American College of Sports Medicine

The Biological Basis of Sex Differences in Athletic Performance

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Consensus Statement for the American College of Sports Medicine

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Purpose of the Consensus Statement

- To provide the latest scientific knowledge and mechanisms for the sex differences in athletic performance.

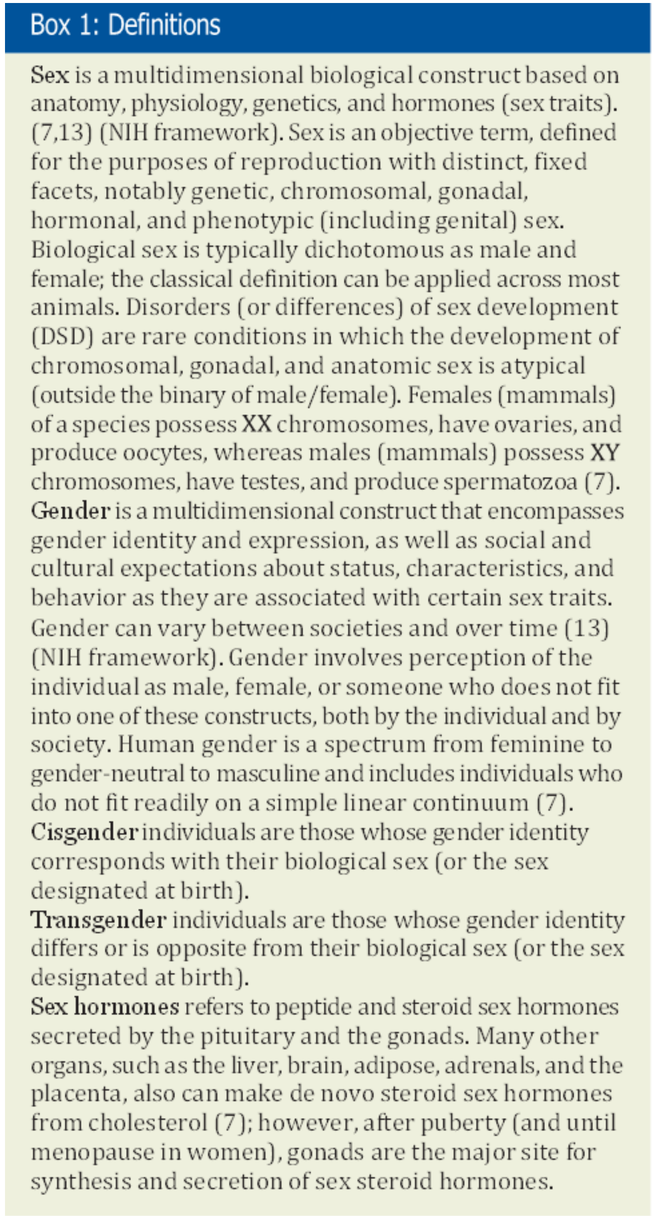
- To highlight the differences in anatomy and physiology between males and females that are primary determinants of the sex differences in athletic performance and in response to exercise training.

- To identify historical and non-physiologic factors that influence the sex differences in performance.

- To identify gaps in the knowledge of sex differences in athletic performance and the underlying mechanisms, providing substantial opportunities for high-impact studies.

Introduction

- Biological sex is a primary determinant of athletic performance because of fundamental sex differences in anatomy and physiology dictated by sex chromosomes and sex hormones.
- Adult men are typically stronger, more powerful, and faster than women of similar age and training status.
- For athletic events and sports relying on endurance, muscle strength, speed and power, males typically outperform females by 10-30% depending on the requirements of the event.
- These sex differences in performance emerge with the onset of puberty and coincide with the increase in endogenous sex steroid hormones, in particular testosterone in males, which increases 30-fold by adulthood, but remains low in females.



Box 1: Definitions

Sex is a multidimensional biological construct based on anatomy, physiology, genetics, and hormones (sex traits). (7,13) (NIH framework). Sex is an objective term, defined for the purposes of reproduction with distinct, fixed facets, notably genetic, chromosomal, gonadal, hormonal, and phenotypic (including genital) sex. Biological sex is typically dichotomous as male and female; the classical definition can be applied across most animals. Disorders (or differences) of sex development (DSD) are rare conditions in which the development of chromosomal, gonadal, and anatomic sex is atypical (outside the binary of male/female). Females (mammals) of a species possess **XX** chromosomes, have ovaries, and produce oocytes, whereas males (mammals) possess **XY** chromosomes, have testes, and produce spermatozoa (7).

Gender is a multidimensional construct that encompasses gender identity and expression, as well as social and cultural expectations about status, characteristics, and behavior as they are associated with certain sex traits. Gender can vary between societies and over time (13) (NIH framework). Gender involves perception of the individual as male, female, or someone who does not fit into one of these constructs, both by the individual and by society. Human gender is a spectrum from feminine to gender-neutral to masculine and includes individuals who do not fit readily on a simple linear continuum (7).

Cisgender individuals are those whose gender identity corresponds with their biological sex (or the sex designated at birth).

Transgender individuals are those whose gender identity differs or is opposite from their biological sex (or the sex designated at birth).

Sex hormones refers to peptide and steroid sex hormones secreted by the pituitary and the gonads. Many other organs, such as the liver, brain, adipose, adrenals, and the placenta, also can make de novo steroid sex hormones from cholesterol (7); however, after puberty (and until menopause in women), gonads are the major site for synthesis and secretion of sex steroid hormones.

Historical Perspectives

- The sex difference in performance is larger than explained by physiological and anatomical differences between males and females particularly among lower ranked athletes.
- This is in part due to women having less opportunity, inequitable access to sports, facilities, and training than men, and higher dropout rates of female athletes than males.
- Both past and present research studies of athletic performance, acute exercise and exercise training involve the testing of more men than women, or a lack of distinction between the sexes.
- Consequently, because of the historical predominance of research and athletic participation of men compared with women, less is known about the physiology of women athletes, limits in their athletic ability, and the acute and adaptive response of women to exercise and training relative to men.

Table 1. Historical Events and Policy Influencing Participation and Equity in Women's Sport and Health Research.

Year	Historical Moments Influencing Participation and Equity in Women's Sport
1884	First women's tennis champion crowned at Wimbledon, England
1896	No women permitted to compete in any Olympic event at the first Olympic Games in the modern era (Athens, Greece)
1900	22 females of 997 athletes competed the Summer Olympic Games (Paris, France)
1912	Women allowed to compete in swimming for the first time at the Olympics (2 events)
1924	One women's sporting event (figure skating) at the First Winter Olympics (Chamonix, France)
1928	Women are first allowed to compete in Athletics (track & field) at the Olympics. Five events were contested but the 800 meters was dropped after 1928 because it was perceived as too stressful for women.
1937	Two-time Olympic track & field gold medalist Babe Didrikson plays in a men's professional golf tournament
1948	First woman (30-year-old Fanny Blankers-Koen, Netherlands) to win four gold medals in a single Olympic Games in track and field (London, UK) helping to make sports more acceptable for women
1960	Women's Olympic 800 m track race reinstated in the Olympics (Rome, Italy)
1967	First woman (Kathrine Switzer) to run the Boston marathon as an officially registered competitor (Boston, USA)
1972	Title IX legislation passed in the USA congress legislated equal education opportunity for females and males including athletic scholarships and educational institutions such as universities
1984	Women's Olympic marathon competed for the first time (Los Angeles, USA)
1999	Serena Williams first Grand Slam (top four) tennis championship propels her into the top money earners among all athletes.
2007	Equal pay for women and men in the Grand Slam professional tennis tournaments achieved
2021	Women's Olympic 1500 m swimming completed for the first time (Tokyo, Japan)
2021	Similar numbers of women and men for the first time participate in the summer Olympics (Tokyo, Japan)
2022	Lia Thomas becomes first transgender athlete to win an NCAA DI title, leading to significant discussion over eligibility requirements for women's sports.
2022	Equal pay for US women's and men's soccer achieved
Year	**Policy and Declarations in Research**
1990	National Institutes of Health (NIH) established the Office of Women's Health Research
1993	National Institutes of Health (NIH) Revitalization Act mandating the inclusion of women in human studies (or the justification for lack of inclusion). The Advisory Committee on Research on Women's Health (ACRWH) and Federal Advisory Committee Act (FACA) committee established to advise and make recommendations on priority issues affecting women's health and sex differences research.
2001	Institute of Medicine report: "Exploring the Biological Contributions of Sex" (Wizemann and Pardue 2001)
2016	NIH enacted a policy of including sex as a biological variable for research involving humans, animals and cells (http://grants.nih.gov/grants/guide/notice-files/NOT-OD-15-102.html).

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Sex Differences in Athletic Performance

- The rate of improvement in athletic performance of women has exceeded that of men in the last 100 years across a multitude of sports as women have gained access to training, equipment, facilities, and opportunities.
- Sex differences in athletic performance that involve strength, power and/or endurance are sizable and determined by biological differences between males and females.
- Adult men on average are stronger, more powerful, and faster over short and long distances than women of similar age and training status.
- Sex differences in the world records and best performances of athletic events that rely on endurance and muscular power range from approximately 10 to 30%.
- These differences primarily represent the physical and anatomical abilities and limitations of males and females, largely independent of motivation, and access/opportunity to elite level training.

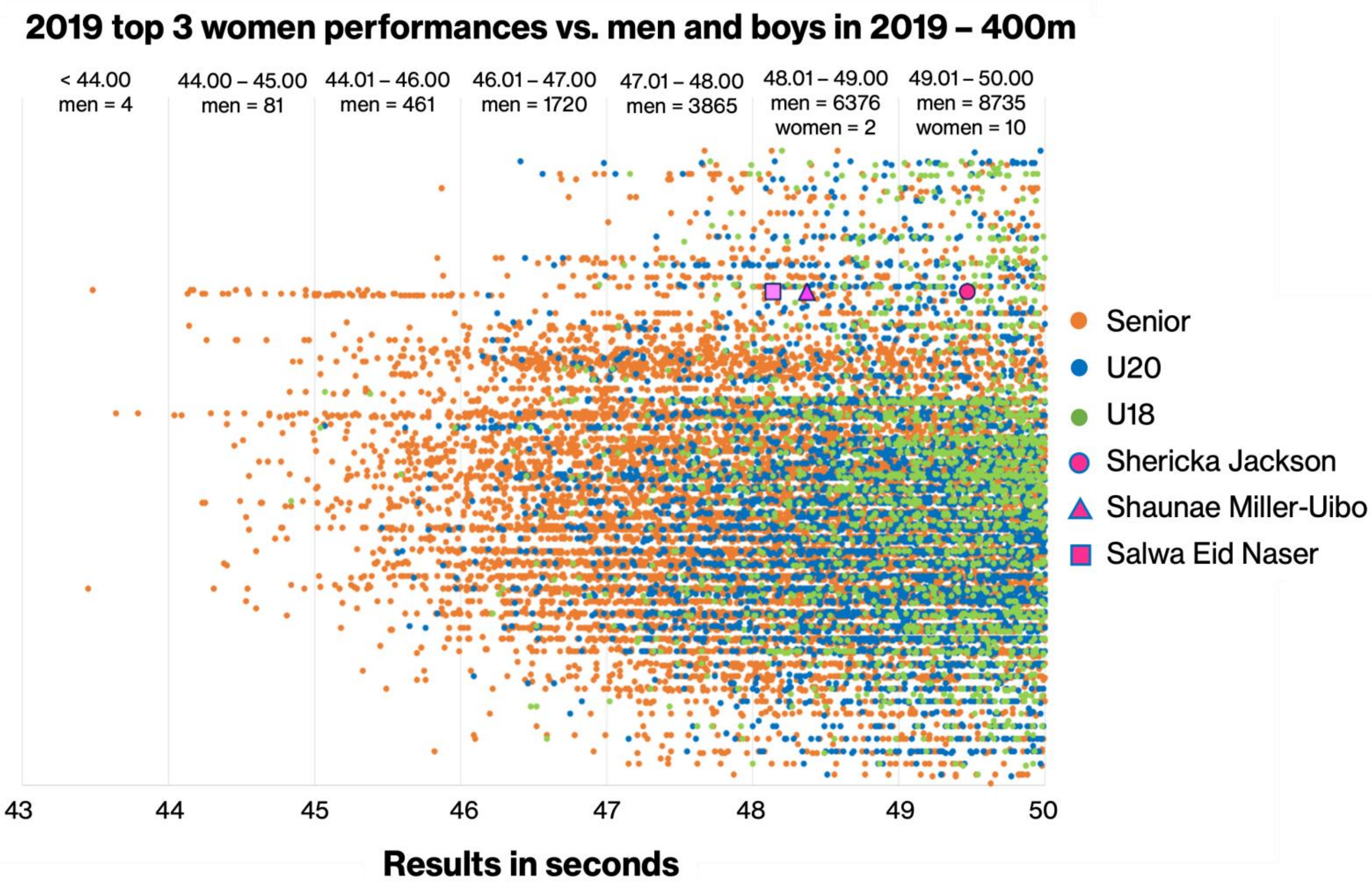
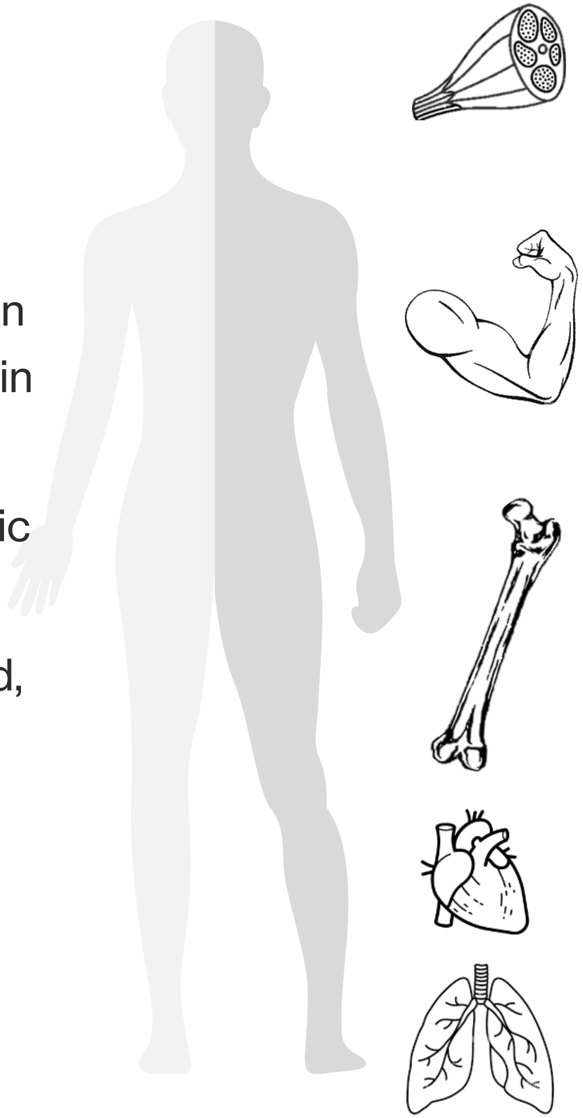


FIGURE 1. Top 400 m Track Running Performances in 2019 of Women (top three) and Men (senior, U20 and U18) Who Ran Faster than 50 seconds.

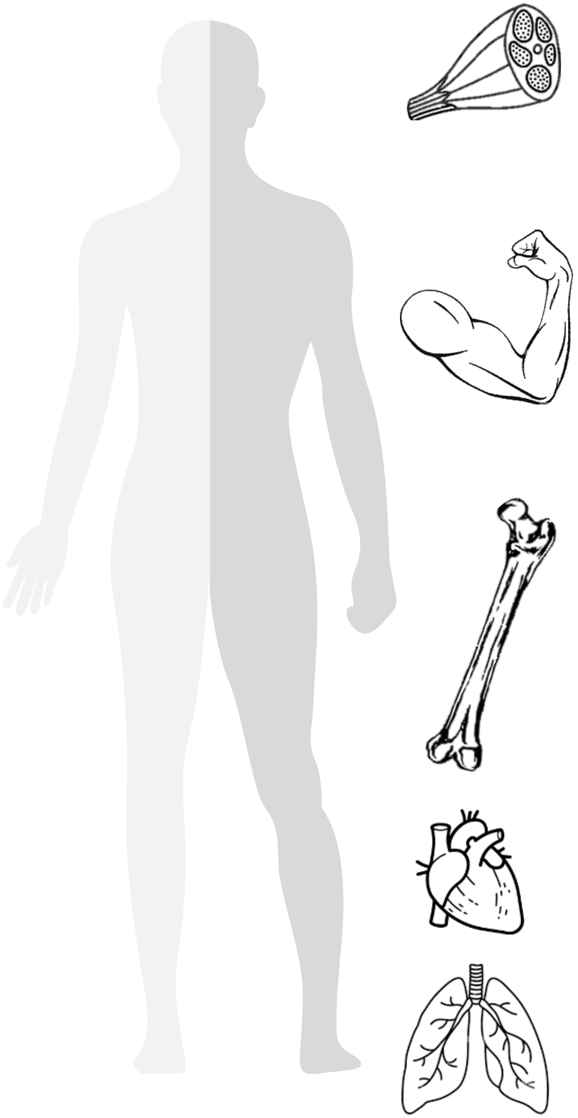
Biological Mechanisms for Sex Differences in Athletic Performance

- Exposure to high levels of endogenous testosterone in males at the onset of puberty (~12 years) is the primary determinant for the large sex difference in athletic performance during puberty and in adulthood.
- Prior to puberty, sex differences in athletic performance are minimal.
- Testosterone, a powerful anabolic steroid, increases ~20 to 30-fold in males during puberty and is 15x higher than adult females.



- The direct and indirect effects of testosterone in males (relative to females) during puberty impact several aspects of athletic performance including muscular and anaerobic power, body composition and anthropometrics, and aerobic power.
- Estradiol, the primary female sex steroid hormone, fluctuates during the menstrual cycle in females and does not have the same anabolic effects as testosterone. It is important in maintaining body composition including bone mass, skeletal muscle, fat mass, and tendon protein metabolism.

Biological Mechanisms for Sex Differences in Athletic Performance



Muscular and Anaerobic Power

- Males have increased skeletal muscle mass than females due to larger muscle fiber cross-sectional area, particularly Type II myosin heavy chain fibers.
- The muscle mass and limb power of males can be twice that of females. For example, compared to similarly active males, females achieve:
  - 50-60% and 60-80% of the upper and lower body strength.
  - 63-67% of peak power during cycling and knee extensor single limb exercise.
  - ~15-50% lower maximal anaerobic power during lower-limb maximal exercise.

Body Composition and Anthropometrics

- Compared to females, males are ~8% taller with longer upper and lower limbs.
- Males are heavier than females, with greater lean body mass (muscle and bone) and lower percentage of fat mass.
- Female athletes typically have ~5-10% more body fat than similarly trained males and ~85% of the lean body mass.

Aerobic Power

- Males have larger airways and lungs, larger ventricular mass and cardiac volumes, and higher hemoglobin concentration and mass than females.
- Elite female endurance athletes' VO_2max is ~10-14% lower than similarly trained males when normalized to body mass.

Biological Mechanisms for Sex Differences in Athletic Performance

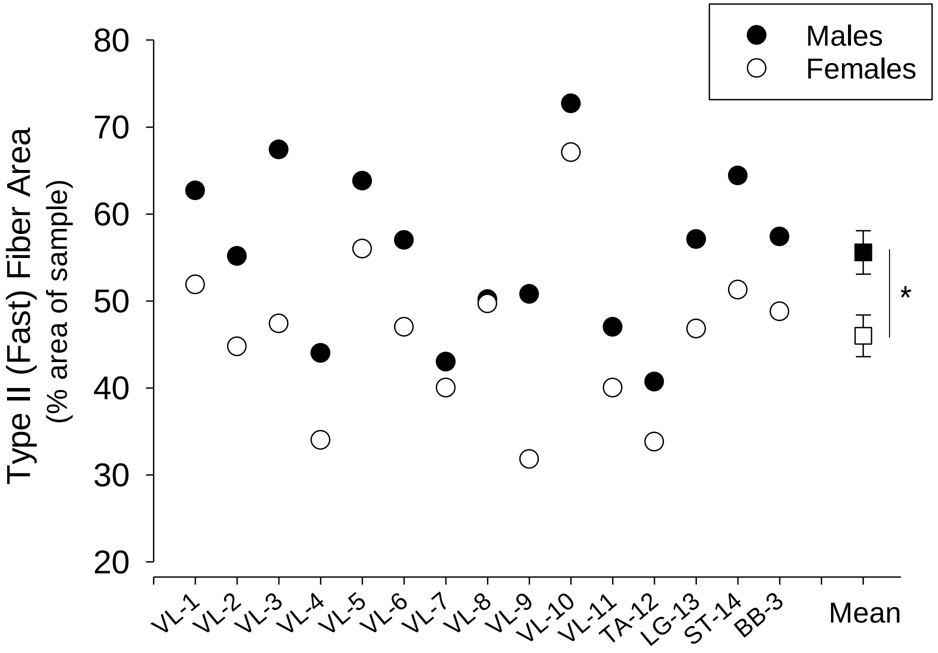


FIGURE 6.

Type II (Fast) fiber area (%, proportional area of the cross section of the sample) of skeletal muscle in males and females.

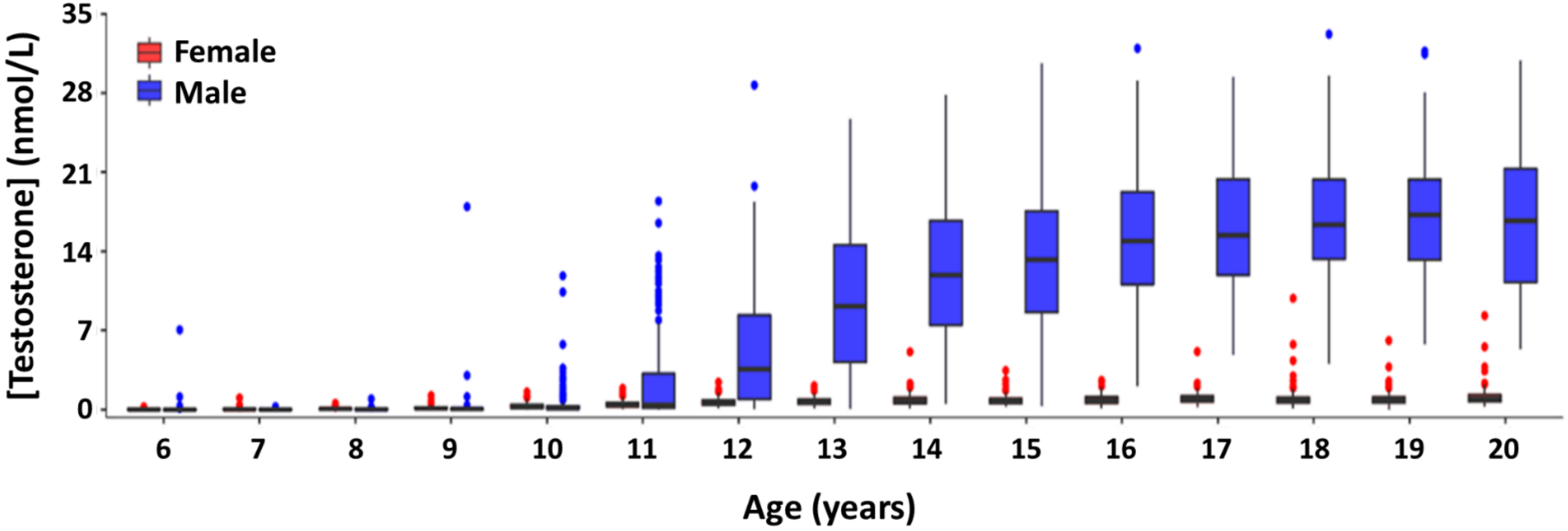


FIGURE 7.

Total testosterone concentrations of the US population aged 6 to 20 years.

Effects of Sex Hormones on Various Physiological Systems

- Many of the sex differences of the major attributes that determine performance are dictated by the strong effect of endogenous sex hormones, primarily testosterone, during and following growth and development.
- Endogenous testosterone in boys will rise 30-fold at the onset of puberty but remains lows in females.
- In contrast, endogenous female sex hormones, like estradiol (E2), experience the menstrual cycle and monthly fluctuations.
- Unlike androgens, E2 does not have the same anabolic effects as testosterone.
- Growth hormone and insulin like growth factor-1 are associated with increased protein synthesis, muscle growth and repair, but does not result in significant increases in strength, exercise capacity, and muscle function.

Table 3. Actions of Sex Steroid Hormones.

Hormone	Synthesis, Action	Effect on Growth and Development
ESTROGENS		
Estrone (E1)	Synthesized from cholesterol, androstenedione intermediate in gonads and adipose tissue; formed from E2 by 17βHSD in the liver, uterus, mammary gland, binds to ERα and ERβ receptors (less potent than E2)	Unclear, main actions through conversion to E2
Estradiol (E2)	Synthesized from cholesterol in ovarian follicles, testicles, adrenal glands, fat, liver, breasts and brains; binds to ERα and ERβ receptors, the most potent estrogen	Breast development, female fat distribution, regulation of menstrual cycle, also on mammary glands, uterus, vagina, bone, fat, skin, liver, brain
Estriol (E3)	Synthesized by placenta in pregnancy, low levels in non-pregnant state; binds to ERα and ERβ receptors (far less potent than E2)	Uterine growth during pregnancy
Estetrol (E4)	Synthesized exclusively in the liver by the human foetus	Its biological function remains unknown
ANDROGENS		
Testosterone	Synthesized from cholesterol in the testes (Leydig cells), adrenal glands, and ovaries (theca cells), binds to the androgen receptor	External genital, prostate, and seminal vesicle development in the male fetus; in puberty genital growth, bone and muscle mass, body hair, voice deepening
Dihydrotestosterone	Synthesized from testosterone by 5α-reductase in the prostate, seminal vesicles, epididymides, skin, hair follicles, liver, brain; binds to the androgen receptor (more potent than testosterone)	External genital development and virilization in fetus; maturation of penis and scrotum at puberty, facial and pubic hair growth

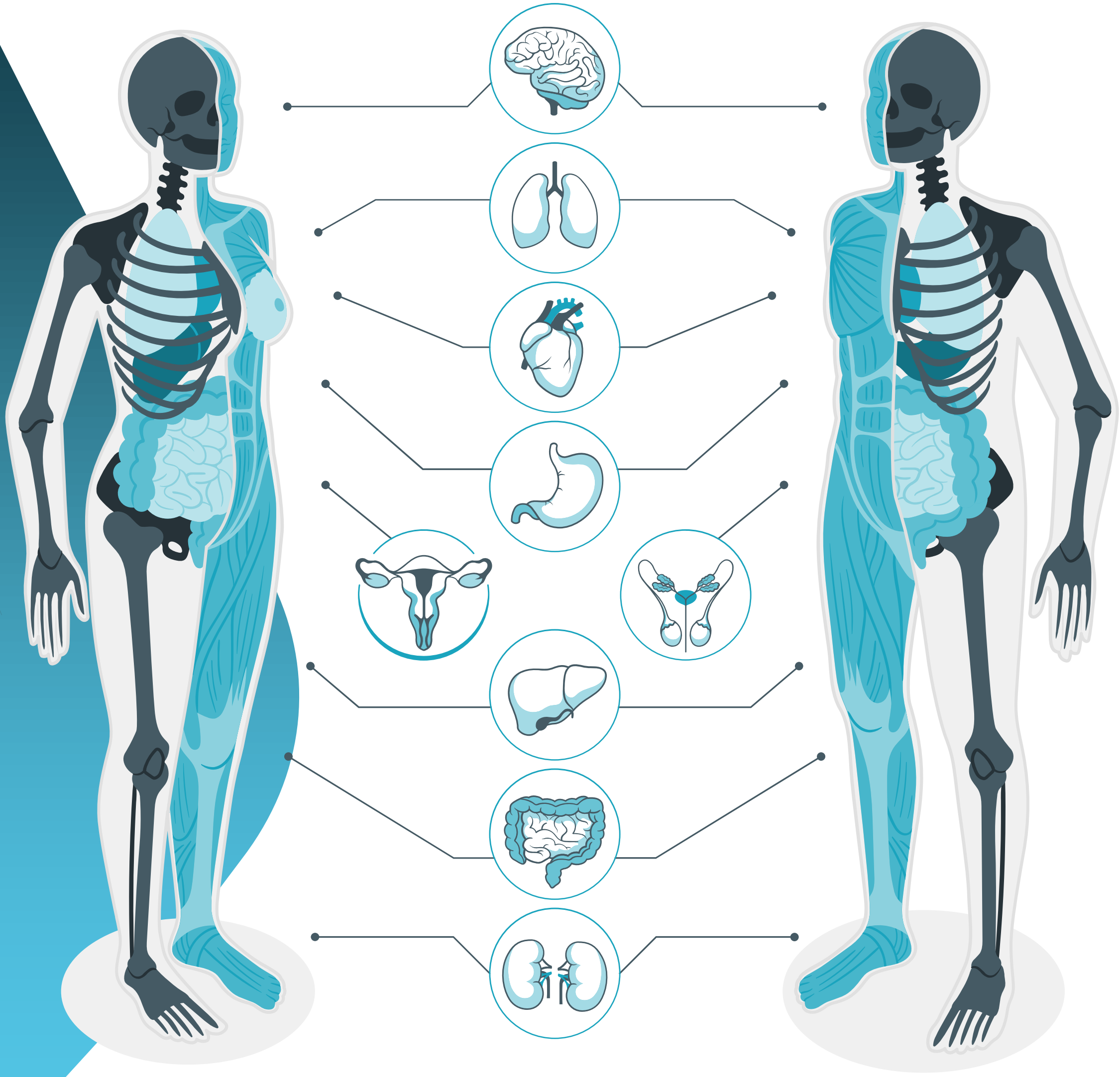
Models That Provide Insight Into The Role of Sex Steroid Hormones

Testosterone suppression/addition conditions (Estrogen suppression/addition conditions)

- Testosterone addition in females results in increased muscle mass and muscle fiber size, increased hemoglobin concentration and mass, improved strength, and endurance performance.
- Testosterone suppression in adult males results in initial decreases in muscle mass, increased fat mass, although the loss of lean mass and strength is not to the levels of adult females at least up to 3 years post.
- Biologic males who undergo partial or complete male puberty followed by testosterone suppression, retain some advantage in power and endurance performance over biological females, at least up to 2 years post.

Hormonal disorders

- Disorders (differences) of sex development (DSD) are rare conditions in which the development of chromosomal, gonadal, and anatomic sex is atypical.
- Their prevalence is overrepresented in elite women athletes by 140-fold relative to the general population.



Models That Provide Insight Into The Role of Sex Steroid Hormones

Polycystic Ovary Syndrome (PCOS): PCOS presents as a combination of signs and symptoms of androgen excess and ovarian dysfunction (oligo-ovulation/anovulation and/or polycystic ovaries) in the absence of other specific diagnoses.

- Such women are biological females with XX chromosomal complement and ovaries and have a feminizing puberty.
- Hyperandrogenism is a key component of PCOS diagnosis. Although women with PCOS may have testosterone levels above the normal range for biological females, it is typically well below the male range.

DSD: Rare conditions in which the development of chromosomal, gonadal, and anatomic sex is atypical (outside the binary of male/female).

- *Androgen insensitivity syndrome (AIS)* is a 46, XY DSD that leads to resistance to androgens, including testosterone.
- *5α-reductase deficiency type 2 (SRD5A2)* is a 46, XY DSD that converts testosterone to dihydrotestosterone. At puberty, these individuals will undergo virilization and develop various degrees of male-like phenotype.
- *Congenital adrenal hyperplasia (CAH)* is a group of autosomal recessive genetic disorders where the adrenal glands lack the proteins and enzymes involved in cortisol biosynthesis. Most commonly, the adrenal glands produce too little cortisol and/or aldosterone and too much androgen leading to varying degrees of hyperandrogenism in XX individuals.

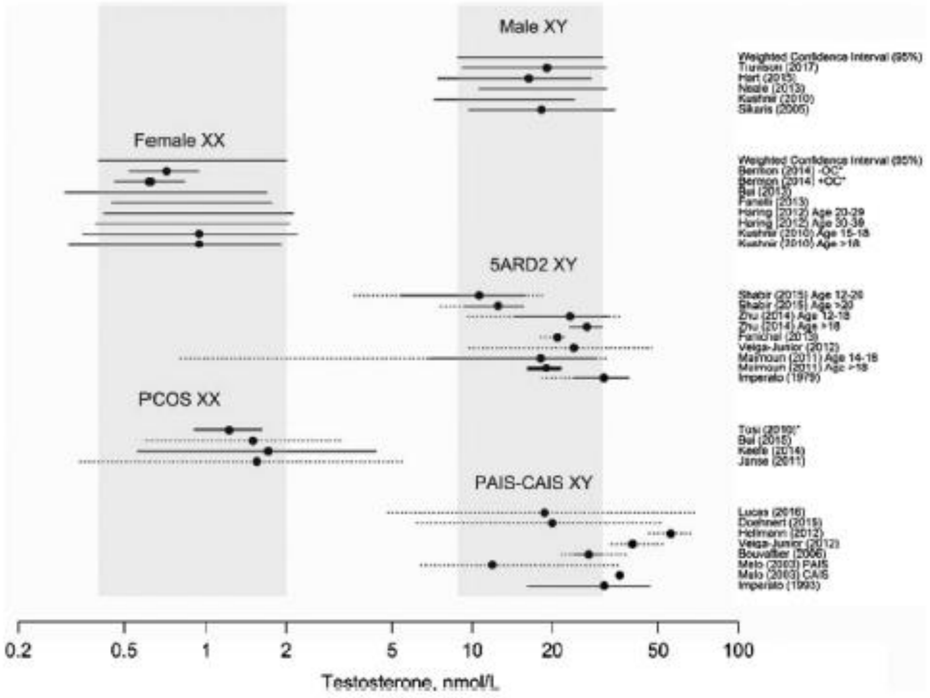
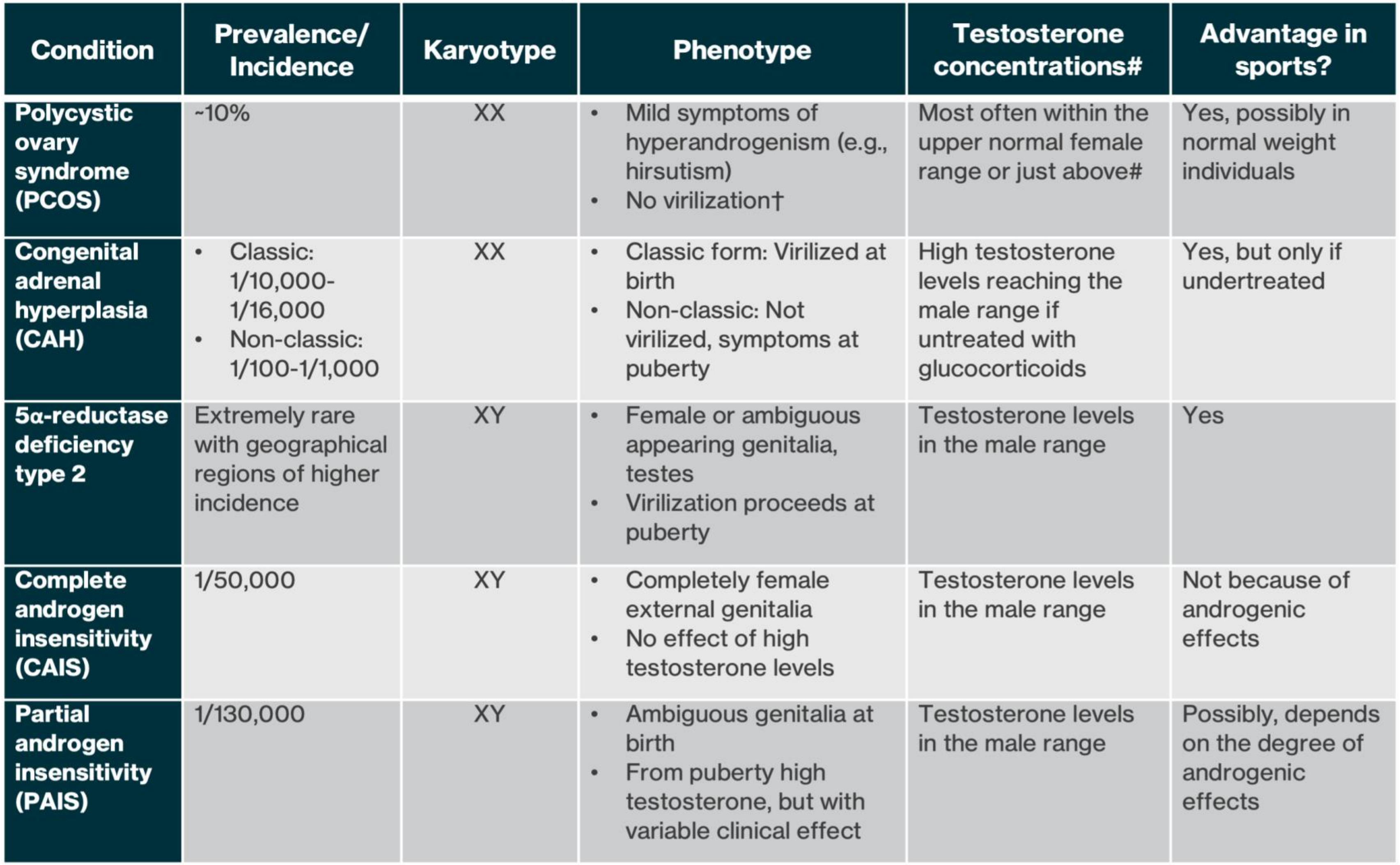


FIGURE 2. Circulating Testosterone Concentrations in Adult Males and Females.

Table 4. Examples of Conditions of Endogenous Hyperandrogenism and Disorders (or Differences) of Sex Development and the Potential Advantage for Physical Performance in Women.



Condition	Prevalence/ Incidence	Karyotype	Phenotype	Testosterone concentrations#	Advantage in sports?
Polycystic ovary syndrome (PCOS)	~10%	XX	• Mild symptoms of hyperandrogenism (e.g., hirsutism) • No virilization†	Most often within the upper normal female range or just above#	Yes, possibly in normal weight individuals
Congenital adrenal hyperplasia (CAH)	• Classic: 1/10,000-1/16,000 • Non-classic: 1/100-1/1,000	XX	• Classic form: Virilized at birth • Non-classic: Not virilized, symptoms at puberty	High testosterone levels reaching the male range if untreated with glucocorticoids	Yes, but only if undertreated
5α-reductase deficiency type 2	Extremely rare with geographical regions of higher incidence	XY	• Female or ambiguous appearing genitalia, testes • Virilization proceeds at puberty	Testosterone levels in the male range	Yes
Complete androgen insensitivity (CAIS)	1/50,000	XY	• Completely female external genitalia • No effect of high testosterone levels	Testosterone levels in the male range	Not because of androgenic effects
Partial androgen insensitivity (PAIS)	1/130,000	XY	• Ambiguous genitalia at birth • From puberty high testosterone, but with variable clinical effect	Testosterone levels in the male range	Possibly, depends on the degree of androgenic effects

#Serum testosterone normal range for female: 0.1-1.8 nmol/L and male: 7.7-29.4 nmol/L.
†Virilizing symptoms: muscle growth, increase in body hair (hirsutism), hair loss of male type, deepening of the voice, breast atrophy, and enlargement of the clitoris.

Training Adaptations to Exercise in Males and Females

- Males and females exhibit similar relative (percentage) increases in performance and adaptations in response to short term (6-12 weeks) high-resistance and endurance training.
- ‘Muscle memory’ may play an important role in individuals who have previously been exposed to high levels of testosterone (e.g., male puberty) and who undergo suppression of testosterone but retain the ability to hypertrophy in response to resistance training and more so than those not exposed to testosterone.
- Males exhibit larger adaptations of ventricular mass than females after long-term endurance training (>9 months) possibly facilitated by high concentrations of endogenous testosterone.

Male athletes have large hearts (left ventricles) compared to females when normalized for lean body mass

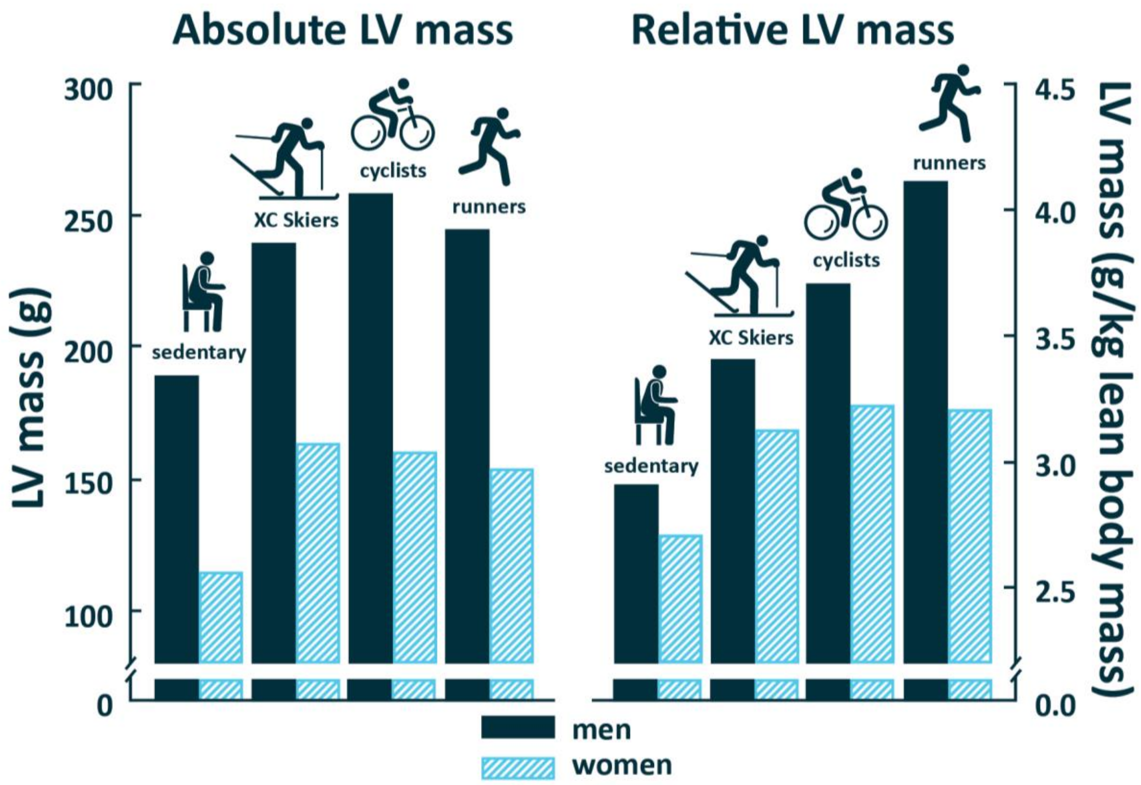


FIGURE 11. Cardiac Mass (Absolute and Relative to Lean Body Mass) of Male and Female Athletes and Sedentary Controls. *LV: left ventricular.*

Summary and Conclusions

- Biological sex is a determinant of athletic performance: adult males are faster, stronger, more powerful than females.
- The fastest and most powerful males outperform the fastest and most powerful females.
- The sex differences in athletic performance where endurance or muscular power are required is ~10-30% and varies depending on the requirements of the event.
- The largest sex differences in performance occurs in sports that rely on muscular power such as weightlifting and jumping.
- The rate of improvement in athletic performance of women has exceeded that of men in the last 100 years across a multitude of sports as women have gained access to training, equipment, facilities, and opportunities.

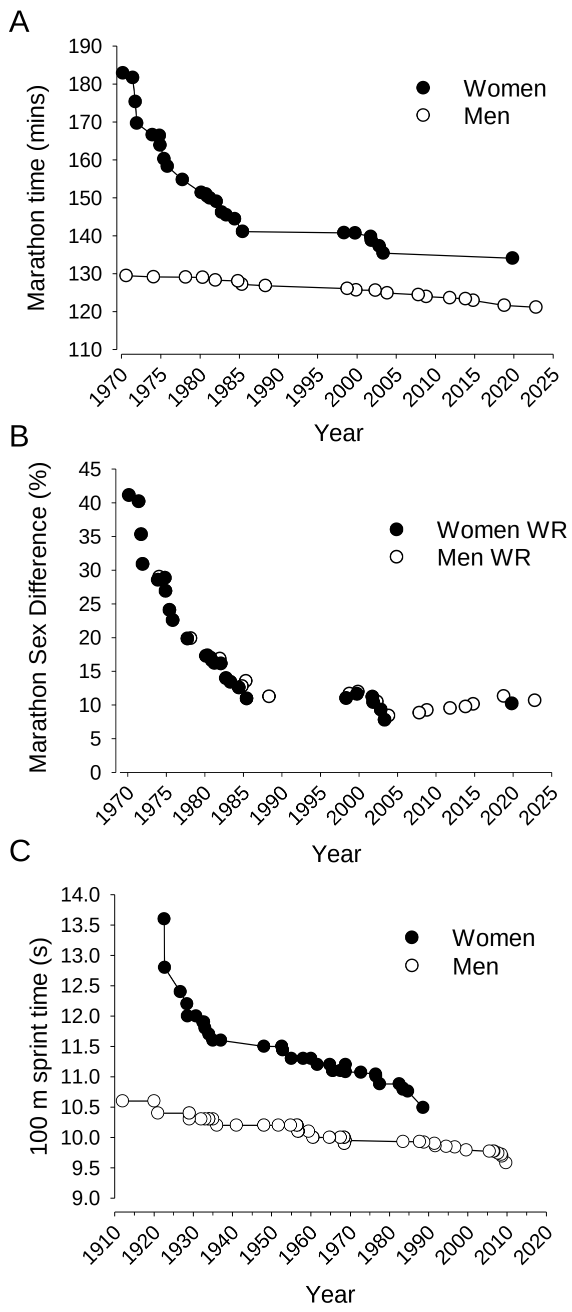


FIGURE 3. Progression of World Record Performances by Men and Women for the Marathon and 100 Meter Sprint.

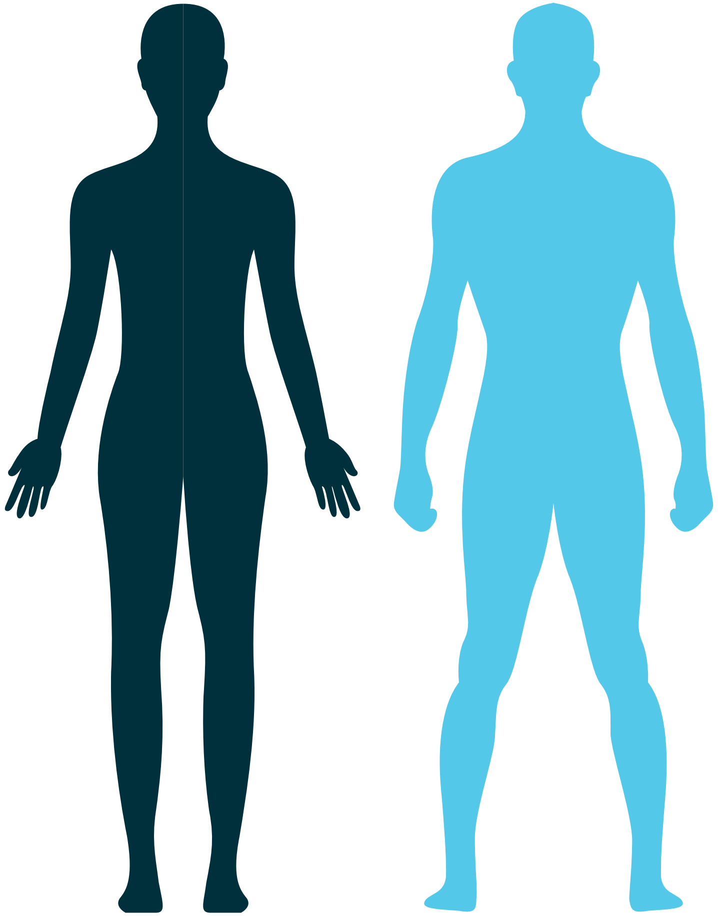
A. World record times in marathon for men and women from when women could legally compete (1970 onwards).

B. The sex difference in the world record (WR) marathon times.

C. World record times in the outdoor 100-meter sprint for men and women from when women could legally compete (1922 onwards).

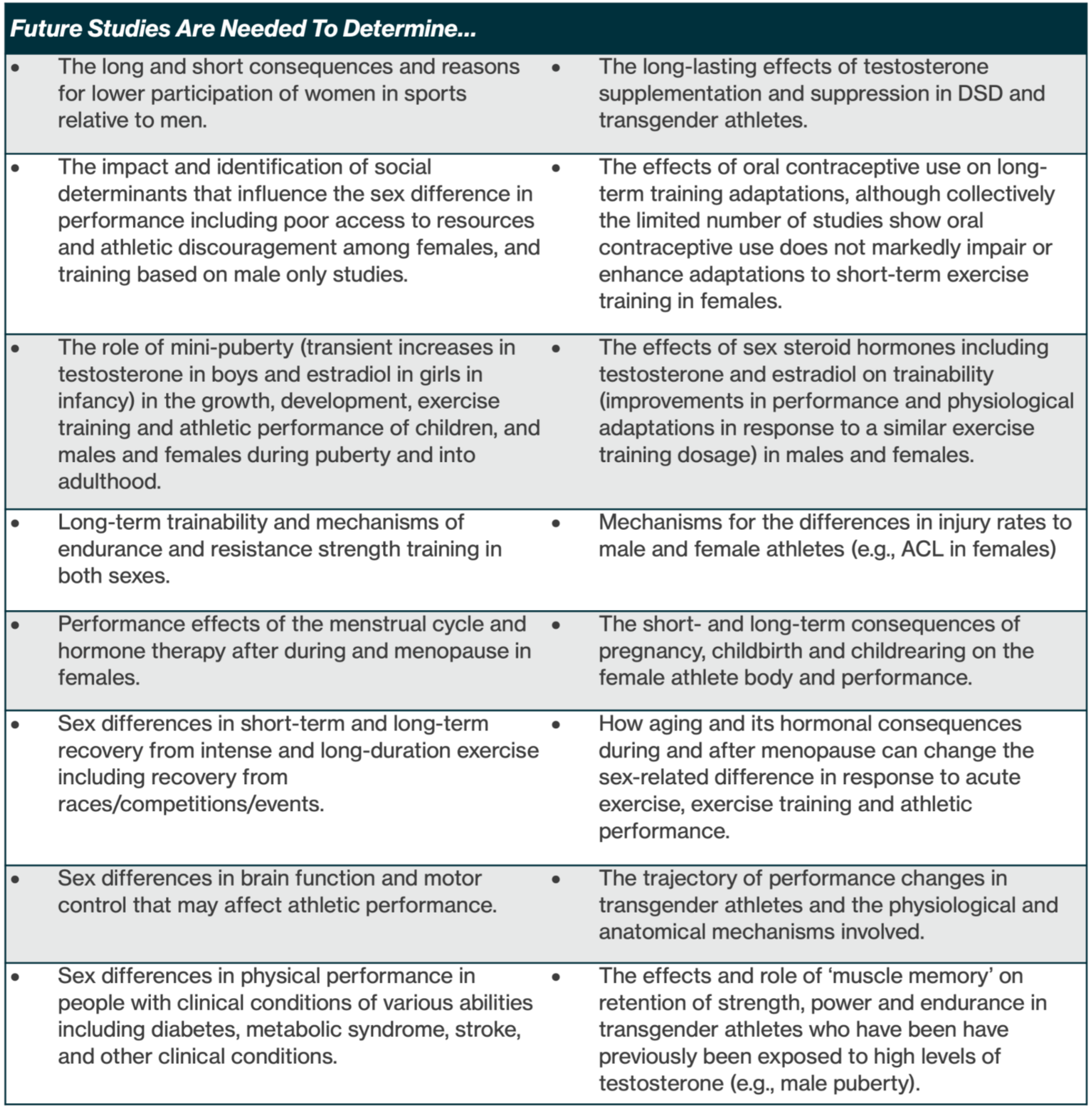
Summary and Conclusions

- The primary cause for the large sex difference in athletic performance is exposure to high levels of endogenous testosterone, a powerful androgenic steroid, that increases ~20-30-fold in males during puberty and is 15x higher than adult females.
- Estradiol, which fluctuates during the menstrual cycle in females, does not have the same anabolic effects as testosterone but is important in maintenance of body composition including bone mass, skeletal muscle, fat mass, and tendon protein metabolism.
- Growth hormone and insulin like growth factor-1 are associated with increased protein synthesis, muscle repair and some improvements in strength but do not explain the large sex differences in athletic performance.
- Non-hormonal factors that may impact the sex differences in height determination and thus athletic performance include possession of the Y chromosome (greater height) and or the X chromosome (shorter height).
- The effects of the sex steroid hormones, particularly the potent, quick-acting and long-lasting effects of testosterone, are evident in: 1) experiments/studies where sex steroid hormones have been added or suppressed in both males and females, 2) studies of the physiology and performance of individuals with various DSDs, and 3) studies of transgender men and transgender women in response to gender affirming hormone treatment (GAHT).



Future Directions and Opportunities

- A mandate to include sex as a biological variable across all studies of athletic performance, and exercise science.
- This would involve including women at all levels, and studies to be adequately powered to understand sex differences in the acute and chronic exercise responses.
- Declare the sex of the participants in the title and abstract of published studies.



Future Studies Are Needed To Determine...	
• The long and short consequences and reasons for lower participation of women in sports relative to men.	• The long-lasting effects of testosterone supplementation and suppression in DSD and transgender athletes.
• The impact and identification of social determinants that influence the sex difference in performance including poor access to resources and athletic discouragement among females, and training based on male only studies.	• The effects of oral contraceptive use on long-term training adaptations, although collectively the limited number of studies show oral contraceptive use does not markedly impair or enhance adaptations to short-term exercise training in females.
• The role of mini-puberty (transient increases in testosterone in boys and estradiol in girls in infancy) in the growth, development, exercise training and athletic performance of children, and males and females during puberty and into adulthood.	• The effects of sex steroid hormones including testosterone and estradiol on trainability (improvements in performance and physiological adaptations in response to a similar exercise training dosage) in males and females.
• Long-term trainability and mechanisms of endurance and resistance strength training in both sexes.	• Mechanisms for the differences in injury rates to male and female athletes (e.g., ACL in females)
• Performance effects of the menstrual cycle and hormone therapy after during and menopause in females.	• The short- and long-term consequences of pregnancy, childbirth and childrearing on the female athlete body and performance.
• Sex differences in short-term and long-term recovery from intense and long-duration exercise including recovery from races/competitions/events.	• How aging and its hormonal consequences during and after menopause can change the sex-related difference in response to acute exercise, exercise training and athletic performance.
• Sex differences in brain function and motor control that may affect athletic performance.	• The trajectory of performance changes in transgender athletes and the physiological and anatomical mechanisms involved.
• Sex differences in physical performance in people with clinical conditions of various abilities including diabetes, metabolic syndrome, stroke, and other clinical conditions.	• The effects and role of 'muscle memory' on retention of strength, power and endurance in transgender athletes who have been have previously been exposed to high levels of testosterone (e.g., male puberty).

Acknowledgements

This slide deck was prepared by the ACSM Evidence-Based Practice Committee in collaboration with the authors.

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