluded sex do not possess sufficient skill to be selected for a single integrated team, or to compete actively on such a team if selected.

In this context "skill" is understood to include physical not just learned capacity. *See infra* notes 40–54 and accompanying text. Together with the original 1975 regulations, the 1979 Policy Interpretation is woven into the fabric of Title IX, including in statutory law. *See infra* notes 51–69 and accompanying text (elaborating on the Title IX scheme).

40. As the bill made its way through Congress, "[a] few people (very few) noticed that athletics might be affected . . . and so there was a discussion on the floor of the Senate about whether [it] required

different reasons, both men's and women's groups supported and/or insisted on this. Men's teams simply did not want to have to include females on their rosters or to be made to subsidize the equality project.[41] Women's groups wanted separate opportunities because they were keen to secure equality in education-based sports, and they understood that it couldn't be achieved without this separation.

In particular, women and women's groups fell into one of two camps. Both accepted that there was a performance gap between male and female athletes that necessitated sex segregation and thus a sports exception to Title IX's general non-discrimination rule. But they disagreed about the source of the gap and thus about the terms of the exception:

One group took the position that sex segregation and thus the sports exception in the regulations would be necessary only for a period, until females were afforded the (equal) training and competition opportunities that would be required eventually to close the performance gap; after that, sport could be co-ed.[42]

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educational institutions to allow women to play on football teams." WARE, *supra* note 25, at 41. The answer from its floor manager Senator Birch Bayh was no. *Id.* "Having inserted that notion into the legislative history, higher education retreated." *Id.* That brief discussion on the Senate floor was significant in two respects: it presaged the decades-long resistance to Title IX that would come from college football and men's sport in general. *See supra* note 26 and accompanying text (summarizing this resistance), and *infra* note 41 and accompanying text (further describing the legislative and regulatory history). And it laid the necessary legal foundation for sex segregation in this setting. The "sports exception" or "carve out" to Title IX's prohibition on sex discrimination in federally funded educational settings powered girls' and women's sport and continues to secure its success today.

41. *See supra* note 26 and accompanying text. The sports question exploded in the aftermath of the bill's passage through Congress. From the time President Richard Nixon signed the Education Amendments into law in the summer of 1972 to the summer of 1975 when Congress formally approved the implementing regulations, the institutional powerhouse that is men's college football went into overdrive to ensure that, in fact men's teams would not have to accommodate female athletes, and that equality for female athletes would not come at the expense of men's revenue producing sports. This activity was particularly heated in 1974 and 1975. In that period, the Senate heard but ultimately declined to pass a bill sponsored by Senator John Tower (R-TX) to amend Title IX to exclude revenue producing sports from compliance tabulation. Had it succeeded, this would have meant that spending on female athletes and women's sports programs could be only be compared with spending on men's non-revenue producing sports, simultaneously insulating (primarily) men's football and basketball programs from Title IX's effects, and reducing schools' obligations to women's programs. Instead, Congress passed an alternative bill sponsored by Senator Jacob Javitz (R-NY), formally the Educational Amendments of 1974, which required the Secretary of the Department of Health, Education, and Welfare (HEW) to develop "with respect to intercollegiate athletic activities reasonable [regulations] concerning the nature of particular sports." The Education Amendments of 1974, Pub. L. 93–380, 88 Stat. 612. Although some advocates for men's sport continued to press the point that men's revenue producing sports should not be made to pay (either directly or indirectly) for women's programming, the Department's focus during this rulemaking process was mainly on the question whether men's and women's sport and teams would be sex segregated. Comments and lobbying from men's groups were consistently against integration. The NCAA, for example, had no interest in having Title IX cover sport at all, and it was opposed to including women in any of its programming.

42. The National Organization for Women (NOW) originally disagreed with the AIAW and the NCAA that the goal should be separate sex sport. In a letter to President Ford, HEW Secretary Casper Weinberger explained NOW's position that "the 'separate but equal' concept is inappropriate for any civil rights regulation and that open access should be required for all athletic teams with one exception.

In general, one might characterize advocates in this first group as holding the view that sex differences were entirely the result of disparate treatment and sex stereotypes, both of which could be eradicated over time. In their view, like the classroom, eventually sport could also be sex-blind. The language they used in this context is reminiscent of that which appears in cases involving race-based affirmative action measures.[43]

The other group took the position that the performance gap was the result of a combination of disparate treatment, sex stereotypes, and biological differences. For those in this second group, even if that part of the performance gap that was the result of disparate treatment and sex stereotype could be eradicated, sex segregation would always be necessary because immutable biological differences would remain.[44] This view is consistent with the Supreme Court's current substantive equality jurisprudence, which distinguishes sex from stereotype, but also race from sex on the ground that the latter but not the former involve inherent differences—these differences are properly considered when doing so serves to empower rather than to subordinate.[45]

Importantly, although textualists reject the role of legislative history in statutory interpretation, to the extent that it remains important to others, and that there is an ongoing debate about what policymakers meant when they used the word "sex" in the drafting period,[46] it is easily resolved in the sports setting. At least in this context, the legislative history is clear that "sex" meant biological sex, which was distinguished from sex stereotype. Specifically, the biological

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When women are effectively excluded from open teams (where skill in the given sport is the criteria, it is still conceded by all that open competition for a tackle football team would result in an all-male team), separate teams should be provided for them on the basis that the training and sports traditionally available to women have been limited and the provision of separate teams until such time as the training gap is filled would best fulfill the purposes of the Act." *See* Letter from Caspar Weinberger, *supra* note 5, at A-6, A-7.

43. *See, e.g.*, Grutter v. Bollinger, 539 U.S. 306 (2003) ("We expect that 25 years from now, the use of racial preferences will no longer be necessary to further the interest [in student body diversity] approved today.").

44. *See* Kathleen Megan, *Transgender Sports Debate Polarizes Women's Advocates*, CT MIRROR (July 22, 2019), https://ctmirror.org/2019/07/22/transgender-issues-polarizes-womens-advocates-a-conundrum/ (quoting our co-author Donna Lopiano: "Title IX was passed 47 years ago to ensure an equal education for girls, but included a 'carve out' allowing separate programs for girls because of the clear biological advantage that males have over females in athletics. 'It was the notion that there are distinct biological differences in sex that are immutable.'"); Memorandum from Patricia Sullivan Lindh, the President's Special Assistant for Women's Programs, to James Cannon, White House Domestic Policy Advisor (May 1, 1975) (on file with the Gerald R. Ford Presidential Library) (noting that allowing schools to field only one "open" team would let them off the hook in terms of providing equal opportunities for women, and that to assure sex equality, schools should have to take into account differences between men and women in "competitive skill and physical ability").

45. *See, e.g.*, United States v. Virginia, 518 U.S. 515, 532–33 (1996).

46. *See, e.g.*, Brief of Walter Dellinger, et al. as Amici Curiae in Support of the Employees, Bostock v. Clayton County, GA, Altitude Express, Inc. v. Zarda, and Harris Funeral Homes, Inc. v. Stephens, 888 F.3d 100 (Nos.17-1618, 17-1623,18-107), 2019 WL 3027045; Brief for the Federal Respondent Supporting Reversal, Harris Funeral Homes, Inc. v. EEOC, et al., 884 F.3d 560 (No.19-107) (debating this question in the context of Title VII of the 1964 Civil Rights Act).

differences between males and females that account for the performance gap, as well as those sex traits and related customs that raised safety and privacy concerns, were key to the discussions and decisions around inclusion and segregation.[47]

Similarly, to the extent that there is debate today about whether Title IX was designed to ensure that girls and women were able not only to participate but also to compete on an equal basis with boys and men, the legislative history also confirms this commitment. While some early proponents of the statute suggested that females were or should be interested only in ("cooperative and inclusive") participation not ("patriarchal capitalist") competition,[48] the stereotypes and

47. The hearings throughout the month of June 1975, before the House of Representatives Subcommittee on Post-Secondary Education of the Committee on Education and Labor, are illustrative, including in that members and witnesses distinguished race from sex, and focused on the extent to which the performance gap was the result of inherent differences between the sexes rather than historical disparate treatment. *See Sex Discrimination Regulations: Hearings Before the Subcomm. on Post-Secondary Educ. of the Comm. of Educ. & Labor*, 94th Cong. 54 (1975) (statement of Bob Blackman, Head Football Coach, Univ. of Illinois) ("HEW has already [taken sex differences into consideration], they have already stated . . . that because of physiological differences between men and women, the women are not expected to compete in the so-called contact sports . . . . So they have already stated the fact that there are differences."); *id.* at 130 (statement of Joan Holt, President, Eastern District, Ass'n for Intercollegiate Athletics for Women) ("[W]e have been discriminated against in the past due to physiological limitations that women do have, we are not capable of getting a place on the men's team, and they then have an obligation, both because of the discrimination of the past and because of our competitive interests, that they would have to provide a separate team for the women in this case."); *id.* at 197 (statement of Rep. McKinney) ("We know that until puberty, girl and boy children have roughly the same athletic capacity. After this point there is a significant difference in their ability in most sports. However, until we stop punishing girl children for being tomboys and allow their full participation in scholastic athletics, we will never know their true capacity as sportspersons."); *id.* at 390 (statement of Bernice Sandler, Dir., Project of the Status and Educ. of Women & Exec. Assoc., Ass'n of Am. Colls.) ("In almost all other areas of discrimination, the precedents and principles developed by the courts in race discrimination cases can readily and easily be applied to sex discrimination problems. Because of the general physical differences between men and women as a whole, the principles developed in other discrimination areas do not easily fit athletic issues, particularly in the area of competitive sports, where the issue of single sex and integrated teams is a difficult one to solve. 'Separate but equal,' which is a discredited legal principle in terms of civil rights, may have some validity when applied to some areas of competitive athletics . . . ."); *id.* at 339 ("Before puberty, males and females are nearly identical in their physical abilities. Tests of strength, muscular endurance, cardiovascular endurance and motor performance show few differences between the sexes up to this age. Beyond that age, however, the male becomes considerably stronger, possesses greater muscular and cardiovascular endurance and is more proficient in almost all motor skills."); *id.* at 343 ("To some, complete integration of the sexes in all sports would appear to be both the simplest and the least discriminatory solution. Upon closer examination, however, it becomes clear that because of the differences in training and physiology, such an arrangement would effectively eliminate opportunities for women to play in organized competitive athletics. For these reasons, this alternative would not appear to be in line with the principle of equal opportunity."); *id.* ("[T]he 'separate-but-equal' principal in competitive athletics can be justified for sex discrimination (but not for race discrimination) because there are general physical differences between [women] and men (but not between blacks and whites).").

48. *See* Interview with our co-author Donna Lopiano, Adjunct Professor of Sports Mgmt., S. Conn. State Univ. (Oct. 13, 2019) (describing the views of some within the "old" NOW and the AIAW who rejected NCAA-style sports administration and competition). This approach to women's sport is

norms they advanced were rejected by other advocates and ultimately by lawmakers.[49] To use a currently topical distinction, education-based sport was not designed to be like selection for the military's special forces, where women are entitled to participate in selection rounds but are rarely, if ever, competitive for full status because of their physical disadvantages relative to men;[50] rather, sport was sex segregated because the goal was parity across all categories of opportunity.

The regulations that were formally presented to, reviewed, and passed over by Congress in 1975 mimic Title IX's hybrid approach, and reflect the general consensus at the time regarding sex segregation in sport. Specifically, they begin with this general nondiscrimination provision:

> 86.41(a) *General.* No person shall, on the basis of sex, be excluded from participation in, be denied the benefits of, be treated differently from another person or otherwise discriminated against in any interscholastic … athletics offered by a recipient, and no recipient shall provide any such athletics separately on such basis.[51]

The provision is followed by the exception, or "carve out," for sex-segregation in sport. The exception emphasizes the two factors that make sex segregation

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described in Ann Travers, *The Sport Nexus and Gender Injustice*, 2 STUD. IN SOC. JUST. 79, 86 (2008) (describing "radical and cultural feminist . . . scholars [who] indict sport in its current patriarchal capitalist iteration and seek to replace it with cooperative and nonhierarchical celebrations of physicality and play based on feminist principles of cooperation and inclusion").

49. DEP'T OF EDUC., OFFICE FOR CIVIL RIGHTS, A POLICY INTERPRETATION: TITLE IX AND INTERCOLLEGIATE ATHLETICS (1979) (making clear the requirement of parity of competitive opportunities); McCormick ex rel. McCormick v. Sch. Dist. of Mamaroneck, 370 F.3d 275, 282 (2d Cir. 2004) (recognizing the difference between the opportunity to participate and the opportunity to compete for the win, including for championships, and holding that Title IX requires schools to provide females with opportunities in both categories that are on par with those provided to males). Notably, when the subject is not trans athletes or (intersex) athletes with differences of sex development, the premise that sex segregated sport exists in part to ensure that there are the same numbers of spots in finals and on podiums for females as for males is generally not controversial. Indeed, even their advocates tend to take this as a given, i.e., they appear to appreciate the benefits, including for their clients, of sex segregation. This has them arguing not for co-ed sport, but rather for what is in effect an exception for those whose sex is male but who identify legally and/or personally as women and girls. *See, e.g.*, *Statement of Women's Rights and Gender Justice Organizations*, *supra* note 29 (arguing that "transgender women and girls" should benefit fully and equally from participation "in women's sports"); Doriane Lambelet Coleman, *Semenya and ASA v. IAAF: Affirming the Lawfulness of a Sex-Based Eligibility Rule for the Women's Category in Elite Sport*, 19 SWEET & MAXWELL'S INT'L SPORTS L. REV. 83 (detailing how a version of this approach was presented in Ms. Semenya's case at CAS) [hereinafter Coleman, *Semenya and ASA v. IAAF*] .

50. Meghann Myers, *A Female Soldier Has Made It Through the Army's Special Forces Selection*, ARMY TIMES (Nov. 14, 2018), https://www.armytimes.com/news/your-army/2018/11/14/a-female-soldier-has-made-it-through-the-armys-special-forces-selection/.For more information on the integration of women into special operations career fields and concerns about sex equality and sex specific or neutral standards in that highly competitive context, see KRISTY M. KAMARCK, CONG. RESEARCH SERV., R42075, WOMEN IN COMBAT: ISSUES FOR CONGRESS (2016), https://fas.org/sgp/crs/natsec/R42075.pdf.

51. 34 C.F.R. § 106.41 (a) (2019).

necessary for the attainment of equality in sport, that is, concerns about competitive fairness and physical safety:

> 86.41(b) *Separate teams*. A recipient may operate or sponsor separate teams for members of each sex where selection for such teams is based upon competitive skill or the activity involved is a contact sport. However, where a recipient operates or sponsors a team in a particular sport for members of one sex but operates or sponsors no such team for members of the other sex, and athletic opportunities for members of that sex have previously been limited, members of the excluded sex must be allowed to try-out for the team offered unless the sport involved is a contact sport. For purposes of this part, contact sports include boxing, wrestling, rugby, ice hockey, football, basketball and other sports the purpose or major activity of which involved bodily contact.[52]

As is the case with Title IX more generally, the affirmative approach is permissive, not mandatory, in the first instance, meaning that if a school can find a way to provide equal training and competition opportunities for females without taking sex into account, they can proceed in a sex-blind way; but if proceeding in a sex-blind way perpetuates disparities, the affirmative approach becomes mandatory.[53]

According to Susan Ware, "[i]n the early days of the law, much discussion centered on whether teams should be coeducational based on skill (the model adopted in elementary and high school physical education classes) and whether women should be eligible to play on men's teams. On the high school and intercollegiate level, a consensus soon emerged that sex-segregated but comparable sports teams were a better model."[54] As our co-author Donna Lopiano has explained, "[i]t was the notion that there are distinct biological differences in sex that are immutable . . . Everybody agreed that . . . if you have boys and girls competing after puberty, who would be more likely to get on a team? Who would win? It would be men. There would be very few women."[55]

From 1975 through 1988, proponents of girls' and women's sport continued to face resistance from boys and men and the male sports establishment, including with respect to funding, facilities, coaching staff, and competition opportunities.[56]

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52. *Id.* § 106.41 (b).

53. *See, e.g.*, Yellow Springs Exempted Village School Dist. Bd. Of Educ. v. Ohio High School Athletic Ass'n, 647 F.2d 651, 656 (6th Cir. 1981) (Title IX "grant[s] flexibility to the recipient of federal funds to organize its athletic program as it wishes [one or separate teams] so long as the goal of equal athletic opportunity is met.").

54. WARE, *supra* note 25, at 5. This model—co-ed "prior to puberty"— is represented in the still-current position of the Women's Sports Foundation (WSF). *See* WOMEN'S SPORTS FOUND., ISSUES RELATED TO GIRLS AND BOYS COMPETING WITH AND AGAINST EACH OTHER IN SPORTS AND PHYSICAL ACTIVITY SETTINGS, https://www.womenssportsfoundation.org/wp-content/uploads/2019/08/issues-related-to-girls-and-boys-competing-with-and-against-each-other-in-sports-and-physical-activity-settings-the-foundation-position.pdf [hereinafter WOMEN SPORTS FOUND., ISSUES RELATED TO GIRLS AND BOYS COMPETING]. Although the original position paper was developed and published several years ago, the WSF re-affirmed it on August 14, 2019. *See id*.

55. Megan, *supra* note 44 (quoting Donna Lopiano).

56. *See* Hogshead-Makar & Zimbalist, *supra* note 2, at Part III (describing this period as "The Initial Backlash"); Mary C. Curtis & Christine Grant, *Landmark Title IX Cases in History*, GENDER EQUITY IN SPORT, http://bailiwick.lib.uiowa.edu/ge/historyRE.html (listing key dates in the resistance).

This resistance was particularly fierce in circumstances that involved cuts to boys' and men's programs that were considered—or described as—necessary to meet Title IX requirements.[57] It culminated in the 1984 decision, *Grove City College v. Bell*, in which the United States Supreme Court sided with the Reagan Administration's position that Title IX and its sex equality requirements applied only to the particular programs that received federal funds, not more broadly to the institutions of which they were a part.[58] Because the federal government did not contribute directly to education-based sports programs, *Grove City* in effect "gutted" Title IX.[59] As a result, the merits of the "idea revolution"—that there should be sex equality across educational settings including in education-based sport—were once again put to Congress.[60]

The Education Amendments of the Civil Rights Restoration Act of 1987 were finally passed in 1988, over President Reagan's veto, extending Title IX's sex equality requirements to all programs within institutions receiving federal funds.[61] As Title IX expert and three-time Olympic Gold Medalist Nancy Hogshead-Makar explains, although sport was not prominent in the legislative history prior to the statute's passage in 1972, "sports for girls and women were the driving narrative behind the imperative to pass the law again in 1988. Sports for women swung Republicans and average families."[62] Since then, although resistance has been ongoing,[63] the legislative, executive, and judicial branches of the federal government have consistently reaffirmed at least the essential aspects of the statutory scheme, including that parity of competitive opportunities matter and that the original regulations remain an integral part of the law.[64]

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57. Cases involving cuts to boys' and men's wrestling were particularly prevalent. *See generally* Bradley David Ridpath et al., *Changing Sides: The Failure of the Wrestling Community's Challenges to Title IX and New Strategies for Saving NCAA Sport Teams*, 1 J. INTERCOLLEGIATE SPORT 255 (2008). *See, e.g.*, Nat'l Wrestling Coaches Ass'n v. Dep't of Educ., 366 F.3d 930 (D.C. Cir. 2004) (affirming district court's finding that the decision to drop wrestling is a matter of institutional preference not a requirement in fact or in effect of Title IX).

58. Grove City College v. Bell, 465 U.S. 555 (1984) (rejecting Association's challenge to Title IX Policy Interpretation).

59. *See* E-mail from Nancy Hogshead-Makar, Chief Exec. Officer, Champion Women, to Doriane Lambelet Coleman, Professor of Law, Duke Law Sch. (Feb. 19, 2020, 3:17 PM) (on file with authors).

60. *See supra* note 13 and accompanying text (introducing "the idea revolution").

61. *See S. 557 (100th): Civil Rights Restoration Act of 1987*, 100th Cong. (1987), https://www.govtrack.us/congress/bills/100/s557 (providing timeline of the history and text of the legislation).

62. *See* E-mail from Hogshead-Makar, *supra* note 59. *See also* WARE, *supra* note 25, at 36–43 (describing this history).

63. *See* Hogshead-Makar & Zimbalist, s*upra* note 2, at Part V (describing the period from 2001 to 2008 as "The Second Backlash").

64. For example, the 1994 Equity in Athletics Disclosure Act requires "co-educational institutions of postsecondary education that participate in a Title IV, federal student financial assistance program, and have an intercollegiate athletic program, to prepare an annual report to the Department of Education on athletic participation, staffing, and revenues and expenses, by men's and women's teams. The Department . . . use[s] this information in preparing its required report to the Congress on gender equity in intercollegiate athletics." *Equity in Athletics Disclosure Act*, U.S. DEPT. OF EDUC. (Jan. 24, 2017), https://www2.ed.gov/finaid/prof/resources/athletics/eada.html. The data in detail are available from *The Equity in Athletics Data Analysis Cutting Tool*, OFFICE OF POSTSECONDARY EDUC., U.S. DEP'T OF

Although the legislative veto was declared unconstitutional in 1983,[65] in 1984, the United States Supreme Court affirmed that "where Congress has specifically delegated to an agency the responsibility to articulate standards governing a particular area"—as it did in 1972 with respect to Title IX's standards governing athletics—"we must accord the ensuing regulation considerable deference."[66] The standards in the 1975 Regulations as well as their 1979 Policy Interpretation have continued to benefit from such protection, even as the Court has increasingly rejected the use of legislative history as a tool for statutory interpretation.[67] In part,

EDUC., http://ope.ed.gov/athletics. In *McCormick ex rel. McCormick v. Sch. Dist. Of Mamaroneck*, 370 F.3d 275, 282 (2d Cir. 2004), the Second Circuit held that a school district was out of compliance with Title IX when it established separate boys' and girls' teams but provided boys with more and more important competitive opportunities. And in 2016, the Obama Administration issued guidance for the inclusion of transgender student-athletes in education-based sports that made clear its commitment to sex segregation when this remains necessary to secure competitive fairness and physical safety. *See infra* note 73 and accompanying text (providing the details of this guidance).

65. INS v. Chadha, 462 U.S. 919, 959 (1983).

66. Kelley v. Bd. of Trs., 35 F.3d 265, 270 (1994) (citing Chevron, U.S.A., Inc. v. Nat. Res. Def. Council, Inc., 467 U.S. 837 (1984)).

67. In 2018, the Eastern District of Michigan explained that heightened deference under *Chevron* is accorded to both the 1975 Regulations and the 1979 Policy Interpretation of the 1975 Regulations "because Congress explicitly delegated to the agency the task of prescribing standards for athletic programs under Title IX." *See* Mayerova v. E. Mich. Univ., 346 F. Supp. 3d 983, 989 (E.D. Mich. 2018) (citing the First Circuit's decision in Cohen v. Brown Univ., 991 F.2d 888, 895 (1st Cir. 1993) and the Sixth Circuit's decision in Miami Univ. Wrestling Club v. Miami Univ., 302 F.3d 608, 615 (6th Cir. 2002)). *See also* Ollier v. Sweetwater Union High Sch. Dist., 768 F.3d 843, 855 (9th Cir. 2014) (affirming its practice of giving *Chevron* deference to the 1979 Policy Interpretation and applying it to the high school setting, citing the Second Circuit's decision in *Mamaroneck*, 370 F.3d at 300, and the Sixth Circuit's decision in Horner v. Ky. High Sch. Athletic Ass'n, 43 F.3d 265, 272–75 (6th Cir. 1994)); Biediger v. Quinnipiac Univ., 691 F.3d 85, 96–97 (2d Cir. 2012) (the Second Circuit reaffirming its decision in *Mamaroneck*); Mansourian v. Regents of Univ. of Cal., 602 F.3d 957, 965 (9th Cir. 2010) (the Ninth Circuit reaffirming that "both the Policy Interpretation and the Clarification are entitled to deference under *Chevron*").

Chevron was reaffirmed by the Court itself in 2013, in *City of Arlington v. FCC*, 569 U.S. 290 (2013) (Justice Scalia writing for the Court and noting that courts cannot substitute themselves as policymakers when this is precisely the job of the federal agencies). *City of Arlington* was a 6/3 decision, with Justices Roberts, Kennedy, and Alito in dissent. Their concern was the extension of what they describe as essentially legislative authority to the executive—and to the consequent creation of an ever-growing administrative state—even in circumstances where Congress did not clearly delegate this authority. *Id.* at 312 (Roberts, C.J., dissenting). In their view, "before a court may grant such deference, it must on its own decide whether Congress—the branch vested with lawmaking authority under the Constitution—has in fact delegated to the agency lawmaking power over the ambiguity at issue." *Id.* at 317. Unless *Chevron* itself is repealed, because Congress "explicitly delegated to the agency the task of prescribing standards for athletic programs under Title IX," both the 1975 Regulations and the 1979 Policy Interpretation should continue to be accorded heightened deference by the courts. *Mayerova*, 346 F. Supp. 3d at 989. Of course, this would not be the case should Title IX, the Regulations, and/or the Policy Interpretation be repealed.

The final deference point relates to the Department of Education's own ongoing interpretation of the 1975 Regulations and the 1979 Policy Interpretation. Such interpretations are afforded regular—not heightened—deference only when the standards themselves are "genuinely ambiguous" and: the agency's interpretation is (1) its own "'authoritative' or 'official position,'" (2) "reasonable"; (3)

this is because the Regulations and Policy Interpretation establish the architecture of and rationale for sex segregated education-based sport; and, they are embedded in an inextricably linked web of related law, including in statutory law. For example, the 1994 Equity in Athletics Disclosure Act (EADA) requires federally funded colleges and universities to produce annual reports regarding their athletic programs so that the Department of Education can monitor compliance with Title IX.[68] The fact that there is deep bipartisan support for girls and women's sport surely influences ongoing deference to the regulations as well.[69]

To date, the movement to include trans people in spaces and opportunities based on their gender identity rather than on their sex has not altered this legal state of affairs at the federal level. That is, as of this writing, there are no new regulations that require recipients of federal education dollars to include transgender people in sport on the basis of their gender identity rather than their biological sex; and there are no federal cases that expand the meaning of "sex" to include or to be replaced by "gender identity" in a Title IX sports context.[70] As they have done under Title VII, a few federal circuits have expanded the meaning of "sex" under Title IX, but so far only in the contexts of restrooms and locker room access.[71]

Supporters of transgender student-athletes have argued that these precedents are applicable to sport: that just as transgender girls must be permitted to use girls' restrooms they must also be permitted to be on girls' sports teams and included without condition in girls' competitions.[72] But as the Obama

"implicate[s] its substantive expertise"; and (4) "reflect[s] 'fair and considered judgment.'" Kisor v. Wilkie, 139 S. Ct. 2400, 2412, 2415–17 (2019) (explaining that deference to agencies under the Court's decision in *Auer v. Robbins*, 519 U.S. 452 (1997), are based in the presumption that "when granting rulemaking power to agencies, Congress usually intends to give them, too, considerable latitude to interpret the ambiguous rules they issue" but that courts need not defer to those interpretations when they are not justified according to these requirements).

68. *See supra* note 64 (discussing the EADA).

69. This bipartisan support for girls and women's sport, in a climate where such issues are often difficult to find, is presumably one of the reasons Republicans have seized on trans inclusion in girls and women's sport as an election issue for the 2020 cycle. *See, e.g.*, James Freeman, Opinion, *Did Democrats Just Create a Problem with Soccer Moms and Dads? A Friday House Vote Could Be the Sleeper Issue of 2020*, WALL ST. J. (May 20, 2019, 4:56 PM), https://www.wsj.com/articles/did-democrats-just-create-a-problem-with-soccer-moms-and-dads-11558385818.

70. As of this writing, the first federal case to address this issue has just been filed in the United States District Court in the District of Connecticut. *See* Soule et al. v. Conn. Interscholastic Athletic Conference et al., No. 3:20-cv-00201, (D. Conn., filed Feb. 12, 2020). Otherwise, a Westlaw search of the All Federal database for "Title w/1 IX & transgender & sport" yields only thirteen cases, none of which apply to selection for sex segregated sports teams. Almost all are bathroom and/or locker room privacy cases. The others are not even indirectly on point.

71. *See, e.g.*, Adams ex rel. Kasper v. Sch. Bd. of St. Johns Cty., 318 F. Supp. 3d 1293 (M.D. Fla. 2018) (restrooms); G.G. ex rel. Grimm v. Gloucester Cty. Sch. Bd., 822 F.3d 709 (4th Cir. 2016), *vacated and remanded*, 137 S. Ct. 1239 (2017) (restrooms); Johnston v. Univ. of Pittsburgh, 97 F. Supp. 3d 657 (W.D. Penn. 2015) (restrooms and locker rooms).

72. *See, e.g.*, Shayna Medley & Galen Sherwin, *Banning Trans Girls from School Sports Is Neither Feminist Nor Legal*, ACLU (Mar. 12, 2019, 5:45 PM), https://www.aclu.org/blog/lgbt-rights/transgender-rights/banning-trans-girls-school-sports-neither-feminist-nor-legal (arguing that "[w]hen

Administration apparently recognized in 2016 when it was interpreting Title IX in its Transgender Guidance to schools, sport is different from restrooms not only in its policy objectives but also in the extent to which sex actually matters:[73] Where sport is designed to develop and showcase the capacities of the physical body—including mental control of the physical body, and the girls' and women's categories are designed to secure sex equality with respect to the benefits that flow from sports, restrooms are designed to provide a space for people to relieve themselves, and girls' and women's restrooms are designed to secure safety and privacy as they do.[74] In law, at least, institutional design and objectives matter, as do the facts about whether individuals are similarly or dissimilarly situated with respect to the characteristics that are relevant to their attainment. In any event, the Trump Administration has withdrawn the Obama Guidance, restoring the original regulatory status quo;[75] and the Department of Education's Office of Civil Rights is investigating a complaint alleging that the Connecticut Interscholastic

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misinformation about biology and gender is used to bar transgender girls from sports in schools receiving federal funds, it amounts to the same form of sex discrimination that has long been prohibited under Title IX"); Dave Zirin, *Transphobia's New Target Is the World of Sports: First It Was Bathrooms, Now It's Athletics*, NATION (Mar. 5, 2019), https://www.thenation.com/article/archive/trans-runner-daily-caller-terry-miller-andraya-yearwood-martina-navratilova (analogizing the two in general).

73. Dear Colleague Letter on Transgender Students from Catherine E. Lhamon, Assist. Sec'y for Civil Rights, U.S. Dep't of Educ. & Vanita Gupta, Principal Deputy Assist. Att'y Gen. for Civil Rights, U.S. Dep't of Justice (May 13, 2016), https://www2.ed.gov/about/offices/list/ocr/letters/colleague-201605-title-ix-transgender.pdf. *Compare*

> Restrooms and Locker Rooms. A school may provide separate facilities on the basis of sex, but must allow transgender students access to such facilities consistent with their gender identity. A school may not require transgender students to use facilities inconsistent with their gender identity or to use individual-user facilities when other students are not required to do so. A school may, however, make individual-user options available to all students who voluntarily seek additional privacy.

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> Athletics. Title IX regulations permit a school to operate or sponsor sex-segregated athletics teams when selection for such teams is based upon competitive skill or when the activity involved is a contact sport. *A school may not, however, adopt or adhere to requirements that rely on overly broad generalizations or stereotypes about the differences between transgender students and other students of the same sex (i.e., the same gender identity) or others' discomfort with transgender students*. Title IX does not prohibit age-appropriate, tailored requirements based on sound, current, and research-based medical knowledge about the impact of the students' participation on the competitive fairness or physical safety of the sport.

Id. at 3 (emphasis added). The first and third sentences in the "Athletics" paragraph are original to the regulations. The second or middle sentence is guidance developed by the administration concerning the application of the traditional rule to the transgender context. The administration's position at least on the first and third points, but arguably also the second, was well-grounded in the legislative history as recognized over the years by the courts interpreting the statute and its regulations. *See, e.g.*, Kelley v. Bd. of Trs., 35 F.3d 265, 270 (7th Cir. 1994) (noting that "Congress itself recognized that addressing discrimination in athletics presented a unique set of problems not raised in areas such as employment and academics").

74. The difference between sport and restrooms is further detailed in Coleman, *Sex in Sports*, *supra* note 27, at nn.316–317 and accompanying text.

75. Andrew Mytelka, *Trump Administration Rescinds Obama-Era Guidance on Transgender Students*, CHRON. OF HIGHER EDUC. (Feb. 22, 2017), https://www.chronicle.com/blogs/ticker/trump-administration-rescinds-obama-era-guidance-on-transgender-students/117025.

Athletic Conference (CIAC) policy allowing unconditional inclusion of trans girls in girls competition violates Title IX.[76]

Regardless of the Trump Administration's motivation for taking up this complaint,[77] as a doctrinal matter it is on sound footing. Not only is the legal history of the sports exception to Title IX's general nondiscrimination rule clear that it is focused on equality for females in relation to males, but it is also generally accepted that sex segregated sport is constitutional because of its grounding in the "inherent [biological] differences between men and women" and because its purposes are to "compensate" women (and girls) for past and ongoing sex-related discriminations, to "promote equal [sports] opportunity [between men and women]," and to "advance full development of [women's and girls'] talent and capacities."[78] As we explore further below, if both "sex" and "gender identity" became the basis for eligibility for girls' and women's sport—or, as applied, if both girls' and boys' sport included both males and females—inherent differences would no longer be the rationale for separate sex sport, and the girls and women's categories would no longer serve their equality and empowerment goals. They would lose their constitutional grounding.

II. THE SCIENTIFIC EVIDENCE SUPPORTING THE SPORTS EXCEPTION

The disagreement among women and women's groups in the 1970s about whether sex differences in athletic ability were merely stereotype or in fact inherent has long since been resolved. In 2008, Gina Kolata of *The New York Times* reported that "even though some scientists once predicted that women would eventually close the gender gap in elite performances—it was proposed that all they needed was more experience, better training and stronger coaching—that idea is . . . largely discredited, at least for Olympic events."[79] As we write this paper in 2020, it is clear that Kolata's point is accurate across the board, at both the elite and non-elite levels of almost all standard sports and events. To say, as some advocacy groups do, that there is "no evidence"—or that it is "myth" and

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76. Dan Brechlin, *Federal Office of Civil Rights Agrees to Investigate Connecticut's High School Transgender Athlete Policy*, HARTFORD COURANT (Aug. 8, 2019), https://www.courant.com/sports/high-schools/hc-sp-high-school-connecticut-transgender-policy-20190808-20190808-j5yfbovklvf4fjrir4ouybssj4-story.html.

77. Mark Joseph Stern, *Betsy DeVos May Force High Schools to Discriminate Against Trans Athletes*, SLATE (Aug. 9, 2019), https://slate.com/news-and-politics/2019/08/trump-education-department-title-ix-trans-athletes-discrimination.html (noting that this decision may be part of a broader anti-trans agenda).

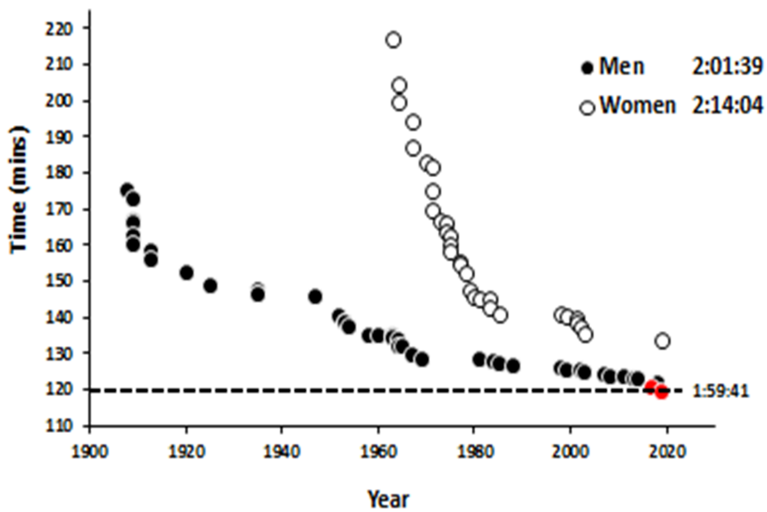
78. Coleman, *Sex in Sport*, *supra* note 27, at 67–70 (quoting United States v. Virginia, 518 U.S. 515, 532 (1996)); *see also* Kelley v. Bd. of Trs., 35 F.3d 265, 272 (7th Cir. 1994) (upholding the constitutionality of the statute and regulations against an equal protection challenge on these grounds); Cohen v. Brown Univ., 991 F.2d 888, 900–01 (same).

79. Gina Kolata, *Men, Women and Speed. 2 Words: Got Testosterone?* N.Y. TIMES (Aug. 22, 2008), https://www.nytimes.com/2008/08/22/news/22iht-22testosterone.15533354.html; *see also* Robinson Meyer, *We Thought Female Athletes Were Catching Up to Men, but They're Not*, ATLANTIC (Aug. 9, 2012), https://www.theatlantic.com/technology/archive/2012/08/we-thought-female-athletes-were-catching-up-to-men-but-theyre-not/260927/.

"outdated stereotype"—that males, including trans women and girls not on gender affirming hormones, are "better" in sport than females is simply to deny science.[80]

Sporting opportunities are not always identical, but there is now substantial parity in training and competition, especially at the elite level, and this has resulted in important performance gains for female athletes. But as the following figure by our co-author Mike Joyner tracking marathon performances illustrates, better training, better races, and more competitive opportunities throughout the world have resulted in gains for both sexes with a compressed time frame for women.

Marathon World Record Progression



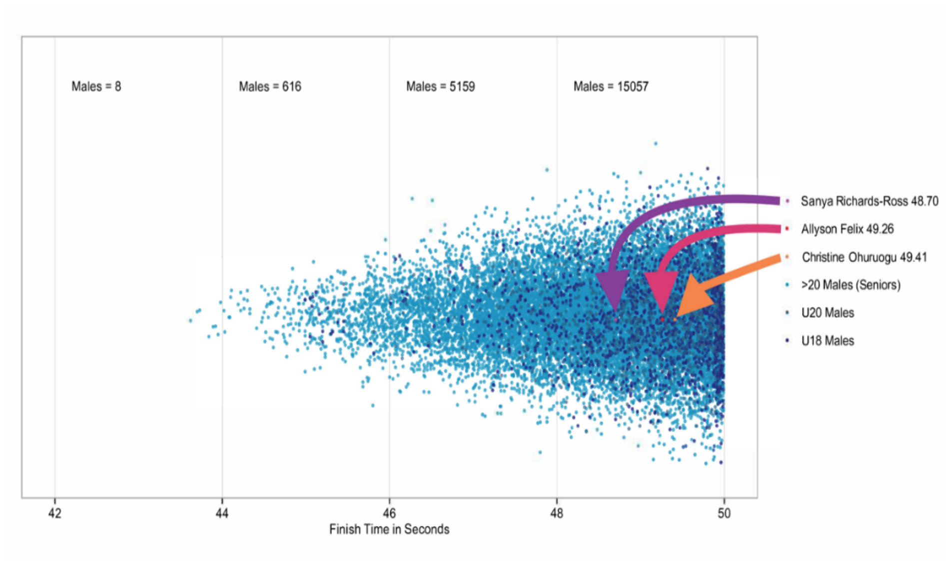
The upshot is that today, depending on the sport and event, the gap between the best male and female performances remains somewhere between 7 to 25 percent; and even the best female is consistently surpassed by many elite and non-elite males, including both boys and men.[81] If elite sport were co-ed or competition were open, even the best female would be rendered invisible by the sea of men and boys

80. *See, e.g.*, Medley & Sherwin, *supra* note 72 (using the terms "myth", "stereotype" and the claim of "no research" to describe the biological evidence in this context); Emilie Kao, *How Pelosi's "Equality Act" Would Ruin Women's Sport*, HERITAGE FOUND. (Apr. 24, 2019), https://www.heritage.org/gender/commentary/how-pelosis-equality-act-would-ruin-womens-sports (quoting Sunu Chandy from the National Women's Law Center using these ACLU talking points).

81. For data comparing male and female performances in a number of events on the track, including the number of males (boys and men) who surpass the very best females, see, e.g., Doriane Lambelet Coleman &Wickliffe Shreve, *Comparing Athletic Performances: The Best Elite Women to Boys and Men*, DUKE CTR. FOR SPORTS LAW & POL'Y (2018), https://law.duke.edu/sites/default/files/centers/sportslaw/comparingathleticperformances.pdf.

who would surpass her. As this next visual using the 400 meters on the track reflects, in percentage terms, the best female is bettered by relatively non-elite boys and men starting at 0.01 percent.[82] Simulating the final 100 meters of that event, it shows three of the fastest ever females on their very best day, against the thousands of boys and men whose performances—just in the single year 2017—would be competitive with or better than them in that final stretch.

Comparing the Best Elite Females to Boys & Men:
Personal Bests For 3 Female Gold Medalists vs 2017 Performances by Boys & Men



The same is true outside of the professional ranks in education-based sport, including in high school regular and post-season competition. For example, in 2016, Vashti Cunningham—the daughter of former NFL quarterback Randall Cunningham—set the high school American record in the high jump outdoors at 6 feet, 4½ inches. Since she joined the professional ranks, she has jumped 6 feet, 6¾ inches, and is ranked in the top ten in the world.[83] Still, in just one year—2018—and just in the state of California, 50 high school boys jumped higher than her high school best. Nationwide, in 2019, 760 boys jumped higher.[84] As the following figure simulating a high jump competition demonstrates, if high school sport were co-ed or competition were open, Cunningham would not have made it to her state

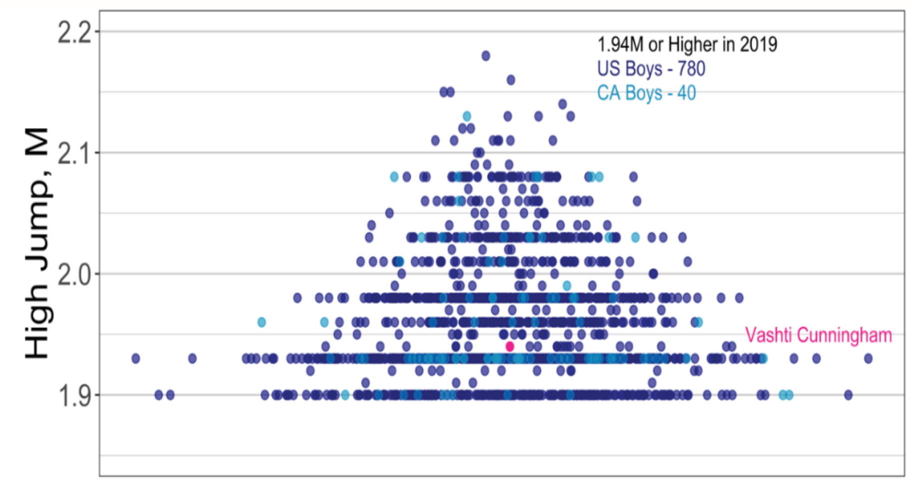
82. Jeff Wald, Doriane Lambelet Coleman, Wickliffe Shreve & Richard Clark, *Comparing the Best Elite Females to Boys and Men: Personal Bests for 3 Female Gold Medalists Versus 2017 Performances by Boys and Men*, DUKE CTR. FOR SPORTS LAW & POL'Y (2018).

83. *Athlete Profile: Vashti Cunningham*, WORLD ATHLETICS, https://www.iaaf.org/athletes/united-states/vashti-cunningham-280887 (last visited Jan. 15, 2020).

84. *See 2019 High School Men's High Jump Rankings*, ATHLETIC.NET, https://www.athletic.net/TrackAndField/Division/Event.aspx?DivID=97967&Event=9&page=7.

meet, she would not be on the national team, and we would not know her name other than as a footnote on her father's Wikipedia page.[85]

High Jump: Best American Boys in 2019
Compared to the Girls' American Record



It is perhaps more important for policy purposes that those girls who are only average high school athletes—for example, those who might just or occasionally win an invitational event or regional competition—would fare even worse. Indeed, a review of age-group performance data confirms what policymakers understood already in the 1970s: if sport were not sex segregated, most school-aged females would be eliminated from competition in the earliest rounds.[86] The following chart illustrates this point, using California intra-state regional results from the 2019 outdoor season, where the best boy in the state jumped 7 feet, 0 inches, and the best girl jumped 5 feet, 10 ½ inches. The average differential was

85. This figure by Jeff Wald is based on data from Athletics.net. According to that database and that of the NAT'L FED'N OF STATE HIGH SCH. ATHLETIC ASS'NS, https://www.nfhs.org/RecordBook/Record-book-result.aspx?CategoryId=1712 (last visited Jan. 28, 2020), only five other females residing and competing in the U.S. have jumped in this range: Alyxandria Treasure (1.92 meters in 2017), Jeannelle Scheper (1.91 meters in 2016), Toni Young (1.93 meters in 2009), Amy Acuff (1.91 meters in 1992), and Latrese Johnson (1.90 meters in 1985).

86. *See supra* notes 44, 54–55 and accompanying text (discussing this concern as it arose in the original policymaking process). *See also* E-mail from Michael J. Joyner, Caywood Professor of Anesthesiology and Perioperative Med., Mayo Clinic Sch. of Med., to Doriane Lambelet Coleman, Professor of Law, Duke Law Sch. (Oct. 6, 2019, 9:08 AM) (on file with authors) ("My younger boys 9 and 7 are good swimmers and they are in mixed races and it is hit or miss boy or girl who wins. The best swimmer in the club is a tall skinny 16-year-old girl who is getting recruited by good schools. She has real ability. She gets crushed by guys who will swim D3 if they choose to."); Coleman, *Sex in Sport*, *supra* note 27, at n.173 (describing the experience in Massachusetts with boys at the girls' state swimming championships).

approximately 12 inches. In percentage terms, across the state the performance gap ranged from 11.88 percent to 20.73 percent.

2019 California Regional High Jump Results[87]

REGION	BEST BOY	BEST GIRL	% DIFFERENCE
Central	2.0828	1.778	14.63%
Central Coast	1.9812	1.6764	15.38%
Los Angeles	1.8796	1.5748	16.22%
North Coast	2.0828	1.651	20.73%
Northern	1.9558	1.6764	14.29%
Oakland	1.8034	1.4732	18.31%
Sac-Joaquin	2.032	1.73355	14.69%
San Diego	2.032	1.7907	11.88%
San Francisco	1.8288	1.4732	19.44%
Southern	2.1336	1.7399	18.45%

The point that from puberty on, co-ed competition relegates most, if not all, females to being only participants in the game is easiest to prove in the case of sports with objective metrics, but "it is well-understood that a version of this story can be told across the board, almost no matter the event."[88] Indeed, the performance gap is so well-understood, and so abundantly documented in easily searchable databases, that it's difficult to take seriously the claim that it is merely

87. We developed this chart using data from the query "California High Jump Results," in ATHLETIC.NET , https://www.athletic.net/ (last visited September 25, 2019).

88. Coleman, *Sex in Sport*, *supra* note 27, at 91; Robinson Meyer, *We Thought Female Athletes Were Catching Up to Men, but They're Not*, *supra* note 79.

"myth" and "false stereotype."[89] Indeed, many on the sport and science side of the discussion have not bothered to try.[90]

Beyond the data, the sex-specific biology underlying the performance gap is also well-studied and well documented. Like other scientific fields that have focused on biological sex differences and that have come to recognize the extensive (beyond reproductive) reach of sex in the human body,[91] sports science and related disciplines—e.g., cardiology, hematology, endocrinology—have advanced tremendously in their understanding of the bases for the sex differences in athletic performance. What is clear from the evidence is that "the differences aren't the result of boys and men having a male gender identity, more resources, better training or superior discipline. It's because they have androgenized bodies."[92] Specifically, scientists agree that "males and females are materially different with respect to the main physical attributes that contribute to athletic performance," and that "the *primary* reason for sex differences in these attributes is exposure in gonadal males to much higher levels of testosterone (T) during growth and development (puberty), and throughout the athletic career."[93]

Before the onset of puberty, males and females produce similar, low levels of T, that is, on the order of 0.25 milligrams (mg) per day. But starting at puberty, male testes begin to produce much more than female ovaries and adrenal glands combined. On average, males (including elite male athletes) produce about 7 mg per day, and females (including elite female athletes) continue to produce about 0.25 mg per day. The normal male range is from 7.7 to 29.4 nmol/L. The normal

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89. For example, domestic databases like Athletics.net provide not only national coverage but also regional, state, and local coverage that goes deep into college, high school, junior high school, and age group results. And international databases run by the governing bodies do a version of the same on a global level. *See supra* notes 81–83 (providing data from the IAAF's interactive database). Nevertheless, in this period the ACLU regularly insists that there is "no evidence" that males are better than females in sport. And even the NWLC publicly repeats this "no evidence" claim and adds that all sex differences are "unfounded stereotype." *See supra* note 80 and accompanying text (citing to these talking points). It is only if one accepts their predicate that the category "women" includes males who identify as female—or, as they put it, "women who happen to be transgender"—that stereotype theory works in the sports space. *See* Coleman, *Sex in Sport*, *supra* note 27, at 105–106, 109–11 (describing and responding to these rhetorical claims as they relate to sport). Otherwise, their argument is either uneducated or convenient science denial. *See* Doriane Coleman, Martina Navratilova & Sanya Richards-Ross, *Pass the Equality Act but Don't Abandon Title IX*, WASH. POST (Apr. 29, 2019), https://www.washingtonpost.com/opinions/pass-the-equality-act-but-dont-abandontitleix/2019/04/29/2dae7e58-65ed-11e9-a1b6-b29b90efa879_story.html?noredirect=on.

90. From statistics, for example, see, e.g., *For Crying Out Loud 2019, Biology in Sports Matters*, STATHOLE SPORTS (Apr. 18, 2019), http://statholesports.com/for-crying-out-loud-2019-biology-in-sports-matters/.

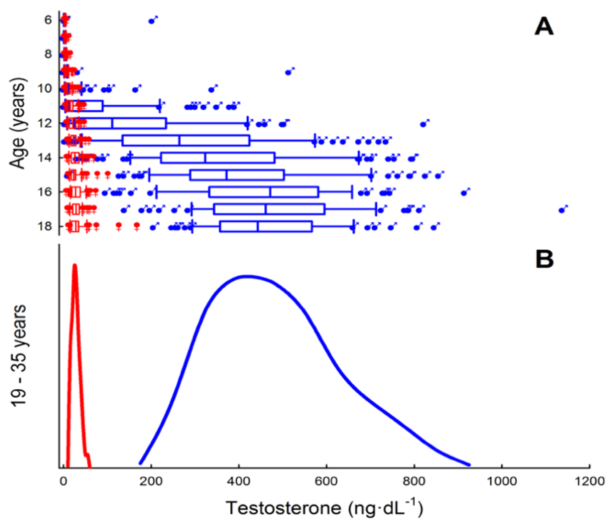
91. *See* EXPLORING THE BIOLOGICAL CONTRIBUTIONS, *supra* note 37 (IOM report examining the evolving study of sex differences and making the case that barriers to knowledge about sex differences must be eliminated).

92. Coleman & Shreve, *supra* note 81.

93. Various experts have recognized the impact of testosterone in athletic performance. *The Role of Testosterone in Athletic Performance*, DUKE CTR. FOR SPORTS LAW & POLICY (Jan. 2019) [hereinafter *Testosterone in Athletic Performance*] (emphasis added), https://law.duke.edu/sites/default/files/centers/sportslaw/Experts_T_Statement_2019.pdf.

female range is from 0.06 to 1.68 nmol/L.[94] In other words, as the following figure from Jonathon Senefeld and our co-author Michael Joyner shows, beginning at puberty, testosterone distributes bi-modally and males (whether they are trans or not) generally produce four to fifteen times more testosterone than females (whether they are trans or not). Female T readings are represented in red, male T readings in blue/purple.

Nationally Representative Data for Total Testosterone
for the U.S. Population Ages 6–35 Years[95]



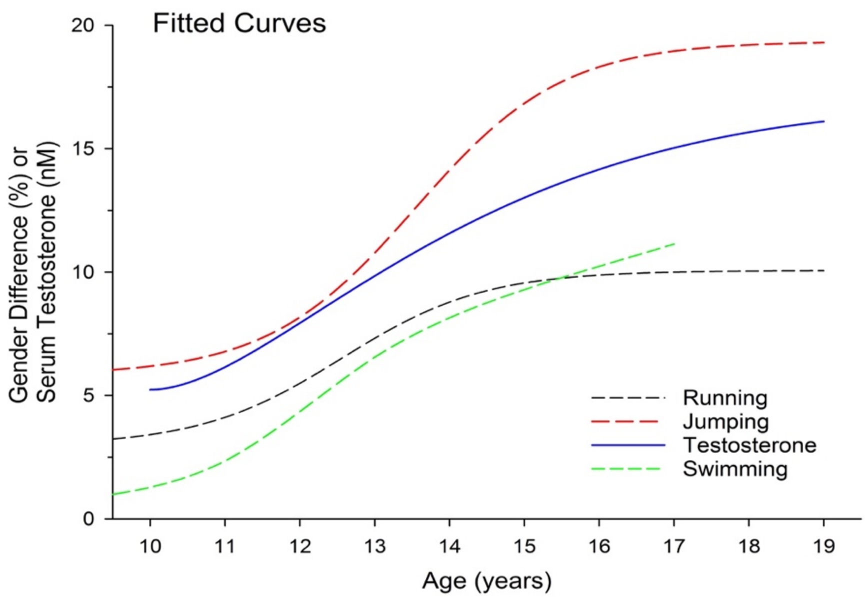
94. Females with polycystic ovaries (PCOS) may have levels upward of 4.8 nmol/L, and those with with untreated congenital adrenal hyperplasia (CAH) may have levels that are higher than that. But no healthy female, e.g., no elite athlete, has a natural T level above 5 nmol/L.

95. Jonathon W. Senefeld & Michael J. Joyner (2019). The data in the figure are from the National Health and Nutrition Examination Survey (NHANES), a study of health of random sample of children and adults in the United States. Using standard, validated clinical laboratory measurement tools (isotope dilution liquid chromatography tandem mass spectrometry) the NHANES laboratory precisely determined total testosterone of 4,229 girls/women and boys/men from ages 6 –35 years. These data are collected biennially to create a longstanding, National database of normative data. Panel A demonstrates the distribution of total testosterone concentration in children age 6–18 for each year using a box-plot to show the 25th, 50th and 75th percentile scores of testosterone. The error bars represent 3 standard deviations (SD) from the mean testosterone, and all outliers (greater or lesser than 3 SD from the mean) are marked using symbols. The girls (red colored box-plots and symbols) have a ~10-fold increase in testosterone (~3 ng·dL^{-1} to ~30 ng·dL^{-1}) that plateaus at 14 years. The boys (blue colored box-plots and symbols) have a substantially greater increase in testosterone than girls, an increase of over 100-fold (~4 ng·dL^{-1} to ~450 ng·dL^{-1}) that begins to plateau at 16 years. Testosterone concentrations are high and steady after age 18 (during years of peak endurance), and the distribution of testosterone for adults in this age range (19-35 years) are displayed in Panel B. This data set of over 1,400 samples from men and women shows the distribution curves from 99 percent of the data, with upper and lower outliers (0.05 percent above and below the mean) removed. The narrow range of the distribution for normative values for women (10-60 ng·dL^{-1}) is much smaller than the large range of normative values for men (175-925 ng·dL^{-1}).

As the next two figures demonstrate, this different exposure literally builds the male body in the respects that matter for sport. Specifically, "compared to biological females, biological males have greater lean body mass (more skeletal muscle and less fat), larger hearts (both in absolute terms and scaled to lean body mass), higher cardiac outputs, larger hemoglobin mass, (also both in absolute terms and scaled to lean body mass), larger $\dot{V}O_{2max}$ (higher aerobic capacity) (also both in absolute terms and scaled to lean body mass), greater glycogen utilization, higher anaerobic capacity, and different economy of motion."[96]

The figure immediately below, from David Handelsman, shows that the emergence of the performance gap in running, jumping, and swimming tracks the rise in male T levels at puberty:

Sex Differences in Athletic Performance Coinciding with the Onset of Male Puberty: Running, Jumping, and Swimming[97]

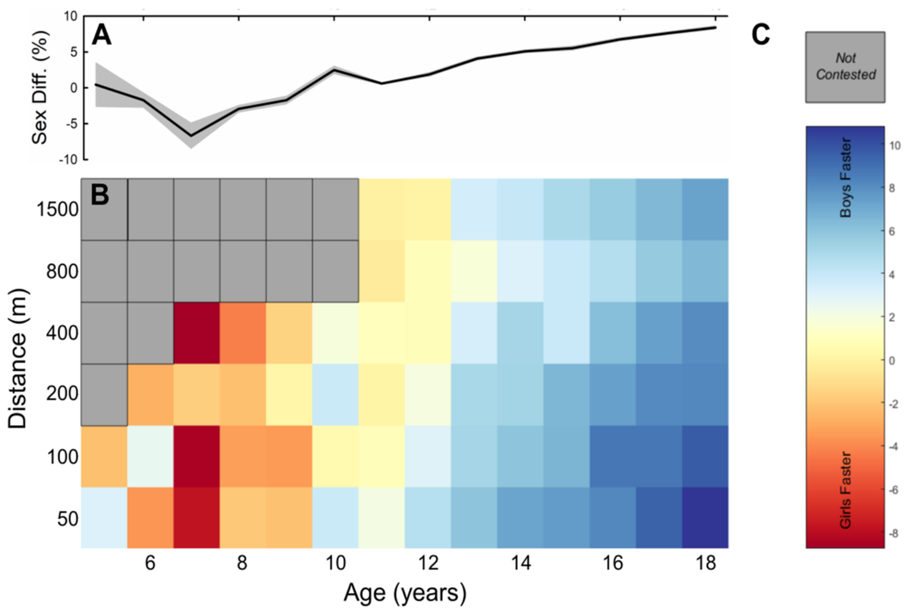


96. *Testosterone in Athletic Performance*, *supra* note 93.

97. This figure is part of a series that was published by David J. Handelsman et al., *Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance*, 39 ENDOCRINE REVS. 803–29 (2018), https://academic.oup.com/edrv/article/39/5/803/5052770/.

This final figure, from our co-author Michael Joyner and his colleague Jonathon Senefeld, homes in on the swimming line. It confirms that pre-pubertal children of both sexes are competitive for the win in co-ed events, with females having some advantage in the six to eight-year-old age brackets. This—together with the requirement of sex-blind approaches when these do not undermine equality goals—is the basis for co-educational programming in elementary school and some age-group competitions.[98] The figure also confirms that from the onset of physical puberty to late adolescence, the competitiveness of females decreases essentially to zero. This—together with the preference for sex conscious approaches when these are necessary to meet equality goals—is the basis for policies that separate males and females in athletic competition starting in middle school and beyond.[99]

Sex Differences in Swimming Performance by Age[100]



98. *See generally* WOMEN'S SPORT FOUND., ISSUES RELATED TO GIRLS AND BOYS COMPETING, *supra* note 54 (describing the circumstances in which it is appropriate legally and scientifically to provide for co-ed and sex segregated sports and physical activities).

99. *See id.* (preferring co-ed sport until puberty). Swimming provides a particularly powerful example of the need for sex segregation in this context because the socio-cultural explanations for the performance gap are neutralized if not eliminated. Women and girls have had significant competitive opportunities in swimming that preceded Title IX, more girls participate in USA swimming than boys, training is systematic, rigorous and mixed from an early age, and records are typically set under standardized conditions. Additionally, swimmers typically come from resource rich homes where sex differences in nutrition or access to medical care are unlikely.

100. Michael J. Joyner & Jonathon W. Senefeld, *Sex Differences in Youth Elite Swimming*, 14 PLOS ONE 5 (2019). The data in the figure are from the top five swimming performances of all-time by US

The State of Connecticut is illustrative. It explains the applicability of these science facts in the FAQs that accompany its public school health, fitness, and performance standards:[101]

> *Why do some standards for boys and girls differ?*
>
> Two factors must be taken into account when determining criterion-referenced health standards: inherent physiologic differences between genders, and differences in health risks between genders. Due to physiologic and anatomic differences between the genders, there may be inherent performance differences between boys and girls for a specific fitness component. For example, differences in cardiac function and body composition between adolescent boys and adolescent girls result in adolescent boys, as a general rule, having a higher aerobic capacity than adolescent girls. Specifically, if the minimum $\dot{V}O_{2max}$ for healthy girls is 28 ml. kg-1. min-1 and for healthy boys, 32 ml. kg-1. min-1, setting the same standard for both on the One-Mile Run Test would not be appropriate. In the case of aerobic capacity, gender differences are taken into account, along with existing data on health risks, in order to determine the standards. In addition to physiologic differences, the two genders do not face the same health risks during their growth. To reflect these differentiated health risks, the standards are adjusted.
>
> *Why are some standards for boys and girls the same?*
>
> When there is no valid reason for expecting a difference in the performance between boys and girls, the standards are the same. For example, young children, particularly in Grades 1-6, do not always possess the physical and physiological differences that appear as children approach puberty (Falls & Pate, 1993). When this is true, the same standards may be used for both genders.
>
> *Why are standards for aerobic endurance lower for girls than for boys?*
>
> Inherent gender-related differences in body composition and in hemoglobin concentration cause aerobic capacity, referred to as VO2 max, for boys and girls who have the same level of physical activity, to be different. The differences prior to puberty are very small or nonexistent (for hemoglobin

swimmers for each 1-year age group from age 5 to 18 years, a database maintained and verified by USA Swimming. These data are using long course, freestyle swimming performances. Panel A demonstrates the sex difference in swimming performance across age (5–18 years). The sex difference in negative (indicating faster performances by girls) until age 10 (no sex differences) and then the sex difference markedly increases (faster boys) with a plateau at age 17. This plateau at ~8.5 percent maintains steady until ~age 50. The black line is the mean sex difference, and the grey area is the 95 percent confidence interval. Panel B demonstrates that similar trends were observed for each major freestyle swimming distance. Notably, the sex difference is largest in 'sprint events' (50, 100 and 200 m) and smallest in 'endurance events' (400, 800 and 1,500 m). Panel C is the legend for panel B. The y-axis for panel C is sex difference (%).

101. CONN. STATE DEP'T OF EDUC., CONNECTICUT PHYSICAL FITNESS ASSESSMENT: THIRD GENERATION 12–13 (2019–2020), https://portal.ct.gov/-/media/SDE/Phys-Ed/CPFA----Test-Administrators-Manual---2019.pdf?la=en.

> concentration), but they increase during puberty and adolescence. These differences are linked in part to differences in the reproductive hormones. The lower VO2 max in girls compared to boys with the same physical activity level are not thought to be associated with increased health risk. The standards for boys and girls reflect the different levels of VO2 max that are associated with increased health risk in adults.[102]

Notably, based on its interpretation of Connecticut anti-discrimination law, the Connecticut Interscholastic Athletics Conference (CIAC) has taken a position that is at odds with the state's physical standards, that is, despite the science and related policy, it permits trans girls—whether or not they were on gender affirming hormones—to compete in girls' events.[103] As a result, in the three year period 2016 to 2019, two trans girls who would not have been successful, had they competed in the boys' division, won fifteen individual state championships in the girls division.[104] It is this set of facts that is the basis for the federal Title IX complaint that the United States Department of Education's Office of Civil Rights is currently investigating.[105]

Apart from testosterone, different sex-linked factors and processes also contribute to sex differences in athletic performance. What this means is that even when trans women and girls use blockers and/or gender affirming hormones, male legacy advantages remain if their therapy begins only after the onset of puberty.[106] These include—among others—different muscle mass, bone density, and airway size.[107] Legacy advantages are more or less pronounced, depending on the age at

102. *Id*.

103. *See infra* note 104 and accompanying text (summarizing the results of CIAC policy).

104. In spring 2018, Terry Miller and Andraya Yearwood placed first and second at the 2018 Class M State Championship in the girls' 100 meters with times of 11.77 and 12.22, respectively. Miller broke the meet record of 12.16 that was set in 1995. *2018 CIAC Spring Championships: Class M Outdoor Track*, CIAC TOURNAMENT CENT., https://content.ciacsports.com/ot18m.shtml (last visited Jan. 28, 2020). The top five finishers from the Class M meet go on to the State Open, which includes the top twenty-five athletes in the state. Miller and Yearwood took 1st and 2nd place there too, with times of 11.72 and 12.29 respectively. *See 2018 CIAC Spring Championships: Open Outdoor Track*, CIAC TOURNAMENT CENT., https://content.ciacsports.com/ot18o.shtml (last visited Jan. 28, 2020). Because they had only run 11.87 and 12.28 going into the State Championships, and the boys' qualifying time was 11.84, neither would have qualified for post-season competition had they been competing in the boys' division. The top six from the State Open represent Connecticut in the New England Championship, which Miller went on to win as well. *See* 2018 New England High School Outdoor Track and Field Championships, RUNNERSPACE.COM, https://new-england-interscholastic-outdoor-championships.runnerspace.com/eprofile.php?do=info&event_id=5773&year=2018 (last visited Jan. 28, 2020).

105. S*ee supra* notes 76–77 and accompanying text (discussing this complaint).

106. Among other related questions, whether male legacy advantages are offset by disadvantages associated with transition is the subject of ongoing inquiry, including by Joanna Harper and colleagues at the University of Loughborough.

107. For an easy to follow description of sex differences in this category, see Yvonne van Dongen's interview with physiologist Alison Heather, *Even Before Birth, Genetic Building Blocks Are Giving Athletes Born Male a Massive Advantage Over Females*, STUFF (July 21, 2019), https://www.stuff.co.nz/sport/other-sports/114327152/even-before-birth-genetic-building-blocks-are-giving-athletes-born-male-a-massive-advantage-over-females; *see also*, *e.g.,* Paolo B. Dominelli et al., *Sex Differences in Large Conducting Airway Anatomy*, J. APPLIED PHYSIOLOGY (1985).

which the person physically transitions, and Joanna Harper has cautioned that they may be offset by the disadvantages associated with taking exogenous hormones and performing in a male frame with female T levels.[108] Finally, legacy advantages are more or less relevant to performance depending on the sport and event. The latter is why, for example, track and field has taken the position that winding down testosterone levels is an acceptable compromise, but power lifting has not.[109]

In contrast, despite the frequent contrary assertion from advocates for unconditional transgender inclusion, there is no evidence that other physical traits—such as height, wingspan, muscle fiber type, or lactic acid processing ability, among others—are similarly determinative of outcomes in sport.[110] As our co-author Doriane Coleman has written elsewhere,

> [t]here is no characteristic that matters more than testes and testosterone. Pick your body part, your geography, and your socioeconomic status and do your comparative homework. Starting in puberty there will always be boys who can beat the best girls and men who can beat the best women.
>
> Because of this, without a women's category based on sex, or at least these sex-linked traits, girls and women would not have the chance they have now to develop their athletic talents and reap the many benefits of participating and winning in sports and competition.[111]

Indeed, even scientists Ross Tucker and Eric Vilain, who are on record in support of gender inclusive policies, have acknowledged that this is why "we separate men and women into categories . . . we want women to be able to win some competitions;"[112] and, "[w]ithout a women's category" based on sex-linked traits, "elite sport would be exclusively male."[113] Because the traits that account for the performance gap are in play starting at the onset of male puberty, the same would be true of non-elite, education-based sport. To paraphrase them both, without a girls' category based on sex, or at least on sex-linked traits, education-based

108. Katherine Kornei, *This Scientist is Racing to Discover How Gender Transitions Alter Athletic Performance—Including Her Own*, SCI. MAG. (July 25, 2018, 9:00 AM), https://www.sciencemag.org/news/2018/07/scientist-racing-discover-how-gender-transitions-alterathletic-performance-including.

109. *Compare* WORLD ATHLETICS ELIGIBILITY REGULATIONS FOR TRANSGENDER ATHLETES, WORLD ATHLETICS, http://www.athletics.org.tw/Upload/Web_Page/WA/Eligibility%20Regulations%20for%20Transgender%20Athletes,%20.pdf, *with* USA POWERLIFTING TUE COMMITTEE REPORT 2019, USA POWERLIFTING,https://www.usapowerlifting.com/wp-content/uploads/2019/05/USA-Powerllifting-TUE-Committee-Report-2019.pdf.

110. *See Testosterone in Athletic Performance*, *supra* note 93 ("No other endogenous physical or physiological factors have been identified as contributing substantially and predominantly to [sex] differences [in athletic performance].").

111. Doriane Lambelet Coleman, *Sex, Sport, and Why Track and Field's New Rules on Intersex Athletes are Essential*, N.Y. TIMES (Apr. 30, 2018), https://www.nytimes.com/2018/04/30/sports/track-gender-rules.html.

112. Coleman, *Sex in Sport*, *supra* note 27, at 91 (quoting Eric Vilain).

113. *Id.* at 86 (quoting Ross Tucker).

competitive sport would be mostly, if not exclusively, male. And so, if we want females to win some competitions, we need to separate them.[114]

III. REAFFIRMING THE MISSION IN LIGHT OF THE CHALLENGE FROM THE IDENTITY MOVEMENT

As we show in Parts I and II, the question presented by advocates for unconditional inclusion of transgender athletes in girls and women's sport is not whether there is a difference between the male body and the female body that justifies current Title IX policy; nor is it whether that policy supports sex segregation in this arena. Rather, the question is the normative one whether, in light of new attention to and growing knowledge about differences of sex development and gender incongruence, we are and should remain committed to equality for females in relation to males in the education-based sports space. Specifically, is that aspect of the idea revolution that was equality for females still viable, or should we be moving on to a new one that rejects the original focus on sex so that we can be inclusive of individuals who are gender diverse?

The voices with the megaphone at the moment prioritize this new and different revolution;[115] but in fact, feminists are split on this issue, as are transgender people whether or not they are also feminists.[116] In this respect, the dispute is as much "in the family"[117] as it is among traditional political opponents.[118] Biological sex, sex equality, and sport are matters that mean a lot to

114. None of this is new to gym teachers and secondary school coaches, who have long used sex specific performance charts both to assess physical health and development and to sort students for competitive games and teams. *See supra* notes 101–102 and accompanying text (setting out the State of Connecticut's standards). Nor is it new to the military, which similarly uses sex specific standards for initial inclusion into the armed services and for fitness reviews, and sex neutral standards in circumstances where operational needs outweigh inclusion and equality concerns. *See generally* KAMARCK, *supra* note 50.

115. *See infra* text and accompanying notes 177–190 (discussing the public positions taken by, among other organizations, the ACLU, the National Women's Law Center, and the Women's Sports Foundation).

116. *Compare* Shasta Darlington, *Transgender Volleyball Star in Brazil Eyes Olympics and Stirs Debate*, N. Y. TIMES (Mar. 17, 2018), https://www.nytimes.com/2018/03/17/world/americas/brazil-transgender-volleyball-tifanny-abreu.html (including the views of Joanna Harper and Tifany Abreu), *with* Scott Gleeson & Erik Brady, *These Transgender Cyclists Have Olympian Disagreements on How to Define Fairness*, USA TODAY (Jan. 11, 2011), https://www.usatoday.com/story/sports/olympics/2018/01/11/these-transgender-cyclists-have-olympian-disagreement-how-define-fairness/995434001/ (comparing the views of Rachel McKinnon with those of some of her female competitors).

117. *See, e.g.,* Coleman, Navratilova, & Richards-Ross, *supra* note 89; Doriane Coleman, *Who Is a "Woman" in Sport*, VOLOKH CONSPIRACY (Mar. 11, 2019, 8:02 AM), https://reason.com/2019/03/11/who-is-a-woman-in-sport/; Dave Zirin, *Martina Navratilova is Expelled From an LGBTQ Advocacy Group Over Transphobia Accusations*, NATION (Feb. 25, 2019), https://www.thenation.com/article/martina-navratilova-athlete-ally-transphobia/.

118. *See, e.g.,* Andrea Jones & Clare Hepler, *Males Don't Belong in Women's Sports—Even If They Don't Always Win*, HERITAGE FOUND. (Nov. 27, 2019), https://www.heritage.org/gender/commentary/males-dont-belong-womens-sports-even-if-they-dont-always-win (one of a series of commentaries on the subject by the foundation); Megan, *supra* note 44 (reporting on filing of a Title IX complaint by the Alliance Defending Freedom).

many people regardless of politics, and so many people are interested in the conversation.

In this final part of the paper, we set out what we see as the most persuasive arguments on both sides of this debate, and we offer a proposal for policy reform that would simultaneously secure Title IX's existing commitment to sex equality and make clear policymakers' authority to develop approaches to the inclusion of gender diverse students in education-based sport that do not undermine that commitment.

A. The Affirmative Case for Sex Equality in Sport

As we see it, the most persuasive argument for sex equality in sport, including in competitive education-based sport, is the following:

Equality for females is a broadly-held commitment and a high value social good. Extending this commitment to education-based sport is part and parcel of securing this value for the individual females who are directly involved, for related stakeholders, and for society more generally. Because of biological ("inherent") differences between males and females, this value cannot be achieved if teams and events are not separated by sex. And, because of the way equal protection doctrine has evolved, there is likely no different—other than sex-based—rationale for segregated sport that is likely to survive constitutional scrutiny: if the classifications "girls' sport" and "women's sport" were based on gender identity rather than sex, they would be difficult if not impossible to sustain. Thus, for both biological and legal reasons, unless society is prepared to forego the benefits that flow from girls' and women's sport, the classification must continue to be based on sex, or at least on reproductive sex-linked traits.

1. Sex Equality is a High-Value Social Good

Both sex equality in general and empowering females in particular are societal priorities. For example, here using the word "gender" as a synonym for "sex" the United Nations Population Fund explains that:

> Gender equality is intrinsically linked to sustainable development and is vital to the realization of human rights for all. The overall objective of gender equality is a society in which women and men enjoy the same opportunities, rights and obligations in all spheres of life. Equality between men and women exists when both sexes are able to share equally in the distribution of power and influence; have equal opportunities for financial independence through work or through setting up businesses; enjoy equal access to education and the opportunity to develop personal ambitions, interests and talents; share responsibility for the home and children and are completely free from coercion, intimidation and gender-based violence both at work and at home.
>
> Within the context of population and development programmes, gender equality is critical because it will enable women and men to make decisions that impact more positively on their own sexual and reproductive health as well as that of their spouses and families. Decision-making with regard to such issues as age at marriage, timing of births, use of contraception, and recourse to harmful practices (such as female genital cutting) stands to be improved with the achievement of gender equality.

> However it is important to acknowledge that where gender inequality exists, it is generally women who are excluded or disadvantaged in relation to decision-making and access to economic and social resources. Therefore a critical aspect of promoting gender equality is the empowerment of women, with a focus on identifying and redressing power imbalances and giving women more autonomy to manage their own lives. This would enable them to make decisions and take actions to achieve and maintain their own reproductive and sexual health. Gender equality and women's empowerment do not mean that men and women become the same; only that access to opportunities and life changes is neither dependent on, nor constrained by, their sex.[119]

That males and females are physically different in relevant ways, and that females are routinely subject to discrimination because of their distinct physical characteristics, explains the UN's commitment to an equality toolbox that includes sex affirmative measures, that is, measures that "see" sex or that are not "sex blind." It is understood that such measures can be effective in ways that sex neutral measures are not: [120]

> Taking gender concerns into account when designing and implementing population and development programmes therefore is important for two reasons. First, there are differences between the roles of men and women, differences that demand different approaches. Second, there is systemic inequality between men and women. Universally, there are clear patterns of women's inferior access to resources and opportunities. Moreover, women are systematically under-represented in decision-making processes that shape their societies and their own lives. This pattern of inequality is a constraint to the progress of any society because it limits the opportunities of one-half of its population. When women are constrained from reaching their full potential, that potential is lost to society as a whole. Programme design and implementation should endeavour to address either or both of these factors.[121]

These principles are codified at the international level in, for example, the UN Convention on the Elimination of Discrimination Against Women, and in European Union law.[122]

The goal to "[*de*]limit the opportunities of one-half of [the] population," as well as the utility of sex conscious approaches to achieving it, have been embraced in the domestic context as well. In the United States, both the means and the ends are supported by a constitutional standard that recognizes the fact of sex differences and the distinction between sex and sex stereotype. The now-classic

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119. *Frequently Asked Questions About Gender Equality* (FAQS), UNITED NATIONS POPULATION FUND, https://www.unfpa.org/resources/frequently-asked-questions-about-gender-equality (last visited Jan. 28, 2020) [hereinafter *Gender Equality FAQs*] .

120. Mona Lena Krook & Diana Z. O'Brien, *The Politics of Group Representation: Quotas for Women and Minorities Worldwide*, 42 COMP. POL. 253 (2010); Stephanie M. Wildman, *Affirmative Action: Necessary for Equality for All Women*, 12 BERKELEY LA RAZA L.J. 429 (2000); Laurel Wamsley, *California Becomes 1st State To Require Women On Corporate Boards*, NPR (Oct. 1, 2018), https://www.npr.org/2018/10/01/653318005/california-becomes-1st-state-to-require-women-on-corporate-boards.

121. *Gender Equality FAQs*, *supra* note 119.

122. *See* Coleman, *Sex in Sport*, *supra* note 27, at 68, n.17.

articulation of this standard comes from Justice Ruth Bader Ginsburg's majority opinion in *United States v. Virginia*:[123]

While the law cannot "rely on overbroad generalizations about the different talents, capacities, or preferences of males and females," it "does *not* make sex a proscribed classification."[124] Indeed, it recognizes that "[p]hysical differences between men and women . . . are enduring" and that these "'[i]nherent differences' . . . remain a cause for celebration, but not for denigration of the members of either sex or for artificial constraints on an individual's opportunity."[125] As applied, this means is that "[s]ex classifications *may* be used to compensate women 'for particular economic disabilities [they have] suffered,' to 'promot[e] equal employment opportunity,' [and] to advance full development of the talent and capacities of our Nation's people";[126] but, they *may not* be used to "den[y] to women, simply because they are women, full citizenship stature—equal opportunity to aspire, achieve, participate in and contribute to society based on their individual talents and capacities."[127]

2. Sex Equality in Sport is a High-Value Social Good

Sport is one of the areas in which the sex equality project has particularly thrived. The goals of competitive sport are "to showcase the best athletes, to produce related goods for stakeholders, and to use sport as a means to spread certain values throughout society. In all three respects, sport seek specifically to reverse society's traditional subordination of women by providing them with opportunities for equal treatment and empowerment."[128]

The Olympic Movement supports sex equality in international sport by setting aside separate competitive opportunities for males and for females. For example:

FIFA sponsors a football (soccer) World Cup for men and a World Cup for women so that both sexes have the chance to field teams, to experience high level international competition, and to be regional and world champions in the sport. Through the production of its various events, FIFA is able to promote the sport and to express its emerging commitment to sex equality—or at least to the value of showcasing empowered females.[129] FIFA President Gianni Infantino explained the impact of the 2019 World Cup on the organization this way:

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123. U.S. v. Virginia, 518 U.S. 533 (1996).

124. *Id*. at 533 (emphasis added).

125. *Id*. (distinguishing the "[s]upposed 'inherent differences'" between the races and national orgins and adding that "'the two sexes are not fungible; a community made up exclusively of one [sex] is different from a community composed of both'"). *See also id*. at 532 ("Without equating gender classifications, for all purposes, to classifications based on race or national origin, the Court . . . has carefully inspected official action that closes the door or denies opportunity to women (or to men).").

126. *Id*. at 533 (emphasis added).

127. *Id*. at 516 (emphasis added).

128. Coleman, *Sex in Sport*, *supra* note 27, at 85.

129. *FIFA Women's World Cup France 2019 Watched by More Than 1 Billion*, FIFA.COM (Oct. 18, 2019), https://www.fifa.com/womensworldcup/news/fifa-women-s-world-cup-2019tm-watched-by-moretha n-1-billion [hereinafter *FIFA Women's World Cup France 2019*]. *See* Andreas Themistokleous, *The Need*

> More than a sporting event, the FIFA Women's World Cup 2019 was a cultural phenomenon attracting more media attention than ever before and providing a platform for women's football to flourish in the spotlight. The fact that we broke the 1 billion target just shows the pulling power of the women's game and the fact that, if we promote and broadcast world-class football widely, whether it's played by men or women, the fans will always want to watch[.][130]

The official blog of the U.S. Department of State added that:

> Every four years, the FIFA Women's World Cup brings the participation and empowerment of women through sports to the international stage and reminds us of the essential contributions of women to societies around the world. From the first tournament held in China twenty eight years ago to France today, the arena of the Women's World Cup not only continues to inspire, but also demonstrates the progress that has been made through the leadership of female athletes, role models and their supporters on gender equality. A key priority for the State Department is to support women and girls' empowerment across economic, political, and social spheres. One of the ways we achieve this is through sports diplomacy . . . as the U.S. Women's National Team holds the Women's World Cup Champion title, the positive impacts of Title IX continue to be felt at home and abroad.[131]

Toward these same combined ends, the sport of athletics (track and field) has men and women competing separately but at the same event in all of the same disciplines and arenas.[132] From the international federation—formerly the IAAF now World Athletics—pay is also equal. For example, a world record at the World Championships is compensated at the rate of $100,000, whether it is set by a male or a female.[133] At the 2019 World Championships, Dalilah Muhammad was the

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for Female Role Models in Sport, MONEY SMART ATHLETE BLOG (Mar. 13, 2019), http://moneysmartathlete.com/2019/03/13/the-need-for-female-role-models-in-sports/ (discussing research on the broader effects of seeing strong female athletes and of the related Irish campaign, "If she can't see it, she can't be it").

130. *FIFA Women's World Cup France 2019*, *supra* note 129.

131. Erin Brown, *The 2019 FIFA Women's World Cup: A Women's Team That Dares To Shine*, DIPNOTE: U.S. DEP'T OF STATE OFFICIAL BLOG (July 8, 2019), https://blogs.state.gov/stories/2019/07/08/en/2019-fifa-women-s-world-cup-women-s-team-dares-shine.

132. Eddie Pells & Pat Graham, *Felix, Other Top Stars, Fight Track's Pregnancy Penalty*, ASSOCIATED PRESS (Sept. 28, 2019), https://www.apnews.com/80b9e2db9a614cef99fadc5f7f0f8902 (noting that some sponsors have subjected female track and field athletes to a "pregnancy penalty", but that exposure in competition is equal because "Diamond League meets have just as many female events as male events" and because "[t]he women's side of the sport has long produced as much talent and star power as the men"). *See also* Peter Bodo, *Follow the Money: How the Pay Gap in Grand Slam Tennis Finally Closed*, ESPN.COM (Sept. 6, 2018), https://www.espn.com/tennis/story/_/id/24599816/us-open-follow-money-how-pay-gap-grand-slam-tennis-closed (noting that while pay is not equal across all tennis events, "the equivalent prize money that men and women receive at Grand Slam events still puts tennis ahead of other leagues and associations in terms of equality").

133. *See, e.g.,* Press Release, IAAF, TDK and QNB to Support World Record Program in Doha (Sept. 17, 2019), https://www.iaaf.org/news/press-release/world-championships-doha-2019-record-programm. In 2019 in Doha, Dalilah Muhammad of Team USA and Team USA's mixed 4x400m relay were paid under this program, which has been the IAAF standard since the 2009. *See IAAF $100,000 IAAF*

only individual athlete to earn the bonus, for her world record in the women's 400 meters hurdles;[134] and for her extraordinary achievements she was subsequently celebrated, alongside Eliud Kipchoge, who broke the two-hour barrier in the marathon, as the sport's Athlete of the Year.[135]

Sex equality in international sport remains an aspiration, not a perfected goal. There is no doubt, however, that we have come a long way toward parity in this setting even as it remains elusive in different institutional contexts. In important part, this is because the sex affirmative measures in use in sport—including sex segregation and a quota system which ensure an equal number of spots on teams, in finals, and on podiums—have not been embraced elsewhere.

Females have most of the same matching opportunities domestically that exist internationally, not only to participate but also to make those teams, finals, and podiums; but here, as the State Department's statement following Team USA's victory in the FIFA Women's World Cup suggests, this is primarily the result of Title IX's equality mandate.[136] In the United States, most sport and athlete development, and most competitions, take place under the auspices of secondary and post-secondary educational institutions and affiliated sports organizations. This includes state interscholastic athletic associations and the NCAA. These institutions and organizations embrace sex equality not only because they have to as recipients of federal funds and actors in interstate commerce, but also because they understand the important social value that is created when opportunities for participation and competition are distributed not only to boys and men but also to women and girls. The set of synergistic goods that flow from sport to individual, institutional, and community stakeholders is believed to be worth the investment.

Thus, starting in high school if not already in middle school, educational institutions and affiliated organizations support separate local, state, regional, and national competitions for males and females which are designed—like elite sport—to isolate and celebrate the champions. They also support a combination of co-ed and sex-segregated opportunities for participation, the latter as pathways to developing competitive athletes and to inculcating the values of fitness and athleticism for lifelong health and wellness. The opportunity to be engaged in competitive sport in particular—regardless of the level at which the competition occurs—is understood to impart additional socially valuable traits including teamwork, sportsmanship, and leadership, as well as individually valuable traits including goal setting, time management, perseverance, discipline, and grit.[137]

World Record Programme Supported by TDK and Toyota – Berlin 2009, WORLD ATHLETICS (Aug. 12, 2009), https://www.iaaf.org/news/news/100000-iaaf-world-record-programme-supported.

134. Scott Cacciola, *Dalilah Muhammad Breaks Her Own World Record in the 400-Meter Hurdles*, N.Y. TIMES (Oct. 4, 2019), https://www.nytimes.com/2019/10/04/sports/dalilah-muhammad-world-record-hurdles.html.

135. OlympicTalk, *Dalilah Muhammad, Eliud Kipchoge Named World Athletes of the Year*, NBC SPORTS (Nov. 23, 2019, 3:43 PM), https://olympics.nbcsports.com/2019/11/23/eliud-kipchoge-dalilah-muhammad-world-athletics-athlete-year/.

136. *See supra* note 131 and accompanying text (quoting that statement).

137. Coleman, *Sex in Sport*, *supra* note 27, at 95–96.

As in the international context, opportunities for participation and competition are still not equal;[138] and compared to boys, girls have "disproportionate drop-out rates . . . which [are] heightened as girls transition from childhood to early adolescence."[139] Nonetheless, because of Title IX and its sports exception, it is no longer just boys and men who have the opportunity to experience the sense of strength and power—both physical and mental—that comes from consistent training and competition; the proverbial "thrill of victory" and "agony of defeat"; the notion of failure as opportunity; and those "fourth and goal" high intensity, high impact moments when the team is counting on the individual to be at their best not only for themselves but also for the collective endeavor. Because of Title IX and its sports exception, it is no longer just boys and men who experience being celebrated as champions in their communities, who are recruited to compete in college, and who provide the optics necessary for those who look like them and come from their circumstances realistically to dream of following in their footsteps. The latter point about optics is controversial in some circles because it is focused on the female phenotype.[140] But as the pervasive

138. Congress continues to require institutions to produce an annual accounting of their efforts toward Title IX's equality mandate. *See supra* notes 64 and 68 and accompanying text (discussing the Equity in Athletics Disclosure Act). And, litigation is ongoing to ensure that they are held accountable also at the local level. *See, e.g.,* Portz v. St. Cloud State Univ., No. CV 16-1115 (JRT/LIB), 2019 WL 6727122 (D. Minn. Dec. 11, 2019) (denying defendants' motion to stay injunction requiring schools to "take immediate steps to provide its female students with an equitable opportunity to participate in varsity intercollegiate athletics and with an equitable athletic-related treatment and benefits at every tier of its athletic department"; injunction was based on a finding that the schools "did not comply with Title IX in its allocation of athletic participation opportunities and treatment and benefits and had not since at least 2014); Robb v. Lock Haven Univ. of Pa., No. 4:17-CV-00964, 2019 WL 2005636 (M.D. Pa. May 7, 2019) (denying summary judgment because facts are in dispute on the issue whether the university's plans to eliminate its women's varsity swim team and demote its women's varsity field hockey team from Division I to Division II discriminated against female student athletes in violation of Title IX's requirement that schools provide "equivalently advanced competitive opportunities"); D.M. by Bao Xiong v. Minn. State High Sch. League, 335 F. Supp. 3d 1136, 1139–40 (D. Minn. 2018), *rev'd and remanded*, 917 F.3d 994 (8th Cir. 2019) (rejecting boy's challenge to girls'-only competitive dance team on the grounds that the exclusion is designed to delimit competitive opportunities for girls in state's high school sports space: "[I]t is not unfair discriminatory practice to restrict membership on an athletic team to participants of one sex whose overall athletic opportunities have previously been limited").

139. NICOLE ZARRETT, ET AL., WOMEN'S SPORTS FOUND., COACHING THROUGH A GENDER LENS: MAXIMIZING GIRLS' PLAY AND POTENTIAL, EXECUTIVE SUMMARY 1 (2019), http://www.womensspo rtsfoundation.org/wp-content/uploads/2019/04/coaching-through-a-gender-lens-executive-summary-web-1.pdf ; Laura Mallonee, *The Importance of Photographing Women in Sports*, WIRED (June 26, 2019, 4:56 PM), https://www.wired.com/story/female-hockey-players-photo-gallery/ ("By age 14, girls drop out of sports at a rate nearly twice that of boys, due to lack of access, social stigma, and other inequities.").

140. *See* Coleman, *Sex in Sport*, *supra* note 27, at 91–93 (discussing the controversy over the optics of the female body).

mantra "If she can't see it, she can't be it" suggests,[141] it is both well-studied and widely-embraced.[142]

Finally, it is because of Title IX and its sports exception—together with the fight that Title IX advocates have put to those who would impede the project—that we have now experienced four generations of empowered little girls becoming empowered women. According to Donna de Varona and Beth Brooke-Marciniak, "Girls who play sport stay in school longer, suffer fewer health problems, enter the labor force at higher rates, and are more likely to land better jobs. They are also more likely to lead. [Ernst & Young] research shows stunningly that 94% percent of women C-Suite executives today played sport, and over half played at a university level."[143] Although we have not been able to verify their particular numbers,[144] and education-based sport is certainly not the only path to

141. *See, e.g.*, Themistokleous, *supra* note 129 (discussing the use of this phrase by the Federation of Irish Sport); Melody Glenn, *If She Can't See It, She Can't Be It: Part 1*, FEMINEM (May 25, 2017), https://feminem.org/2017/05/25/cant-see-cant-part-1/ (using this phrase in support of female role models in emergency medicine). The phrase is a variant of others such as "you can't be what you can't see" that have also been applied to the cause of women's equality and the use of female role models in that context. *See, e.g.*, Tasnuva Bindi, *If You Can't See It, You Can't Be It: Female Founders Crushing Stereotypes*, STARTUP DAILY (May 13, 2014), https://www.startupdaily.net/2014/05/cant-see-cant/ (using this phrase in support of female role models in business, tech, and politics).

142. It is beyond legitimate dispute that role models are effective when their observable characteristics and trajectories are relevant to the aspirant. This is why, for example, we say that girls need to see women in positions of authority and that children of color need to see people of color in those same positions. What we can see—the optics—matter. And the point of reference is the viewer or aspirant, not the individual who would self-identify as a role model. *See* Coleman, *Sex in Sport*, *supra* note 27, at n.256; ZARRETT, ET AL., *supra* note 139, at 3 (listing "female coaches" as one of the things that can encourage girls to stay engaged in sport once they have chosen to participate: "Girls more readily identify with and see a female coach as a mentor and role model, which in turn, can help counter stereotypes and boost girls' confidence, self-efficacy, and sense of belonging."). *See also* Coleman, *Semenya and ASA v. IAAF*, *supra* note 49 ("It is well understood that the empowerment effects of [sex segregated female sport] are different from those that result from seeing men compete together, and also different from seeing open competition among men and women.").

143. Beth A. Brooke-Marciniak & Donna de Varona, *Amazing Things Happen When You Give Female Athletes the Same Funding as Men*, WORLD ECON. FORUM (Aug. 25, 2016), https://www.weforum.org/agenda/2016/08/sustaining-the-olympic-legacy-women-sports-and-public-policy/.

144. *See also* Rebecca Hinds, *The 1 Trait 94 Percent of C-Suite Women Share (And How to Get It)*, INC. MAG. (Feb. 8, 2018), https://www.inc.com/rebecca-hinds/the-1-trait-94-percent-of-c-suite-women-share-and-how-to-get-it.html (citing these EY statistics and noting that being "former or current athletes" is "a trait that Meg Whitman, Indra Noovi, Marissa Mayer, and many other top female executives possess"); Monica Miller, *4 Female C-Suite Executives Who Played College Sports*, NCAA AFTER THE GAME (Mar. 8, 2018), http://www.ncaa.org/student-athletes/former-student-athlete/4-female-c-suite-executives-who-played-college-sports (noting that being a former athlete is a characteristic top female executives share); Valentina Zarya, *What Do 65% of the Most Powerful Women Have in Common? Sports*, FORTUNE (Sept. 22, 2017), https://fortune.com/2017/09/22/powerful-women-business-sports/ (same). We were especially interested in the study design that resulted in the 94 percent figure and so sought to establish how the company that ran the survey—Longitude—identified its recipients. A representative from the company explained that "[a]t the time of recruiting for a particular study, our vendors reach out to the general survey audience and screen respondents according to the survey requirements. Due to the nature of our work, we therefore deploy purposive sampling methods where we purposely target a specific type of audience to eventually qualify the right people." E-mail from

the C-Suite,[145] its multiple health, welfare, competence, and confidence effects have been well-understood for decades.[146] Indeed, as the award-winning sports reporter Christine Brennan offered in the wake of Team USA's victory at the 2019 FIFA Women's World Cup:

> This is a watershed moment. The 1999 U.S. Women's World Cup victory was a revelation. Back then, the nation fell in love with what it created with Title IX. But this, the 2019 U.S. Women's World Cup victory—this is an affirmation. This is the nation saying, 'We want to see more of this.' We've been watching these little girls running to practice every day in our neighborhoods for a couple of decades. They grow up and this is what happens. They become strong, powerful, fearless women who can do anything. The success of the 2019 U.S. soccer team is set against the backdrop of more than 100 women in Congress and 25 women in the Senate. This is that conversation, #MeToo, women speaking out, equal pay, it's all wrapped in one.[147]

The women on this and other teams stand on the shoulders of their predecessors and all of them started in school.[148]

3. Sex Segregation is Necessary to Protect This Good

If schools could not "carve out an exclusive [girls' and] women's category defined by sex, females and their associates would be excluded from the most important of the[] benefits" that flow from participation in competitive sport.[149] As we explain in Part II, this is because females as a group are not competitive with males as a group beginning from the onset of male puberty. Starting then,

Ali Syed, Research Operations Manager, Longitude to Eugene Volokh, Gary T. Shchwartz, Distinguished Professor of Law, UCLA Law Sch. (May 20, 2019, 8:40 AM) (on file with authors). We were not provided with further detail about how the company's purposive approach may have influenced who received and responded to the survey. The approach may have caused the number to be higher than it would have been otherwise.

145. Sport is one way that individuals can gain the set of traits that are commonly associated with success. It is ultimately that set of traits that is valuable to employers. *See, e.g.*, Christina DesMarais, *7 Reasons Athletes Make the Best Employees*, INC. MAG. (Nov. 22, 2017), https://www.inc.com/christina-desmarais/heres-why-kids-who-play-sports-do-better-in-life.html?cid=search (describing the traits are commonly associated with athleticism); Coleman, *Sex in Sport*, *supra* note 27, at 96 (noting that the traits athletes develop "are socially valuable in part because they are highly transferrable . . . which is why 'executives like to hire athletes'"); Nanette Fondas, *Research: More Than Half of Top Female Execs Were College Athletes*, HARV. BUS. REV. (Oct. 9, 2014), https://hbr.org/2014/10/research-more-than-half-of-female-execs-were-college-athletes (same).

146. *See* Coleman, *Sex in Sport*, *supra* note 27, at 95–96; Donna Lopiano, *Modern History of Women in Sports: Twenty-five Years of Title IX*, 19 CLIN. SPORTS MED. 163, 163–73 (2000).

147. E-mail from Christine Brennan, Sports Columnist, CNN, to Doriane Lambelet Coleman, Professor of Law, Duke Law Sch. (Aug. 17, 2019, 10:14 AM) (on file with authors) (discussing CNN broadcast on day of Team USAs return from France to the parade in New York City).

148. *Women's Interest in Sport Continues to Grow,* IBERDROLA, https://www.iberdrola.com/about-us/womens-sport/other-sports/women-sport-today (last visited Jan. 28, 2020) (detailing "the influence of participation in sports at school [beginning in the 1970s] on women's sustained interest in sports now").

149. Coleman, *Sex in Sport*, *supra* note 27, at 96.

even the very best females are surpassed by second-tier males, and second-tier females have no realistic chance to be anything but early participants in the game.

The case for re-affirming the sports exception is based in the goods produced by girls' and women's sport and in the causal link between sex segregation and those goods. The more specific case for not including—or for conditioning the inclusion of—transgender women and girls in girls' and women's sport is related: If they haven't been on feminizing hormones for a relevant period of time,[150] trans women and girls remain fully male-bodied in the respects that matter for sport; because of this, their inclusion effectively de-segregates the teams and events they join.[151] Beyond this basic structural point is the fact that if they are just decent athletes, they will displace females who are the classification's raison d'être,[152] including in championship positions.[153] This matters for the individual females who are displaced, for those who would aspire to be champions, and for the broader expressive effects we expect from the classification. Even an exception risks swallowing the rule and defeating the category.

Finally, the position that there is no legally cognizable difference between females and trans women and girls destroys the legal basis for separate sex sport.[154] This position—encapsulated in the movement mantra, "Girls who are transgender are girls. Period."[155]—is presumably designed to erase sex-linked traits from consideration in the analysis whether the two groups are similarly situated for purposes of equal protection doctrine. If we are not permitted legally to notice that girls who are female and girls who are transgender are dissimilarly situated with respect to their anatomy and physiology, and if we are not permitted to distinguish among them in circumstances where sex actually matters, we will have dismantled the legal scaffolding that supports separate sex sport. Unlike restrooms, which are segregated for safety and privacy, sport does not have an argument that it needs to separate girls from boys, men from women, for any reason other than sex.[156] And, sex discrimination, including sex segregation, is only lawful if it is necessary.

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150. *Feminizing Hormone Therapy*, MAYO CLINIC, https://www.mayoclinic.org/tests-procedures/ mtf-hormone-therapy/about/pac-20385096 (last visited Jan. 28, 2020).

151. *See supra* notes 91–102 and accompanying text (summarizing the effects of male puberty on the body).

152. *See supra* notes 81–88 and accompanying text (explaining that even second-tier males routinely surpass not only second-tier females but also the very best elite females). We don't separate men from women, girls from boys, in competitive sport because they have a different gender identity; we separate them because they have different sex-linked anatomy and physiology. *See supra* and *infra* notes 111–114 and 218 and accompanying text (elaborating on this point).

153. *See infra* notes 181–182 and accompanying text (noting recent victories by trans women athletes on and not on hormones).

154. *See supra* notes 77–78 and accompanying text (describing this legal point).

155. *See, e.g.*, *Support Trans Student Athletes*, ACLU, https://action.aclu.org/petition/support-trans-student-athletes?ms_aff=NAT&initms_aff=NAT&ms=190726_lgbtrights_transathletepledge&initms=190726_lgbtrights_transathletepledge&ms_chan=tw&initms_chan=tw&redirect=transathletesbelong (last visited Jan. 28, 2020).

156. For additional analysis of the difference between sport and restrooms, see *supra* notes 72–74 and accompanying text.

B. The Affirmative Case for Inclusion on the Basis of Gender Identity

There are important arguments on the other side. From our perspective, this is the most persuasive case:

A just and ethical society aspires to be inclusive of and to secure equal protection for all of its citizens, especially for its most vulnerable. Because schools are one of the settings in which children learn societal values, a just and ethical society inculcates inclusivity through its educational programming, and then ensures that all students have equal access to high value spaces and opportunities. Education-based sports are among the high value spaces and opportunities schools provide. Eligibility rules for teams and events that sort students based on biological sex may have the effect of excluding those who are transgender. (This effect exists when individual transgender students are sufficiently uncomfortable with the barrier to entry that they choose to exclude themselves.) When this happens, they are denied equal access to sports. It also denies their schools and athletic associations the ability to pursue their pedagogical goals and to perfect themselves as just and ethical institutions. Finally, where a particular student is especially vulnerable, schools and organizations acting in quasi loco parentis are denied the means to secure their health and welfare.

1. Equality and Inclusivity as Hallmarks of a Just and Ethical Society

A just and ethical society aspires to be inclusive of and to secure equal protection for its most vulnerable citizens. Policies that exclude or deny them equal access are flawed as a matter of principle because they have these effects, and because they impede the perfection of a virtuous society. Where the policies are otherwise valuable, a just and ethical society should provide for exceptions. Where their value is in doubt and cannot be established, they should be dismantled. The goal should be to acknowledge everyone's humanity, to practice generosity, and to make room at the table for everyone. It is often difficult but especially important to do so in the face of incomprehensible or inexperienced difference.

In the international context, "social integration to create an inclusive society … [is] one of the key goals of social development."[157] For example, the United Nations Department of Economic and Social Affairs understands social integration to be "a dynamic and principled process of promoting the values, relations and institutions that enable all people to participate in social, economic, cultural, and political life on the basis of equality of rights, equity and dignity."[158] Social inclusion "is understood as a process by which efforts are made to ensure equal opportunities for all, regardless of their background, so that they can achieve their full potential in life."[159]

157. UNITED NATIONS DEP'T OF ECON. & SOC. AFFAIRS, CREATING AN INCLUSIVE SOCIETY: PRACTICAL STRATEGIES TO PROMOTE SOCIAL INTEGRATION 4 (2009) (draft), https://www.un.org/esa/socdev/egms/docs/2009/Ghana/inclusive-society.pdf.

158. *Id.* at 3.

159. *Id.*

In the domestic context, these same inclusion and equal access goals motivated the creation of the Civil Rights Division of the Department of Justice in 1957, the passage of the 1964 Civil Rights Act, and, among other subsequent civil rights legislation, the Americans with Disabilities Act. Throughout, the idea has been to re-define "We the people" in our Constitution to include all of us within its protections. And then, through the law and the social movements that constantly re-work its application, to evolve the culture and social norms also to be inclusive of and even generous toward those who were previously excluded. As we do, we not only make room at the table but we also perfect our society.

In both the international and domestic contexts, civil and human rights advocates have called on states and institutions to make room at the table for trans people specifically, by protecting them from discrimination and securing their full social integration according to these principles. This advocacy

> [s]eeks to persuade institutional decisionmakers to develop policies designed to recognize, normalize, include, and empower . . . trans people who throughout history have been erased or severely marginalized and often subject to violence . . . [T]he trans community . . . is . . . particularly "associated with high levels of stigmatization, discrimination and victimization, contributing to negative self-image and increased rates of other mental disorder." For example, in the United States, "[t]ransgender individuals are at a higher risk of victimization and hate crimes than the general public" and "[a]dolescents and adults with gender dysphoria are at increased risk for suicide." In less tolerant parts of the world, trans people are at even greater risk of violence, social isolation, and reduced life span.[160]

We are in the midst of this particular social movement, which has garnered important support. In the United States, the 116th Congress passed H.R. 5 - The Equality Act in 2019, which re-defines "sex" in federal civil rights law to include "gender identity."[161] This move was designed to make it unlawful to discriminate against individuals based on their gender identity; among other things, it would disallow distinctions among people on the basis of sex. Because it faces significant opposition in the Republican-controlled Senate and President Trump likely would not sign it, it probably will not become law; but the vote in the House of Representative expresses an important social and political viewpoint. Also in 2019, a consortium of the most important human rights organizations within the United Nations signed a joint statement "call[ing] on States [and other stakeholders] to act urgently to end [among other things] . . . discrimination against . . . transgender and intersex . . . adults, adolescents and children."[162] Like H.R. 5, this statement is

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160. Coleman, *Sex in Sport*, *supra* note 27, at 102. For example, in the United States, the Human Rights Campaign "envisions a world where LGBTQ people are ensured of their basic rights, and can be open, honest and safe at home, at work and in the community." *HRC's Mission Statement*, HUMAN RIGHTS CAMPAIGN, https://www.hrc.org/hrc-story/mission-statement (last visited Jan. 28, 2020). Its Transgender Equality Council advocates specifically for full inclusion and equality for "transgender children and gender expansive youth." *Explore: Transgender Children & Youth*, HUMAN RIGHTS CAMPAIGN, https://www.hrc.org/explore/topic/transgender-children-youth (last visited Jan. 28, 2020).

161. Equality Act, H.R. 5, 116th Cong. (2019).

162. *Ending Violence and Discrimination Against Lesbian, Gay, Bisexual, Transgender and Intersex People,* UNITED NATIONS (Sept. 2015), https://www.ohchr.org/Document/Issues/Discrimination/

not itself formal law, but it nevertheless demonstrates important support for the cause.

2. The Mission of Schools in a Just and Ethical Society Includes Providing Equal Access and Inculcating and Expressing Inclusivity

Part of the mission of educational institutions in any society is to inculcate and express community values. The extent to which they do depends on whether the institutions are public or private, and also on the degree of consensus within the community about what those values are. Where there is ideological homogeneity, values are most likely to be inculcated through the schools. Where there is ideological heterogeneity, this is less likely.

In a just and ethical society, there is or should be a high degree of consensus that inclusivity and equality are among the most important societal values. Educational institutions within such a society are likely to be permitted or even required by the government and citizenry to inculcate and express both. Doing this successfully means ensuring that school programming is accessible to all students. This is especially important with respect to high value spaces and opportunities which are most likely to be arbitrarily exclusive if they are not carefully monitored.

Education-based sport, including competitive sport, is understood to be a high value space and opportunity. This is because of the direct physical and health benefits it yields, and because in elementary and secondary school sports are also—if not mostly—a co-curricular social space where students learn to interact successfully with their peers. Because of this, all students should have access to school sports and related structures should be designed to make this possible.

It is noteworthy that school sports programming has traditionally provided the basis for inculcating inclusivity. While this is especially evident in the context of noncompetitive games, it is also apparent in lower level competitive ones. "Everyone can play" policies, rotation and substitution practices, and the selection of teams balanced by ability are all ways in which the existing practices of competitive education-based sport express and inculcate inclusivity.

Providing equality of opportunity for transgender students is consistent with this approach and the values that drive it. Because they may be excluded in effect by programming that sorts students according to their sex, it is arguably incumbent on schools and athletic organizations either to sort students differently or to accommodate them within existing structures according to their gender identity. Like other students, transgender students should have the benefit of the positive social, health, and empowerment effects of school sports. Rashaan

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Joint_LGBTI_Statement_ENG.PDF (adopted by the International Labour Organization, Office of the High Commissioner of the United Nations Human Rights Council, UNDP, UNESCO, UNFPA, UNHCR, UNICEF, UNODC, UN Women, World Food Programme, World Health Organization, and UNAIDS); *see also* UNITED NATIONS, THE ROLE OF THE UNITED NATIONS IN COMBATTING DISCRIMINATION AND VIOLENCE AGAINST LESBIAN, GAY, BISEXUAL, TRANSGENDER AND INTERSEX PEOPLE: A PROGRAMMATIC OVERVIEW (2019), https://www.ohchr.org/Documents/Issues/Discrimination/LGBT/UN_LGBTI_summary_2019.pdf.

Yearwood, an educator who is also the father of a transgender girl, expresses the point this way:

> My daughter is a trans-female. That means she needs to compete on girls' teams in order to feel most comfortable. [This isn't about competition for her.] She's running because she wants to be part of a team at this age. You know, comradery. Perseverance, grit, teamwork. My job is to raise a healthy child. And we all know that being part of groups and being included allows students to develop in a healthier way than when you're excluded."[163]

Because all students gain from exposure to important social values, including transgender children in school activities like sport according to their gender identity separately supports the institutions' broader pedagogical goals.

3. Schools Need to be Able to Take Care of the Especially Vulnerable Child

Schools stand in quasi loco parentis. Although they are not formally in the shoes of parents, they do have physical custody of the children during the school day while they are on campus, and their charge is not only to ensure that the children are safe but also that they are prepared to engage and to learn. Where an individual child is especially vulnerable—where they might not be safe or when the environment is such that they might be unable successfully to participate—schools should have the tools to address their circumstances.

This is a commonplace. When a child has a peanut allergy, we say that other children cannot bring peanut butter to school. When a child becomes ill, it is or should be "all hands on deck." The interests of the at-risk child are understood to outweigh the interests of others in their teachers' focused attention or in their lunch preferences or even their nutritional needs. This balancing analysis does not always come out in the vulnerable child's favor—for example when they are disruptive of the educational process, when they risk the health and welfare of other children, or when the school is not and cannot be equipped to handle their special needs. But it should come out in their favor when the interests on the other side are not so significant.

Not all transgender children are struggling and fragile. Being trans does not mean having dysphoria.[164] But many are and do. *Individual* transgender students may be struggling and fragile because of the discordance between their sex and their gender identity, because they are in the process of transitioning socially and maybe also physically, and because of the ways in which others perceive and treat them:

> The disconnect between their experienced gender and their assigned gender can result in acute stress called gender dysphoria. Gender dysphoria can be a source of profound suffering. A recent study of transgender teens found that more than 50 percent of transgender males and almost 30 percent of transgender females reported attempting suicide. Transgender adolescents are often vulnerable to

163. Nia Hamm, *Father of Transgender Student Athlete Pushes Back Against Petition to Change Competition Policy*, FOX 61 (June 26, 2018), https://fox61.com/2018/06/26/father-of-transgender-student-athlete-pushes-back-against-petition-to-change-competition-policy/.

164. *See* Safer & Tangpricha, *supra* note 31, at 2451 (explaining this point).

> bullying and family rejection. And even when families are supportive, it can be a very difficult transition for both the teen and the parents.[165]

The medical standard of care for trans and gender diverse children includes living and having others treat them in accordance with their gender identity.[166] Although medicine can't prescribe other-than-medical policy, schools should take that standard under advisement as they develop their policies; and they should follow it in individual instances when the benefits of doing so outweigh the costs. As applied, taking care of transgender children means including them in sex segregated spaces and opportunities like sport on the basis of their gender identity. Where the *individual* child is especially vulnerable, supporting their successful social transition is arguably more important than the integrity of the sex-segregated competitions they would enter. If the student is a transgender girl, supporting her is arguably more important than the interests of all female students in winning.

This last argument is often coupled with evidence that transgender teens are at an especially high risk of suicide. For example, Helen Carroll of the National Center for Lesbian Rights explains that "[s]port can be life-saver for transgender people, who are at high risk of suicide . . . 'They've been fighting themselves and feeling like they're in the wrong body, and sport gives them a place to be happy about their body and what it can do.'"[167] Carroll is right on the facts; an extraordinarily disturbing 30 to 50 percent of transgender teens report attempting suicide.[168] Carroll herself continues to be invaluable to all stakeholders in her support for trans athletes within existing structures.[169] But of course her point is

165. Caroline Miller, *Transgender Kids and Gender Dysphoria*, CHILD MIND INST., https://childmind.org/article/transgender-teens-gender-dysphoria/ (last visited Jan. 28, 2020). *See also* Doriane Lambelet Coleman, *Transgender Children, Puberty Blockers, and the Law: Solutions to the Problem of Dissenting Parents*, 19 AM. J. BIOETHICS 82 (2019) (addressing the question whether and how the law is able to assist transgender children whose families are not supportive).

166. News Release, Endocrine Soc'y, Endocrine Society Urges Policymakers to Follow Science on Transgender Health (Oct. 29, 2019), https://www.eurekalert.org/pub_releases/2019-10/tes-esu102919.php ("As noted in our evidence-based guideline, transgender individuals, both children and adults, should be encouraged to experience living in the new gender role and assess whether this improves their quality of life."). *See also* Jason Rafferty, *Ensuring Comprehensive Care and Support for Transgender and Gender-Diverse Children and Adolescents*, 142 PEDIATRICS 1 (2018); https://pediatrics.aappublications.org/content/pediatrics/142/4/e20182162.full.pdf (American Academy of Pediatrics does the same.); Joshua Safer & Vin Tangpricha, *Care of the Transgender Patient*, ANNALS OF INTERNAL MED. (July 2, 2019), https://annals.org/aim/article-abstract/2737401/care-transgender-patient (American College of Physicians guidelines support the same.).

167. Christie Aschwanden, *Trans Athletes Are Posting Victories and Shaking Up Sports*, WIRED (Oct. 29, 2019, 12:00 PM), https://www.wired.com/story/the-glorious-victories-of-trans-athletes-are-shaking-up-sports/.

168. Rokia Hassanein, *New Study Reveals Shocking Rates of Attempted Suicide Among Trans Adolescents*, HUMAN RIGHTS CAMPAIGN BLOG (Sept. 12, 2018), https://www.hrc.org/blog/new-study-reveals-shocking-rates-of-attempted-suicide-among-trans-adolescen.

169. *See generally* Cyd Zeigler, *LGBTQ Sports Advocate Helen Carroll Retires From NCLR*, OUTSPORTS (June 1, 2017, 10:27 PM), https://www.outsports.com/2017/6/1/15723406/helen-carroll-nclr-lgbtq-sports-retire and *infra* note 225 and accompanying text (discussing her work with Pat Griffin on the NCAA transgender guidelines).

an application of more general ones, about the empowerment effects of sport for females and its therapeutic effects for those who are suffering as a result of difficult personal and mental health issues whatever their source.[170] It is an unfortunate fact that major depression and associated feelings of hopelessness are on the rise among children in the United States, with girls being especially affected.[171] Suicide is now the second leading cause of death among adolescents in general.[172] Risk factors include "psychiatric disorders and comorbidities, family history of depression or suicide, loss of a parent to death or divorce, physical and/or sexual abuse, lack of a support network, feelings of social isolation, and bullying"[173] as well as "barriers to access treatment, homosexual orientation" and being an "early or late developing girl[]."[174] Educational institutions that have the necessary resources should follow the evidence and do what they can to mitigate these risks regardless of the child at issue.[175]

There is a related, overlapping claim from vulnerability. It is that *as a group*, transgender children are struggling and fragile so that their interests in being included in sex-segregated spaces and opportunities on the basis of their gender identity always trump the interests of classmates who, *as a group*, cannot be described as similarly vulnerable. This is a standard move in advocacy circles which has, in turn, influenced sports policymakers on the ground. For example, the Executive Director of the National Federation of State High School Associations Karissa Niehoff argues that:

> [This] is not about the winning and losing. It's about the successful development of these [transgender] kids. [I]f we don't treat them respectfully, their development is going to lose. That's a much bigger issue than someone not getting a medal or a place in a race. Much bigger issue.[176]

170. *See generally* Emily Pluhar et al., *Team Sport Athletes May Be Less Likely To Suffer Anxiety and Depression Than Individual Sport Athletes*, 18 J. SPORTS, SCI., & MED. 490 (2019) (noting positive mental health effects of sports in general while distinguishing results in team and individual sports); Nick Pearce et al., *The Role of Physical Activity and Sport in Mental Health*, FACULTY OF SPORT & EXERCISE MED. UK (May 2018), https://www.fsem.ac.uk/position_statement/the-role-of-physical-activity-and-sport-in-mental-health/.

171. Patti Neighmond, *A Rise In Depression Among Teens and Young Adults Could Be Linked to Social Media Use*, NPR (Mar. 14, 2019, 11:01 AM), https://www.npr.org/sections/health-shots/2019/03/14/703170892/a-rise-in-depression-among-teens-and-young-adults-could-be-linked-to-social-medi.

172. Melonie Heron, *Deaths: Leading Causes for 2017*, 68 NAT'L VITAL STAT. REP. 1 (2019).

173. *Teen Suicide*, AMERICA'S HEALTH RANKINGS, https://ww.americashealthrankings.org/explore/health-of-women-andchildren/measure/teen_suicide/ state/ALL (last visited Jan. 28. 2020).

174. Stephanie Secord Fredrick et al., *Can Social Support Buffer the Association Between Depression and Suicidal Ideation in Adolescent Boys and Girls?*, 55 PSYCHOL. IN THE SCHOOLS 490, 491 (2018).

175. *See generally* CTRS. FOR DISEASE CONTROL & PREVENTION, NAT'L CTR. FOR INJURY PREVENTION & CONTROL, DIV. OF VIOLENCE PREVENTION, THE RELATIONSHIP BETWEEN BULLYING AND SUICIDE: WHAT WE KNOW AND WHAT IT MEANS FOR SCHOOLS (2014), https://www.cdc.gov/violenceprevention/pdf/bullying-suicide-translation-final-a.pdf.

176. Mary Albl, CIAC's *Transgender Policy Faces Test With New Lawsuit*, DYESTAT (June 24, 2019, 1:20 PM), https://www.runnerspace.com/gprofile.php?mgroup_id=44531&do=news&news_id=580238.

Niehoff's statement reflects the sense that the successful development of different kids is not similarly dependent on equality, inclusion, and success in school and sport; and that to the extent it might be, this will either be an only occasional conflict, or else the opportunity to participate will be enough for most or all kids who are not transgender. It also reflects the view that although education-based sport sometimes promotes competition and winning, this is ultimately not its primary institutional focus.

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We close out this section with brief reactions to four arguments that are not persuasive from our perspective. They include some that are particularly prominent in the public relations strategies of the advocacy groups that currently control the megaphone.

The first of these is the argument, grounded in science denial, that we have already addressed in Part II.[177] It is fact, not myth or stereotype, that beginning at the onset of male puberty, an insurmountable performance gap between males and females emerges such that even the very best females are not competitive for the win against males, including against second-tier males. If we care about sex equality in sport, that is, if we care about seeing females in finals and on the podium however they might happen to identify, competitive sport has to be segregated on the basis of sex.

The second is the suggestion that because there are few transgender women and girls relative to the numbers of females, any disruption of the competitive hierarchy is unlikely to be substantial enough to jeopardize sex equality goals.[178] That some transgender women and girls may be on feminizing hormones is said to reduce their potential impact even further. As we explain in Part III(C) below, we agree that a consistent course of hormone replacement therapy (HRT) can wind down the male advantage to the point that a policy exception at the development elite and collegiate levels is justified. But we don't think that transition hormones should be a requirement for participation in secondary school competition; and in any event, many transgender teens do not want or have access to hormones. As students in the latter category are increasingly comfortable coming out at school—which from our perspective is a good thing—the number of "out" trans kids is growing beyond the small percentages described in earlier population surveys. This increase is not yet well understood, but it appears to be an upward trajectory.[179] Because it is well-established that athletic but not necessarily elite

177. *See supra* Part II. *See, e.g.*, Medley & Sherwin, *supra* note 72 (describing as "myth" and "impermissible sex stereotype" the fact of the sex-linked performance gap, and as "arbitrary" the rules of sports governing bodies that use sex-linked traits as the basis for classification into and out of the women's category, and claiming that there is "ample evidence that girls can compete and win against boys").

178. *See, e.g.*, *id.* ("The truth is, transgender women and girls have been competing in sports at all levels for years, and there is no research supporting that they maintain a competitive advantage.").

179. *See* Rafferty, *supra* note 166 (discussing recent statistics); Michelle M. Johns et al., *Transgender Identity and Experiences of Violence Victimization, Substance Use, Suicide Risk, and Sexual Risk Behaviors Among High School Students—19 States and Large Urban School Districts, 2017*, 68 CDC MORBIDITY & MORTALITY WKLY. REP. 67 (reporting a 1.8 percent incidence rate as of 2017); Jesse Singal, *When Children*

males dominate females in almost every sport and event, which is true without regard to how individuals identify, it is reasonable to expect that trans girls not on hormones will affect results in important ways—as athletes with 46,XY differences of sex development have in the international arena.[180] It is not a fluke that, in the last three years, we have seen the first trans girls as state champions,[181] the first trans woman as DII national champion,[182] and the first potentially consequential trans woman in a DI sport.[183]

The third is the political and sociological claim[184] that transgender girls are girls and, because of this, their reproductive sex-linked traits are irrelevant to the conversation about their classification into spaces and opportunities designed specifically to empower females.[185] This claim is weak not only because it has its

Say They're Trans, ATLANTIC (July/Aug. 2018), https://www.theatlantic.com/magazine/archive/2018/07/when-a-child-says-shes-trans/561749/ (reporting on rise in numbers of people identifying as trans).

180. *See* Coleman, *Sex in Sport*, *supra* note 27, at 106–108 (responding to the numbers argument in that context).

181. *See 2018 CIAC Spring Championships: Class M Outdoor Track*, *supra* note 104 and accompanying text (discussing Connecticut state championships in track and field).

182. Press Release, Franklin Pierce Univ., NATIONAL CHAMPION! Telfer Claims Women's Track & Field's First NCAA Title (May 26, 2019), https://www.franklinpierce.edu/about/news/National_Champion_CeCe_Telfer.htm.

183. Kyle Hansen, *Montana Cross Country Runner, Belgrade Native to Make History as Transgender Athlete*, MISSOULIAN (Aug. 30, 2019), https://missoulian.com/sports/college/big-sky-conference /university-of-montana/montana-cross-country-runner-belgrade-native-to-make-history-as/article_2a 37bd80-9eea-519d-8636-040473b84cc8.html. As of this writing, June Eastwood's performances appear to be consistent with Joanna Harper's hypothesis that, at least for distance runners, a year of consistent use of gender affirming hormones winds down the male advantage to the point that trans women return to their place in the hierarchy, e.g., roughly speaking if they were the tenth best man they will be approximately the tenth best woman. Eastwood's announcement that she was transitioning from male to female, and from the Montana men's team to the Montana women's team, sounded alarm bells within the sport, however, because her pre-transition times in high school and early college, especially in the middle distances, would have immediately put her at or close to the professional women's world records. In this respect she was, and depending on how she runs going forward may still be, the most significant trans woman athlete to date.

184. We characterize this as a political and sociological claim because it is based in an effort to expand the standard definitions of female, girl, and woman beyond their basis in female reproductive sex to include a subset of individuals whose reproductive sex is male. It is one of a number of strategies that might be employed to secure equality for trans people. There is a counterargument that this is a factual claim since gender identity likely has a neurobiological basis and may be related to our natural reproductive inclinations. Even if this is eventually established, however, individuals would still have either male or female reproductive sex, which is what the words and dichotomies male/female, girl/boy, and man/woman are generally understood to connote; and we would still need words that did this descriptive work. The arguments that we wouldn't or shouldn't, or that it shouldn't or couldn't be the ones we use now because they exclude trans people, are undoubtedly political.

185. *See, e.g.*, Medley & Sherwin, *supra* note 72 (rejecting the "policing of gender [that] has been used to justify subjecting transgender student athletes to numerous additional barriers to participating in sports, from onerous medical requirements to segregation in locker rooms to outright bans on their participation"); *Statement of Women's Rights and Gender Justice Organizations*, *supra* note 29 (rejecting any distinctions among cis and trans women and girls on the argument that "Transgender girls are girls

advocates making easily dismissed arguments about testes and T levels being no different than—for example—height and wingspan, but also because it ignores the reasons these spaces and opportunities exist and censors legitimate discussions about the implications of erasing biological sex even where it is undoubtedly relevant. This includes contexts in which sex is outcome determinative, like competitive sport. It also includes contexts in which sex differences are an affirmative individual and societal good. Discussions about sex and sex-linked anatomy and physiology must be had kindly, but it is wrong to censor them.[186]

The fourth is the argument from intersectional feminism that it is good for all women that we accept that transgender women are women, and that transgender girls are girls.[187] Accepting trans women and girls is the good and right thing to do for a lot of reasons, including that our default should be inclusion unless there are persuasive reasons to make distinctions. But the suggestion that women should understand that eliding relevant sex differences is good for them particularly—even if they don't know it—is patronizing and otherwise deeply problematic.[188] From what we have gathered, it appears to be based in a number of different assumptions all of which we reject: that sex classifications are always

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and transgender women are women. They are not and should not be referred to as boys or men, biological or otherwise").

186. For an analysis of the harm caused by the censorship of females talking about the female body see Doriane Lambelet Coleman, *A Victory for Female Athletes Everywhere*, QUILLETTE (May 3, 2019), https://quillette.com/2019/05/03/a-victory-for-female-athletes-everywhere/.

187. *See, e.g*, *Statement of Women's Rights and Gender Justice Organizations*, *supra* note 29 ("[W]e . . . reject the suggestion that cisgender women and girls benefit from the exclusion of women and girls who happen to be transgender"; "we recognize the harm to all women and girls that will flow from allowing some women and girls to be denied opportunities to participate and cast out of the category of 'woman' for failing to meet standards driven by stereotypes and fear"; "we speak from experience and expertise when we say that nondiscrimination protections for transgender people—including women and girls who are transgender—are not at odds with women's equality or well-being, but advance them."); *Support Trans Student Athletes*, *supra* note 155 ("The marginalization of trans student-athletes is rooted in the same kind of gender discrimination and stereotyping that has held back cisgender women athletes. Transgender girls are often told that they are not girls (and conversely transgender boys are told they are not really boys) based on inaccurate stereotypes about biology, athleticism, and gender. . . . Girls who are transgender are girls. Period."). *See also, e.g.*, Carol Hay, *Who Counts as a Woman*, N.Y. TIMES (Apr. 1, 2019), https://www.nytimes.com/2019/04/01/opinion/trans-women-feminism.html (noting the origins of this claim in intersectional feminism); Jack Guy, *Women or 'Womxn'? Students Adopt Inclusive Language*, CNN (Nov. 27, 2018, 11:38 AM), https://www.cnn.com/2018/11/27/uk/womxn-inclusive-language-gbr-scli-intl/index.html (describing the "growing use of inclusive language, designed to avoid excluding particular groups of people" including that "Womxn is a more inclusive term which promotes intersectionality" and is thus "more inclusive of all kinds of women, including trans women" and that "Womxn is used to demonstrate our commitment to inclusiveness").

188. Especially patronizing is the suggestion that these organizations have particular "experience and expertise" about women—including about how they should define themselves and their wellbeing—that women themselves don't have. *See, e.g.*, *Statement of Women's Rights and Gender Justice Organizations*, *supra* note 29 ("[W]e speak from experience and expertise when we say that nondiscrimination protections for transgender people—including women and girls who are transgender—are not at odds with women's equality or well-being, but advance them."). It is this kind of talk that has alienated many, including many women, who might otherwise be natural allies.

harmful or at least a net harm to women and girls; that all sex classifications are based in false and damaging sex stereotypes; that women all want or should want to be freed from the yoke that is their secondary sex characteristics and cultural expectations around femininity; that women and girls are by nature or necessity inclusive and self-sacrificing, so that the category that describes them itself should be generously so; and that women and girls—and their allies—don't or shouldn't care as much as boys and men do about competition and being competitive for the win. We reject each of these because they are themselves false and damaging sex stereotypes.

The last of these is especially problematic as we discuss the future of Title IX. It has led a group of prominent civil rights organizations to return to the posture of some of their 1970s counterparts who argued that high-end NCAA-style competitions were not for women;[189] today, they have determined to limit their advocacy to protecting opportunities for women and girls to participate—not necessarily to win—in sport.[190] It is presumably just helpful coincidence and not coordinated strategy that their position aligns with the position of some in the trans advocacy community that because trans women and girls are women and girls, their victories in events in which females retain opportunities to participate should be celebrated, not discredited.[191] This move is particularly insidious as applied to the high school sports space which can be described as relatively unimportant to protect if it's really just about participation.

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189. *See supra* notes 42 and 48 and accompanying text (describing that earlier position); and Interview with our co-author Donna Lopiano, President & Founder, Sports Mgmt. Res. (Oct. 13, 2019), (noting that in the development of Title IX, "the focus on participation opportunities came first, followed by the focus on competition, because we had to build the ranks of those participating before we could think about competition, but also because early advocates preferred a health-focused, student-led, physical education model that would concentrate on intramural or junior varsity style events, as distinguished from the varsity and NCAA commercial model for competition they rejected").

190. *Id.* (noting that women's organizations that fought for both participation and competition opportunities in earlier periods have decided as a strategic matter to focus their efforts going forward on participation numbers and not to use organizational resources to continue to secure and protect the right of women and girls also to win, i.e., also to spots in finals and on podiums); E-mail from N.F. to M.R. (Mar. 23, 2019, 3:17 PM) (on file with authors) (sharing that "the Title IX advocacy community is in lockstep" in its commitment to the unconditional inclusion of trans kids in high school sports on the basis of their gender identity so that the right of cis-girls to more than just participation in this—as opposed to the college sports—space "is not the battle of [the organizations] at this time"). This position appears to be reflected in the approach of the Connecticut CIAC, among other state athletic associations. *See New Hampshire House Bill 1251*, SAVE WOMEN'S SPORTS (Jan. 15, 2020), https://savewomenssports.com/original-articles/f/new-hampshire-house-bill-1251-hearing (quoting a testimonial from Connecticut mother, Christy Mitchell, "I was astounded to hear from state officials that 'girls have the right to participate not to win.'").

191. *See, e.g.*, Rachel McKinnon, *I Won a World Championship. Some People Aren't Happy.*, N.Y. TIMES (Dec. 5, 2019), https://www.nytimes.com/2019/12/05/opinion/i-won-a-world-championship-some-people-arent-happy.html ("Trans women are women. We are female . . . It is a human right to be able to compete. I will continue to show up. I hope you'll consider cheering."); Dave Zirin, *Transphobia's New Target Is The World of Sports*, *supra* note 72 ("Terry Miller and Andraya Yearwood finished first and second place respectively in the state open indoor-track championships last month. Instead of celebrating one of the great moments in their lives, they were immediately put on the defensive about their right to compete in the first place.").

The proposition that females don't need to be competitive for the win is no longer viable; see the FIFA Women's World Cup.[192] The proposition that showcasing strong female-bodied champions is not a high value social good is no longer viable; see Serena Williams and Allyson Felix.[193] We do not doubt that they are well-intentioned, but coming in 2020, from organizations that otherwise decry sex stereotypes and that previously championed the right of women and girls also to equality of competitive opportunity, they are nothing short of extraordinary. We need to take care of transgender women and girls, but the path should not involve weakening the commitment to females. And here we should be clear: It is weakening the commitment to females and to sex equality to accept that the boys' state championship will probably *always* be won by a male where the girls' state championship will *not always* be won by a female.

C. Updating Title IX for Its Next Half Century

Biological sex matters. It is real, not socially constructed; and it affects peoples' lives, opportunities, and experiences in even the most benign or egalitarian situations and societies. In particular, because of their different reproductive biology and secondary sex characteristics, females in general have different physical capacities and experiences than males. This is true regardless of how they identify.

Sex matters in ways that are empowering and celebrated, and also in ways that are damaging and censured. For females, physical—including sexual—violence perpetrated primarily by males is a destructive commonplace, as are the routine exclusions and subordinations they experience based on their phenotype and their reproductive biology. Sometimes these exclusions and subordinations are driven by false stereotypes. But they may also be driven by a reluctance to re-imagine structures to accommodate real and otherwise appreciated sex-linked physical differences. Regardless, sex is relevant if not defining.

Sex equality also matters. Although we can imagine a world in which sex is not relevant or defining, in which we classify people on entirely different terms or else not at all, this isn't ours. As ours exists, because sex matters, so does sex equality. The United Nations is not wrong to think about the world's population in male and female halves, because this is how we tend in the first instance to sort ourselves, and then how our experiences and opportunities line up. They generally line up this way, again at least in the first instance, without regard to race, class, or gender identity. Because of this, it is also not wrong to make anti-subordination commitments specifically to the female half of the world's population. This should not be our only anti-subordination commitment, but is it an entirely rational and important one.

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192. *See also* ZARRETT, ET AL., *supra* note 139, at 3 (noting that one of the things that can work to encourage girls to stay engaged in sport once they have chosen to participate is "[a]n emphasis on winning . . . when combined with an emphasis on fun and skill development . . . . Healthy forms of competition are ideal for fostering girls' engagement").

193. Mallonee, *supra* note 139 ("One of the biggest things researchers are finding that keeps girls engaged in sports is access to their heroes and mentors—even if it's just seeing them . . . [t]o see a banner or a poster or an ad featuring someone like you is monumental.").

Sex equality can sometimes be achieved without affirmative consideration of sex, and in this period in the United States, sex-blind policies are preferred. But when sex blindness would be counterproductive, ineffective, or insufficiently remedial, sex conscious approaches should be tools in the equality toolbox. These are especially useful in circumstances where, to fix inequities, it is important to see, not to erase, the female body. This includes at least aspects of the workplace; the military; medicine and bio-medical research; and competitive sport. If we were to have to ignore sex differences in these circumstances, sex equality would remain elusive.

Efforts to secure inclusion and equality for transgender people that are premised on erasing sex and sex differences—conceptually and from the discourse—are fundamentally incompatible with these facts, priorities, and approaches. Where sex, including being able to name it, is central for many if not most females, both are anathema for many in the transgender community. For this reason, but also because it fits their legal and political strategy, some trans rights advocates seek to redefine sex to be or to include gender identity; and further to ensure that no distinctions can be made on the basis of sex on the ground that such distinctions are a rejection of transgender people.[194] Those who do not play ball are labeled "transphobic" and, if they are liberal and feminist, also as "trans exclusionary radical feminists" (TERFs), which is intended as an insult.[195]

The competitive sports question is hard, maybe even impossible to resolve with a win on all sides, because what females need to have recognized is precisely what advocates for trans students suggest should be erased. For example, if we continue to be committed to equality for females in relation to males in the high school sports space—equality not only for its own sake but also for the myriad individual, institutional, and societal benefits that flow from its terms—we need structures that recognize sex differences in athletic performance and that sort athletes on the basis of sex.[196] At the same time, because they are properly focused on the individual children in their care—and not on the implications for others of their approach—erasure of these same sex differences has been built into the therapeutic model developed by pediatricians working with transgender children, and impressed on their educational custodians.[197]

As we have already discussed, efforts to will this collision away do not work because they rest on a series of ultimately unacceptable fictions: That all sex is socially constructed stereotype that inures to the detriment of women. That there are no cognizable differences between women who are transgender and women who are not. And that "women" is a concept that, in its best iteration, describes

194. *See supra* notes 29–30 and accompanying text.

195. Colleen Flaherty, *'TERF' War*, INSIDE HIGHER ED (Aug. 29, 2018), https://www.insidehighered.com/news/2018/08/29/philosophers-object-journals-publication-terf-reference-some-feminists-it-really. *See* R (on the Application of Miller) v. College of Policing & Chief Constable of Humberside, [2020] EWHC 225 (Admin) [225], ¶ 241–46 (Eng.) (describing and quoting the expert witness statement of Professor Kathleen Stock on the use of the term 'TERF' in the context of the gender-related divisions among feminist academics).

196. *See supra* notes 112–114, 149–156 and accompanying text.

197. *See supra* note 166 and accompanying text.

people who are relatively anti-competitive and selfless and so do not mind being relegated to the bench if this is necessary to secure the health and welfare of others who may be more vulnerable.[198]

The competitive sports question is also hard because it involves claims for inclusion and equality from both sides; and, because of how sport and sex-linked biology work together, including one group necessarily means excluding or limiting the opportunities of the other. The carve-out that is the sports exception to Title IX's general, sex-blind nondiscrimination rule recognizes this. And so, to secure the inclusion of and equality for females, it formally permits—but also sometimes requires—schools to exclude males from their sports and events.[199] Carving out what would be, in effect, an exception to this exception for the subset of males who identify as women and girls would result in their inclusion; but it would have exclusive effects in the other direction. Longer term, it would inevitably signal that we don't actually need sex segregation, which would result in the full re-integration of sport and thus the re-exclusion of females. Shorter term, because competition itself is exclusionary in the sense that making teams requires try-outs and cuts, and making it through to the finals and championships involves a version of the same—there can be only one state, regional, or national champion—carving out an exception to the sex segregation rule for males who identify as women and girls will result in the exclusion of females from teams, finals, and podiums.[200]

The problem is hard but, in general, there are four possible approaches: affirming the carve-out as a biological classification tied to natal sex; re-imagining the carve-out as an identity classification; re-imagining the carve-out as a biological classification tied to the onset of male puberty; and formalizing an accommodations approach.

1. Affirming the Carve-Out as a Biological Classification Tied to Natal Sex

The first option is to affirm the traditional approach. This approach ties eligibility to natal sex, which would generally be based on the sex recorded at birth on the individual's birth certificate. It is mostly efficient and effective because natal sex and sex recorded at birth are typically the same, and both typically correspond to the relevant primary and secondary sex characteristics that matter for sport.

Nevertheless, the traditional approach is both over and underinclusive: On the one hand, it includes trans boys and trans men who go on puberty blockers and gender affirming hormones beginning at the onset of female puberty; as a result, these athletes develop the male secondary sex traits that girls' and women's sport exist to exclude. On the other hand, it excludes trans girls and trans women who do the same at the onset of male puberty, and who, as a result, never develop those traits.

198. *See supra* notes 185–193 and accompanying text.

199. *See supra* notes 52–53 and accompanying text.

200. *See supra* notes 104–105 and accompanying text (detailing how this has already happened in the State of Connecticut and how the related data are being used in a Title IX OCR complaint).

In addition, many jurisdictions now permit people who are transgender to change the sex that is recorded on their birth certificates so that it accords with their gender identity; in some places, parents can do the same for their children.[201] Depending on the jurisdiction, the individual need not have gone on hormones before making this switch; that is, the switch may be permitted on some form of self-declaration.[202] As a result, at least for some trans people, the sex recorded on the birth certificate is no longer a reliable proxy either for natal sex or for the relevant sex traits.

Because of these administrative and policy concerns, but also because the law requires sex-related criteria to be closely tailored to institutional ends, we do not support this approach. In our view, transgender women and girls should not be excluded from girls' and women's sport if they have not gone through any part of male puberty. Moreover, to include transgender men and boys who are on gender affirming androgens is, in effect, no different from condoning the use of performance enhancing drugs. Still, whether it is as a matter of choice or inertia, many jurisdictions continue to provide that natal sex as recorded on the individual's birth certificate is the standard for eligibility for sex segregated sport.[203]

2. Re-imagining the Carve-out as an Identity Classification

The second option is to abandon the carve-out for females only. This would necessarily entail a rejection of the legitimacy and value of the claim from females for equality in relation to males in the education-based competitive sports space. It would involve either the full integration of sports and events, that is, all would be co-ed; or it would involve a challenge to re-imagine girls' and women's sport as a category that includes anyone who identifies as a girl or woman most broadly defined, even if they retain their full male-linked performance advantages. The best analog would be to an all-women's college that admits and retains students who identify as women regardless of their sex.[204]

Advocates for transgender rights have persuaded many secondary school athletic associations to adopt this approach. The unfounded claim that it is required by Title IX may have been at play in some cases.[205] Nevertheless, it is

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201. *See generally ID Documents Center*, NAT'L CTR. FOR TRANSGENDER EQUAL., https://transequality.org/documents (last updated Jan. 2020) (providing state-by-state information and details on New York City rules permitting parents to change their child's birth certificate).

202. *See id.*

203. *See High School Policies*, TRANSATHLETE, https://www.transathlete.com/k-12_(last visited Jan. 28, 2020).

204. *See, e.g.*, Jeremy Bauer-Wolf, *At Women's Colleges, Rules Vary Widely for Trans and Nonbinary Students*, EDUC. DIVE (Nov. 18, 2019), https://www.educationdive.com/news/at-womens-colleges-trans-and-nonbinary-applicants-face-inconsistent-rules/567537/; Rebecca Brenner Graham, *Women's Colleges Should Admit Trans Students. It's Wholly Consistent with Their Mission*, WASH. POST (Jan. 10, 2019), https://www.washingtonpost.com/outlook/2019/01/10/womens-colleges-should-admit-trans-women-its-wholly-consistent-with-their-mission/.

205. *See supra* notes 70–76 and accompanying text (discussing the state of the law); *supra* note 203 (providing an up-to-date description of state high school athletic association policies). *See e.g.*, *Complaint Targets Transgender HS Track Athletes*, ESPN (June 20, 2019), https://www.espn.com/high-school/story/_/id/27015115/complaint-targets-transgender-hs-track-athletes (discussing the claim that

viable in the long run only if these advocates can convince law and policy makers at the national level that Title IX should be revised to these ends. Specifically, they will need to convince the federal government that the original Title IX carve-out for females in sport is not a commitment it wants to keep; but that we still need—and need to support with federal funds—two classifications, both of which would be comprised of a combination of males and females, and both of which would see males in championship positions.

These are important hurdles, particularly in an adverse political climate. Not only have the last two administrations held firm to the premise that distinctions on the basis of sex in Title IX sport are necessary and appropriate, but also, this policy choice appears to be based in or at least consistent with a clear, bipartisan, nationwide consensus in favor of the traditional approach.[206] Nevertheless, the option is attractive to those who prefer that education-based sport focus on opportunities for participation not competition, including whenever possible in co-ed settings.[207] It is also attractive to those whose focus is specifically on the health and welfare of transgender people, rather than on females, on the view that at least in this period, the former need support more than the latter.[208] Finally, it is attractive to those who prefer a wait-and-see to a precautionary approach to restrictions on eligibility; they predict that trans women and girls won't have an important impact on girls' and women's sport, but that we can re-evaluate if they do.

The best argument in favor of this approach today is based in the view that almost everyone has a gender identity that aligns with their natal sex, in the still small numbers of trans girls and women who seek to be classified according to their gender identity, and in the fact that, until recently, we had not known of any in championship positions. Until recently, including them was—in effect—a non-category defeating accommodation within the existing sex segregated structure. As Rachel McKinnon has argued,

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Title IX requires the inclusion of trans girls in girls sport); *Reference Guide for Transgender Policy*, CONN. INTERSCHOLASTIC ATHLETIC CONF., https://www.casciac.org/pdfs/Principal_Transgender_Discussion_Quick_Reference_Guide.pdf (last visited on Feb. 19, 2020) (explaining that "[t]he CIAC has concluded that it would be fundamentally unjust and contrary to applicable state and federal law to preclude a student from participation on a gender specific sports team that is consistent with the public gender identity of that student for all other purposes").

206. *See supra* notes 69–76 and accompanying text. *See, e.g., Most Oppose Transgender Athletes on Opposite Sex Teams*, RASMUSSEN REP. (June 4, 2019), https://www.rasmussenreports.com/public_content/lifestyle/social_issues/most_oppose_transgender_athletes_on_opposite_sex_teams (finding that "just 28% of American Adults favor allowing transgender students to participate on the sports team of the gender they identify with"). Given that this is a breakout conversation, see s*upra* note 69, this number is likely to shift in one or the other direction, as is the number representing undecideds, i.e., 18 percent in the same survey.

207. *See infra* note 208 and accompanying text (describing this position).

208. *See* Navratilova, Coleman & Richards-Ross, *supra* note 89 (noting that "Advocates of the Equality Act who know sports or aren't science deniers . . . [argue] that it's time to shift our focus from supporting female-bodied athletes for whom Title IX has already done a lot of work, to supporting transgender women and girls who [now] need our help more").

> Since the 2004 Athens Olympics, there have been over 54,000 Olympians. Not one of them has been openly trans. There also aren't any cases of men pretending to be (trans) women. Next year, there are a few athletes who have the potential to be the first openly trans athlete to compete in the Games. None are a medal favorite. This is not the beginning of the end of women's sports.[209]

This moment is passing quickly, however, as more children identify as transgender; as we are learning to embrace them as they are; as they are increasingly comfortable coming out in high school even if they are not on hormones; and as advocacy to establish trans rights is increasingly successful in other contexts.[210] This includes recent legislation in the United States and in many countries around the world that permits trans people more easily to reform their identity documents to provide that their legal sex is their gender identity.[211] As we have already noted, it is not a coincidence that it is in the last three years we have seen the first male-to-female transgender state, national, and international champions in girls' and women's Olympic events,[212] and that international regulators are working to ensure that policies are in place to address the expected increase in numbers.[213]

McKinnon herself made history when she won gold in the women's sprint event at the 2018 and 2019 Masters Track Cycling World Championships and in the process set a women's world record.[214] She is a trans woman who has met the hormonal conditions required for inclusion in women's cycling events; she is playing by the rules established by her governing body.[215] Those rules are in play, however. On the one hand, many have expressed concern that they insufficiently account for the legacy advantages retained by trans women who physically transition after puberty.[216] On the other, some, including McKinnon, have argued that they should be revised to permit unconditional inclusion on the view that trans women are women based on their gender identity, without respect to the decisions they might take privately about gender affirming hormones or

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209. McKinnon, *supra* note 191.

210. *See supra* note 179.

211. *See, e.g.*, *ID Documents Center*, *supra* note 201 (providing up-to-date information on relevant state laws and practices).

212. *See supra* notes 181–182 and 209 and accompanying text.

213. Press Release, World Athletics, International Federations Discuss Consensus on Establishing Rules for Transgender Athletes (Oct. 31, 2019), https://www.worldathletics.org/news/press-release/international-federations-rules-transgender-a.

214. Karleigh Webb, *Trans Cyclist Rachel McKinnon Keeps Winning Championships and Her Detractors Don't Like It*, OUTSPORTS (Oct. 23, 2019), https://www.outsports.com/2019/10/23/20928252/rachel-mckinnon-trump-cycling-trans-athletes-transphobia-world-championships.

215. McKinnon, *supra* note 191.

216. *See, e.g.*, Sean Ingle, *Sports Stars Weigh in on Row Over Transgender Athletes*, GUARDIAN (Mar. 3, 2019), https://www.theguardian.com/society/2019/mar/03/sports-stars-weigh-in-on-row-over-transgender-athletes (summarizing this argument). For a good description and evaluation of the debate around legacy advantages, see generally Ross Tucker, *On Transgender Athletes and Performance Advantages*, SCI. SPORT (Mar. 24, 2019), https://sportsscientists.com/2019/03/on-transgender-athletes-and-performance-advantages/?doing_wp_cron=1576790435.8559970855712890625000.

surgery.[217] Although the call for unconditional inclusion has not yet succeeded in the elite sport space, related efforts directed at state high school athletic associations across the United States have altered that landscape.

3. Re-Imagining the Carve-Out as a Biological Classification Tied to Puberty

In 2019, in the challenge brought by Caster Semenya to the eligibility criteria for the women's category in the sport of track and field, the Court of Arbitration for Sport (CAS) explained that:

> the purpose of the male-female divide in competitive athletics is not to protect athletes with a female legal sex from having to compete against athletes with a male legal sex. Nor is it to protect athletes with a female gender identity from having to compete with athletes with a male gender identity. Rather, it is to protect individuals whose bodies have developed in a certain way following puberty from having to compete against individuals who, by virtue of their bodies having developed in a different way following puberty, possess certain physical traits that create such a significant performance advantage that fair competition between the two groups is not possible.[218]

Consistent with this rationale, the third approach affirms the carve-out for those who have not experienced male puberty. We peg this to male puberty to include in the classification all those who cannot be said to have developed the male sex-linked advantages that justify sex-segregated sport. It would include all females—however they identify—so long as they are not on masculinizing hormones; and all trans girls who, because they were on blockers and then feminizing hormones, have not experienced male puberty. This option is a challenge to imagine education-based sport as analogous to the medical setting, where sex and associated physical characteristics remain relevant; and where gender identity and expression are for the individual to resolve and others to respect as they would any central aspect of an individual's personhood.

This option is attractive for several reasons:

It is fully consistent with the carve-out's raison d'être and with its legal grounding.[219] In the language of the law, an approach that hews closely to this rationale is, as required, narrowly tailored and neither over- nor under-inclusive.

Moreover, as in other modern contexts where physical facts remain relevant to the enterprise, it distinguishes only on those objective grounds and otherwise respects the inherently personal nature of gender identity and expression. That is, it does not seek to establish, judge, or sort anyone on those different grounds that—in contrast with the physical—are ultimately unrelated to the institution's goals. But it does commit to respecting them without challenge. As it should be

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217. *See, e.g.*, Charlie Ashworth, *Women's Sports: Rachel McKinnon Believes Trans Women Have a 'Human Right' to Compete*, GIVE ME SPORT (Oct. 21, 2019), https://www.givemesport.com/1514948womens-sports-rachel-mckinnon-believes-trans-women-have-a-human-right-t-ocompete ("By preventing trans women from competing or requiring them to take medication, you're denying their human rights.").

218. Mokgadi Caster Semenya & Athletics S. Afr. v. Int'l Ass'n of Athletics Fed'ns, CAS 2018/O/5794 ¶ 559 (2019).

219. *Id.*

developmentally, there is no questioning by a school or athletic association of a child's credibility about or commitment to a particular gender identity or expression; nor is there a requirement that they agree to be fixed for a season or an academic year to their expressed preferences. They can be who they are, including in flux, throughout the relevant period.

Consistent with Title IX's original design, all females who are not on transition hormones—however they might identify—have a space in which they can not only play but also compete for the win. Except in the rare case of an exceptionally precocious child star, the policy cannot be said to incentivize a student's choice to go on gender affirming hormones. And because they have benefitted from either endogenous or exogenous male testosterone levels, the subset of trans kids who start on hormones only after the onset of puberty is not be eligible to compete in the female category; but they are eligible to participate and welcome in the male category, and—importantly—their private needs and choices will not dictate outcomes for others. In this respect, this option is the least disruptive of the existing model that does a lot of good work for the vast majority of stakeholders.

It would be most easily implemented in circumstances where school sports teams don't have to train separately, that is, where only competition itself needs to be sex segregated. In such contexts, the social aspects of participation in education-based sport would not be linked to sex or gender. Swimming, cross country, and track and field are among the sports where—at least as practiced in some places—a version of this model already exists.[220]

The principal costs associated with this approach are as follows:

Because it is not simply a re-naming of the existing sex-segregated structure, imagining the classifications as we suggest would take work, even if everyone were on board. This work would range from the relatively simple and technical to the more difficult and conceptual. For example, we would have to decide what to call the classifications and how to establish where students belong. We have labeled the classifications "male" and "female" here, but they could be labeled differently. Uniform rules would need to be changed to allow students to select the style that makes them most comfortable regardless of sex or gender. And the notion of school sports as sex or gender-specific social spaces would need to be wound down. The latter would be resisted by traditionalists but also by some trans kids and their advocates who embrace binary sex classifications and see inclusion within them as having the potential to contribute to their successful transition.[221]

Finally, regardless of how respectful and welcoming the environment is made for gender diverse students within the categories, those who may be passing do not want to be outed by sex classifications. Others who are not passing but who suffer from dysphoria and are deeply (not just politically) hurt by references to their sex-linked traits may continue to be effectively excluded from participation

220. *See, e.g.*, Josh Weinreb, *Thetford Academy Transgender Runner Embraces Her Identity and Gains Freedom*, VALLEY NEWS (May 25, 2019, 9:25 AM), https://www.vnews.com/Running-career-has-helped-Thetford-Academy-senior-Bel-Spelman-navigate-her-gender-identity-24764677.

221. *See supra* note 166 and accompanying text (noting this strategy).

and competition. Still others who do not suffer from dysphoria but who prefer to occupy spaces where sex is irrelevant may reject school sport because it is still so focused. To the extent the institution could and should produce important health and welfare benefits for these individuals, this approach would not be effective. As is the case today for kids who for various reasons eschew school sports, some will remain left out or will choose to exclude themselves.

4. Formalizing an Accommodations Approach

The fourth option is to affirm the commitment to the Title IX carve-out for females but also formally to grant authority to policymakers to accommodate gender diverse students in ways that are not category defeating. Accommodations are often preferred in circumstances that involve competing rights claims.[222] To date, some form of this approach has been preferred by those working most thoughtfully on inclusion in the elite sports space, for example within the Olympic Movement, the NCAA, and the National Scholastic Athletics Foundation (NSAF).[223]

Although it has not been formally tested to date, the NCAA policy is especially relevant as it operates within institutions governed by Title IX. It permits transgender student-athletes to compete either according to their natal sex or their gender identity. In the latter case, if the athlete is a trans man, they are required to have a therapeutic use exemption (TUE) if they are on gender affirming hormones (testosterone); and if they are a trans woman, they are required to have been on testosterone suppressants for at least a year before they are eligible for women's teams and competitions.[224] We do not have enough studied experience with trans women and girls in sport to know that suppression to a certain level for a given period of time is sufficient to wind down male-linked advantages to the point where they are not category defeating in particular sports and events. Nevertheless, the rule fits the model because it presumes an ongoing primary commitment to female athletes, which is the raison d'être for the sports exception to Title IX's non-discrimination rule; and it includes trans women when they meet

222. *See, e.g.*, *Notice, Enforcement Guidance: Reasonable Accommodation and Undue Hardship Under the Americans with Disabilities Act*, U.S. Equal Emp. Opportunity Comm'n (Oct. 17, 2002), https://www.eeoc.gov/policy/docs/accommodation.html (applying the model in the context of conflicts between employers and employees with disabilities). Accommodation is related to compromise. *See, e.g.*, Dale Eilerman, *Agree to Disagree: The Use of Compromise in Conflict Management*, MEDIATE (Oct. 2006), https://www.mediate.com/articles/eilermanD7.cfm (describing when compromise is useful in mediation).

223. Almost all elite sports institutions have adopted a rule of conditional inclusion based on testosterone levels. *See, e.g.*, *IOC Consensus Meeting on Sex Reassignment and Hyperandrogenism*, INT'L OLYMPIC COMM. (2015), https://stillmed.olympic.org/Documents/Commissions_PDFfiles/Medical _commission/201511_ioc_consensus_meeting_on_sex_reassignment_and_hyperandrogenism-en.pdf; *NCAA Inclusion of Transgender Student-Athletes*, NAT'L COLLEGIATE ATHLETIC ASS'N (2011), https://13248aea-16f8-fc0a-cf26-a9339dd2a3f0.filesusr.com/ugd/2bc3fc_4a135824fabc462183c71357c93a99b4.pdf; *National Scholastic Athletic Foundation Transgender Participation Policy and Procedure*, NAT'L SCHOLASTIC ATHLETICS FOUND. (2019), https://www.nationalscholastic.org/nbin/transgender/.

224. *NCAA Inclusion of Transgender Student-Athletes*, *supra* note 223, at 13.

relevant physical conditions.[225] At least conceptually, because testosterone is the primarily driver of the performance gap, the accommodation is viable as category affirming not defeating. As an evidentiary matter, and thus legally, the rule would be especially defensible if the NCAA were to establish a maximum allowable T level that is within the female range and then to develop a protocol for monitoring compliance.[226]

A different example of the accommodations approach outside of elite sports can be found in the policies of state athletic associations that have experience integrating male students who are not transgender into girls' sports and events. This happens where there is no boys' team and the male students can show—consistent with Title IX requirements—that they are the excluded sex. Where particular males threaten to disrupt the championship experience and hierarchy, officials have sought solutions to their inclusion that are consistent with the goals of the carve-out, such as adding lanes or running separate male and female sections of a final, and featuring separate podiums for male and female finishers. Consistent with the goals of the sports exception to Title IX's general non-discrimination rule, this has ensured that male student-athletes are not precluded from participating in their chosen sports, but also that there cannot be a male winner of the girls state championship.[227] These strategies aren't perfect fits, given that trans girls and women identify as girls and women, not as boys and men. But since sport is segregated on the basis of sex, not identity, and identity is ultimately irrelevant to sports performance, they can be useful as examples of solutions that might resolve certain impasses.

Other models that could be adapted depending on the sport and event are quotas and adjusted scores and start lines. Quotas might be especially useful in team sports situations. Joanna Harper and Tiffany Abreu have suggested they could work in volleyball and basketball, for example.[228] The basic concept of adjusted scores and start lines comes from golf, which designate different Tee boxes for males and females and—to level the playing field for golfers of different abilities—use adjusted scores (handicaps) to compare relative performances.

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225. According to the Justice Department, the NCAA rule was developed in "consult[ation] with medical experts, athletics officials, affected students, and [with advocates for transgender student-athletes]." Dear Colleague Letter, *supra* note 73 (citing NCAA Inclusion of Transgender Student-Athletes 2, 30–31, and Pat Griffin & Helen J. Carroll, On the Team: Equal Opportunity for Transgender Student Athletes (2010)). On the Team itself notes that "policies that may be appropriate at the college level may be unfair and too complicated for [the high school] level of competition." It thus encourages the development at the high school level of age-appropriate policies. *Id.* at 26. It was co-authored by two of the leading players in this area, Helen Carroll of the National Center for Lesbian Rights (NCLR) and Pat Griffin of the University of Massachusetts Amherst, in consultation with Shannon Minter, also of the NCLR, and Eric Vilain, who also consulted on the IOC policy. Both Minter and Vilain are leading experts in their respective fields, i.e., civil rights litigation and biological sex, respectively.

226. As of this writing, although we expect that most trans girls and women on hormones follow the medical standard of care which has a target of well under 5 nmol/L, the NCAA has not set a maximum allowable level, nor does it monitor compliance.

227. *See, e.g.*, Coleman, *Sex in Sport*, *supra* note 27, at 173–77 (describing the State of Massachusetts' approach to the inclusion of boys in girls' swimming events).

228. Darlington, *supra* note 116.

Different start lines could be adjusted based on the sport's average performance gap between males and females, in the manner that the distance between Tee boxes is adjusted to reflect the relative power of female and male golfers, and scores could be adjusted at the outset on the same group—rather than individual—basis. More complicated iterations of golf's handicapping system have been described elsewhere.[229] Ultimately, the key to such approaches would be assuring their efficacy and their administrative feasibility.

Like accommodations in general, accommodations in sport have the benefit of being adaptable over time based on new knowledge. For example, as we learn more about the nature and extent of the legacy advantages of going through male puberty, as well as about their particular effects in different sports and events, the specific requirements within the model could be adjusted without altering the commitment to the model itself. And as we develop a better sense of the political community's relative commitments to female sport on the one hand and to trans inclusion on the other, the reasonableness of specific conditions within models will also evolve.

The merits of and problems inherent in accommodations models are that they tend mostly, but not entirely, to satisfy principal policy goals while reducing, but not eliminating, the concerns of affected individuals. In other words, like all compromises, accommodations generally mean that no one gets everything they wanted; and, depending on the specifics, one or the other side still faces a complete loss. As it considers the question of transgender inclusion, sport is no different. Purists on both sides of the debate decry all proposed concessions: Those who want girls' and women's sport to remain exclusively for females say they cannot abide a solution that would ever see a transgender athlete in a championship position, even if she is following all of the rules. Those who want girls and women's sport to be unconditionally inclusive of transgender athletes say they cannot abide a solution that recognizes that there is a difference between females and transgender women and girls: "Transgender women are women. Period. Transgender girls are girls. Period." Those who argue from "the messy middle" can struggle to get a foothold. But given the stakes on both sides, it is surely worthwhile also to consider solutions in this space.

D. Our Recommendations

Because sex equality in education-based sport produces enormous value, and because the development of inclusive policies is separately consistent with educational institutions' goals, policymakers should affirm Title IX's original design and work to include gender diverse students within that design. Because institutional goals are different in non-elite and elite settings, approaches to inclusion should track those different goals. Throughout, policymakers should endeavor to develop strategies that will encourage as many students as possible to remain engaged in school sports as participants and as competitors.

Where it can be effective to all ends to combine teams or at least team practices and only to segregate competition itself on the basis of sex, the approach

229. *See, e.g.*, Aschwanden, *supra* note 167 (discussing the concept in general and the work of Alison Heather and colleagues in particular).

we detail in Part IIIC3—re-imagining the carve-out as a biological classification pegged to puberty—should be preferred. So long as it doesn't result in diminished coaching opportunities for females who remain underrepresented in those ranks or deter female students from staying engaged with sport, it is the most inclusive, least intrusive, and simplest to administer. Existing co-ed arrangements can be an ongoing model for this purpose.

Where combined teams or practices coupled with sex segregated competition cannot accomplish institutional goals, the accommodations approach detailed in Part IIIC4 should be adopted. This will be the case in circumstances where sex segregated teams and events remain necessary to secure parity of opportunity for females. Where the accommodations approach is adopted, trans students will train and compete consistent with their gender identity so long as their inclusion can be relevantly conditioned. The NCAA transgender policy is illustrative of a hormonal condition in this category; others that do not require medicalization— such as handicaps, offsets, and quotas—exist as more appropriate models for the high school sports space.

In high school intramural, junior varsity, and regular season play, where institutional goals are primarily related to health and fitness and to the development of social skills, unconditional inclusion of gender diverse students according to their gender identity rather than their sex will usually be category affirming. Exceptions will arise where this is not the case, for example in contact sports situations where physical safety is tied to sex-linked differences, and where regular season play determines invitational and post-season opportunities. But to the extent that including trans students according to their gender identity merely makes others uncomfortable, educators should be encouraged to educate, including to inculcate empathy and inclusivity, rather than to exclude.

Once the focus shifts to competition and to the establishment of hierarchy and the isolation and celebration of champions, unconditional inclusion of trans girls and women who have benefited from male puberty becomes category defeating. Conditional inclusion in this context is therefore appropriate. This position will not satisfy purists on either side of the issue and both have strong arguments in support of their views. Most immediately, it won't satisfy those who believe the category is inevitably defeated by the inclusion of students whose natal sex is male regardless of how their participation is conditioned. And it won't satisfy either medical providers who have built girls sport or invariable inclusion on the basis of gender identity into their treatment design or trans advocates whose movement strategy is to elide the differences between sex and identity. Ultimately, however, the standard that prevails should be one that provides for reasonable accommodations given institutional goals.

Finally, because the legal landscape has become muddied in this period, to the point that there are questions about what Title IX does or should require, the re-commitment to its original design should be codified by statute along with an allowance for reasonable, non-category defeating accommodations.[230] To the

230. The Obama and Trump Administrations were both put to this question in the context of claims for transgender inclusion and both have re-affirmed the federal government's commitment to sex equality, albeit in different forms. *See supra* notes 73–75 and accompanying text. But because the

extent possible the legislation should be based in existing language so as not to disrupt the well-established body of accompanying law, with definitions and clarifications as appropriate given the current context. Consistent with this prescription, we propose the following draft language:

> No person shall, on the basis of sex, be excluded from participation in, be denied the benefits of, be treated differently from another person or otherwise discriminated against in any interscholastic athletics offered by a recipient, and no recipient shall provide any such athletics separately on such basis.
>
> However, to secure Title IX's commitment to sex equality, a recipient may operate or sponsor separate teams and events based on sex where selection and advancement are affected by sex-linked competitive advantages or the activity involved is a contact sport in which physical safety is implicated.
>
> So long as they do not imperil female students' physical safety or diminish their competitive opportunities, a recipient that operates or sponsors separate sex teams and events may include persons of the excluded sex when their gender identity is concordant. On the same conditions, a recipient that sponsors a team for only one sex may include persons of the excluded sex. Reasonable accommodations consistent with these conditions are encouraged.
>
> For purposes of this statute, sex retains its dictionary definition as "either of the two divisions, designated female and male, by which most organisms are classified on the basis of their reproductive organs and functions."[231] It does not include sex stereotypes or legal or gender identity.

CONCLUSION

Title IX expresses society's commitment to sex equality in educational settings. At the time of the statute's enactment in 1972, this commitment was revolutionary. Today, in no small part because Americans across the political spectrum are invested in the goal, Title IX's value is mostly a given.[232] From the focus on increasing the numbers of women in STEM to the effort to eradicate the conditions that enable sexual assault, the idea that women belong as equals on campus persists. Notably, the commitment to this idea is not merely normative. As Nicholas Kristof wrote in his year-end column for the *New York Times* in 2019, "few forces change the world so much as education and the empowerment of women."[233]

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executive branch has discretion in the interpretation of federal regulations, and because administrations come and go, they can foster unnecessary confusion and ensure that the matter remains unsettled.

231. *Sex*, AM. HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE (5th ed. 2020).

232. Sandra Guy, *Title IX at 45*, SOC'Y OF WOMEN ENG'RS MAG. (Mar. 20, 2017), https://alltogether.swe.org/2017/03/title-ix-45/ ("Title IX is hugely popular, and it's a bipartisan issue. We don't expect that to change.").

233. Nicholas Kristof, *This Year Has Been The Best Year Ever*, N.Y. TIMES (Dec. 31, 2019), https://www.nytimes.com/2019/12/28/opinion/sunday/2019-best-year-poverty.html. *See also* Ana Revenga & Sudhir Shetty, *Empowering Women is Smart Economics*, 49 IMF FIN. & DEV. (2012), https://www.imf.org/external/pubs/ft/fandd/2012/03/revenga.htm.

The structure of the Title IX regulatory scheme makes clear that the goal is sex equality, not sex neutrality. Consistent with American equal protection jurisprudence and our general political inclinations, the latter is merely the preferred means to the former end. Like other sex equality measures, Title IX recognizes that females often remain disadvantaged in relation to males because of their reproductive biology and because of stereotypes about them based on that biology. Sex affirmative approaches are appropriate when sex neutrality cannot effectively address that disadvantage. Thus, such approaches may be used to overcome entrenched discriminatory patterns that are not explained by inherent differences; see special provisions for women and girls in fields in which they remain underrepresented. And they may be used to ensure that such differences are not unnecessary obstacles to important opportunities; see separate sex sport.

Notwithstanding our general preference for sex neutral measures, the sports exception to Title IX's general nondiscrimination rule has long been one of the statute's most popular features.[234] This affirmative approach is understood to be necessary to ensure that the sex-linked differences that emerge from the onset of male puberty do not stand as obstacles to sex equality in the athletic arena. From the beginning, it was understood that any different, sex neutral measure would ensure precisely the opposite—that spaces on selective teams and spots in finals and on podiums would all go to boys and men. The sports exception makes it possible for women and girls also to benefit from the multiple positive effects of these experiences, and for their communities and the broader society to reap the benefits of their empowerment.

The challenge in the beginning of the Title IX era was to conceive of and equally to support females as athletes, coaches, and sports administrators. We continue to fight for equal support as important institutions still stumble—see, for example, the dearth of female coaches in NCAA programs;[235] Nike's recently-revealed failure to keep its brightest female stars under contract when they become pregnant;[236] and USA Soccer's refusal to provide equal pay to the members of its male and female teams.[237] But as Title IX concludes its first semi-centennial, we no longer struggle as we did in the beginning with the basic concept of females as athletes. It is no longer commonplace for an athletic department to assume that a female is on the field to land a husband rather than a medal. Female puberty, pregnancy, and motherhood remain visible indicia of difference, but because of

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234. *See supra* note 62 and accompanying text (quoting Nancy Hogshead-Makar on this point).

235. Jeré Longman, *Number of Women Coaching in College Has Plummeted in Title IX Era*, N. Y. TIMES (Mar. 30, 2017), https://www.nytimes.com/2017/03/30/sports/ncaabasketball/coaches-women-titleix.html.

236. Alisia Montaño, *Nike Told Me to Dream Crazy, Until I Wanted a Baby*, N. Y. TIMES (May 12, 2019), https://www.nytimes.com/2019/05/12/opinion/nike-maternity-leave.html. The company was smart enough to continue to pay Serena Williams through her pregnancy, but other stars—including most notably Allyson Felix—were not similarly treated. Scott Davis, *Serena Williams Supports Nike After Its Maternity Pay Controversy, Saying the Company Is 'Learning from Mistakes and Doing Better'*, BUS. INSIDER (May 28, 2019, 12:51 PM), https://www.businessinsider.com/serena-williams-backs-nike-maternity-pay-controversy-2019-5.

237. Andrew Das, *U.S. Women's Soccer Team Granted Class Status in Equal Pay Lawsuit*, N. Y. TIMES (Nov. 8, 2019), https://www.nytimes.com/2019/11/08/sports/uswnt-equal-pay-lawsuit.html.

the sports exception, they are no longer disqualifying. Indeed, when the promotion is done right, these are affirmatively empowering and celebrated.[238]

The challenge as we move into Title IX's second semi-centennial is to persuade institutions finally to address the remaining disparities in their support of female athletes and female sport at the same time that we enter a new revolutionary period in which we are being asked to imagine that "female" includes individuals of both biological sexes so long as they identify as women and girls. This ask reflects the intellectual choice to conceive of sex as a social construct rather than as a fact of biology tied to reproduction, and also the strategic choice of trans rights advocates to work toward law reform that would disallow any distinctions on the basis of reproductive sex. A popular manifestation of this strategy is their insistence that we accept as threshold truth rather than as political claim the proposition that "Trans women are women, period."

The problem is that female sport is by design and for good reasons, a reproductive sex classification. These reasons have nothing to do with transphobia and everything to do with the performance gap that emerges from the onset of male puberty. Whether one is trans or not, if one is in sport and cares about sex equality, this physical phenomenon is undeniably relevant. Changing how we define "female" so that it includes individuals of both sexes, and then disallowing any distinctions among them on the basis of sex, is by definition and in effect a rejection of Title IX's equality goals. Whatever their earlier allegiances, and however they would seek to re-tool the relevant vocabulary to obscure this point, we should be clear that those push for these changes today are committed to sex neutrality, not to sex equality.

We need to find a path to equality also for trans people. And we need to be thoughtful about how they are included within an institution whose design is at odds with who they are. But given the enormous social utility and popularity of that design, as well as the work that still needs to be done to fulfill its promise, a path that involves a rejection of its principal terms is a non-starter.

In this paper, we have provided the legal history and the science that make sense of the sports exception to Title IX's general nondiscrimination rule. We have also developed the policy arguments for affirming the commitment to sex equality in the education-based sports space, and for including trans kids in that space in ways that support their healthy development without undermining either the statute's sex equality goals or its allowance for sex affirmative measures to achieve them. Finally, we have described and evaluated the options that are and ought to be on the table as civil rights advocates and policymakers work through this challenge. We do not expect that we have thought of everything; indeed, because the science and social norms are evolving as we write, we assume that regular

238. This video from the Olympic Channel, *Aiming for the Olympics After Child-Birth ft. Allyson Felix/ Top Performer*, YOUTUBE (Oct. 21, 2019), https://www.youtube.com/watch?v=TNuL38NRppg is illustrative. *See also, e.g.,* Annabelle Timsit, *Serena Williams's New Ad Gives Working Moms the Nuanced Representation They Deserve*, QUARTZ AT WORK (Aug. 29, 2018), https://qz.com/work/1372139/serena-williams-thismama-ad-offers-a-powerful-vision-of-working-moms/. For a summary of the development of the market for female sport, see Ross Andrews, *Women's Sports Popularity is Growing, According to Nielsen Study*, GLOB. SPORT MATTERS (Nov. 13, 2018), https://globalsportmatters.com/business/2018/11/13/womens-sports-popularity-is-growing-according-to-nielsen/.

updating will be necessary. But we hope that the structure, background, and arguments we've set out will be useful in the process.

Exhibit O

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ORIGINAL RESEARCH

TRANSGENDER HEALTH

Early Hormonal Treatment Affects Body Composition and Body Shape in Young Transgender Adolescents

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ABSTRACT

Background: Transgender adolescents aspiring to have the body characteristics of the affirmed sex can receive hormonal treatment. However, it is unknown how body shape and composition develop during treatment and whether transgender persons obtain the desired body phenotype.

Aim: To examine the change in body shape and composition from the start of treatment with gonadotropin-releasing hormone agonists (GnRHa) until 22 years of age and to compare these measurements at 22 years with those of age-matched peers.

Methods: 71 transwomen (birth-assigned boys) and 121 transmen (birth-assigned girls) who started treatment from 1998 through 2014 were included in this retrospective study. GnRHa treatment was started and cross-sex hormonal treatment was added at 16 years of age. Anthropometric and whole-body dual-energy x-ray absorptiometry data were retrieved from medical records. Linear mixed model regression was performed to examine changes over time. SD scores (SDS) were calculated to compare body shape and composition with those of age-matched peers.

Outcomes: Change in waist-hip ratio (WHR), total body fat (TBF), and total lean body mass (LBM) during hormonal treatment. SDS of measures of body shape and composition compared with age-matched peers at 22 years of age.

Results: In transwomen, TBF increased (+10%, 95% CI = 7−11) while total LBM (−10%, 95% CI = −11 to −7) and WHR (−0.04, 95% CI = −0.05 to −0.02) decreased. Compared with ciswomen, SDS at 22 years of age were +0.3 (95% CI = 0.0−0.5) for WHR, and 0.0 (95% CI = −0.2 to 0.3) for TBF. Compared with cismen, SDS were −1.0 (95% CI = −1.3 to −0.7) for WHR, and +2.2 (95% CI = 2.2−2.4) for TBF. In transmen, TBF decreased (−3%, 95% CI = −4 to −1), while LBM (+3%, 95% CI = 1−4) and WHR (+0.03, 95% CI = 0.01−0.04) increased. Compared with ciswomen, SDS at 22 years of age were +0.6 (95% CI = 0.4−0.8) for WHR, and −1.1 (95% CI = −1.4 to −0.9) for TBF. Compared with cismen, SDS were −0.5 (95% CI = −0.8 to −0.3) for WHR, and +1.8 (95% CI = 1.6−1.9) for TBF.

Clinical Implications: Knowing body shape and composition outcomes at 22 years of age will help care providers in counseling transgender youth on expectations of attaining the desired body phenotype.

Strengths and Limitations: This study presents the largest group of transgender adults to date who started treatment in their teens. Despite missing data, selection bias was not found.

Conclusions: During treatment, WHR and body composition changed toward the affirmed sex. At 22 years of age, transwomen compared better to age-matched ciswomen than to cismen, whereas transmen were between reference values for ciswomen and cismen. **Klaver M, de Mutsert R, Wiepjes CM, et al. Early Hormonal Treatment Affects Body Composition and Body Shape in Young Transgender Adolescents. J Sex Med 2018;15:251−260.**

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Key Words: Transgender Persons; Adolescent; Gonadotropin-Releasing Hormone Analogues; Cross-Sex Hormonal Treatment; Body Composition; Body Shape

INTRODUCTION

Adolescents with gender dysphoria aspire to have body characteristics that are similar to those of the affirmed sex. From 12 years of age, adolescents with male-to-female gender dysphoria, referred to as transwomen, and adolescents with female-to-male gender dysphoria, referred to as transmen, can be treated with gonadotropin-releasing hormone analogues (GnRHa) to suppress puberty. Subsequently, at 16 years of age and if the person still pursues gender-affirming treatment, cross-sex hormonal treatment (CHT) is added to induce the secondary sexual characteristics of the affirmed sex.[1]

During puberty, with increasing sex steroid levels, girls develop more body fat that is deposited mainly in the gluteal and femoral region (so-called gynoid region).[2,3] This leads to a female body shape with a low waist-to-hip ratio (WHR).[3,4] Pubertal boys obtain more lean body mass (LBM) and store body fat mainly in the abdominal region (also referred to as the android region),[3] resulting in a male body shape with a higher WHR than seen in girls.[3,4] It is unknown how total and regional body fat, LBM, and body shape develop in transgender adolescents treated with GnRHa and CHT, and whether this results in a similar body composition and body shape as the affirmed sex in young adulthood.

Therefore, the 1st aim of this study was to examine the effects of treatment with GnRHa and CHT on total body and regional body fat, LBM, and body shape in adolescents with gender dysphoria. A 2nd aim of this study was to compare the achieved amount of total and regional body fat, LBM, and WHR of these transwomen and transmen at 22 years of age with reference values of the affirmed sex and to examine whether they obtained the desired body composition and body shape in young adulthood. A 3rd aim was to examine the influence of pubertal stage at start of treatment on the achieved body composition and body shape at 22 years.

METHODS

Study Design and Study Population

We retrospectively reviewed the medical records of all adolescents diagnosed with gender dysphoria (*Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision*[5]) at the VU University Medical Center (Amsterdam, the Netherlands) until December 2015. All persons who started hormonal treatment before 18 years of age, started the treatment protocol as described below,[1] had undergone whole-body dual-energy x-ray absorptiometry (DXA) during treatment, and according to their age had their medical checkups in young adulthood (>20.5 years) were eligible for this study. Data obtained during routine medical checkups on anthropometry, laboratory measurements, and whole-body DXA were collected at 3 time points: start of GnRHa, addition of CHT, and result at 22 years of age (range = 20.5−23.5 years). The local ethics committee approved the study and the necessity for informed consent was waived.

Treatment Protocol

The treatment protocol, also referred to as the Dutch protocol, has been published in detail.[1] At a minimum age of 12 years and stage B2 (breast) for girls and Tanner stage G3 (genital) for boys, subcutaneous GnRHa 3.75 mg for 4 weeks was started. From 16 years of age, CHT was added with increasing doses to initiate pubertal development. Transwomen were prescribed oral 17β-estradiol starting at 5 μg per kilogram of body weight per day, which was increased by 5 μg/kg per day every 6 months until the maintenance dose of 2 mg/day was reached. Transmen used initially mixed testosterone esters (Sustanon; Organon Pharmaceuticals, Oss, The Netherlands) intramuscularly starting at 25 mg per square meter of body surface area every 2 weeks, which was increased by 25 mg/m^2 every 6 months until the maintenance dose of 250 mg every 3 to 4 weeks was achieved. When GnRHa were started after 16 years of age, CHT was added after 3 to 6 months with a start dosage of 17β-estradiol 1 mg/day or intramuscular Sustanon 75 mg/week. After 6 months, this was increased to 17β-estradiol 2 mg/day in transwomen and Sustanon 250 mg every 3 to 4 weeks in transmen. From 18 years, patients were eligible for gonadectomy, after which treatment with GnRHa ceased. From the start of treatment, patients were advised to maintain a healthy lifestyle with sportive activities and an adequate calcium intake to prevent bone loss.

Anthropometry and Whole-Body DXA

At each visit, body height, body weight, waist circumference, and hip circumference were measured. Body height was measured to the nearest 0.1 cm using a Harpenden stadiometer. Body weight was measured while the subject wore only underwear without shoes to the nearest 0.1 kg. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Waist circumference, defined as the smallest abdominal circumference, and hip circumference, measured at the level of the trochanter major, were determined with a tape measure to the nearest 0.1 cm. From these 2 measurements, the

WHR was calculated, which was used as a measure for body shape.

Whole-body and regional body fat, LBM, and total mass were measured using DXA. Until 2002, the Hologic QDR 2000 (Hologic Inc, Bedford, MA, USA) was used. From 2002, a Hologic Delphi apparatus (Hologic Inc) was used with software version 8.26, which was updated in 2005 to version 12.3.3. In 2011, the Hologic Delphi was replaced by a Hologic Discovery 13.1 (Hologic Inc), which was updated to version 3.3 in 2012 and to version 4.5.3 in 2015. During the review of medical records, DXA scans were included when they were obtained within 4 months before or after the start of GnRHa or CHT or within 1.5 years before or after the 22nd birthday. All available DXA scans from participants were obtained and reanalyzed with the most recent software version (version 13.5.3). The android region and gynoid region were defined using the software provided by Hologic. The lower boundary of the android region coincides with the upper edge of the pelvis and the height equals 20% of the distance from the upper edge of the pelvis to the bottom of the chin. The upper boundary of the gynoid region is below the upper edge of the pelvis by 1.5 times the height of the android region. The gynoid region equals twice the height of the android region.

Statistical Analyses

STATA 13.1 (StataCorp, College Station, TX, USA) was used for statistical analyses. Linear mixed model regression analyses with observations clustered within participants were performed to examine mean changes in measurements of body composition and body shape from the start of GnRHa to 22 years of age. Linear mixed models also properly deal with missing data.[6] When outcome variables were not normally distributed, the natural logarithm was obtained for analyses. Analyses were adjusted for Tanner stage at start of treatment, and BMI at start of treatment using centered variables. Student t-tests were used to examine whether changes in body shape and body composition during GnRHa monotherapy differed from changes after the addition of CHT.

Tanner stage at start of treatment, time, and the interaction between Tanner stage and time were added to the linear mixed model regression analysis to examine the influence on the achieved body composition and body shape at 22 years of age. In transwomen, Tanner stage at start was defined by testes volume and this resulted in the following categories: less than or equal to 8 mL (early puberty), 10 to 15 mL (mid-puberty), and at least 20 mL (late puberty).[7,8] In transmen, Tanner stage at start of treatment was defined by breast development.[7] Because a small number of transmen had Tanner stage II ($n = 3$) or III ($n = 8$) at the start of CHT, the 2 groups were classified as starters in early and mid-puberty. Transmen with Tanner stage IV or V were classified as starters in late puberty. Analyses were adjusted for BMI at 22 years of age.

We calculated standard deviation scores (SDS) to compare measures of body composition and body shape in participants at 22 years of age with reference values from age-matched peers with no (treatment for) gender dysphoria, also referred to as ciswomen and cismen. In transwomen and transmen, SDS were calculated for both ciswomen and cismen in order to compare measures with the at birth assigned sex and the affirmed sex. For the mean age of start of GnRHa (15 years in both transwomen and transmen) and for the age of 22 years, age-specific reference values [4,9-12] were retrieved from literature.

RESULTS

71 transwomen and 121 transmen who started with GnRHa and CHT from 1998 through 2014 were included in the present analyses (Figure 1). The general characteristics of the participants are presented in Table 1.

Change in Body Shape and Body Composition During Treatment in Transwomen

The results of the mixed model analyses showed that in transwomen waist circumference (+8 cm, 95% CI = 5–10, $P < .001$) and hip circumference (+17 cm, 95% CI = 13–21, $P < .001$) increased and WHR decreased (−0.04, 95% CI = −0.05 to −0.02, $P < .001$). The percentage of total body fat increased (+9%, 95% CI = 8–11, $P < .001$) and thus the percentage of LBM decreased (−9%, 95% CI = −11 to −8, $P < .001$; Table 2, Figure 2). Percentage of body fat increased in the android region (+9%, 95% CI = 6–12, $P < .001$) and the gynoid region (+11%, 95% CI = 9–12, $P < .001$; Table 2). Changes in body composition and body shape measurements were not different after adjustment for Tanner stage at start of treatment, or BMI at start of treatment.

Change in Body Shape and Body Composition During Treatment in Transmen

Transmen showed increases in waist circumference (+6 cm, 95% CI = 4–8, $P < .001$), hip circumference (+5 cm, 95% CI = 2–7, $P < .001$), and WHR (+0.03, 95% CI =

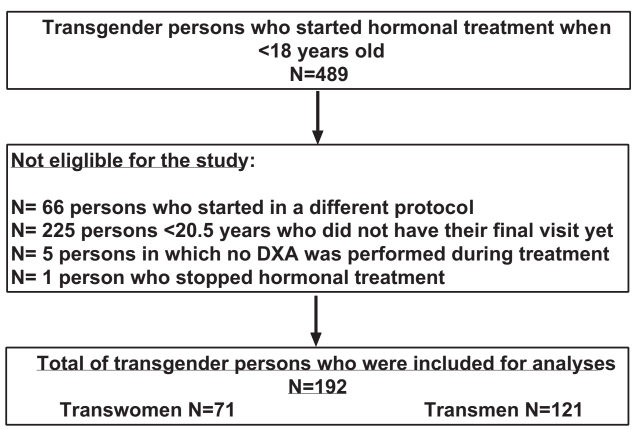

Figure 1. Flowchart of participant inclusion process. DXA = whole-body dual-energy x-ray absorptiometry.

Table 1. Characteristics of adolescents who started treatment with GnRHa and CHT at the VU University Medical Center from 1998 through 2014*

	Transwomen	Transmen
Adolescents	71	121
Age at start of GnRHa (y)	14.5 ± 1.8	15.3 ± 2.0
Age at start of CHT (y)	16.4 ± 1.1	16.9 ± 0.9
Ethnicity, %		
Caucasian	98	94
Asian	1	2
Black American	1	2
Occurrence of menarche, %†	—	84
BMI at start (kg/m^2)	19.8 (18.0–22.0)	20.6 (19.1–23.1)
Duration of GnRHa monotherapy (y)	2.1 (1.0–2.8)	1.0 (0.5–2.9)
Duration of GnRHa + CHT (y)	3.1 (2.5–3.6)	2.4 (2.0–3.1)
Duration of CHT monotherapy (y)	2.8 (1.6–3.4)	3.0 (1.9–3.4)
E2 level at start of GnRHa (pmol/L)	50 (20–79)	112 (70–202)
E2 level at start of CHT (pmol/L)	25 (20–31)	28 (23–36)
E2 level at 22 y of age (pmol/L)	121 (81–154)	70 (43–135)
T level at start of GnRHa (nmol/L)	10.0 (4.3–14.0)	1.0 (1.0–1.3)
T level at start of CHT (nmol/L)	1.0 (1.0–1.0)	1.0 (1.0–1.0)
T level at 22 y of age (nmol/L)	1.0 (0.8–1.0)	16.0 (8.8–37.0)
SDS at start vs ciswomen		
BMI	0.1 (−0.1 to 0.4)	0.4 (0.4–0.8)
Waist	0.6 (0.3–0.9)	0.6 (0.3–0.8)
Hip	0.0 (−0.2 to 0.2)	1.1 (0.1–0.5)
WHR	0.9 (0.6–0.9)	0.2 (0.0–0.3)
Total body fat	−0.9 (−1.0 to −0.7)	−0.1 (−0.2 to 0.1)
Lean body mass	2.5 (2.0–2.8)	1.3 (1.0–1.5)
SDS at start vs cismen		
BMI	0.4 (0.1–0.7)	0.7 (0.7–1.1)
Waist	0.1 (−0.2 to 0.4)	0.1 (−0.2 to 0.3)
Hip	0.3 (0.0–0.6)	0.7 (0.4–0.8)
WHR	−0.2 (−0.3 to 0.0)	−1.0 (−1.0 to −0.7)
Total body fat	1.6 (1.5–1.8)	2.0 (1.9–2.0)
Lean body mass	−0.7 (−0.9 to −0.6)	−1.1 (−1.1 to −1.0)

BMI = body mass index; CHT = cross-sex hormonal treatment; E2 = estradiol; GnRHa = gonadotropin-releasing hormone analogues; SDS = SD score; T = testosterone; WHR = waist-to-hip ratio.

*Data are presented as number, mean ± SD, median (interquartile range), or SDS (95% CI).

†Data were missing for 8% of transmen.

0.01–0.04, $P < .002$). Percentage of total body fat decreased (−3%, 95% CI = −4 to −2, $P < .001$), so percentage of LBM increased (+3%, 95% CI = 2–4, $P < .001$; Table 2, Figure 2). Percentage of body fat decreased in the gynoid region (−5%, 95% CI = −6 to −3, $P < .001$) with no change in the android region (+1%, 95% CI = 0–3, $P = .18$; Table 2). Changes in body composition and body shape measurements were not different after adjustment for Tanner stage at start of treatment, or BMI at start of treatment.

Body Shape and Body Composition at 22 Years Compared With Peers

SDS of body shape and body composition in transgender persons for both ciswomen and cismen are presented in Table 3.

Influence of Tanner Stage at Start on Body Shape and Body Composition at 22 Years

Transmen who started CHT in early or mid-puberty had a higher WHR than transmen who started treatment in late puberty. Transwomen tended to have a lower WHR starting in early or mid-puberty than those who started in late puberty. No differences in percentage of total body fat or percentage of total LBM were found across Tanner stages at start of treatment in transwomen and transmen (Table 4).

DISCUSSION

This study of 71 transwomen and 121 transmen shows that measurements of body shape and body composition change

Table 2. Measurements of body shape and body composition at the start of GnRHa, the start of CHT, and at 22 years of age in transwomen (n = 71) and transmen (n = 121)

	Start of GnRH	Start of CHT	22 y of age
Transwomen			
Body weight (kg)	58 (56–61)	66 (63–69)	76 (71–82)
BMI (kg/m^2)	20.2 (19.4–20.9)	21.3 (20.5–22.0)	23.2 (21.6–24.8)
Waist circumference (cm)*	71 (69–73)	75 (73–77)	79 (77–82)
Hip circumference (cm)*	89 (87–91)	95 (93–97)	106 (102–110)
WHR*	0.81 (0.79–0.82)	0.79 (0.78–0.80)	0.77 (0.75–0.79)
Body fat			
Total body (%)*	25 (23–26)	31 (29–32)	34 (32–36)
Android (%)*	23 (21–25)	28 (26–31)	32 (28–36)
Gynoid (%)*	29 (27–30)	36 (34–38)	40 (38–42)
Lean body mass			
Total body (%)*	75 (74–77)	69 (68–71)	66 (64–68)
Transmen			
Body weight (kg)	58 (56–61)	63 (60–65)	69 (66–71)
BMI (kg/m^2)	21.6 (20.9–22.3)	22.5 (21.7–23.2)	23.9 (23.0–24.7)
Waist circumference (cm)*	71 (69–72)	73 (71–74)	77 (75–79)
Hip circumference (cm)*	92 (90–93)	95 (93–97)	96 (94–99)
WHR*	0.77 (0.76–0.78)	0.76 (0.75–0.77)	0.80 (0.78–0.82)
Body fat			
Total body (%)*	30 (29–31)	33 (32–35)	27 (26–28)
Android (%)*	29 (27–30)	33 (32–35)	30 (28–32)
Gynoid (%)*	36 (35–37)	39 (38–40)	31 (30–33)
Lean body mass			
Total body (%)*	70 (69–71)	67 (66–68)	73 (72–74)

BMI = body mass index; CHT = cross-sex hormonal treatment; GnRHa = gonadotropin-releasing hormone analogues; WHR = waist-to-hip ratio.
*Percentages of missing data for anthropometrics were 11% in transwomen and 18% in transmen for start of GnRHa, 10% in transwomen and 13% in transmen for start of CHT, and 71% in transwomen and 76% for visit at 22 years of age. For measurements of body composition examined by whole-body dual-energy x-ray absorptiometry, percentages of missing data were 12% in transwomen and 11% in transmen for start of GnRHa, 36% in transwomen and 45% in transmen for start of CHT, and 64% in transwomen and 65% in transmen at 22 years of age.

toward the values of the affirmed sex during treatment with GnRHa and CHT. As a result of these changes, in young adult transwomen at 22 years of age, SDS for WHR, body fat, and LBM showed greater similarity to ciswomen than to cismen. In transmen at the same age, SDS for WHR, body fat, and LBM were between reference values for ciswomen and cismen. The achieved body fat and LBM at 22 years were similar across different Tanner stages at start of treatment in transwomen and transmen. However, in transmen, an earlier Tanner stage at start of treatment appeared to be associated with a closer resemblance of body shape to their affirmed sex at 22 years, and this tended to be the same in transwomen.

Compared with ciswomen and cismen in adolescence, transgender adolescents who are treated with GnRHa and CHT exhibit greater changes in body composition. A larger increase in percentage of body fat has been seen in transwomen compared with ciswomen within the same lifespan.[10] Transmen exhibit decreased percentage of body fat, whereas percentage of body fat in cismen remains stable during puberty.[10] This observation is likely explained by the fact that prepubertal girls already have more body fat than prepubertal boys, and therefore transgender persons have a different body composition at the start of hormonal treatment than age-matched peers of the affirmed sex.[13] Also, compared with adult transgender persons treated with CHT,[14,15] larger changes in body shape and body composition are seen in transgender persons who start in adolescence. Moreover, transgender persons who start treatment in adolescence have at 22 years of age a body composition that approaches the affirmed sex more closely than transgender persons who start CHT in adulthood.[15]

The appropriate moment of starting gender reassignment continues to be a topic of debate.[16] The findings of this study favor starting treatment in an early stage of puberty, because this appears to be associated with a closer resemblance of body shape to the affirmed sex at 22 years. This observation can be explained in part by the fact that in early puberty there is no distinct sex-specific body fat distribution, but also other factors can contribute to this difference. For instance, the period of gonadal suppression is generally considered a period of status quo. However, it can be postulated that a body of a transwomen

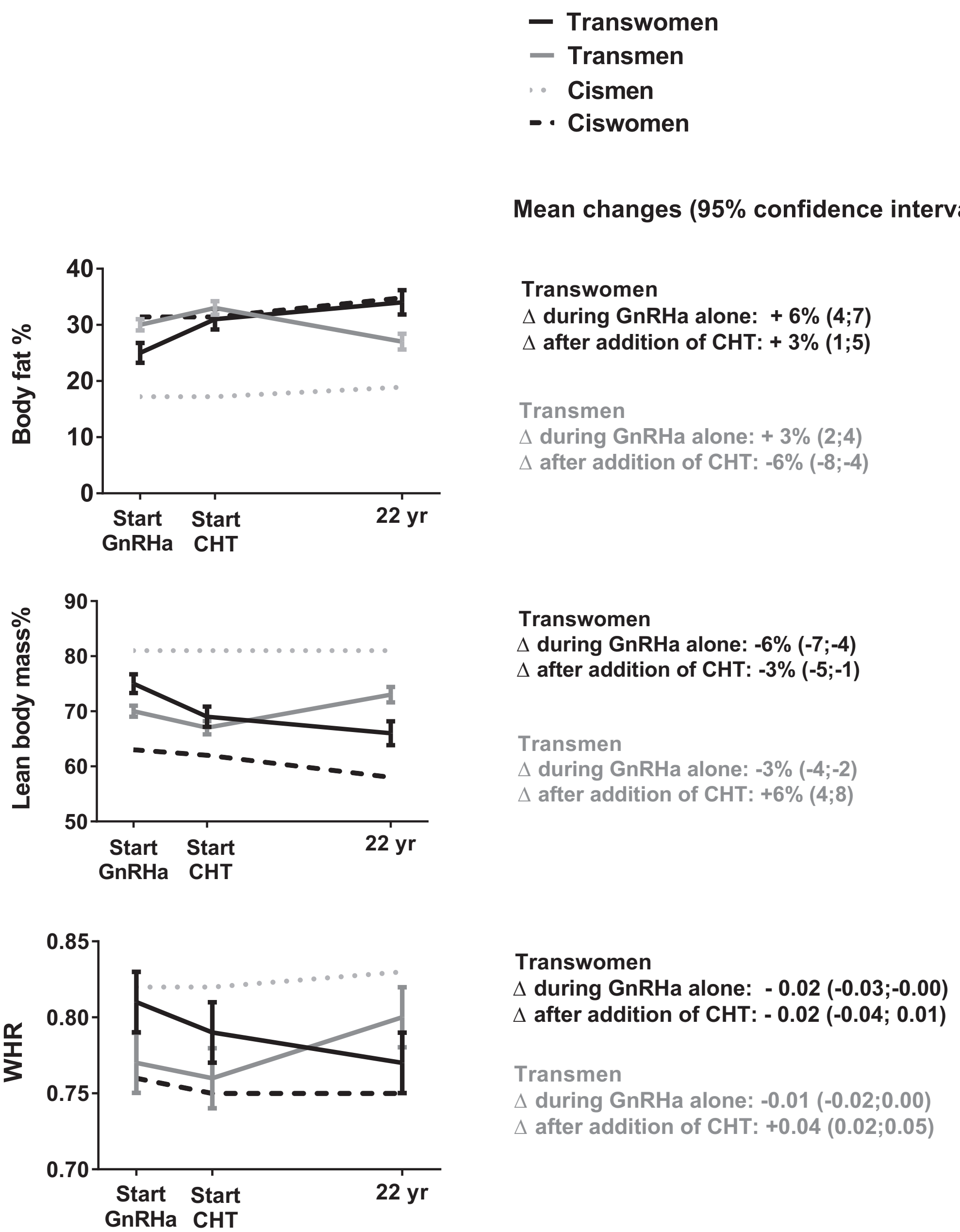

Figure 2. Changes (+95% CI) in percentage of total body fat, percentage of total body lean mass, and WHR in transwomen and transmen from the start of GnRHa to 22 years of age examined with mixed-model analyses using reference values for ciswomen and cismen. Reference data for ciswomen and cismen are shown for percentage of body fat,[10] percentage of lean body mass,[10] and WHR.[4] Mean differences between changes during GnRHa alone and changes after the addition of CHT in transwomen were +3 (95% CI −0 to 5) for percentage of total body fat, −3 (95% CI −5 to 0) for percentage of lean body mass, and 0.00 (95% CI −0.02 to 0.03) for WHR and in transmen were +9 (95% CI 7–11) for percentage of total body fat, −9 (95% CI −11 to −7) for percentage of lean body mass, and −0.04 (95% CI −0.06 to −0.02) for WHR. CHT = cross-sex hormonal treatment; GnRHa = gonadotrophin-releasing hormone analogues; WHR = waist-to-hip ratio.

in a prolonged androgen-deprived state might respond differently to estrogens than a body that has had greater androgen exposure. Although programming properties of androgens are most pronounced prenatally, during puberty programming effects have been described in the brain.[17] Therefore, other sex dimorphic organs such as body fat might also undergo androgen-induced programming that results in a lesser response to estrogens. To achieve a better outcome (ie, greater resemblance to the affirmed sex), both this phase of gonadal suppression can be modulated as the phase of gonadal suppression combined with CHT. Although in this study the period of CHT did not differ much between pubertal groups, previous

Table 3. SDS of body shape and body composition in trans persons at 22 years of age for ciswomen and cismen

	Transwomen (n = 71)		Transmen (n = 121)	
	SDS for ciswomen	SDS for cismen	SDS for ciswomen	SDS for cismen
BMI	+0.4 (−0.2 to 1.0)	+0.4 (−0.2 to 1.0)	+0.5 (0.3–0.8)	+0.6 (0.3–0.8)
Waist circumference	+1.1 (0.8–1.6)	−0.1 (−0.4 to 0.3)	+0.8 (0.5–1.1)	−0.1 (−0.4 to 0.3)
Hip circumference	+1.4 (1.0–1.9)	+1.8 (1.3–2.4)	+0.2 (−0.2 to 0.5)	+0.3 (−0.2 to 0.7)
WHR	+0.3 (0.0–0.5)	−1.0 (−1.3 to −0.7)	+0.6 (0.4–0.8)	−0.5 (−0.8 to −0.3)
Total body fat	−0.4 (−0.8 to 0.0)	+2.1 (2.1–2.3)	−1.1 (−1.4 to −0.9)	+1.8 (1.6–1.9)
Android fat	−0.1 (−0.3 to 0.3)	+0.8 (0.6–1.1)	−0.3 (−0.4 to 0.0)	+0.7 (0.5–0.9)
Gynoid fat	−0.1 (−0.4 to 0.3)	+2.1 (1.8–2.3)	−1.7 (−1.8 to −1.5)	+0.9 (0.8–1.1)
Lean body mass	+1.3 (0.8–1.8)	−1.4 (−1.5 to −1.2)	+3.0 (2.8–3.3)	−0.9 (−0.9 to −0.8)

BMI = body mass index; SDSs = SD scores; WHR = waist-to-hip ratio.

Table 4. Measurements of body shape and body composition at 22 years of age shown per category of Tanner stage at start of treatment and differences between those categories

	Tanner stages at start of treatment			Difference between Tanner stages	
Transwomen	Early puberty (n = 16)	Mid-puberty (n = 21)	Late puberty (n = 34)	ΔEarly vs mid-puberty	ΔEarly vs late puberty
Age at start (y)	13.2 (12.8–13.5)	13.3 (13.1–14.0)	15.6 (14.3–17.2)		
Duration of GnRHa monotherapy (y)	2.7 (2.4–3.1)	2.7 (2.1–3.1)	1.0 (0.6–1.6)		
Duration of GnRHa + CHT (y)	3.0 (2.6–3.6)	3.1 (2.6–3.7)	3.1 (2.3–3.5)		
BMI (kg/m^2)	23.8 (21.5–26.2)	20.9 (18.7–23.1)	24.2 (22.8–25.6)	2.9 (−0.3 to 6)	−0.4 (−3.1 to 2.3)
SDS for ciswomen	0.6 (−0.2 to 1.5)	−0.4 (−1.2 to 0.4)	2.1 (0.3–1.3)		
WHR	0.75 (0.71–0.79)	0.75 (0.69–0.80)	0.78 (0.76–0.80)	0.00 (−0.07 to 0.07)	−0.03 (−0.08 to 0.02)
SDS for ciswomen	0.0 (−0.5 to 0.5)	0.0 (−0.8 to 0.6)	0.4 (0.1–0.6)		
Total body fat (%)	33 (29–38)	30 (25–35)	34 (32–36)	3 (−4 to 10)	−1 (−6 to 4)
SDS for ciswomen	−0.2 (−0.8 to 0.4)	−0.6 (−1.4 to 0.0)	−0.1 (−0.4 to 0.1)		
Lean body mass (%)	67 (62–72)	70 (65–75)	66 (64–68)	−3 (−10 to 4)	+1 (−4 to 6)
SDS for ciswomen	1.5 (0.3–2.8)	2.3 (1.0–3.5)	1.3 (0.8–1.8)		

Transmen	Early to mid-puberty (n = 11)	Late puberty (n = 110)	ΔEarly to mid vs late puberty
Age at start (y)	12.3 ± 0.5	15.6 ± 1.7	
Duration of GnRHa monotherapy (y)	3.5 (3.4–3.9)	0.9 (0.5–2.0)	
Duration of GnRHa + CHT (y)	2.2 (2.0–2.5)	2.5 (1.9–3.2)	
BMI (kg/m^2)	22.5 (19.8–25.1)	23.9 (23.0–24.7)	−1.4 (−4.2 to 1.4)
SDS for cismen	0.1 (−0.9 to 1.1)	0.7 (0.3–1.0)	
WHR	0.85 (0.80–0.90)	0.79 (0.77–0.80)	0.06 (0.02 to 0.12)
SDS for ciswomen	0.3 (−0.5 to 1.2)	−0.7 (−1.0 to −0.5)	
Total body fat (%)	26 (21–31)	27 (26–29)	−1 (−6 to 4)
SDS for cismen	1.7 (1.3–2.0)	1.8 (1.7–1.9)	
Lean body mass (%)	74 (69–79)	73 (72–74)	1 (−4 to 6)
SDS for cismen	−0.8 (−1.1 to −0.4)	−0.9 (−0.9 to −0.8)	

BMI = body mass index; CHT = cross-sex hormonal treatment; GnRHa = gonadotropin-releasing hormone analogues; SDS = SD score; WHR = waist-to-hip ratio.

studies have shown that in adult transwomen[18]—but not in transmen[19]—a longer period of CHT establishes ongoing changes in body composition after the 1st year of treatment, which also could be applicable to body fat distribution and body shape. Therefore, one can postulate that starting CHT earlier than the current recommended age of 16[20] would improve outcomes in young adulthood.

We observed that transwomen at 22 years more closely resembled the affirmed sex regarding total body fat than transmen did. Body composition is the result of an interplay among multiple factors, including hormonal status, genetic predisposition, and lifestyle features such as diet and physical activity levels. A variance in these factors could explain this difference in treatment results between transwomen and transmen. Before the start of GnRHa, this difference was already present. Transmen had a percentage of total body fat very similar to that of ciswomen (SDS = −0.1), but transwomen had a percentage of body fat closer to that of ciswomen (SDS = −0.9) than to that of cismen (SDS = 1.6). The cause of the increased percentage of body fat and BMI in transwomen is unknown, but it can be postulated that psychological stress from gender dysphoria and an inactive lifestyle[21] could have contributed. Alternatively, the genetic predisposition, independent of hormonal treatment, of transmen could have resulted in less comparable values to their affirmed sex at 22 years than that of transwomen.[22] It can be debated whether the 46,XX karyotype[23] or other autosomal genes[24] are responsible.

As shown in Figure 2, the largest changes in transwomen were seen during GnRHa monotherapy (ie, during the suppression of testosterone). In transmen, the largest change was observed after the start of testosterone treatment. Therefore, it can be postulated that the suppression or addition of testosterone has a greater impact than the suppression or addition of estradiol. However, it is unclear whether the larger increase in body fat during GnRHa monotherapy in transwomen is due solely to the direct absence of testosterone action or the hypogonadal state itself. Indeed, also in transmen an increase in body fat was seen during GnRHa monotherapy. The larger change in body fat in transmen after the addition of testosterone could be due to the known lipolytic and anabolic effects of testosterone,[25] which in turn could be enhanced by practicing more sports or strength training in later adolescence.

This study is the 1st examining the effects of GnRHa and CHT on body shape and body composition in a large cohort of transgender adults who started treatment in their teens. A limitation of our study is the presence of missing data, which is seen more often in studies with a retrospective design when data are collected during regular patient care. However, our missing data were missing ad random and analyses between persons with missing data and persons without missing data did not indicate selection bias. Another limitation of our study is that (change in) body fat and LBM are dependent on other factors such as diet and physical activity and those were not systematically recorded.

This study provides insight into the effects of GnRHa and CHT on body shape and body composition during treatment in adolescence. Transgender adolescents starting treatment can be better informed on the extent to which their bodies will change and on what to expect of the results of such changes in young adulthood. Also, the finding that an early start of treatment in transmen results in a body shape that more closely resemble those of the affirmed sex than a late start supports early medical intervention.

The transgender persons included in this study were the first adolescents to be treated with the Dutch protocol.[1] Despite the favorable results on body shape and body composition, future research is warranted to improve current treatment protocols or devise alternative treatment protocols when GnRHa are not available.[26] Further, this study focused on body shape and body composition as important features of physical appearance, but it would also be of interest to determine the effects on body composition in the context of cardiovascular risk. For example, visceral fat seems to play an important role in the onset of insulin resistance and the metabolic syndrome,[27,28] and thus the study of changes in subcutaneous and visceral fat depots and their relation to cardiometabolic outcome could be relevant in the future.

CONCLUSION

Transwomen who started treatment with GnRHa and CHT in adolescence showed an increase in body fat with a decrease in LBM and WHR. At 22 years of age, their body shape and body composition were more similar to those of ciswomen than to those of cismen. In transmen, an increase in LBM and WHR was seen with a decrease in body fat during therapy, and at 22 years they had values between reference values for ciswomen and cismen. The achieved body fat and LBM at 22 were similar across different Tanner stages at start of treatment in transwomen and transmen. However, in transmen, start of treatment in early or mid-puberty resulted in a body shape more similar to that of the affirmed sex, and this tended to be the same in transwomen.

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REFERENCES

1. Delemarre-van de Waal HA, Cohen-Kettenis PT. Clinical management of gender identity disorder in adolescents: a protocol on psychological and paediatric endocrinology aspects. **Eur J Endocrinol 2006;155:131-137**.
2. Wells JCK. Sexual dimorphism of body composition. **Best Pract Res Clin Endocrinol Metab 2007;21:415-430**.
3. Taylor RW, Grant AM, Williams SM, et al. Sex differences in regional body fat distribution from pre- to postpuberty. **Obesity 2010;18:1410-1416**.
4. Fredriks AM, van Buuren S, Fekkes M, et al. Are age references for waist circumference, hip circumference and waist-hip ratio in Dutch children useful in clinical practice? **Eur J Pediatr 2005;164:216-222**.
5. American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4th ed, text rev. Washington, DC: American Psychiatric Association; 2000.
6. Twisk JWR, de Boer M, de Vente W, et al. Multiple imputation of missing values was not necessary before performing a longitudinal mixed-model analysis. **J Clin Epidemiol 2013;66:1022-1028**.
7. Tanner JM, Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. **Arch Dis Child 1976;51:170-179**.
8. Prader A. Testicular size: assessment and clinical importance. **Triangle 1966;7:240-243**.
9. Fredriks AM, van Buuren S, Wit JM, et al. Body index measurements in 1996–7 compared with 1980. **Arch Dis Child 2000;82:107-112**.
10. van der Sluis IM, de Ridder MAJ, Boot AM, et al. Reference data for bone density and body composition measured with dual energy x ray absorptiometry in white children and young adults. **Arch Dis Child 2002;87:341-347**.
11. Stults-Kolehmainen MA, Stanforth PR, Bartholomew JB. Fat in android, trunk, and peripheral regions varies by ethnicity and race in college aged women. **Obesity 2012;20:660-665**.
12. Stults-Kolehmainen MA, Stanforth PR, Bartholomew JB, et al. DXA estimates of fat in abdominal, trunk and hip regions varies by ethnicity in men. **Nutr Diabetes 2013;3:1-6**.
13. Taylor RW, Gold E, Manning P, et al. Gender differences in body fat content are present well before puberty. **Int J Obes 1997;21:1082-1084**.
14. Klaver M, Dekker MJHJ, de Mutsert R, et al. Cross-sex hormone therapy in transgender persons affects total body weight, body fat and lean body mass: a meta-analysis. **Andrologia** https://doi.org/10.1111/and.12660. E-pub ahead of print.
15. Klaver M, Dekker MJHJ, Schreiner T, et al. Cross-sex hormone therapy and the effects on fat distribution in transgender persons. Presented at: 24th WPATH Symposium; Amsterdam, The Netherlands; 2016.
16. de Vries ALC, Klink D, Cohen-Kettenis PT. What the primary care pediatrician needs to know about gender incongruence and gender dysphoria in children and adolescents. **Pediatr Clin North Am 2016;63:1121-1135**.
17. Schulz KM, Sisk CL. The organizing actions of adolescent gonadal steroid hormones on brain and behavioral development. **Neurosci Biobehav Rev 2016;70:148-158**.
18. Mueller A, Zollver H, Kronawitter D, et al. Body composition and bone mineral density in male-to-female transsexuals during cross-sex hormone therapy using gonadotrophin-releasing hormone agonist. **Clin Endocrinol Diabetes 2011;119:95-100**.
19. Mueller A, Haeberle L, Zollver H, et al. Effects of intramuscular testosterone undecanoate on body composition and bone mineral density in female-to-male transsexuals. **J Sex Med 2010;7:3190-3198**.
20. Hembree WC, Cohen-Kettenis P, Delemarre-van de Waal HA, et al. Endocrine treatment of transsexual persons: an Endocrine Society clinical practice guideline. **J Clin Endocrinol Metab 2009;94:3132-3154**.
21. Jones BA, Arcelus J, Bouman WP, et al. Barriers and facilitators of physical activity and sport participation among young transgender adults who are medically transitioning. **Int J Transgend 2017;18:227-238**.
22. Samaras K, Spector TD, Nguyen TV, et al. Independent genetic factors determine the amount and distribution of fat in women after the menopause. **J Clin Endocrinol Metab 1997;82:781-785**.
23. Arnold AP. The organizational-activational hypothesis as the foundation for a unified theory of sexual differentiation of all mammalian tissues. **Horm Behav 2009;55:570-578**.

24. Chagnon YC, Rice T, Pérusse L, et al. Genomic scan for genes affecting body composition before and after training in Caucasians from HERITAGE. **J Appl Physiol 2001; 90:1777-1787**.
25. Geer EB, Shen W. Gender differences in insulin resistance, body composition, and energy balance. **Gend Med 2009; 6:60-75**.
26. Tack LJW, Heyse R, Craen M, et al. Consecutive cyproterone acetate and estradiol treatment in late-pubertal transgender female adolescents. **J Sex Med 2017;14:747-757**.
27. Després JP, Lemieux I. Abdominal obesity and metabolic syndrome. **Nature 2006;444:881-887**.
28. Tchernof A, Després JP. Pathophysiology of human visceral obesity: an update. **Physiol Rev 2013;93:359-404**.

Exhibit P

Excellence Award, the (UK) Biochemical Society's Teaching Excellence Award, the (UK) Physiological Society's Otto Hutter Teaching Prize, and Fellowship of the British Pharmacological Society & its Zaimis Prize.

Posted in **Career**, **Career Development**, **Collaboration**, **Community of Practice**, **Course Design**, **Curriculum**, **Professional Development**, **Teaching Strategies**, **Undergraduate Physiology** on **August 25, 2021 [https://blog.lifescitrc.org/pecop/2021/08/25/the-capstone-experience-implementing-lessons-learned-form-a-pandemic-educational-environment-to-create-inspirational-real-world-educational-experiences/]** by **Margaret Stieben** (**Posts** | **Profile**)
Leave a comment

Comment

Exhibit 073

AUGUST 18TH, 2021

The Olympics, sex, and gender in the physiology classroom

The recent Tokyo Olympic Games present an opportunity for a number of intriguing discussions in a physiology classroom. Typical discussion topics around the Olympic Games involve muscle strength, muscle power, aerobic fitness, bioenergetics, and a number of other physiological factors that determine athletic performance. Coronavirus, immunity, disease transmission, and similar topics may be unique areas of discussion related to the Tokyo Olympic Games. Another topic that has been prevalent in the news for the Tokyo Olympic Games is the role of sex and gender in athletic competition.

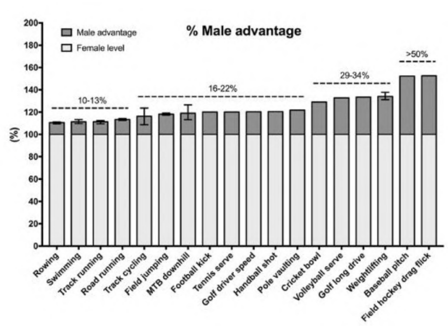
Before and during the Tokyo Olympic Games several athletes were featured in news headlines due to either gender identity or differences of sexual development (DSD, also sometimes called disorders of sexual development). Male-to-female transgender athletes competing in women's sports in the Tokyo Olympic Games include weightlifter Laurel Hubbard, archer Stephanie Barrett, cyclist Chelsea Wolfe, soccer player Quinn, and volleyball player Tifanny Abreu, (1, 2). There have also been news stories about Caster Semenya, Christine Mboma, and Beatrice Masilingi being ineligible to participate in the Olympics due to their DSD causing their serum testosterone concentrations to be above the allowed limits for female athletes (3, 4). In addition to physiology sex and gender are interwoven with culture, religion, and politics, so how to discuss sex and gender in the physiology classroom needs to be carefully considered by each instructor depending on the campus climate, policies, and individual comfort level with walking into these potential minefields. However, sex and gender in sports are very appropriate topics to discuss from a physiological perspective.

Although sex and gender have been used interchangeably in common conversation and in the scientific literature, the American Psychological Association defines sex as "physical and biological traits that distinguish between males and females" (5) whereas gender "implies the psychological, behavioral, social, and cultural aspects of being male or female (i.e., masculinity or femininity)" (6). Using these definitions can be helpful to draw a clear distinction between gender (and/or gender identity) as a social construct and sex as a biological variable, which can help focus the discussion on physiology.

As reviewed by Mazure and Jones (7) since 1993 the NIH puts a priority on funding research that includes women as well as men in clinical studies and includes an analysis of the results by sex or gender. Mazure and Jones (7) also summarized a comprehensive 2001 Institute of Medicine sponsored evaluation that concluded that every cell has a sex. A 2021 Endocrine Society scientific statement provides considerable information on the biological basis of human sexual dimorphism, disorders of sexual development, and lack of a known biological underpinning for gender identity (8). On August 12, 2021 a PubMed search using the term "Sex Matters" (in quotation marks) returned 179 results, with many of the linked papers demonstrating the importance of sex for health, disease, and overall biological function (without quotation marks there were 10,979 results). Given that there have been various discussions in the news media and across social media blurring the distinction between sex and gender, it is very important that students in physiology understand that sex in humans is an important biologically dimorphic trait of male or female.

Relevant to a discussion of the Olympic Games, the differences in performance between male and female running has been analyzed for world's best and world's 100th best (9), annual world's best performance (10), world record performance (11-13), Olympic and elite performance (13-16), High School performance in CA, FL, MN, NY, and WA (17), and 100 all-time best Norwegian youth performance (18). Hilton and Lundberg (19) also provided an excellent review of the large differences in athletic performance between men and women in numerous sports. Overall, by mid-puberty males outperform comparably aged and trained females by 10-60%, depending on the sport (see figure 1 of Hilton and Lundberg, reproduced here with no changes under the Creative Commons license https://creativecommons.org/licenses/by/4.0/).

Fig. 1 The male performance advantage over females across various selected sporting disciplines. The female level is set to 100%. In sport events with multiple disciplines, the male value has been averaged across disciplines, and the error bars represent the range of the advantage. The metrics were compiled from publicly available sports federation databases and/or tournament/competition records. *MTB* mountain bike



Hilton and Lundberg (19) also reviewed the present state of research regarding the effects of male-to-female hormone treatment on muscle strength and body composition and concluded that men typically have 45% more muscle mass than women, and male-to-female hormone treatment reduces muscle mass by ~5%. These authors also concluded that men typically have 30-60% higher muscle strength than women, and male-to-female hormone treatment reduces muscle strength by 0-9%. Overall, Hilton and Lundberg (19) conclude that transwomen retain considerable advantages over cisgender women even after 1-3 years of male-to-female hormone treatment. Harper at al. (20) also reviewed the research regarding the effects of male-to-female hormone treatment on muscle strength and body composition and came to the same conclusions as Hilton and Lundberg. Harper et al. (20) further concluded that male-to-female hormone treatment eliminates the difference in hemoglobin concentrations between cisgender men and women. In a single research project, Roberts et al. (21) observed that before transition male-to-female members in the US Air Force completed a 1.5 mile running fitness test 21% faster than comparably aged cisgender women. After 2.5 years of male-to-female hormone treatment the transwomen completed the 1.5 mile running fitness test 12% faster than comparably aged cisgender women. (Figure 1 Hilton and Lundberg)

All of the previously mentioned information is important to consider when asking if transwomen can be fairly and safely included in women's sports. It is also important to note that the effects of male-to-female hormone treatment on important determinants of athletic performance remain largely unknown. Measurements of VO2max in transwomen using direct or indirect calorimetry are not available. Measurements of muscle strength in standard lifts (e.g. bench press, leg press, squat, deadlift, etc.) in transwomen are not available. Nor have there been evaluations of the effects of male-to-female hormone therapy on agility, flexibility, or reaction time. There has been no controlled research evaluating how male-to-female hormone treatment influences the adaptations to aerobic or resistance training. And there are only anecdotal reports of the competitive athletic performance of transwomen before and after using male-to-female hormone treatment.

The safe and fair inclusion of transgender athletes and athletes with DSD in women's sports is a topic being debated in many states and countries, and by many sporting organizations including the International Olympic Committee. In the end, whether it is safe and fair to include transgender athletes and athletes with DSD in women's sports comes down a few facts that can be extrapolated, lots of opinions, and an interesting but complicated discussion. This is a worthwhile discussion in a physiology classroom because it allows a good review of the biologically dimorphic nature of human sex. However, the safe and fair inclusion of transgender athletes and athletes with DSD in women's sports is also a discussion that should be approached with caution due to the many opinions this topic entails that reside outside of physiology.

1. The Economist explains: Why are transgender Olympians proving so controversial? The Economist. https://www.economist.com/the-economist-explains/2021/07/16/why-are-transgender-olympians-proving-so-controversial. [Accessed: August 12, 2021, 2021].

2. Pruitt-Young S. Live Updates: The Tokyo Olympics Canadian Soccer Player Quinn Becomes The First Out Trans And Nonbinary Gold Medalist NPR. https://www.npr.org/2021/08/06/1025442511/canadian-soccer-player-quinn-becomes-first-trans-and-nonbinary-olympic-gold-meda. [Accessed: August 12, 2021, 2021].

3. The Clock Ticks on Caster Semenya's Olympic Career https://www.nytimes.com/2021/06/28/sports/olympics/caster-semenya-olympics-gender.html. [Accessed: August 12, 2021, 2021].

4. Tokyo 2020: Two Namibian Olympic medal contenders ruled ineligible for women's 400m due to naturally high testosterone levels CNN. https://www.cbs58.com/news/tokyo-2020-two-namibian-olympic-medal-contenders-ruled-ineligible-for-womens-400m-due-to-naturally-high-testosterone-levels. [Accessed: August 21, 2021, 2021].

5. APA Dictionary of Psychology: sex. American Psychological Association. https://dictionary.apa.org/sex. [Accessed: August 12, 2021, 2021].

6. APA Dictionary of Psychology: gender. American Psychological Association. https://dictionary.apa.org/sex. [Accessed: August 12, 2021, 2021].

7. Mazure CM, and Jones DP. Twenty years and still counting: including women as participants and studying sex and gender in biomedical research. BMC Womens Health 15: 94, 2015.

8. Bhargava A, Arnold AP, Bangasser DA, Denton KM, Gupta A, Hilliard Krause LM, Mayer EA, McCarthy M, Miller WL, Raznahan A, and Verma R. Considering Sex as a Biological Variable in Basic and Clinical Studies: An Endocrine Society Scientific Statement. Endocr Rev 2021.

9. Sparling PB, O'Donnell EM, and Snow TK. The gender difference in distance running performance has plateaued: an analysis of world rankings from 1980 to 1996. Med Sci Sports Exerc 30: 1725-1729, 1998.

10. Tang L, Ding W, and Liu C. Scaling Invariance of Sports Sex Gap. Front Physiol 11: 606769, 2020.

11. Cheuvront SN, Carter R, Deruisseau KC, and Moffatt RJ. Running performance differences between men and women:an update. Sports Med 35: 1017-1024, 2005.

12. Thibault V, Guillaume M, Berthelot G, Helou NE, Schaal K, Quinquis L, Nassif H, Tafflet M, Escolano S, Hermine O, and Toussaint JF. Women and Men in Sport Performance: The Gender Gap has not Evolved since 1983. J Sports Sci Med 9: 214-223, 2010.

13. Sandbakk O, Solli GS, and Holmberg HC. Sex Differences in World-Record Performance: The Influence of Sport Discipline and Competition Duration. Int J Sports Physiol Perform 13: 2-8, 2018.

14. Millard-Stafford M, Swanson AE, and Wittbrodt MT. Nature Versus Nurture: Have Performance Gaps Between Men and Women Reached an Asymptote? Int J Sports Physiol Perform 13: 530-535, 2018.

15. Seiler S, De Koning JJ, and Foster C. The fall and rise of the gender difference in elite anaerobic performance 1952-2006. Med Sci Sports Exerc 39: 534-540, 2007.

16. Nuell S, Illera-Dominguez V, Carmona G, Alomar X, Padulles JM, Lloret M, and Cadefau JA. Sex differences in thigh muscle volumes, sprint performance and mechanical properties in national-level sprinters. PLoS One 14: e0224862, 2019.

17. Higerd GA. Assessing the Potential Transgender Impact on Girl Champions in American High School Track and Field. In: Sports Management. PQDT Open: United States Sports Academy, 2020, p. 168.

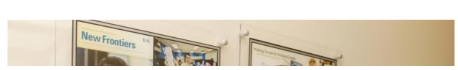
18. Tonnessen E, Svendsen IS, Olsen IC, Guttormsen A, and Haugen T. Performance development in adolescent track and field athletes according to age, sex and sport discipline. PLoS One 10: e0129014, 2015.

19. Hilton EN, and Lundberg TR. Transgender Women in the Female Category of Sport: Perspectives on Testosterone Suppression and Performance Advantage. Sports Med 2020.

20. Harper J, O'Donnell E, Sorouri Khorashad B, McDermott H, and Witcomb GL. How does hormone transition in transgender women change body composition, muscle strength and haemoglobin? Systematic review with a focus on the implications for sport participation. Br J Sports Med 2021.

21. Roberts TA, Smalley J, and Ahrendt D. Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organisations and legislators. Br J Sports Med 2020.

Dr. Greg Brown is a Professor of Exercise Science in the Department of Kinesiology and Sport Sciences at the University of Nebraska at Kearney



where he has been a faculty member since 2004. He is also the Director of the General Studies program at the University of Nebraska at Kearney. He earned a Bachelor of Science in Physical Education (pre-Physical Therapy emphasis) from Utah State University in 1997, a Master of Science in Exercise and Sport Science (Exercise Physiology Emphasis) from Iowa State University in 1999, and a Doctorate of Philosophy in Health and Human Performance (Biological Basis of Health & Human Performance emphasis) from Iowa State University in 2002. He is a Fellow of the American College of Sports Medicine and an American College of Sports Medicine Certified Exercise Physiologist.

Posted in **Classroom Content**, **Diversity**, **engagement**, **Teaching Strategies** on **August 18, 2021 [https://blog.lifescitrc.org/pecop/2021/08/18/the-olympics-sex-and-gender-in-the-physiology-classroom/]** by **Margaret Stieben** (**Posts** | **Profile**)
Leave a comment

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AUGUST 11TH, 2021

The COVID-19 Pandemic: An Opportunity for Change in my Teaching

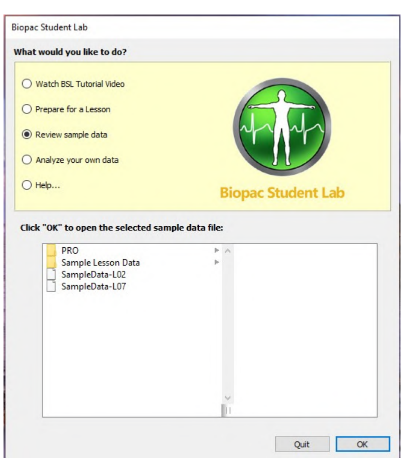
As the 2020-21 academic year ended, I sighed with relief. I had survived the switch to an online teaching format, wearing a mask while teaching when I had to have a class in-person, and the loss of my father. But as quickly as my sighs of relief subsided, I began to wonder, "What will happen next academic year?" Will I be teaching all my classes in-person, will my classes be online, or will I have some classes or labs online and others in-person? As these questions swirled in my head, I began to reflect on this past year. Teaching online was tough. There were activities that bombed. But there were activities that rocked. And there were activities that could be improved. And believe it or not, there were some great things that came from teaching online. Some had to do with content, some had to do with skills, and some had to do with community. Now comes the challenge of choosing what I should take with me, and what I should leave behind? And as I reflected, I realized there are two experiences from this past year I want to use this year, whether I am teaching in-person or online. One had to do with the idea of community and the other had to do with skills. While others came up, I decided to be kind to myself and focus on two.

1. Forming an Inclusive Scientific Community

Prior to the COVID-19 pandemic, I had never taught a course online nor had I taken a class online. I had attended webinars but had never presented an online seminar either. Now I was being asked to teach courses online to students I had never met, and these students had never met each other in-person either. When I reflected on my teaching in-person, I realized I had never worried about whether I knew the students immediately or whether they knew each other. I assumed their presence in class with me and with the other students would allow relationships to form and a learning community to be built. But now they were just images on a screen and often, just names since cameras were not always on.

Now that I was teaching online, I had to be more intentional about building a learning community. This was to help not only me but also my students. Research has shown that students do not just want to be faces in a crowd (1, 2). They want to be recognized by the professor and by their peers. And as the pandemic progressed, they needed this more personal interaction. Creating a community would foster interaction and make students comfortable to share in an online environment (1, 2). To begin, I included icebreaker activities to allow me and the students to learn more about each other. And these icebreakers were not a one and done activity. They continued throughout the first several weeks of class. As the semester continued, polls or questions replaced the icebreakers. These were questions anyone could answer. They could be content questions, well-being checks, or simple questions about plans for the weekend or favorite ice cream. All meant to foster community. When in the classroom, peer interactions can be observed by the instructor. In the online classroom, it was more difficult to monitor interactions and those who were uncomfortable with group work could disappear when the breakout rooms opened.

Including these activities online allowed me and the students to feel like we were in this class together. While I was not a student, I was no longer "The Sage on the Stage." We, the professor and the students, were in this online learning community together. When an online activity was successful, we celebrated together. If something did not work, what discussed the activity and what we could change. This community was most evident when my father fell ill and then passed away. These students I had been working with stepped up and helped me during this emotionally challenging time. While I still guided their learning, they took more on themselves, and they helped each other and me. The entire year we had spoken about grace and that we all needed to give and receive it. They gave me grace when I needed it most. Who would not want to take this community into the in-person classroom?



2. Promoting Scientific Soft Skills

With the initial move to online teaching, one of the challenges faced was laboratory experiments. Many laboratory exercises require specialized equipment (3). In my case, this was the Biopac Student Lab System®. One of the benefits of this system is that students get to record physiologic data on each other. The cost of and logistical issues regarding supervision and liability for the Biopac® home system prevented me from using this as an option. However, one of the benefits of the Biopac Student Lab System® is the free access to sample data and the free analysis software for downloading offered by the company (Figure 1). Additionally, as I had been using these systems for over 10 years, I had previously recorded student data at my fingertips (Figure 2). Students could download the software to their personal computers and open any shared data for analysis. While the students were not actually recording the data themselves, this provided an alternative for learning about physiological processes with data from subjects. This also allowed me to have the students focus more on how they presented the results and how they discussed the science behind the results. We could focus on the writing of the results and the understanding of the science because the students were no longer focusing on the possibility of user error as to why they did not get the results expected.

As I was reflecting, I realized that with lab exercises moving online that the reduction in focus on learning how to use equipment and collect data was a positive (3). This allowed students to focus on writing and

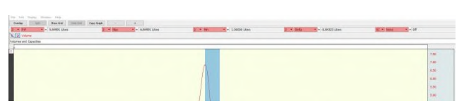


Exhibit Q

Women's Sports Policy Working Group

BRIEFING BOOK

A REQUEST TO CONGRESS AND THE ADMINISTRATION

TO SAFEGUARD GIRLS' AND WOMEN'S SPORT

&

INCLUDE TRANSGENDER ATHLETES

The Women's Sports Policy Group acknowledges the complexity of this issue.
We are committed to transparency and continual refinement of our work.
The most recent update of this Briefing Book will be posted at
https://womenssportspolicy.org/references/ as the first document at the top of the page.

Prepared by The Women's Sports Policy Working Group (Revised as of February 27, 2021)
https://womenssportspolicy.org/
Contact: Donna Lopiano for additional information as needed (Donna.Lopiano@gmail.com or call 516-380-1213)

SAFEGUARDING GIRLS' AND WOMEN'S SPORTS AND INCLUDING TRANSGENDER ATHLETES

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WOMEN'S SPORTS POLICY WORKING GROUP

Donna de Varona, OLY. Two-time Olympic gold medalist in swimming. In 1965, UPI and AP voted her outstanding woman athlete in the world after she set 18 world records and fastest times. de Varona was a sports broadcasting pioneer as the youngest and one of the first women to work in the industry. As an Emmy recipient, she used her visibility to advise and advocate for the protection and promotion of Title IX as well as for the Ted Stevens Olympic and Amateur Sports Act. As the first President and Chair of the Board of the Women's Sports Foundation, she helped build the organization into a sustainable, influential entity. She has served on presidential commissions for five U.S. Presidents. Currently, de Varona is a member of the International Olympic Committee Communications Commission, and was recently voted onto the U.S. Olympic and Paralympic Committee Board of Directors.

Martina Navratilova, OLY. Former professional tennis player and coach. In 2005, *Tennis* magazine selected Navratilova the greatest female tennis player for the years 1975 - 2005. She is considered one of the best female tennis players of all time. Over her career, she won 18 Grand Slam singles titles, 31 Grand Slam women's doubles titles (an all-time record), and 10 Grand Slam mixed doubles titles, for a combined total of 59 major titles, marking the Open Era record for the most Grand Slam titles won by one player, male or female. Coached later in her career by the first trans-woman tennis player, Renée Richards, and long active in LGBTQ rights work and with the women's tennis tour, Navratilova is particularly well-positioned to contribute to thoughtful policy on the inclusion of trans women/girls in women's sport.

Donna A. Lopiano, Ph.D. President and founder of Sports Management Resources, LLC, Adjunct Professor of Sports Management, Southern Connecticut State University, former Chief Executive Officer of the Women's Sports Foundation (1992-2007), Director of Women's Athletics, University of Texas at Austin (1975-1992). President of The Drake Group—an organization focused on academic integrity in college sport. A Title IX sports pioneer, Lopiano specializes in gender equity in the educational and Olympic and elite sports spaces. As an athlete, she participated in 26 national championships in four sports and was a nine-time All-American at four different positions in softball, a sport in which she played on six national championship teams.

Nancy Hogshead-Makar, J.D., OLY, CEO Champion Women, civil rights lawyer, two-time Olympian, three-time gold medalist and one silver in swimming, U.S. National Team for eight years, 12 Halls of Fame, including the International Women's Sports Hall of Fame and the International Swimming Hall, 20 years of teaching Sports Law and Administration, current Professor at Rutgers University's Global Sports Business MS Program. Women's Sports Foundation - President 1991-1993, Legal Advisor, 2003-2010, Senior Director of Advocacy, 2010-2014.

Tracy Sundlun, CEO, Everything Running, Inc., Founding Board Member, National Scholastic Athletics Foundation. Co-Founder and original Director of the National Scholastic (High School) Indoor & Outdoor Track & Field Championships (1984 – Present). Co-Founder, Rock 'n' Roll Marathon Series, at the time the largest running series in the world with over 500,000 participants annually in 29 events in 7 countries (1998 – 2016). Former club and collegiate track coach (including Georgetown, Colorado, USC), guiding over 100 men and women in every event from 15 countries competed in the Olympic Games and international competitions. Six-time Olympic Coach and Manager (1972 – 2016). Inducted into Running USA Hall of Champions.

Doriane Coleman, J.D. Professor of Law and Co-Director of the Center for Sports Law & Policy at Duke Law School; Senior Fellow at the Kenan Institute for Ethics and Associate of the Trent Center for Bioethics, Humanities & History of Medicine at Duke University & School Medicine; former collegiate and Swiss national champion in the 800 meters on the track. She has worked for years in domestic and international arenas on anti-doping policy and rules defining eligibility for the women's category. Her writing on sex in sport is widely referenced by policymakers considering the hard questions posed by trans and intersex inclusion in girls' and women's sport.

SUPPORTERS

Willie Banks, **OLY**, three-time Olympian and former world record holder in the triple jump

Juniper Eastwood, Trail runner, former D1 Track and Cross-Country runner. First D1 athlete to compete on a women's team while openly identifying as transgender

Joanna Harper, former elite marathoner, transgender athlete and researcher

Wendy Hilliard, nine-time member and two-time captain of Team USA in rhythmic gymnastics

Micki King, **OLY**, Olympic gold medalist, ten-time national champion in springboard & platform diving

Greg Louganis, OLY, four-time Olympic gold medalist in springboard and tower diving, second diver in history to sweep both events in consecutive Olympics, 47 national and 13 world championships

Edwin Moses, **OLY**, two-time Olympic gold medalist, two-time World Champion, former world record holder, undefeated in the 400 meter hurdles for 10 years and 107 consecutive races

Benita Fitzgerald Mosley, **OLY**, Olympic gold medalist, two-time Olympian, and eight-time national champion in the 100 meters hurdles

Digit Murphy, President and Head Coach of the National Women's Hockey League's Toronto Six, 1st female coach to reach 200 wins in the NCAA, coach of numerous Olympians and All-Americans

Diana Nyad, one of the greatest ever long-distance swimmers credited with a record setting swim around Manhattan island and being first person to swim from Cuba to Florida without a shark cage

Renee Richards, tennis player, one of the first professional athletes to identify as transgender

Sanya Richards-Ross, OLY, four-time Olympic gold medalist, six-time World Champion, ranked #1 in the world in the 400 meters from 2005 to 2009 and in 2012

Sally Roberts, three-time national wrestling champion, 2003 World Cup Champion, 2003 & 2005 World bronze medalist and a 2008 Olympic alternate

Lyn St. James, former Indycar and LeMans racecar driver, first woman to win Indianapolis 500 Rookie of the Year award, and one of *Sports Illustrated*'s "Top 100 Women Athletes of the Century"

Pam Shriver, OLY, Olympic gold medalist, winner of over 100 professional singles and doubles championships over 19 years, International Tennis Hall of Fame

Inge Thompson, **OLY**, ten-time national champion cyclist, three-time Olympian and two-time podium finisher at the Women's Tour de France

Champion Women, non-profit legal advocacy organization for girls and women in sports; harnessing the power of sport for social justice

The Drake Group, non-profit advocacy organization committed to defending academic integrity and protecting the health and well-being of athletes participating in collegiate sport

National Scholastic Athletics Foundation, non-profit organization created to fund competitive opportunities for high school track and field athletes and host the indoor and outdoor high school nationals

Wrestle Like A Girl, non-profit organization empowering girls and women using the sport of wrestling to become leaders in life

SAFEGUARDING GIRLS' AND WOMEN'S SPORTS AND INCLUDING TRANSGENDER ATHLETES

REQUEST

We ask Congress and the Administration to affirm Title IX's long-standing commitment to providing biological females[1] with equal experiences and opportunities in competitive sport, and to protecting their safety in contact sports, by permitting recipients of federal funds to continue to operate or sponsor separate athletic teams and events for males and females. In addition, we ask Congress and the Administration newly to provide for the participation of transgender girls and women within girls' and women's sports programs with appropriate conditions if they have experienced all or part of male puberty (which is the scientific justification for separate sex sport). These conditions should apply throughout interscholastic and intercollegiate sport, and the U.S. Olympic and Paralympic Movement. This request is limited to *competitive* interscholastic, intercollegiate, and developmental elite athletic programs. It does not affect physical education, intramurals, or recreational sports sponsored by municipalities, schools, and colleges.

THE ISSUE

Girls'/Women's Competitive Sport Needs Safeguards and Trans Girls/Women Need to be Included with Appropriate Conditions.

Sports have been continuously sex-segregated for over 100 years, across disciplines where male sex-linked advantages affect competitive opportunities for females. Congress passed Title IX in 1972 and approved its implementing regulations governing competitive sport in 1975, explicitly permitting girls' and women's sport to exist separate from boys' and men's sport. Law and sports policy makers understood that from the onset of male puberty, male bodies develop such that they are, as a group, faster, stronger, and more powerful than female bodies as a group. The performance gap between male and female athletes that emerges from that point typically ranges from 8-20% depending on the sport and event, and "up to 50% where explosive power and complex movement skills are pivotal."

Science not Ideology Dictates the Need for Sex Segregation in Sports.

If sports were not sex-segregated, female athletes would rarely be seen in finals or on victory podiums. Congress has long understood the benefits of sport and the benefits of having the opportunity to train, compete and win. Repeatedly, Congress has affirmed that it wanted both our sons and our daughters to realize those benefits, which are well-documented in the academic literature. Girls and women learn the benefits of teamwork in pursuit of conference, state and national championships; the self-esteem that flows from competent performance of physical skills; the life-changing power of competing against the best and standing on the podium; confidence borne of testing the limits of strength, speed, skill and reaction time; and the power of personal

[1] We use "female" throughout to denote a person's biological sex regardless of their gender identity. We use "trans(gender) girl/woman" throughout to denote a person born male who identifies as a girl/woman.

achievement and public recognition when setting school, meet and other records. And as sports double as an academic and social tool, these lessons and benefits reverberate well beyond the playing field throughout the lives of all female athletes.

The legislative history of Title IX is clear that Congress also understood that even when height, size, and weight are equal, males are incrementally stronger and generate more explosive force, so that if males and females are forced to compete against each other, the physical safety of females is differently at risk.

At the time Title IX's athletics regulations were passed, no one raised the issues of gender identity apart from biological sex, or whether trans girls/women with the post-pubescent advantages of biological males should be allowed to participate in the space created by Congress to secure the sport experiences of biological females. Today, however, trans girls/women are asking for the right to compete in girls' and women's sport, directly against female athletes, even when they retain some or all of their male sex-linked strength, power, and related performance advantages. For many people, the issue is not whether trans girls/women should be included in women's sport. Rather, it is whether female athletes can continue to be safeguarded *and* trans girls/women included within women's sports consistent with their gender identity.

States are Passing Conflicting Laws.

States have taken one of three general approaches to the issue of trans-inclusion in girls' and women's sport. Ten states expressly require males and females to participate in high school sports according to their birth sex, thereby prohibiting participation in girls' sports by trans girls, whether or not they have begun male puberty or have had hormone therapy. In contrast, seventeen states and the District of Columbia expressly require the inclusion of trans girls in girls' sports without regard to the extent to which they may retain the male-linked physical traits that otherwise justify excluding males from female sport on competitive fairness and safety grounds. Another seventeen states have adopted a policy similar to the NCAA rule, which allows trans girls to compete after taking gender-affirming hormones for a year. Finally, six states have no policy one way or the other regarding gender identity and sport.

Pending Legal Challenges.

None of the policies mentioned has been immune from a legal challenge. In Connecticut, one of the states that allows trans girls to compete in girls' sports without regard to whether they have experienced male puberty or are on gender affirming hormones, four female athletes and their mothers have sued their state high school athletic association. They contend that Connecticut's rule, which ignores biological sex and focuses on gender identity, has deprived them of school and state records they would otherwise have held, and from advancing in competitions, including qualifying for state and regional championships and becoming state champions, spots they would otherwise have won. Instead, the rule has allowed two trans girls to dominate their events. The Department of Education has concluded that the state's policy regarding transgender athletes violates Title IX's mandate of equal opportunity for both sexes since biological males are able to win in both the male and the female divisions. At the other end of the country and the political spectrum, Idaho has seen a similar legal battle erupt after it adopted a law mandating that athletic eligibility be based only on birth sex. To date there has been no approach that would include trans girls/women while preserving competitive opportunities for females.

The Cultural Battle Outside of the Courts has Not Allowed for Respectful Dialogue on Science, Policy, and Best Practices.

Transgender advocates accuse female athletes, their parents, and supporters of transphobia simply because they recognize the significance of sex in sport. Others seek unnecessarily to exclude all trans girls from all girls' sports regardless of whether they have experienced male puberty or are undergoing gender-affirming therapies. The conflicting positions have sparked a rhetorical battle about who will suffer more harm: trans girls who are prevented from competing as girls, or females who are forced to compete against athletes who have the male sex-linked advantages girls' and women's sport was designed to exclude. Throughout, surveys consistently show Americans want sports opportunities for girls and women. Only a minority of Americans — just 29% according to one recent survey — favor allowing transgender students to participate on the sports team consistent with their gender identity.

Conflicting Federal Legislative Proposals Take an "Either/Or" Approach.

Various bills in the 116th Congress would either require identical treatment of — no distinctions allowed between — females and trans girls (H.R. 5 - The Equality Act), or they would preclude all trans girls/women from participating in girls'/women's sports, which would be restricted to biological females (H.R. 5603, H.R. 8932 and S. 4649).

The Supreme Court in Bostock did not Resolve the Question of Separate Sex Sport.

Trans girls/women and their advocates argue that the Supreme Court's decision in Bostock v. Clayton County, 590 U.S.___, 140 S. Ct 1731 (2020), mandates the unconditional inclusion of trans girls/women in women's sports. This is misleading at best, as *Bostock* was about workplace discrimination under Title VII, not about sex segregation in competitive sport; in its decision, the Court expressly stated that it was defining "sex" to mean "biological sex" not "gender identity"; and it expressly reserved for another day — did not decide — the issue whether distinctions on the basis of sex are permissible for bathrooms, locker rooms, and sport.

THE RESOLUTION

It is essential that we continue to safeguard girls' and women's sport. It is also good policy to be inclusive when doing so does not harm the female sports competition or the individuals separate sex sport is designed to protect. Congress and the Administration should make it clear that institutions governed by Title IX of the Education Amendments of 1972 (Title IX), the Ted Stevens Olympic and Amateur Sports Act (the Sports Act), and Title VII of the Civil Rights Act of 1964 (Title VII) will:

> (1) continue to be obligated to provide males and females with equal sporting opportunities on the basis of biological sex, and
>
> (2) be newly obligated to provide ways to include trans girls/women in girls'/women's sports that ensure competitive fairness and playing-safety without diminishing the protection of biological females.

This two-step approach safeguards the integrity of the existing competitive sport process in which millions of girls and women participate annually. It also incrementally and thoughtfully expands the development of additional sports opportunities for emerging trans girls/women.

Separate sex competitive sport has always been an exception to our general non-discrimination laws. This exception is justified by real physical sex-linked differences that emerge from the onset of male puberty and that have significant implications for athletic performance and playing-safety. The lawfulness of this long-standing exception should be re-affirmed.

At the same time, the government should make it legally possible for trans girls/women to participate in girls'/women's sport in ways that do not affect competitive fairness and playing-safety. Because the onset of male puberty — normally around ages 11 – 12 in boys — is the physical justification for separate sex sport,[2] trans girls and women who have never experienced the onset of male puberty should be included without condition. Trans girls and women who have experienced the onset of male puberty should be included in ways that recognize their male sex-linked advantages in strength, power, and endurance. Some — but not all — trans girls and women are on gender-affirming hormones. Depending on the duration of treatment and the sport and the event, hormones may mitigate those advantages. However, because the evidence is increasingly clear that hormones do not eliminate the legacy advantages associated with male physical development, accommodations can and should take these advantages into account.

Finally, it is important that there be national standards to ensure uniformity across the states. Competitive sport, i.e., sport that primarily focuses on adversarial engagement for places, prizes, and the win, and that leads to records, titles, championships, and ultimately to Team USA, is an interconnected system comprised of high schools, colleges, and universities, and non-school club teams and programs. The former are governed by Title IX. The latter are generally under the jurisdiction of, or sponsored by, the U.S. Olympic and Paralympic Committee (USOPC) and/or regional and national sport governing bodies (NGBs). This integrated system is only local in the first instance, as teams and athletes move from intra-state to interstate and international arenas as competition progresses. Inconsistent local, state, national, and international eligibility standards can create practical impediments to success for individual athletes, teams, and ultimately for the system as a whole.

The International Federations (IFs), whose singular responsibility is the management, promotion, and protection of their sport and its athletes throughout the world, are the most vested in and knowledgeable about the science, safety, and competitive fairness of any entity in their particular domain. They have already committed themselves both to safeguarding the female category and to scientific, evidence-based criteria for the conditional inclusion of trans girls/women in

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[2] Endocrinologists explain that puberty in boys should start between ages 9-13 and in girls between ages 8-12; that puberty usually takes 4-5 years to complete so that 95% of boys will have started puberty by age 13. This timing is consistent with the formal position of the Women's Sports Foundation providing that "[p]rior to puberty, females and males should compete with and against each other on coeducational teams." Women's Sports Foundation, Issues Related To Girls and Boys Competing With And Against Each Other In Sports And Physical Activity Settings at 1 (Aug. 14, 2019) (adding that "prior to puberty, there is no gender-based physiological reason to separate females and males in sports competition"), available at https://www.womenssportsfoundation.org/advocacy/girls-and-boys-competing-with-and-against-each-other-in-sports-and-physical-activity-settings/.

girls'/women's sport. The resulting standards are reviewed on an ongoing basis to ensure they are consistent with sport's policy goals and the best available scientific evidence on competitive fairness and safety. To date, no American sports organization or governing body has established a commitment to, or the capacity for, doing this work in a better way or at a higher level than the IFs. Adopting international standards for inclusion and accommodation would thus be a substantively sound and administratively efficient approach to national policy. Equally important is that pegging USA standards to international standards would ensure that our country's athletes and teams — including our juniors who are Team USA's future — can move seamlessly from domestic to international competition, and that none of our elite athletes are ineligible at the outset.

This proposal is designed for *competitive* girls' and women's sport, i.e., sport whose focus is adversarial engagement for places in rounds, finals, on podiums, and for the championship, and for the experiential, financial, and ancillary rewards that flow from success in this space. It is not designed for *participation* or *recreational* sport, i.e., sport whose focus is friendly play for social engagement, health, and welfare. Given its different focus and goals, eligibility standards for participation sport can and should be different from those of competitive sport.

TRANS INCLUSION CHART for Scholastic & Non-Scholastic Competition	**SEX STATUS OF TRANS GIRL/WOMAN**		
	Athlete *has not* experienced (any stage of) male puberty	**Athlete *has* experienced some or all of male puberty & is *not on hormones* or has not mitigated their legacy advantage**	**Athlete *has* experienced some or all of male puberty & is *on hormones* and has mitigated their legacy advantage**
Non-Contact Sports Competition	**Included without condition (no different requirements)**	**Included but no head-to-head competition**	**Included consistent with international rules e.g., NCAA rule**
Contact Sports Competition	**Included without condition (no different requirements)**	**Included but no head-to-head competition**	**Included consistent with international rules e.g., NCAA rule**

The choice to peg eligibility to international rules is explained in the text immediately above the table. The current NCAA rule is superficially consistent with international rules; however, because the NCAA is not specific about the degree of mitigation required and does not monitor trans women for compliance, it is significantly flawed as administered. This problem is described below, in Q&A #26. The NCAA rule is noted here as an example of a domestic rule that, if properly administered, is a reasonable accommodation consistent with international rules.

Trans women/girls who are not on gender affirming hormones, i.e., who have full male advantage, or who have not mitigated their advantage at least to the point of meeting the international standard for their sport, should be fully included without condition on girls' and women's teams for all aspects of team activities except for competition itself and any aspects of practice that might implicate playing-safety. In high school, for example, the athlete would participate fully in the camaraderie and socialization associated with team membership. The only firm restriction is head-to-head competition against females.

Respectful alternatives to head-to-head competition should be developed by the institution responsible for the competition and the athletes, who should be afforded flexibility to take into consideration the nature and requirements of the sport and event, the institution's mission, administrative feasibility, and local conditions. Regardless, the goal of the accommodation should be to provide a competitive opportunity under the umbrella of girls’ and women’s sport. Examples of accommodations that might be adopted depending on the school, sport, and event, might include handicapping, multiple leagues, events, and/or podiums.

The effect of this approach will be that sometimes, a trans girl/woman not on hormones who chooses to compete in girls'/women's sport won't have a direct competitor. This is not a preferred, but also not an unusual situation. For example, sometimes a runner or relay team has to compete against the clock, and sometimes athletes in competitions sorted by weight classes lack an opponent and have to choose to win by forfeit or move up a weight class and compete with a disadvantage. Because this may not be comfortable for some trans athletes, the choice to compete in the boys'/men's category or the girls'/women's category should always be up to the individual based on their personal circumstances and preferences. Either way, they have a place in sport.

Under this proposal, females who identify as boys and men or as gender fluid are always eligible to compete in the girls'/women's category so long as they are not on male gender affirming hormones. Sex-linked traits drive the conditions, not gender identity.

Some events are hybrids, involving both competition and participation, for example, the various mass participation events like road races, triathlons, cross country skiing events, and other similar competitions all over the country and the world, in which participants of all ages and abilities from rank beginners to Olympic Champions toe the line together. These events range in size from a few hundred to many thousands, and while for the great majority of the participants the goal is to get a finisher medal and perhaps a personal best, for some the goal is an overall award or an age-group or other category award, which could be anything from a trophy to thousands of dollars. With virtually no exceptions, these events are conducted under the aegis of and sanctioned by the sport’s NGB, and as such are subject to their eligibility rules and thus those of the IF. As both a participatory and a competitive event, any transgender athlete would be welcome to participate without any mitigation at all, but if they want to compete for and accept any prizes, they must meet / comply with the NGB’s and IF’s mitigation requirements for that sport.

MODEL STATUTORY AND REGULATORY LANGUAGE TO SAFEGUARD WOMEN'S SPORTS & INCLUDE TRANS ATHLETES

The best way to resolve the issue of safeguarding opportunities for females within girls' and women's sport while including trans athletes is to enact standalone federal legislation. This approach would ensure clarity and consistency in the law's treatment of the issue by the federal government, the states, and sport governing bodies. The model language immediately below is thus for a standalone federal statute. Following that is language to amend the Title IX regulations governing separate sex sport, 34 C.F.R. § 106.41, and the Equality Act, in the event lawmakers prefer one or both alternative approaches. All three options are based in and compatible with the Title IX regulations. Approaching law reform related to girls'/women's competitive sport in this way ensures that the extensive web of related statutory, administrative, and case law that exists in this area is not unnecessarily voided by our proposed trans-inclusive law reform measures.

PROPOSED STANDALONE STATUTE

Schools receiving federal funds and sport governing bodies engaged in interstate commerce [covered entities][3] may operate or sponsor separate competitive sports teams and events based on biological sex[4] where group-based sex-linked traits affect playing-safety and competitive capacity.

(A) Covered entities shall provide equal athletic opportunities, treatment, services and benefits in kind, quality and availability to male and female athletes.[5]

(B) Covered entities may restrict eligibility for the female sport category only to females if any male sex-based differences would have a negative impact on the right of females to achieve equality of athletic opportunity.[6]

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3 Schools receiving federal funds are subject to Title IX of the Education Amendments of 1972. Sports governing bodies include public and private non-profit high school and age-group athletic associations, intercollegiate athletic associations, the U.S. Olympic and Paralympic Committee, and their member National Governing Bodies. These organizations may be subject to Title IX and/or the Ted Stevens Olympic and Amateur Sports Act.

4 See National Institutes of Health (NIH), Office of Research on Women's Health, Sex & Gender, https://orwh.od.nih.gov/sex-gender, last accessed on January 1, 2021 (explaining that "'[s]ex' refers to biological differences between females and males, including chromosomes, sex organs, and endogenous hormonal profiles. 'Gender' refers to socially constructed and enacted roles and behaviors which occur in a historical and cultural context and vary across societies and over time.")

5 For purposes of this statute, "males" means biological males and "females" means biological females. *Id. See also* U.S. Department of Education, Office for Civil Rights, Title IX 1979 Policy Interpretation, *available at* https://www2.ed.gov/about/offices/list/ocr/docs/t9interp.html

6 *See* McCormick v. School District of Mamaroneck, 370 F.3d 275 (2nd Cir. 2004) (holding that recipients must provide girls with equal opportunities to compete in championship games.); U.S. Department of Education, Office for Civil Rights, Title IX 1979 Policy Interpretation, *available at* https://www2.ed.gov/about/offices/list/ocr/docs/t9interp.html

(1) With respect to competitive opportunities, if a covered entity provides male athletes and teams the opportunity to advance to invitational, conference, state, regional, national, and international competition in the boys' and men's division, it must provide a parallel opportunity to female athletes similarly to advance in the girls' and women's division.[7]

(C) Covered entities that operate or sponsor separate-sex teams and offer a team in a particular sport for members of one sex but operate or sponsor no such team for members of the other sex, and athletic opportunities for members of that sex have previously been limited, members of the excluded sex must be allowed to try-out for the team offered except if the sport involved is a contact sport and the position at issue implicates playing-safety because of sex-linked differences in size, weight, strength, or explosive force. Covered entities may, but are not required, to prohibit members of the excluded sex from trying out for such positions. For the purposes of this part, contact sports include but are not limited to boxing, wrestling, rugby, ice hockey, football, basketball and other sports the purpose or major activity of which involves bodily contact.[8]

(D) Treatment of Transgender Athletes

Where a covered entity operates or sponsors separate sex teams and events, transgender athletes shall be accommodated as follows:

(1) Treatment of Transgender Boys and Men

(a) Trans boys/men who have not taken gender-affirming hormones may be included in girls' and women's sport or they may compete in boys' and men's sport consistent with (C), the contact sport exception.

(b) Trans boys/men who have begun taking gender-affirming hormones

(i) may compete in boys' and men's sport consistent with (C)(the contact sport exception), but

(ii) may not compete head-to-head against female athletes in girls' and women's sport.

(2) Treatment of Transgender Girls and Women

(a) Trans girls/women who have not begun male puberty do not have significant male sex-linked advantages; they shall be included in girls' and women's sport without conditions or limitations.

(b) Trans girls/women who have experienced all or part of male puberty and who have sufficiently mitigated their male sex-linked advantages through surgery and/or gender affirming hormones consistent with the rules of

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7 *Id.*

8 This provision would re-codify the contact sports exception in the Title IX Regulation, 34 C.F.R. § 106.41(b).

their sport's international federations, may participate in girls'/women's sport without further conditions or limitations.

(c) Trans girls/women who have experienced all or part of male puberty and who have not at all, or only partially, mitigated their male sex-linked advantages according to the international federation standards in their sport may be included in girls'/women's sport but not in head-to-head competition against female athletes.[9]

(E) The private medical information (PMI) necessary to determine an athlete's eligibility must be available to the relevant sports authority. The information, which shall be kept confidential, is strictly limited to confirmation of the athlete's biological sex and of their hormone status over the relevant period of time.[10] All challenges to an athlete's eligibility shall be resolved by the relevant sports authority based on this confirmation.[11]

(F) Policy, training and competition must encourage a safe, respectful, and affirming environment for all athletes.[12]

(G) This statute only applies to competitive sport, when the principal objective is to win individual or team championships, titles, medals, or prize money. It does not apply to recreational sport such as physical education classes or intramural events, the principal objective of which is to participate for health and enjoyment.

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[9] Head-to-head competition is when two or more athletes compete directly against one another other, for example in the same heat in the pool or on the track, or on the same court in basketball and volleyball. Trans girls/women who have not at all, or only partially, mitigated their male sex-linked advantages who want to be included under the girls'/women's sport umbrella must be accommodated by means that do not involve head-to-head competition. Acceptable accommodations should be developed by sports administrators who are experts in the affected sports and events, but they need not reinvent the wheel. Existing models for co-ed sport and weight and age divisions can be borrowed for this purpose. Examples of acceptable accommodations might include separate events, heats, divisions, or handicapping that permits separate scoring, separate teams, or separate recognition.

[10] This information should be included on the standard pre-season physical eligibility form that is completed and signed by the athlete's physician. The form should include the following questions for the physician to answer: whether the athlete is or is not transgender; if they are, whether they are or are not on puberty blockers and/or gender affirming hormones; and if they are, the dates of treatment and testosterone levels they have maintained during the relevant period.

[11] Assuming the relevant sports authority has confirmed the athlete's eligibility according to the relevant rule, no challenge to their inclusion should be entertained in the absence of admissible evidence of fraud.

[12] In addition to educational programs-to ensure a respectful environment, sport governance organizations should adopt and implement policies specifying that any challenge to the eligibility of an athlete shall be to a specified official of the relevant sports authority by confidential email, such query or complaint and reply thereto also subject to (D) above.

PROPOSED AMENDMENT TO THE EQUALITY ACT (H.R. 5 - 2019)

Amend SEC. 9. MISCELLANEOUS. as follows:

Within Section 1101. DEFINITIONS AND RULES., by inserting

“(4) SEX.—The term ‘sex’ includes—

“(A) biological sex, including the sex characteristics that account for the physical and physiological differences between males and females;[13]
"(B) sex stereotype;
“(C) pregnancy, childbirth, or a related medical condition;
“(D) sexual orientation; and
"(E) gender identity.~~; and~~
~~**“(D) sex characteristics, including intersex traits.**~~[14]

“Section 1106. RULES OF CONSTRUCTION.

“(A) Sex – Nothing in section 1101 or the provisions of a covered title incorporating a term defined or a rule specified in the section shall be construed –

“(1) To limit the protection against an unlawful practice on the basis of pregnancy, childbirth, or a related medical condition provided by section 701(k), or

“(2) To limit the obligation of programs and institutions covered by Title IX of the Education Amendments of 1972, the Ted Stevens Olympic and Amateur Sport Act, and Title VII of the Civil Rights Act of 1964 to provide separate opportunities on the basis of biological sex when this is necessary to protect the right of biological females to equality in competitive athletics, or

“(~~2~~)(3) To limit the protection against an unlawful practice on the basis of sex available under any provision of Federal law other than that covered title, prohibiting a practice on the basis of sex.”

13 See National Institutes of Health (NIH), Office of Research on Women's Health, Sex & Gender, https://orwh.od.nih.gov/sex-gender, last accessed on January 1, 2021 (explaining that "'[s]ex' refers to biological differences between females and males, including chromosomes, sex organs, and endogenous hormonal profiles. 'Gender' refers to socially constructed and enacted roles and behaviors which occur in a historical and cultural context and vary across societies and over time.")

14 "Sex characteristics" as a term and category includes intersex traits which appears in (4) (A) above.

PROPOSED AMENDMENT TO THE TITLE IX REGULATIONS (34 C.F.R. § 106.41)

(a) *General.* No person shall, on the basis of sex, be excluded from participation in, be denied the benefits of, be treated differently from another person or otherwise be discriminated against in any interscholastic, intercollegiate, club or intramural athletics offered by a recipient, and no recipient shall provide any such athletics separately on such basis.

(b) *Separate teams.* Notwithstanding the requirements of paragraph (a) of this section, a recipient may operate or sponsor separate teams **based on biological sex** where selection for such teams is based upon competitive skill or the activity involved is a contact sport. However, where a recipient operates or sponsors **separate-sex teams and offers** a team in a particular sport for members of one sex but operates or sponsors no such team for members of the other sex, and athletic opportunities for members of that sex have previously been limited, members of the excluded sex must be allowed to try-out for the team offered, **except if** the sport involved is a contact sport **and the position at issue implicates physical playing-safety because of sex-linked differences in size, weight, strength, and explosive force.**[15] **A recipient may, but is not required to, prohibit members of the excluded sex from trying out for such positions.** For the purposes of this part, contact sports include **but are not limited to** boxing, wrestling, rugby, ice hockey, football, basketball and other sports the purpose or major activity of which involves bodily contact.

(c) *Treatment of Transgender Athletes.*

(1) **Because trans girls/women who have not begun male puberty do not have significant male sex-linked advantages, they shall be included in girls' and women's sport without conditions or limitations.**

(2) **Trans boys/men who have not taken gender-affirming hormones may be included in girls' and women's sport without conditions or limitations.**

(3) **Trans girls/women who have experienced all or part of male puberty and who have sufficiently mitigated their male sex-linked advantages — through surgery and/or gender affirming hormones consistent with the rules of their international federations — may participate in girls'/women's sport without additional conditions or limitations.**

(4) **Trans girls/women who have experienced all or part of male puberty and who have not, or only insufficiently, mitigated their male sex-linked advantages according to the international federation standards in their sport may be accommodated within girls'/women's sports but not in head-to-head competition with female athletes.**

15 Because the contact sport exception is permissive not mandatory, schools may allow girls/women to try out for positions on boys'/men's contact sports teams. This is least controversial when the position at issue — as opposed to the sport in general — does not involve a high risk of significant physical impact. See, e.g., Vanderbilt kicker Sarah Fuller first woman to score in Power 5 football game, ESPN News Service, December 12, 2020.

(5) The private medical information (PMI) necessary to determine an athlete's eligibility must be available to the relevant sports authority. The information, which shall be kept confidential, is strictly limited to confirmation of the athlete's biological sex and of their hormone status over the relevant period of time.[16] All challenges to an athlete's eligibility shall be resolved by the relevant sports authority based on this confirmation.[17]

(6) Policy and training should encourage a safe, respectful, and affirming environment for all women and girls.

16 This information should be included on the standard pre-season physical eligibility form that is completed and signed by the athlete's physician. The form should include the following questions for the physician: whether the athlete is or is not transgender; if they are, whether they are or are not on puberty blockers and/or gender affirming hormones; and if they are, the dates of treatment and testosterone levels they have maintained during the relevant period.

17 Assuming the relevant sports authority has confirmed the athlete's eligibility according to the relevant rule, no challenge to their inclusion should be entertained in the absence of admissible evidence of fraud.

DEFINITIONS

ACCOMMODATION — The process of adapting or adjusting to someone or something without changing the underlying goal or design, e.g., in a workplace or educational program. In the context of sport, accommodation means adjusting an aspect of girls'/women's event to include trans girls with male sex-linked advantages in a way that does not diminish participation and competitive opportunities for females. Examples of accommodations already in use in sport include handicapping, separate heats, separate scoring and/or separate and equal teams. This list is not exhaustive.

ANTI-DOPING — The effort against doping in sport. Doping is the use of prohibited substances and methods. Prohibited Substances Lists in the United States are maintained by the United States Anti-Doping Agency (USADA) and the National Collegiate Athletic Association (NCAA). Testosterone is a steroid on both Prohibited Substances Lists. Its exogenous use by athletes is banned. The testosterone levels of international-caliber athletes are monitored by regular urine and blood tests to ensure they do not fluctuate beyond both their own naturally-occurring levels, and the normal group ranges for their sex.

CISGENDER (CIS) — An adjective that describes a person who is neither transgender nor gender fluid. It is also used to describe a person whose gender identity is consistent with their natal sex.

CIS MALE — A person whose biological sex is male who is neither transgender nor gender fluid.

CIS FEMALE — A person whose biological sex is female who is neither transgender nor gender fluid.

COMPETITIVE FAIRNESS — The state of play when the rules reflect — and events are conducted — consistent with the design of the sport. For example:

- Weight categories are fair when groups of comparably sized athletes are matched against one another. For example, a wrestling match is considered fair when the competitors compete in their narrowly defined weight classes and referees ensure that competitors' actions are authorized from within a range of permissible maneuvers.
- Age categories are fair when they recognize and mitigate competitive differences conferred on the body due to the age of the competitor.
- Similarly, sex segregated sport classifies athletes by their biological sex because of the significant performance gap between male athletes and female athletes, and to ensure that female athletes have the same competitive opportunities as their male counterparts. In this context, competitive fairness requires rules that safeguard the female category and the female athletes who reasonably rely on its integrity.

CONFIDENTIAL MEDICAL INFORMATION — Information, including protected health information (PHI), that is normally treated confidentially but is relevant for the determination of eligibility for sports participation and therefore shared in a limited way for this limited purpose.

FEMALE — An individual whose biological sex is female. Biological sex is sometimes referred to as natal sex. In contrast with males, females have ovaries, not testes; they make eggs, not sperm; and their endocrine system is estrogenic, not androgenic.

GENDER — Sometimes used as a synonym for sex; or to connote the complex relationship between physical sex-linked traits and one's internal sense of self as male, female, both, or neither; or one's sex-related expression.

GENDER AFFIRMING HORMONES — Medication taken by some trans people to counter their biological sex and affirm their gender identity. For example, trans girls/women may take estrogen to counter their male secondary sex traits and to feminize their bodies. Similarly, trans boys/men may take testosterone to counter their female secondary sex traits and to masculinize their bodies.

GENDER AFFIRMING SURGERY — Procedures undertaken by some trans people to construct or remove secondary sex traits to better reflect their gender identity, e.g., surgery to remove or construct breasts, and/or surgery to remove testes or ovaries and/or construct gender-conforming genitals.

GENDER IDENTITY — A person's deeply held inner sense of themselves as male, female, fluid, or neither. A person's gender identity may be different from their biological sex.

LEGACY ADVANTAGE — The permanent or long-lived physical effects of experiencing puberty in the male body. The term refers to the considerable size and strength advantages that remain even after hormone treatments or surgical procedures.

MALE — An individual whose biological sex is male. Biological sex is sometimes referred to as natal sex. In contrast with females, males have testes, not ovaries; they make sperm, not eggs; and their endocrine system is androgenic not estrogenic.

PERFORMANCE GAP — The percentage difference between male athletic performances and female athletic performances that result from biological sex-linked differences. Some individual females surpass some individual males, but depending on the sport and event, the gap between elite male performances and elite female performances overall generally ranges from 8-20%, and up to 50% in sports and events featuring explosive power. The very best elite female performances are regularly surpassed by non-elite male performances. Together with the commitment to sex equality, the substantial performance gap justifies separate sex teams and events.

PLAYING-SAFETY — The physical safety of athletes on the field of play.

PUBERTY — The period of sexual maturation and the development of fertility. Sexual maturation includes the development of secondary sex characteristics—the physical features associated with a male phenotype on the one hand, and a female phenotype on the other. In girls, the onset of puberty is generally between ages 8 and 13. In boys, it is generally between ages 9 and 14.

SEX ASSIGNED / RECORDED AT BIRTH — The designation of a newborn child's sex on their official birth record based on inspection of their external genitalia. This designation may be incorrect in the case of an infant with a difference of sex development (DSD) that affected the development of their genitals. Sex recorded on birth certificates, passports, or drivers' licenses may or may not reflect biological sex and should not be determinative of eligibility for competition.

SEX / BIOLOGICAL SEX — Male or female, one of two classifications by which most organisms are grouped on the basis of their reproductive organs and functions. A person's sex also refers to the cluster of sex-linked characteristics or traits—i.e., chromosomal, gonadal, endocrinological (hormonal), and phenotypic characteristics, commonly used to distinguish males from females.

SEX-LINKED DIFFERENCES — Physical and physiological differences that are tied to being biologically male or biologically female. For purposes of sport, the main sex-linked differences are tied to the endogenous (natural) production in biological males of much higher levels of testosterone beginning from the onset of male puberty and continuously throughout the competitive athletic career.

SEX SEGREGATION — Refers to separating people by sex or by particular sex-linked traits such as testosterone. Formal sex segregation in competitive sports is constitutional because it is empowering not subordinating, and because it is the only way to ensure that females as a group have the same sports opportunities, experiences and successes as males as a group.

TESTOSTERONE / TESTOSTERONE RANGES — A hormone classified as an anabolic, androgenic steroid that builds tissue. In childhood, males and females produce about the same, small amount of testosterone. At the onset of puberty, the male testes begin to produce much more than the female ovaries. From that point forward, the normal female range[18] remains low and narrow, from 0.06 to 1.68 nmol/L, and the normal male range is relatively high and wide, from 7.7 to 29.4 nmol/L.

TRANSGENDER (TRANS) — An adjective describing a person whose gender identity is not the same as their biological sex. The person may or may not choose to transition medically through the use of gender-affirming hormones or surgery.

TRANS BOY/MAN — A person whose biological sex is female, while their gender identity is male; one who transitions from female to male.

TRANS GIRL/WOMAN — A person whose biological sex is male, while their gender identity is female; one who transitions from male to female.

UNCONDITIONAL INCLUSION — Inclusion in a category, classification, or group without preconditions, such as including a trans girl/woman in girls'/women's sport without first requiring her to reduce her male sex-linked advantages.

[18] We use the word "normal" throughout this document consistent with its standard scientific meaning, i.e., the normal range is the range within which almost all readings or levels occur. In medicine, the normal range is sometimes also referred to as the reference range.

FREQUENTLY ASKED QUESTIONS

I. ABOUT SCIENCE AND SEX

Q1. What is "biological sex"?
A1. Biological sex is the designation of an individual as male or female based on reproductive organs and associated primary and secondary sex characteristics. Biologically, they are either female with ovaries/eggs and an estrogenic endocrine system, or they are male with testes/sperm and an androgenic endocrine system.

Q2. What are sex differences?
A2. Sex differences are anatomical and physiological differences that are determined by or related to biological sex. Males on the one hand and females on the other have distinct genetic and chromosomal, gonadal, endocrinological, and phenotypic (external secondary) characteristics. The field of sex differences in biomedical research specifically studies these distinctions, which have implications not only for reproduction and sport, but also for immunology and cardiovascular health, among other things. As the Institute of Medicine has explained, "basic biochemical differences" exist between males and females even "at the cellular and molecular levels."

Q3. Why do we have separate sex sport?
A3. We have separate sex sport and eligibility criteria based on biological sex because this is the only way we can assure that female athletes have the same opportunities as male athletes not only to participate but also to win in competitive sport. We also separate males and females in contact sports for reasons related to on-the-field playing-safety. From the onset of male puberty, male bodies develop such that they are as a group faster, stronger, and more powerful than female bodies as a group. The performance gap between male and female athletes that emerges from that point typically ranges from 8-20%, but up to 50% depending on the sport and event. If we did not separate athletes on the basis of biological sex - if we used any other physical criteria - we would never see females in finals and on podiums.

Q4. Couldn't we have eligibility criteria for the two divisions (male and female) based on some different (other than sex) physical criteria?
A4. No. There are no other physical criteria that could be used to determine eligibility that would similarly assure sex equality in competitive sport. Based on those different criteria, e.g., matching leg length, wing span, height, weight, etc., males as a group would always outperform females as a group because their biological sex differences, primarily testosterone levels in the male range from the onset of puberty and throughout the athletic career. Team USA stars Missy Franklin and Ryan Lochte illustrate this point well. They are both multiple Olympic and world champions in swimming. Both had first class training, coaching, and support. Both are 6'2" with reported 6'4" wingspans. Both held the world record in the 200 meters backstroke. But had they raced each other on their best days, Lochte would have finished about a half lap ahead of Franklin. In 2012, the year Franklin set her world record, her time of 2:04.06 would have placed her in a tie for 50th in the U.S. men's Olympic Trials.

Q5. If a boy and a girl are the same height, weight, and body build, aren't they likely to be essentially the same athletically?

A5. No. Testosterone-driven sex differentiation at puberty results in males developing larger hearts and higher capacity for oxygen transport and carbohydrate processing, as well as different skeletal and muscular composition. All of these characteristics provide males with superior strength, speed, power, and endurance.

Q6. What do scientific experts estimate is the sports performance advantage of post pubescent males?

A6. Experts estimate the male advantage is normally between 8 and 20% depending on the sport and event, and up to 50% in sports and events featuring explosive power. For example: Team USA's best female high jumper is Vashti Cunningham, NFL star Randall Cunningham's daughter. She is regularly ranked among the top ten best female high jumpers in the world. Her best jump as a professional (6' 6 ½") is regularly surpassed by dozens of U.S. high school boys.

As the chart immediately below — comparing California high school performances — shows, this isn't a phenomenon exclusive to professionals. Because the performance gap emerges at the onset of male puberty, as a group, high school girls have no chance against high school boys as a group.

2019 CALIFORNIA REGIONAL HIGH JUMP RESULTS[19]

REGION	BEST HIGH SCHOOL BOY	BEST HIGH SCHOOL GIRL	% DIFFERENCE
Central	6'10"	5'10"	14.63%
Central Coast	6'6"	5'6"	15.38%
Los Angeles	6'2"	5'2"	16.22%
North Coast	6'10"	5'5"	20.73%
Northern	6'5"	5'6"	14.29%
Oakland	5'11"	4'10"	18.31%
Sac-Joaquin	6'8"	5'8 1/4"	14.69%
San Diego	6'8"	5'10 1/2"	11.88%
San Francisco	6'0"	4'10"	19.44%
Southern	7'0"	5'8 1/2"	18.45%

[19] This chart is based on data from Athletics.net, California High Jump Results, accessed on September 25, 2019.

Q7. Are advocacy groups correct when they say that it's a myth and an outdated stereotype that females can't compete with males?

A7. No. It is a fact - not myth or outdated stereotype - that starting from the onset of male puberty, i.e., starting in middle school, there is an average 8-20% performance gap between males and females, which reaches to 50% in some sports and events. The proposition that better resources and support for female athletes can change biological imperatives and competitive results is false. Some individual females can and will outperform some individual males. But even the very best female athletes are routinely surpassed not only by the very best male athletes but also by second tier male athletes. For example, the world records in the indoor men's and outdoor women's shot put are quite similar — 74' 10 1/2" for the men and 74'3" for the women. But the women's shot put is 8.8 lbs. while the men's is almost twice as heavy at 16 lbs. The same pattern holds for the women's world records in all of the races on the track from 100 meters to 10,000 meters. Indeed, not only are those records surpassed by many men each year, they are also surpassed by many high school boys. The pattern also holds for high school athletes who aren't yet superstars. With rare exceptions, from the onset of male puberty, even the best high school girls have no chance to succeed against high school boys.

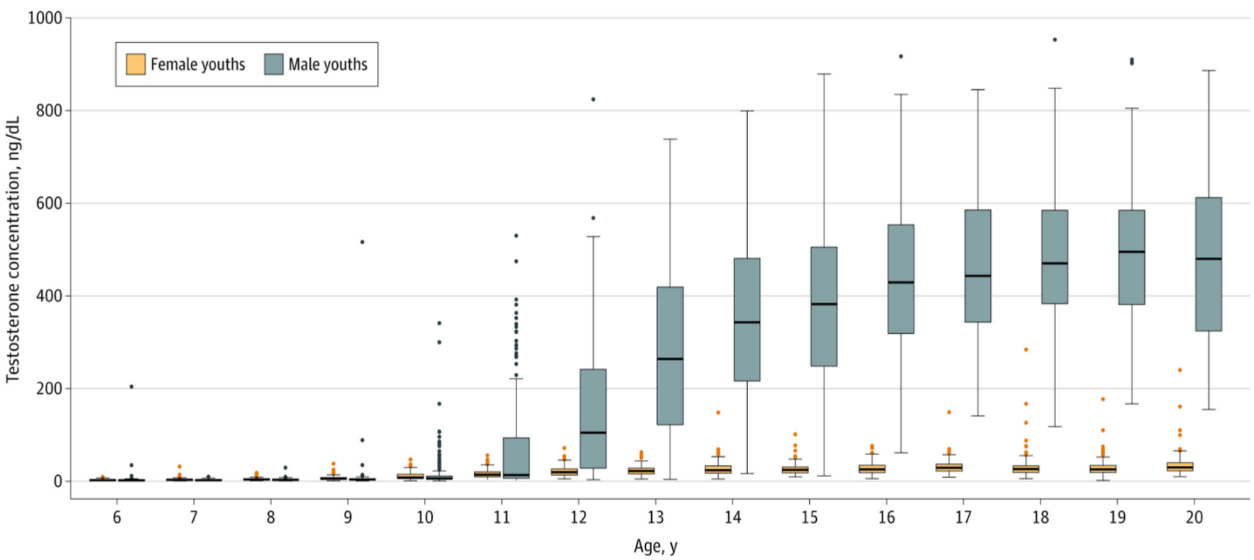
Q8. What does testosterone have to do with separate sex sport—why are we always hearing about testosterone in this context?

A8. Testosterone is an anabolic-androgenic steroid. *Anabolic* steroids build body tissue, including but not limited to bone and muscle tissue and red blood cells. *Androgenic* steroids are responsible for male sex differentiation, i.e., for the development of male primary sex characteristics (in utero), and male secondary sex characteristics (in puberty). Because of its body building and sex differentiation effects, testosterone produced *endogenously* (naturally within the human body) is the primary driver of the sex differences in athletic performance, i.e., of the performance gap between male and female athletes. Beginning at puberty, at approximately age 11, the male testes begin producing significantly more testosterone than they did earlier in childhood, and also significantly more than is ever produced by female ovaries. This increased production triggers the onset of male puberty, and thereafter builds and sustains the male body in the respects that matter for sports performance: speed, strength, power, and endurance. The *exogenous* use of testosterone (doping) is banned by all national and international sports organizations because of these anabolic effects.

Q9. What do people mean when they say that there is a "male range" and a "female range" for testosterone?

A9. Both males and females produce testosterone naturally in their bodies, males primarily in the testes and females primarily in the ovaries. Starting from the onset of male puberty, generally about age 11, testes begin to produce much more testosterone than ovaries. From that point forward, the normal female range is between 0.06 and 1.68 nanomoles per liter (nmol/L), and the normal male range is between 7.7 and 29.4 nmol/L. The gap between top of the female range and the bottom of the male range is 6.02 nmol/L. Converted to ng/dL — the metric typically used in medicine in the U.S. — the normal female range is from 1.73 to 48.45 ng/dL, the normal male range is from 222 to 848 ng/dL, and the gap between the top of the female range and the bottom of the male range is 173 ng/dL.

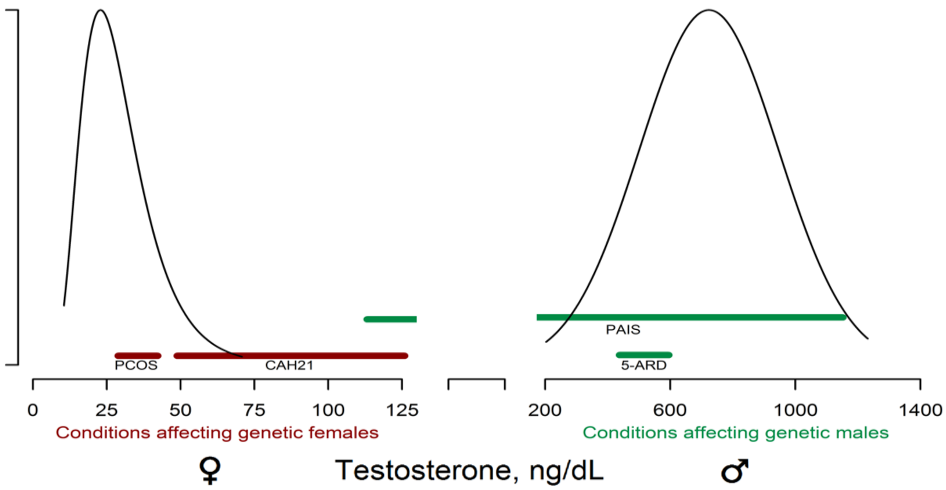
The figure below was published this year in the Journal of the American Medical Association (JAMA). It represents data from the U.S. National Health and Nutrition Examination Survey (NHANES). It shows the increase in testosterone concentration in male youth starting from age 11 onward, as well as the gap that emerges as a result between male and female testosterone levels.



(from J. Senefeld et al., JAMA Research Letter (2020))

Q10. Don't some healthy females produce testosterone in the "male" range?

A10. No. Although females do produce testosterone, mainly in their ovaries, healthy post-pubertal females never produce testosterone levels as high as post-pubertal males. Throughout childhood, up until the onset of male puberty, male and female testosterone levels are about the same; but from the onset of male puberty, male testes produce significantly more testosterone than female ovaries. From that point forward, normal female testosterone levels fall in a narrow range between 0.06 and 1.68 nanomoles per liter (nmol/L), and male levels fall in a broader range between 7.7 and 29.4 nmol/L. The gap between the normal male range and the normal female range is wide. As the following figure indicates, there is no overlap. Some biological females have higher than normal female testosterone levels, for example if they have polycystic ovaries, but again, no healthy female has a testosterone level even close to the normal male range.



This figure shows the normal female testosterone range on the left and the normal male range on the right. It also shows the abnormal testosterone ranges that can be produced by people with certain differences of sex development (DSDs). Some people with DSD prefer to describe themselves as intersex. The conditions marked in red are among those that affect genetic (biological) females. Those marked in green are two that affect (genetic) biological males. Those conditions are described further in the answer to Question 27 below.

Some advocates for trans and intersex athletes claim that there is an overlap in the normal ranges. This claim is not supported by the data or the current peer-reviewed literature. Their argument depends on the existence of a small number of outlier (abnormal) readings, i.e., on a small number of higher-than-normal female T readings and a small number of lower-than-normal male T readings. These abnormal readings are used by advocates to construct a "spectrum" that *appears* to negate the normal bimodal distribution by "filling in" the gap between the two ranges.[20] The figure above shows one way this optical effect can be achieved. It requires ignoring that more than 99% of the population has readings in the normal ranges, and then "filling in" the gap between those ranges with readings from the less than 1% of the population that has an intersex condition.

As the leading experts in the field have established, however, the overlap argument is not supported by the data points themselves, which do not distinguish between (1) doped and non-doped females; (2) females and males with differences of sex development; and (3) male readings taken at rest and following strenuous exercise—the latter has been established to lower normal levels temporarily. Additionally, they measure testosterone by immunoassay — which is inaccurate at lower testosterone concentrations in women — rather than by state-of-the-art methodology, i.e., by mass spectrometry.[21] Once those errors are corrected, the overlap disappears.

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[20] Advocates may refer to this older paper to support their claim: Healy ML, et al., Endocrine profiles in 693 elite athletes in the postcompetition setting. Clin Endocr. 2014; 81(2): 294-305. PMID: 24593684.

[21] Handelsman DJ, Hirschberg AL, Bermon S. Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. Endocr Rev. 2018;39(5):803-29. Epub 2018/07/17. Clark RV, Wald JA, Swerdloff RS, Wang C, Wu FCW, Bowers LD, Matsumoto AM 2019 Large divergence in testosterone concentrations between

Q11. Don't elite female athletes have high testosterone levels—isn't this what makes them good athletes?

A11. No. Elite female athletes generally have testosterone levels within the normal female range, i.e., below 1.68 nmol/L. If they have the condition known as polycystic ovary syndrome (PCOS), they may have testosterone levels up to 3 nmol/L, or, in rare instances, up to 4.8 nmol/L. This is why some sports organizations, wishing to be inclusive of all possible healthy biological females, set their maximum testosterone level at 5 nmol/L.

Q12. Why have many sports organizations adopted a testosterone test for their eligibility standard for inclusion in women's sport?

A12. Testosterone is an excellent proxy for biological sex and a valid basis for an eligibility rule for the women's category for the following reasons:

- Testosterone is the primary driver of the sex differences in athletic performance;
- Sport already tests for and monitors testosterone levels as part of the normal anti-doping process; and
- Different sex testing protocols are more intrusive and, in some cases, less accurate.

No other single criterion so comprehensively addresses sport's and society's concerns about the testing protocol.

Q13. Why have some sports organizations adopted the testosterone level of 5 nmol/L as the upper limit for inclusion in the female category?

A13. Some sports organizations have adopted the level of 5 nmol/L as the upper limit for inclusion in the female category because it represents the outermost bounds that a healthy biological female — regardless of her legal or gender identity — can reach naturally. Almost all females, including elite athletes, have testosterone levels well below 5 nmol/L. The normal female range is between 0.06 and 1.68 nmol/L. Even females with the condition known as polycystic ovary syndrome (PCOS) — which can dramatically raise testosterone levels — only very occasionally reach 3 nmol/L, with rare readings up to 4.8 nmol/L. Setting the level at 5 nmol/L assures that no otherwise healthy biological female could be excluded by the standard. Given that 5 nmol/L is already high, however, some international federations are considering the lower limit of 3 nmol/L.

Q14. Why is only the female category policed for testosterone levels—why doesn't sport also set an upper limit for the male category?

A14. The female category was carved out from open (mixed or co-ed) sport as a protected space where females could compete only against each other and not also against males. It was designed specifically to exclude males, i.e., people with male sex-linked performance advantages. Testosterone is the primary driver of these sex-linked advantages. The male category is not policed because it does not need protection from itself; it was not designed to exclude or regulate males with natural male testosterone levels. Elite sport does, however, monitor testosterone levels in all athletes, male and female, for exogenous use of (i.e., doping with) androgens, including testosterone.

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men and women: Frame of reference for elite athletes in sex-specific competition in sports, a narrative review. Clin Endocrinol (Oxf) 90:15-22.

Q15. Are advocacy groups correct when they say that there is no evidence that trans girls/women have an advantage over females in sport?

A15. No. They are wrong. Trans girls/women are biologically male. Consequently, unless they go on puberty blockers and then on gender affirming hormones before the onset of male puberty, they benefit from normal male sex development and differentiation. There is overwhelming evidence that individuals who are biologically male — however they identify — have an athletic advantage over individuals who are biologically female—however they identify. Gender identity is unrelated to athletic ability. Additionally, there is convincing evidence[22] that, depending on the task, skill, sport, or event, trans women maintain male sex-linked (legacy) advantages even after a year on standard gender-affirming hormone treatment.

Q16. Are advocacy groups correct when they say that any remaining advantages males have over females in sport are the result of cultural stereotypes and lesser opportunities for development, training, and competition?

A16. No. They are wrong. Although stereotypes and opportunities can affect the degree of the performance gap between the best females and the best males, the data and science are clear that for almost all sports and events the gap itself is biologically-based and immutable.

Q17. What does it mean physically or biologically to say that someone is "transgender"?

A17. A transgender person is currently defined as someone who identifies as other than their biological sex. For example, a trans girl/woman is someone who identifies as a girl/woman even though they are biologically male. A person does not need to take gender affirming hormones or have surgery to be considered transgender. Some transgender people are not on hormones and have not had surgery. Some transgender people take hormones but do not have surgery. And some transgender people do both. Whether a transgender person takes hormones, the level at which they choose to set their hormones, and whether they have surgery, are all matters of personal choice, medical advice, and/or opportunity.

Q18. Do all trans girls/women have a testosterone advantage?

A18. No. Those trans girls/women who *never* experience the onset of male puberty do not develop the secondary sex characteristics that are responsible for the performance gap between male and female athletes. Preventing male puberty involves taking puberty blockers before its onset, and thereafter transitioning to gender affirming hormones that keep testosterone levels consistently within the female range. In contrast, trans girls/women who go on blockers and/or gender affirming hormones and/or have a gonadectomy only *after* they experience some or all of male puberty retain a "legacy advantage" as a result of this experience. The degree of their legacy

[22] (1) Roberts TA, Smalley J, Ahrendt D. Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organisations and legislators. Br J Sports Med. 2020. Epub 2020/12/09. (2) Hilton EN, Lundberg TR. Transgender Women in The Female Category of Sport: Perspectives on testosterone suppression and performance advantage. Sports Medicine. 2021;51:(in press) (PMID 33289906 and doi: 10.1007/s40279-020-01389-3). (3) Handelsman DJ, Hirschberg AL, Bermon S. Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. Endocr Rev. 2018;39(5):803-29. Epub 2018/07/17. See also (4) Gooren LJ, Bunck MC. Transsexuals and competitive sports. Eur J Endocrinol. 2004;151(4):425-9. (5) Wiik A, Lundberg TR, Rullman E, et al. Muscle Strength, Size, and Composition Following 12 Months of Gender-affirming Treatment in Transgender Individuals. J Clin Endocrinol Metab. 2020;105(3). Epub 2019/12/04.

advantage depends on a combination of factors including: the extent to which they have experienced puberty; whether they had a gonadectomy (surgical removal of their testes); the levels at which they maintain their circulating testosterone; and the particular sport and event in which they compete.

Q19. What is meant by "legacy advantages" in the discussion of trans girls/women in girls/women's sport?

A19. Legacy advantages are the male sex-linked advantages that remain even after a trans girl/woman has gone on gender affirming hormones and/or gender affirming surgery. They are the benefits for sport of having gone through all or part of puberty as a male.

Q20. Does transgender inclusion have anything to do with doping or performance enhancing drugs (PEDs), and if so, what's the connection?

A20. Doping is the exogenous use — the taking — of prohibited performance enhancing drugs (PEDs), including testosterone and other body building androgens. These are among the substances that propelled the East German women to victory in the Olympic Games and World Championships in the 1970s and 1980s, costing clean American women and Team USA to lose out on medals they would otherwise have won. Some American athletes have also doped with androgens, but not in the systematic and state-sponsored way as the East Germans, and more recently the Russians. Trans girls/women who want to be included in girls'/women's events are not doping; that is, they aren't taking PEDs to compete. But their natural testosterone levels build strength, speed, and power in the same way that doping does; and because their natural levels are much higher than even those of doped female athletes, the effect on competition is the same or more overwhelming for the clean females in the field.

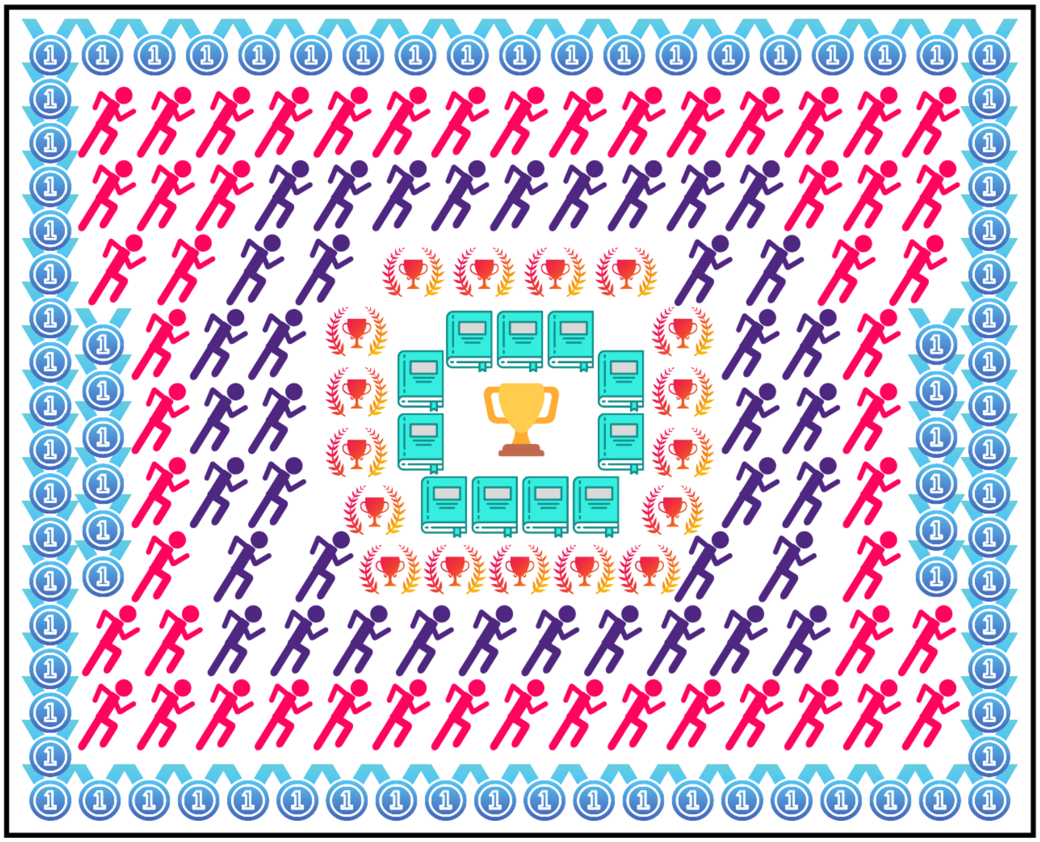
Q21. Do we have any data on the impact of trans girls with no medical intervention in girls' high school sports?

A21. Yes. The data that exist about trans girls with no medical intervention are consistent with the fact that they are biologically male. For example, based on its interpretation of the State of Connecticut's Equality Act, the Connecticut Interscholastic Athletics Conference (CIAC) permits trans girls to compete in girls' events even if they have not yet gone on puberty blockers or gender affirming hormones. (The CIAC places no physical or physiological conditions on their inclusion in girls' events). Two trans girls who used to compete on their schools' boys' teams moved to the girls' teams when they came out as trans. They immediately dominated their events at their conference, state, and regional competitions, even though their performances would have been insufficient to qualify them for post-season play had they competed in the boys' divisions. And although they started competing in girls' events before they began taking gender-affirming hormones, they continued to be among the best girls in their events even after they publicly stated they had started on puberty blockers and hormones. All told, just these two trans girls took "15 women's state championship titles (titles held in 2016 by nine different Connecticut female athletes) and . . . more than 85 opportunities to participate in higher level competitions from female track athletes in the 2017, 2018, and 2019 seasons."[23]

[23] Verified Complaint for Declaratory and Injunctive Relief and Damages, Seoule et al. v. CIAC, Case No. 3:20-cv-00201, paragraph #77, filed in the United States District Court for the District of Connecticut (Feb. 12, 2020). These results are limited to conference, state and regional championships. They do not include all of the

2017-2020 Impact on Female Students in Connecticut from Participation of Two Trans Girls in One Sport

Loss of Sports Participation Opportunities and Major Awards in a State with a Policy of Unconditional Inclusion of Trans Girls Without the Application of Mitigation Standards



This chart reflects the impact on female track and field athletes that resulted from the Connecticut Interscholastic Athletic Conference's policy of unconditional inclusion of trans girls based on gender identity. These impacts occurred at conference, class, state, and New England championships, as well as three invitational track and field meets over a period of four years. Each impact is an instance that an individual female athlete was affected by this policy.

Championships and Awards - 133 Impacts

Team Championship: 23 females were denied a Connecticut State Open team championship

Individual & Relay Championships: 93 instances where a female was denied an individual or relay championship

All-New England Awards: 17 instances where a female was denied an All-New England honor

Records - 11 Impacts

Meet Records: 11 instances where a female lost a meet record

Participation - 91 Impacts

Finals Participation: 39 instances where a female was denied the opportunity to advance to finals

Meet Qualification: 52 instances where a female was denied the opportunity to advance to a championship meet

regular season or invitational events at which opportunities to move on through competitions to finals and/or wins and podium spots were affected.

T MILLER - SPRINTS
55 meters indoors and 100 meters outdoors

GRADE	Hormone Status*	Event	Connecticut Boys' State Rankings	Connecticut Girls' State Rankings
9th	not on gender affirming hormones	Indoor-55m	662nd	32nd
		Outdoor-100m	326th	2nd
10th	not on gender affirming hormones	Indoor-55m	377th	5th
		Outdoor-100m	181st	1st
11th	not on gender affirming hormones	Indoor-55m	118th	1st
		Outdoor-100m	165th	1st
12th	on gender affirming hormones	Indoor-55m	335th	3rd
		Outdoor-100m	- / -	- / -

Miller competed on the boys' track team her freshman year and through the winter of her sophomore year. She came out publicly as transgender in the middle of 10th grade, and then switched to the girls' team for her remaining two-and-a-half years of eligibility.

Her hormone status for each season is derived from publicly-available information.[24] Because that information indicates she went on hormones for the first time only at the end of the 2019 outdoor season, i.e., sometime in May, and because her best time that year was run before then, she is listed here as "not on hormones" for the year.

The table shows rankings for the 55 meters indoors first, followed by the 100 meters outdoors. The rankings in blue font show the division she actually competed in, and the point at which she switched from the boys' to the girls' division. Simply by walking off of the track in the boys' events and walking onto the track in the girls' events, she went from barely being in the top 400 in the state to being #1 in the state.

The girls' rankings for her 9th grade year are those she would have achieved based on her times as run in boys' events. The boys' rankings for her sophomore, junior, and senior years are those she

[24] See, e.g., Beyond the Labels: Meet Terry Miller, Runner's Space.com, May 26, 2019, available at https://www.runnerspace.com/gprofile.php?mgroup_id=44531&do=news&news_id=576791 (implying that Miller attended NSAF Nationals as a spectator not a competitor in her junior year, 2019, because she was not eligible to compete there, and Miller herself suggesting that she began taking hormones only in the latter part of that same year).

would have achieved based on her times as run in girls' events. There were no rankings for the 100 meters outdoors her 12th grade year (2020) because the season was cancelled due to COVID.

A YEARWOOD - SPRINTS
55 meters indoors and 100 meters outdoors

GRADE	Hormone Status*	Event	Connecticut Boys' State Rankings	Connecticut Girls' State Rankings
9th	not on gender affirming hormones	Indoor-55m	- / -	- / -
		Outdoor-100m	422nd	4th
10th	on gender affirming hormones	Indoor-55m	392nd	5th
		Outdoor-100m	470th	3rd
11th	on gender affirming hormones	Indoor-55m	194th	2nd
		Outdoor-100m	449th	5th
12th	on gender affirming hormones	Indoor-55m	170th	1st
		Outdoor-100m	- / -	- / -

Yearwood competed on the girls' team all four years in high school. She came out publicly as transgender in the 9th grade. Her hormone status for each season is derived from publicly available information.[25] The table shows rankings for the 55 meters indoors first, followed by the 100 meters outdoors. The boys' rankings listed on the table are those she would have achieved based on her times run in girls' events. There were no rankings for the 100 meters outdoors her 12th grade year (2020), because the season was cancelled due to COVID.

We don't have statistics on the number of trans girls who have competed in girls' events in high school sports. However, it appears that, at least in the past, most were already on gender-affirming hormones by the time they sought to participate on girls' teams; trans advocacy groups seems generally to assume that this is the case when they speak to the issue. However, we are at a juncture

[25] See, e.g., Jeff Jacobs, As We Rightfully Applaud Yearwood, We Must Acknowledge Many Questions Remain, Hartford Current, June 17, 2017, available at https://www.courant.com/sports/hc-jacobs-column-yearwood-transgender-0531-20170530-column.html (reporting that Yearwood's father "said his daughter will begin consultations in June [2017] about hormonal treatment”). That was at the end of 9th grade. The fact that she competed at NSAF Nationals in 11th grade (March 2019) means that she was on hormones in 10th grade.

in history where trans girls who are not on hormones are just beginning to ask to be included in girls' competitions. In part this is because the standard of care in trans-medicine now recommends that trans-kids "come out" socially before they transition medically; and many physicians now require that kids wait until they are 16 to go on gender-affirming hormones. For a trans girl, going out for a girls' school sports team is one way to come out socially. We are thus increasingly likely to face situations like that in Connecticut where trans athletes seek to compete in girls'/women's sport while not on hormones.

Q22. Do we have any data on the impact of trans boys with or without medical intervention in high school sports?

A22. Yes. The medical community now recommends that trans kids "come out" socially before they transition medically. While some trans girls have opted to go out for a girls' school sports team as one way to come out socially, this option is not so easily available to trans boys who, because they are biologically female, are unlikely to make a boys' team. As a result, some trans boys have chosen to come out socially while remaining on the girls' team. This has allowed them to continue to participate and to remain competitive in high school sport. Some trans girls have chosen this same path, coming out socially while remaining on the boys' team.

Q23. When post-pubescent trans girls take gender-affirming hormones, do their athletic performances decline? If so, does any performance or "legacy" advantage remain?

A23. Going on gender affirming hormones causes a decline in circulating levels of testosterone which, if consistently maintained over time, has some effect on athletic performance. This effect seems to be primarily on endurance, not on strength and power. The effect on speed seems to be dependent on the extent to which the event is endurance- as opposed to strength- and power-based. Thus, the nature and extent of the decline in male performance advantage, also known as the "legacy advantage", appears to depend on the sport and the event. It also depends on the extent to which the individual experienced male puberty before they began their physical transition, and on how high they choose to maintain their testosterone levels once they do go on gender affirming hormones. Regardless, as we explain in our answer to Question 15, the current state of the peer reviewed literature is that legacy advantages remain significant.

Q24. Why do some sports organizations and governing bodies — including the NCAA — require that trans girls/women reduce their testosterone levels for a year before they can compete in girls'/women's events?

A24. The NCAA, the IOC, and many international federations (IFs) and national governing bodies (NGBs), require trans girls/women to reduce their testosterone levels for at least a year before they can compete in girls'/women's events. This accommodation is a policy compromise, based in the hypothesis that if a trans girl/woman reduces her testosterone levels into the female range and keeps her levels consistently within that range for at least a year, her male-linked advantages will decline to the point that it is fair to include her in girls'/women's competition. The hypothesis itself is based in the fact that trans girls/women are biologically male and that testosterone is the primary driver of the performance gap between male and female athletes. Just how much gender affirming hormones reduces her male sex-linked advantages and what "legacy advantages" remain is the subject of ongoing investigation.

Q25. Is there strong scientific evidence that trans girls/women have an unfair advantage over biological females even after a year of androgen-suppressing treatment?

A25. Yes. As our answer to Question 15 details, several peer-reviewed studies, including one based on data from the U.S. military, have confirmed that trans women retain their male sex-linked advantages even after a year on gender affirming hormones. This is especially the case for sports and events that are not endurance-based. Because of these retained advantages, USA Powerlifting and World Rugby have recently concluded that it isn't possible fairly and safely to include trans women in women's competition. Other international sports federations have rejected the International Olympic Committee's 2015 guidance suggesting that trans women be included in women's competition so long as they reduce their testosterone levels to the bottom of the male range (under 10 nmol/L). The latter federations, e.g., those that govern the sports of track and field, tennis, cycling, and rowing, have reduced the required testosterone level to within the female range.

Q26. Is the NCAA's testosterone rule for trans women athletes sufficient to ensure fairness to and the safety of the biological females in the field?

A26. No, not as currently administered. The NCAA rule is superficially similar to that of the IOC and other sports governing bodies in that it focuses on testosterone levels; however, as administered it currently lacks their rigor and detail. It provides only that trans women athletes need to be on gender affirming hormones for at least a year. It does not specify that they need to bring their testosterone levels into the female range; it does not require them to keep their levels consistently within that range; and it does not monitor their compliance. The hypothesis that reducing testosterone levels winds down the male performance advantage sufficient to ensure fairness to and safety for the female athletes in the field depends not only on getting those levels into the female range, but also maintaining them consistently within that range throughout the operative period. The NCAA rule has been properly criticized, including by trans women athletes and their coaches, for its lack of monitoring and guidance in these respects.

Q27. What if any is the relationship between intersex and trans athletes?

A27. Intersex conditions result from differences in biological sex development. They are also known as differences of sex development or DSDs. There are many different intersex conditions, but those that are relevant for sport all involve biological males — individuals with an XY karyotype, testes, and testosterone levels in the male range — whose sex development was atypical in some respect. For example, their external genitalia might not be fully formed or their androgen receptors may be less than typically sensitive. Athletes with such intersex conditions may be raised as male or female. People who are transgender do not generally consider themselves to be intersex. The two are related in sport to the extent that they may both involve biological males with full or partial male advantage who seek eligibility to compete in girls'/women's sport.

The following table is illustrative. It is from an exhibit in the case brought by South African runner Caster Semenya against her international federation (the IAAF now World Athletics) at the Court of Arbitration for Sport (CAS) in Switzerland. Semenya is sometimes described as intersex. In 2019, CAS upheld the federation's eligibility rules for the women's category. Those rules require affected athletes to verifiably reduce their testosterone levels to within the normal female range for a 12-month period before they can compete in that category. Switzerland's Supreme Court affirmed the CAS decision in 2020.

COMPARING BIOLOGICAL SEX TRAITS
FOR PURPOSES OF GIRLS' AND WOMEN'S SPORT
(from IAAF Exhibit in Semenya and ASA v. IAAF)

	Typical Male	Person with 5-ARD (not on hormones)	Person who is Transgender MTF (not on hormones	Typical Female
Chromosomes	46 XY	46 XY	46 XY	46 XX
Gonads and Gametes	Testes & Sperm	Testes & Sperm	Testes & Sperm	Ovaries & Eggs
Endocrine system	Androgenic	Androgenic	Androgenic	Estrogenic
Sex hormones	Testosterone levels in male range	Testosterone levels in male range	Testosterone levels in male range	Testosterone levels in female range
Primary sex characteristics (develop in utero)	Testes, epididymis & vas deferens, prostate	Testes, epididymis & vas deferens, vestigial prostate	Testes, epididymis & vas deferens, prostate	Ovaries, fallopian tubes, uterus, vagina
Virilisation on puberty	Yes	Yes	Yes	No
Secondary sex characteristics (develop at puberty)	Male	Male	Male	Female
External genitalia	Penis, scrotum	Varies	Penis, scrotum	Clitoris, labia
Legal sex	Male	Varies	Varies	Female
Gender Identity	Male	Varies	Female	Female

II. ABOUT CURRENT LAW ON SEX AND SPORT

Q28: What law or laws currently provide for separate sex sport?
A28: Separate sex sport is regulated by a combination of statutes, regulations, and caselaw. This includes the Ted Stevens Olympic and Amateur Sports Act, Title IX and its regulations, the Equity in Athletics Disclosure Act, and court decisions interpreting their terms.

Q29: Are advocacy groups correct when they say that the law affords females the right to participate, not the right to win and set records, in sport?
A29: No. They are wrong. The point of the laws that create and regulate separate sex sport is to ensure that females have the same opportunities as males not only to participate but also to succeed. In addition to competing, this includes the fair ability to win and set records in regional, national, and international competitions. No male or female has an individual legal right to win or set records in their respective divisions, but as a class, females have the legal right to win and set records in girls' and women's sport, just as males that have that right in boys' and men's sport.

Q30: How would the redefinition of "sex" in federal law to include gender identity affect the legal status quo? For example, would it allow schools and sports organizations including the NCAA and USOPC to continue to maintain separate sex sport?
A30: The re-definition of "sex" to include "gender identity" in a law that prohibits discrimination "on the basis of sex" would mean that programs receiving federal funds and operating in interstate commerce could not lawfully distinguish a biological female from a trans girl/woman. This would make it prima facie unlawful to do what is currently permitted, i.e., to have teams and events that are separated on the basis of biological sex. It would also make it prima facie unlawful to use testosterone — a sex-linked trait — as an eligibility criterion for inclusion in girls' and women's elite sport, e.g., as is currently required by the NCAA, the USOPC, the IOC, and the international sports federations. Both separate sex sport itself and eligibility criteria based on biological sex and sex-linked traits like testosterone are currently lawful exceptions to general prohibitions on sex discrimination. For this to remain the case, the Equality Act would need to be amended to provide for an express exception for sport.

Q31: Why do proponents of the Equality Act (EA) assert that the redefinition of sex won't affect girls' and women's sport?
A31. Many of the EA's advocates argue that the proposed EA Act won't affect Title IX, without explaining why. Alternatively, others argue that, even if it does, Congress could restore separate sex sport after the EA's enactment, through specific legislation or regulations addressing sport. Restoring separate sex sport after the EA's enactment is highly unlikely as a matter of standard legal analysis, legislative history, and politics.

The EA is designed to amend the Civil Rights Act of 1964. The definitions in that statute have been and will continue to be the basis for interpreting or defining the same words as used in all other civil rights legislation. That is, Congress cannot re-define "sex" in the principal statute and not have that definition apply directly or indirectly to the use of that term in other legislation. In fact, many of the EA proponents intend precisely this—make the change to the definition in the principal legislation, and this will automatically change the definition in related legislation. Moreover, as a matter of standard legal analysis, absent a legislative carve out for sport — i.e., an explicit acknowledgement of an exception — any newly enacted, categorical prohibition on discrimination between biological females and trans girls/women would be presumed to supersede any earlier legislation to the contrary, including Title IX.

The legislative history of the EA makes clear that its proponents intend for it to apply to sport with no conditions or exceptions and thus, to prohibit any distinctions between biological females and trans girls/women. At the House Judiciary Committee Hearings, both the witnesses and Democrats on the Committee insisted that trans girls/women be included in girls' and women's sport without any conditions because "trans girls are girls, trans women are women, period." And on the floor of the House, a bill was rejected by a vote of 181 to 228 that would have retained the longstanding exception in Title IX for separate sex sport based on biology. (Specifically, Congressman Steube proposed legislation providing that, "Nothing in this Act or any amendment made by this Act may be construed to diminish any protection under Title IX of the Education Amendments of 1972.") The Equality Act then passed the House by a vote of 236 to 173. This legislative history would be instructive in the future were the question to arise whether Congress intended to permit or preclude distinctions on the basis of biological sex.

The natural experiment with state versions of the EA also make clear that an explicit exception is necessary to maintain sex segregated sports and spaces. In those contexts, trans advocates argue that under the state EAs, it is impermissible to separate or in any way differently to treat trans girls within girls' sport. They make these arguments even though state legislatures did not consider sports as they were enacting their EA legislation.

Q32. How does the recent Supreme Court decision in *Bostock v. Clayton County* (2020) affect separate sex sport—does it prohibit all distinctions on the basis of sex, including in sport?

A32. In *Bostock*, the Supreme Court ruled that "sex" in Title VII means "biological sex." Contrary to what many proponents of the EA argue, *Bostock* did <u>not</u> define (or re-define) "sex" to include "gender identity." Rather, it held that Title VII's general prohibition of discrimination "on the basis of sex" precludes discrimination that takes into account a transgender employee's sex and gender identity. Firing a person because they are transgender — i.e., because their gender identity is nonconforming — requires taking their sex into account, and this is prohibited by Title VII. Because the case involved Title VII's general non-discrimination provision, not an existing exception that allows taking sex into account, the Court wrote that it was leaving the lawfulness of exceptions — including in bathrooms, locker rooms, and sport — for another day. *Bostock* explicitly did not rule on the lawfulness of the current scheme under Title IX and the other sport statutes.

Proponents of the EA nevertheless assert that *Bostock* applies to sport, completely ignoring the Court's express pronouncement to the contrary. Specifically, in cases pending in the lower courts, they argue that *Bostock* supports the redefinition of "sex" to include "gender identity", and that the decision requires the inclusion of trans girls/women in girls' and women's Title IX sport. Notably, however, they are inconsistent in their application of *Bostock* to the question whether administrators can lawfully distinguish biological females from transgender women and girls. For example, in pending federal cases in Connecticut and Idaho, advocates for transgender athletes argue that their inclusion in girls' high school sports must be full and unconditional, without regard to whether they are on gender affirming hormones. However, in the Idaho matter, in which college sports are also at issue, they don't challenge the NCAA rule which distinguishes female athletes from transgender athletes by requiring trans women to undergo a year of gender affirming hormone treatments before they can compete in women's sport. They support the position that in college, conditions on transgender inclusion are permissible. This distinction between high school and college may make good policy sense; but it is an acknowledgement of the continued lawfulness not only of the NCAA rule, but also more generally of what that rule represents, i.e., the lawfulness of distinctions on the basis of sex in sport. It is also a tacit acknowledgment of the fact that — as the Supreme Court itself announced — *Bostock* is not dispositive in this area.

Q33. Does the law currently allow schools to distinguish females from trans girls/women? Can accommodations be developed that lawfully provide for their conditional inclusion in girls'/women's sport?

A33: The sex exception to general nondiscrimination law requires the exclusion of biological males from most girls' and women's sport. There is no case yet that finally resolves the question whether an exception to this general rule should be made for biological males who identify as women and girls. It is standard practice, however, for the courts to permit (and sometimes even to require) accommodations when there are good reasons for doing so, and when this is possible without imposing an undue burden. Thus, accommodations that would allow trans girls/women to compete in girls'/women's sport should be permissible so long as they meet these standard criteria.

III. ABOUT POLICY

Q34: What are the principles that the Women's Sport Policy Working Group used to develop its approach to trans-inclusion in girls'/women's sport?

A34. The principles that guided the Working Group in the development of its approach to trans inclusion in girls'/women's sport are the following:

1. Women's sport is designed to provide a space where biological females – whatever their gender identity – can compete only against each other and not also against biological males—whatever their gender identity. The design is based in compelling data and scientific evidence on the immutable performance gap between male athletes and female athletes. This separate sex space should be preserved and safeguarded. Girls' and women's participation in competitive sport nurtures individual health and development, contributes to the welfare of the community, and powers society's perception of the strength and value of women and girls.

2. Trans girls and women are biologically male and so per the design would normally be excluded. However, because their inclusion could also produce real value both for the individuals concerned and for society, we should work to avoid unnecessary distinctions and exclusions.

3. Physical sex-linked differences between males and females are largely determined from the onset of male puberty; it is these differences that justify separate sex sport, and thus, they must be taken into account in developing responsible policy for girls' and women's sport.

4. Protocols for co-ed sports are instructive, as is the related tradition in law and policy of looking for ways to include rather than to exclude when this is possible without doing harm to an otherwise valuable institutional design. Being transgender does not change the fact of one's biological sex. Where it is recognized in existing co-ed sports policy that sex is relevant to fairness and safety, it cannot be ignored simply because an individual identifies as transgender. Similarly, where existing co-ed sports policy recognizes that sex is not relevant to fairness and safety, the goal should be unconditional inclusion.

5. Specifically rejected as guiding principles are the unscientific, politically driven mantras that claim that:

    - "sex-linked differences including testosterone levels are indistinguishable from other differences like height, weight, wingspan, and foot shape";
    - "the performance gap between male and female athletes is based in myth, stereotype, and cultural inequities";
    - "the physical legacy advantages associated with developing as a biological male don't exist or matter to sports performance";
    - "there is no evidence that transwomen and girls have a competitive advantage over females"; and
    - "females only have the right to participate not to win".

    These patently false claims have no place in a serious discussion of the policy question whether and how to include transgender athletes in girls' and women's sport.