American College of Sports Medicine

The Biological Basis of Sex Differences in Athletic Performance

Consensus Statement for the American College of Sports Medicine
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 anatomical 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). Transgender 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, adrenal, 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.
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\textsubscript{2}\text{max} 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>
<thead>
<tr>
<th>Table 3. Actions of Sex Steroid Hormones.</th>
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<tbody>
<tr>
<td><strong>Hormone</strong></td>
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<tr>
<td><strong>ESTROGENS</strong></td>
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<tr>
<td>Estrone (E1)</td>
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<tr>
<td>Estradiol (E2)</td>
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<tr>
<td>Estriol (E3)</td>
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<tr>
<td>Estetrol (E4)</td>
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<tr>
<td><strong>ANDROGENS</strong></td>
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<tr>
<td>Testosterone</td>
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<tr>
<td>Dihydrotestosterone</td>
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</table>
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.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Prevalence/Incidence</th>
<th>Karyotype</th>
<th>Phenotype</th>
<th>Testosterone concentrations#</th>
<th>Advantage in sports?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polycystic ovary syndrome (PCOS)</td>
<td>-10%</td>
<td>XX</td>
<td>• Mild symptoms of hyperandrogenism (e.g., hirsutism)</td>
<td>Most often within the upper normal female range or just above#</td>
<td>Yes, possibly in normal weight individuals</td>
</tr>
<tr>
<td>Congenital adrenal hyperplasia (CAH)</td>
<td></td>
<td>XX</td>
<td>• Classic form: Virilized at birth</td>
<td>High testosterone levels reaching the male range if untreated with glucocorticoids</td>
<td>Yes, but only if undertreated</td>
</tr>
<tr>
<td>5α-reductase deficiency type 2</td>
<td>Extremely rare with geographical regions of higher incidence</td>
<td>XY</td>
<td>• Female or ambiguous appearing genitalia, testes</td>
<td>Testosterone levels in the male range</td>
<td>Yes</td>
</tr>
<tr>
<td>Complete androgen insensitivity (CAIS)</td>
<td>1/50,000</td>
<td>XY</td>
<td>• Completely female external genitalia</td>
<td>Testosterone levels in the male range</td>
<td>Not because of androgenic effects</td>
</tr>
<tr>
<td>Partial androgen insensitivity (PAIS)</td>
<td>1/130,000</td>
<td>XY</td>
<td>• Ambiguous genitalia at birth</td>
<td>Testosterone levels in the male range</td>
<td>Possibly, depends on the degree of androgenic effects</td>
</tr>
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</table>

#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.

**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.

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**Future Studies Are Needed To Determine...**

<table>
<thead>
<tr>
<th>Future Studies Are Needed To Determine...</th>
<th>Study Area</th>
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<tbody>
<tr>
<td>The long and short consequences and reasons for lower participation of women in sports relative to men.</td>
<td>The long-lasting effects of testosterone supplementation and suppression in DSD and transgender athletes.</td>
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<tr>
<td>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.</td>
<td>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.</td>
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<td>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.</td>
<td>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.</td>
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<td>Long-term trainability and mechanisms of endurance and resistance strength training in both sexes.</td>
<td>Mechanisms for the differences in injury rates to male and female athletes (e.g., ACL in females).</td>
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<td>Performance effects of the menstrual cycle and hormone therapy after during and menopause in females.</td>
<td>The short- and long-term consequences of pregnancy, childbirth and childrearing on the female athlete body and performance.</td>
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<td>Sex differences in short-term and long-term recovery from intense and long-duration exercise including recovery from races/competitions/events.</td>
<td>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.</td>
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<tr>
<td>Sex differences in brain function and motor control that may affect athletic performance.</td>
<td>The trajectory of performance changes in transgender athletes and the physiological and anatomical mechanisms involved.</td>
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<tr>
<td>Sex differences in physical performance in people with clinical conditions of various abilities including diabetes, metabolic syndrome, stroke, and other clinical conditions.</td>
<td>The effects and role of ‘muscle memory’ on retention of strength, power and endurance in transgender athletes who have been previously been exposed to high levels of testosterone (e.g., male puberty).</td>
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Acknowledgements

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References


