DOI 10.26773/smj.251020

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REVIEW PAPER

Biological Gender in Sport: A Review Paper

Biljana Vitošević[1], Milica Filipović[1]

[1]University of Priština in Kosovska Mitrovica, Faculty of Sport and Physical Education, Medical Department, Leposavić, Serbia

Abstract

It is well established that categorizing athletes based on biological sex is a fundamental principle in competitive sports to ensure fairness. However, the inclusion of transgender and intersex athletes in recent years has intensified debates about equality and inclusivity. Referring to physiological differences between the sexes, particularly the hormonal influence on athletic performance, this paper examines key biological and ethical challenges related to gender categorization in sports. A literature review, along with an analysis of existing protocols and case studies, was conducted to assess the implications of gender identity in competitive sports. The methodology involved systematically reviewing peer-reviewed scientific articles, institutional policy documents, and relevant legal cases to provide a comprehensive overview. This approach ensured a balanced synthesis of biological evidence and sociopolitical context. The role of testosterone suppression in transgender athletes is analyzed, revealing that while hormonal interventions can reduce certain physiological advantages, some disparities persist post-transition. Ethical and policy considerations are also explored, highlighting the tension between human rights and the necessity of maintaining competitive integrity and equal opportunities. This paper concludes that while existing policies strive to balance inclusion and fairness, further research into the long-term effects of hormone therapy and potential policy innovations, such as open categories or alternative classification systems, may be necessary to ensure equitable competition in the future. The study underscores the need for evidence-based approaches in shaping sports policies while acknowledging the evolving understanding of gender identity in athletics.

Keywords: *gender, performance, sex verification, intersex, fair competition*

Introduction

The categorization of athletes based on biological gender has been a fundamental principle in competitive sports for over a century. Back in the fifties of the last century, the psychologist Money commented on the difference between these two terms, so according to him, "sex" refers to biological characteristics, and "gender" refers to one's perception of oneself as male or female (Martínková et al., 2022). Therefore, sex is a biological term that is initially determined during embryonic development and gametogenesis and is based on the combined effect of genetic factors and sex hormones that dictate secondary sex characteristics. On the other hand, gender is a multifaceted conception that represents a psychological self-perception framed with social, cultural and behavioral determinants (Martínková et al., 2022). Historically, sports have been divided into male and female categories to ensure fair competition, given the well-documented physiological differences between sexes. These differences include variations in muscle mass, bone density, cardiovascular capacity, and hormonal influences, particularly testosterone levels, which significantly impact athletic performance (Handelsman et al., 2018).

The scientific and ethical discourse surrounding gender in sports has become increasingly complex, especially with the inclusion of transgender and intersex athletes. Policies set by organizations such as the International Olympic Committee (IOC) and World Athletics have evolved over time, attempting to balance inclusivity with competitive fairness (Pielke, 2022). However, the effectiveness of these policies remains a subject of ongoing debate. While some argue that gender identity should dictate participation, others contend that biological advantages persist even after hormonal interventions (Harper et al., 2021).

Correspondence:

Biljana Vitošević
University of Priština in Kosovska Mitrovica, Faculty of Sport and Physical Education, Dositeja Obradovića b.b., 38218 Leposavić, Serbia
E-mail: biljana.vitosevic@pr.ac.rs

Recent research has explored the impact of testosterone suppression and its influence on muscle strength and endurance, with findings suggesting that male physiological advantages may not be entirely mitigated post-transition (Hilton & Lundberg, 2021). Furthermore, sex verification methods, including genetic testing and hormonal assessments, have raised ethical concerns regarding privacy and discrimination (Bermon & Kajėniene, 2021).

Despite increased attention, there remains a lack of comprehensive studies addressing the physiological and regulatory implications of transgender and intersex participation in sports. This gap in the literature highlights the importance of rigorous research to inform fair and inclusive athletic policies.

This paper aims to examine the biological basis of gender differences in sports, the evolution of gender categorization, and the implications of current policies on transgender and intersex athletes. By synthesizing scientific findings and policy perspectives, this study will provide insights into the ongoing debate over fairness and inclusion in competitive sport.

Methods

This study employed a narrative review methodology, synthesizing findings from peer-reviewed journal articles, policy documents, and case studies published in the fields of physiology, sports science, ethics, and gender studies. Key databases such as PubMed, Scopus, and Google Scholar were systematically searched using keywords including gender, performance, sex verification, intersex, fair competition, and specific phrases such as "transgender athletes," "testosterone and sports performance," and "gender verification in sports." Case studies of high-profile athletes were included to contextualize policy discussions. The review aimed to integrate current scientific evidence with evolving legal and ethical perspectives relevant to gender inclusion in competitive sports. Inclusion Criteria: Peer-reviewed articles only; Studies published from the year 2000 onward, with exceptions for foundational works; Publications in English; Research focused on human subjects in the context of sports; Direct relevance to competitive sports, including physiological, ethical, legal, or performance-related topics; Well-documented case studies involving transgender or intersex athletes that have influenced policy discussions.

Discussion

A critical evaluation of sex-based physiological differences is essential for interpreting performance disparities and informing eligibility criteria in competitive sports. These biological distinctions underpin the rationale for sex-segregated categories and are central to the ongoing debate regarding the inclusion of transgender and intersex athletes. One of the key factors influencing athletic performance is the difference in anthropometric measures, muscle mass, bone density, cardiovascular capacity, and lung function between biological males and females. These physiological characteristics contribute to disparities in speed, strength, and endurance across different sports disciplines (Handelsman et al., 2018).

Muscle Mass - On average, males have greater muscle mass than females, a difference primarily driven by testosterone levels (Handelsman et al., 2018). Testosterone increases muscle fiber size, particularly type II (fast-twitch) fibers, which are crucial for explosive movements and power output in sports. Gene expression due to sexual dimorphism determines differences in the phenotype, which further leads to significant differences in the morphological composition of skeletal muscles (Welle et al., 2008). In addition to hormonal signaling, the proportion of fiber types is also influenced by the type of exercise. Thus, for example, sprint training can increase the percentage of fast-twitch muscle fibers of type II in women (Esbjörnsson Liljedahl et al., 1996). The difference in the type of fiber between the sexes determines the difference in the contractile properties of skeletal muscles. Faster relaxation is characteristic of male skeletal muscles, and slower in female skeletal muscles, which is consistent with the higher proportion of type I muscle fibers in women. These muscle fibers in women also affect slower Ca2+ kinetics, lower strength, and slower shortening and relaxation of muscle fibers (Schiaffino & Reggiani, 2011).

Bone Density - Bone density is another significant factor affecting athletic performance. Males generally have higher bone mineral density, which contributes to greater skeletal strength and a lower risk of fractures (Tenforde et al., 2015). This difference is particularly relevant in contact sports, where stronger bones reduce injury risk and enhance physical resilience (Nattiv et al., 2021). The effects of hormone therapy on bone density in transgender athletes remain a complex topic, as estrogen therapy can lead to bone loss over time, but studies indicate that baseline differences persist post-transition (Bermon & Kajėniene, 2021).

Cardiovascular Capacity - Cardiovascular efficiency, including heart size and stroke volume, plays a crucial role in endurance sports. Males have larger hearts and greater stroke volume, allowing for more oxygenated blood to be pumped per heartbeat (Lundby & Montero, 2019). Women have a shorter left ventricular intracavitary diameter and wall thickness than men (de Morais et al., 2018). Additionally, higher hemoglobin levels in males result in better oxygen transport and aerobic performance (Eastwood et al., 2009). Even after hormone therapy, transgender women may retain cardiovascular advantages over cisgender female athletes (Harper et al., 2021).

Lung Function - Lung capacity and respiratory function also differ between biological sexes. Males typically have larger lung volumes, higher maximal oxygen uptake (VO2 max), and greater ventilatory capacity compared to females (Santisteban et al., 2022). These factors contribute to superior performance in endurance-based activities, such as long-distance running and cycling. While hormone therapy can influence respiratory function, studies indicate that transgender women maintain lung function characteristics closer to their sex assigned at birth (Harper et al., 2021).

Understanding the biological differences is essential since it is known that both anthropometric and physiological characteristics are conditioned by genetic and hormonal influence and definitely make a difference between men and women in sports performance.

Testosterone and Hormonal Influences on Strength and Endurance

Hormones are mainly responsible for the integrated functioning of physiological systems, for normal growth and development. Testosterone is a key androgenic hormone that affects skeletal muscle ergogenically and anabolically, conditioning hypertrophy, increasing muscle strength and endurance in a dose-dependent manner (Kraemer et al., 2017). It is primarily produced in the testes in males and in smaller quantities in the ovaries and adrenal glands in females. The physiolog-

ical effects of testosterone on athletic performance have been extensively studied, demonstrating a significant impact on muscle hypertrophy, erythropoiesis, and energy metabolism (Handelsman et al., 2018).

Effects on Muscle Mass and Strength - Testosterone enhances muscle protein synthesis, leading to increased muscle fiber size, particularly in type II (fast-twitch) fibers that are critical for explosive movements and power-based sports. Research indicates that men generally have 30-40% more muscle mass than women, contributing to higher absolute strength levels (Hilton & Lundberg, 2021). Testosterone is the primary androgen in skeletal muscles, which interacts with androgen receptors to act as a transcription factor, resulting in increased protein synthesis (Kraemer et al., 2020). Studies also show that even after testosterone suppression, transgender women retain a higher proportion of muscle mass and strength compared to cisgender women (Harper et al., 2021).

Effects on Endurance and Oxygen Utilization - Testosterone significantly influences aerobic capacity through its impact on hemoglobin and red blood cell production. Higher testosterone levels correlate with increased erythropoiesis, leading to greater oxygen-carrying capacity and improved endurance performance (Eastwood et al., 2009). Males generally have hemoglobin concentrations 12-15% higher than females, which enhances aerobic metabolism and endurance in sports such as long-distance running and cycling (Lundby & Montero, 2019).

Impact of Hormonal Suppression - For transgender athletes undergoing hormone therapy, the reduction of testosterone levels leads to physiological changes that impact strength and endurance. Studies have demonstrated that testosterone suppression in transgender women results in decreased muscle mass, reduced hemoglobin levels, and lower aerobic capacity (Harper et al., 2021; Roberts et al., 2021).

The debate over testosterone regulation in sports remains contentious, with policymakers attempting to balance fair competition with inclusion. The position of the IOC on transgender athletes is such that they agree that trans athletes should be included in sports competitions, but in order to maintain the guarantee of fair competition, they have introduced restrictive measures. Criteria include declaring their identity to be female and maintaining a total serum testosterone level below 10 nmol/L for at least 12 months prior to competing and during competition (IOC, 2015; Pielke, 2022). Fulfillment of these criteria is necessary to reduce the biological advantage of men over women and to make competition in female category fair and safe. However, some sports federations such as World Athletics have recently lowered the criteria for plasma testosterone levels to <5 nmol/L (Bowman-Smart et al., 2024). When considering the duration of testosterone suppression, although it was originally suspected that a 12-month period might not be sufficient to reduce the male advantage, studies with crossover hormone treatments have found that a plateau is reached in the first or second year (Elbers et al., 1997). About 12 longitudinal studies have investigated the effects of testosterone suppression on muscle mass in transgender women (Hilton & Lundberg, 2021). The results showed that within 12 months, testosterone suppression to female reference levels resulted in a moderate loss of muscle mass, averaging -5%. Research on testosterone suppression and estrogen supplementation for 1-3 years conducted by Gooren and Bunck (2004) showed a decrease in testosterone to 1nmol/L after 1 year, and muscle mass was reduced by -9% compared to the basal value. The MRI results after 3 years found an additional reduction of -3%, for a total of -12% after 3 years of treatment.

The phenomenon of muscle memory should also be mentioned, as it refers to the existence of a cellular phenotype associated with prior exposure to testosterone, implying an increase in the number of myonuclei during muscle hypertrophy (Hamilton et al., 2021). Horwath et al. (2020) found in their study that administering exogenous testosterone for 10 weeks in young women induces changes in skeletal muscle morphology, manifested as type II muscle fiber hypertrophy accompanied by an increased number of satellite cells but not new myonuclei. They observed a 31% increase in satellite cells, which contribute to the self-renewal and reparative capacity of myofibrils following exogenous testosterone application. Further research is needed to confirm and clarify whether, and to what extent, the number of myonuclei is maintained in transgender women or individuals with DSD, as this could indicate that high levels of testosterone persist even after suppressive therapy.

Senefeld et al. (2023) examined the impact of gender-affirming hormone therapy (GAHT) on an elite transgender college swimmer. The study analyzes performance before and after two years of hormone therapy, showing that the athlete's swimming times slowed but remained competitive compared to top-ranked female swimmers. Despite performance declines, the transgender swimmer ranked higher in NCAA women's categories than in men's. The study highlights ongoing debates on fairness, suggesting that physiological advantages from male puberty persist beyond two years of GAHT, raising implications for sports regulations. That so-called "prolonged legacy effect" (greater than 2 years) associated with endogenous testosterone has been noted especially in shorter event distances (100, 200, and 500 m) which are closely related to muscular strength.

This highlights the need to evaluate the impact of hormone therapy on a sport-specific basis and across different levels of competition to ensure fairness for all athletes. It is also crucial to assess its effects on reproduction and fertility, as well as on metabolic and cardiovascular health (Moustakli & Tsonis, 2023). Equally important is its impact on cognitive and mental well-being. Therefore, a multidisciplinary approach is essential in assessing the health, cognitive, and social well-being of individuals undergoing this therapy, both to safeguard their overall well-being and to establish effective risk mitigation strategies.

Despite the criteria for testosterone reduction, it remains unclear whether fairness and safety in the women's category have been fully ensured. Additionally, it is recommended that criteria be established within each federation rather than applied universally. It is widely believed that different sports require distinct physiological determinants for performance success, meaning that universal criteria may not guarantee equality across all sports.

These questions remain open to revisions, refinements, and clarifications to uphold equality and fairness, the fundamental values of sports competitions. Given the increasing number of intersex athletes competing at various levels each year, improving analytical methods for testosterone measurement (e.g., assessing bioavailable T instead of circulating T) and adopting an integrative approach that incorporates omics sciences (genomics, transcriptomics, metabolomics, and proteomics) may be necessary (Fossati et al., 2019).

Sex Verification and Gender Testing

Gender verification tests in athletic performance were introduced by the International Association of Athletics Federations (IAAF) in 1950 and later by the IOC in 1968. The reason for the introduction of these tests was dozens of controversial cases since the 1930s related to suspicions in women's competitions. The first verifications of gender were the introspection of naked bodies in front of a commission, then in the 1960s they were replaced by chromatin tests, whereby a buccal swab of the mucous membrane was tested for the presence of a Barr body characteristic only of the female sex (Bassett et al., 2020). The first Olympic athlete to be disqualified using this method was Polish athlete Ewa Kłobukowska in 1967. She was banned from competitions even though repeated tests in the following years were positive (Elsas et al., 2000). This case highlighted the need to introduce more precise, genetic tests.

More reliable PCR (polymerase chain reaction) tests appeared in 1992 and were genetically based on the identification of the SRY gene or DYZ1 region on the Y chromosome. However, after some controversial results of these tests at the Barcelona Olympic Games (Serrat & García de Herreros, 1996) and later in Atlanta in 1996, the IOC Executive Committee decided to stop verifying gender with these tests (Tucker & Collins, 2010). The Millennium Games in Sydney in 2000 were the first Olympic Games in three decades where women were not subjected to gender verification tests. After that, the focus was on hormone testing, especially testosterone levels (Sudai, 2017). Discussions and dilemmas are mainly conducted due to some disorders such as hyperandrogenism and intersex traits and the impossibility of finding the right attitude towards them.

Disorders of sexual development (DSD) are complex congenital conditions with atypical chromosomal, gonadal and anatomical sex development (García-Acero et al., 2020). Different etiologies lead to different phenotypes that are inconsistent with the chromosomal set. In addition to genetic disorders such as Klinefelter syndrome (XXY), Turner syndrome (XO) and mosaicism (mixing of cell lines with X and Y chromosomes), there are also conditions resulting from the absence or reduced secretion of key hormones for sex development (Ritchie et al., 2008). Androgen insensitivity syndrome (AIS) is a condition of complete or partial resistance to androgens in 46, XY individuals. Androgens are fundamental elements for the expression of the male sex (Imperato-McGinley & Zhu, 2002; Melo et al., 2005). The enzyme 5α-reductase type 2 plays a key role in the chain of conversion of testosterone to the biologically active metabolite dihydrotestosterone (Batista et al., 2018). Changes in androgen secretion and defects in the androgen receptor can disrupt this conversion. The result of these alterations is the development of female physical characteristics due to hormonal resistance. Another disorder of sexual development is congenital adrenal hyperplasia (CAH), which most often leads to a lack of the enzyme 21-hydroxylase, which disrupts the biosynthesis of cortisol and androgens (Tucker & Collins, 2010). The accumulation of cortisol precursors is directed to the biosynthesis of sex hormones. This internal hormonal status and excess testosterone production in women can lead to a competitive advantage.

Theoretically, all disorders of sexual development involving excess androgens provide an advantage over other competitors in female competitions, as testosterone promotes increased muscle mass, leading to greater strength, agility, and endurance. However, although the percentage of these disorders is small within the overall sports population, clear recommendations and guidelines regarding competition conditions and ethical considerations are necessary in such cases.

Case Studies and Controversies

Caster Semenya: A middle-distance runner from South Africa, Semenya was subjected to extensive sex verification testing due to her naturally high testosterone levels (hyperandrogenism condition) (Loland, 2020). The Court of Arbitration for Sport upheld regulations requiring athletes with differences in sex development (DSD) to lower their testosterone levels to compete in women's events (Loland, 2020). The IAAF (International Association of Athletics Federations) considered Semenya's case as an unfair competitive advantage even though the increased testosterone was the result of her natural hyperandrogenism (World Athletics, 2018). In 2023, the European Court of Human Rights ruled in favor of Semenya, treating the case as discrimination. The debate about this case is still intense because it raises a number of questions and uncertainties about the stable and dynamic inequality among the competitors (Heerdt, 2025). On the other hand, there is a debate on the ethical side, in terms of the correctness of the decision on testosterone suppression because some authors consider this intervention as doping (Loland, 2020).

Lia Thomas: A transgender swimmer who competed at the NCAA (National Collegiate Athletic Association) level, Thomas transitioned from male to female and adhered to NCAA testosterone suppression guidelines. Her success in women's swimming events ignited discussions on whether testosterone suppression is sufficient to level the playing field or whether residual advantages remain (Grand'Maison et al., 2025).

Laurel Hubbard: A transgender weightlifter from New Zealand who qualified for the Tokyo 2020 Olympics, Hubbard faced both support and criticism regarding her participation in the female category. Critics argued that her years of training and muscle development before transitioning provided a competitive edge, while supporters emphasized the importance of inclusion and human rights (Scovel et al., 2023).

Hannah Mouncey: An Australian transgender athlete who initially played for the Australian men's handball team before transitioning in 2016. Mouncey applied to enter the 2017 AFL Women's (AFLW) draft but was denied entry due to concerns over fairness, particularly regarding her size and strength. Despite meeting testosterone level requirements, the AFLW cited potential competitive imbalance as the reason for exclusion. The decision sparked significant debate over the inclusion of transgender athletes in contact sports. Mouncey was later allowed to compete in state-level women's football, continuing her advocacy for transgender rights in sports (Ordway et al., 2023).

This issue intersects with ethical concerns, including human rights, fairness in competition, and the potential psychological impact on athletes whose gender identity does not align with their assigned sex at birth. The discourse on gender identity in sports continues to evolve, with some advocating for open categories or alternative solutions to ensure both inclusion and fairness (Bermon et al., 2021).

Ethical, Social, and Policy Considerations

The inclusion of transgender and intersex athletes in competitive sports presents a complex ethical dilemma between ensuring fair competition and promoting inclusivity.

Proponents of inclusion argue that sports should be accessible to all individuals regardless of gender identity, highlighting the importance of human rights and mental well-being (Bianchi, 2017). Research indicates that excluding transgender athletes from participating in sports aligned with their gender identity can result in detrimental psychological effects, such as increased anxiety and depression (Jones et al., 2020). To mitigate these concerns, institutions like the IOC and NCAA have implemented testosterone suppression policies that aim to create fairer conditions for transgender women competing in female categories (Harper et al., 2021). Advocates further emphasize that sports policies must evolve to reflect modern understandings of gender, biology, and identity, promoting diversity and inclusion (Longa, 2025).

Conversely, critics of inclusion without strict regulation point to enduring physiological advantages conferred by male puberty, such as greater muscle mass and bone density, which may not be fully reversed through hormone therapy (Handelsman et al., 2018). These differences raise concerns about maintaining competitive integrity, particularly in sports reliant on strength and endurance. As a result, some sports governing bodies have enacted more stringent eligibility requirements, mandating lower testosterone thresholds over extended periods. These measures aim to strike a balance between fairness and inclusion in a rapidly evolving athletic landscape.

Policy Challenges and Future Directions

Sports organizations continue to face the complex task of developing regulatory frameworks that uphold both inclusivity and fairness. One proposed approach is the introduction of open categories, where competitions would not be segregated by gender but rather structured around individual performance metrics, allowing broader participation irrespective of biological sex (Martínková, 2020). Another potential strategy involves supplementing existing gender-based divisions with weight classifications, similar to systems used in combat sports, to enhance competitive equity. In addition, scholars emphasize the urgent need for ongoing scientific investigation to better understand the long-term effects of hormone therapy on athletic performance and to assess whether current policies achieve their intended outcomes (Bianchi, 2021). As the intersection of gender identity, biology, and sport remains deeply contested, balancing fairness and inclusion will persist as a central policy dilemma. While organizations strive to implement equitable guidelines, the debate will likely continue as scientific research and social perspectives evolve.

Conclusion

Historical definitions of biological gender in sports have clearly reached their expiration date. Over time, it has become evident that these definitions must evolve, incorporating attributes of progress and complexity into existing standards. The same applies to rules and regulations, which require updates to remain aligned with core sports values.

Based on the methodology applied in this review, which included a structured analysis of peer-reviewed literature, policy documents, and case studies, we determined that there is a substantial body of evidence confirming the physiological distinctions between biological sexes. These differences, especially in muscle mass, bone density, oxygen utilization, and hormonal profiles, have a measurable impact on athletic performance. Our review also revealed the inconsistencies and challenges present in current international sports policies, which often attempt to reconcile fairness with inclusivity but lack a unified or empirically grounded framework.

Scientific evidence demonstrates clear physiological differences between the sexes that impact performance, particularly in muscle mass, bone density, and oxygen utilization. Policies on gender diversity and inclusion are still evolving, and sports present a particularly sensitive domain, given the expectation that equality and fairness should prevail. While it goes without saying that sports should be inclusive and welcoming to all, fair criteria are essential to ensure clear and unambiguous conditions for participation and competition.

Furthermore, continued research into the long-term effects of hormone therapy on athletic performance, advancements in analytical methods for determining testosterone levels, incorporating breakthroughs in omics sciences and policy innovations such as open categories or alternative classification systems may help address this ongoing issue. The future of gender categorization in sports will likely require a nuanced, evidence-based approach to navigate these complex challenges effectively.

Acknowledgments
There are no acknowledgments.

Conflict of Interest
The authors declare that there is no conflict of interest.

Received: 21 February 2024 | **Accepted:** 15 July 2025 | **Published:** 01 October 2025

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