

Expert Declaration
Concerning Injury Risks Associated with Transgender
Participation in Female Athletics

DR. CHAD THOMAS CARLSON, M.D., FACSM

TABLE OF CONTENTS

Table of Contents	ii
Introduction	1
Credentials	6
I. OVERVIEW	8
II. A BRIEF HISTORY OF THE RATIONALE FOR SEPARATION OF SPORT BY SEX	10
III. UNDERSTANDING THE CAUSES OF SPORTS INJURIES	14
A. The epidemiological model of injury	15
B. The biomechanical model of injury	19
IV. THE PHYSICS OF SPORTS INJURY	21
V. GENDER DIFFERENCES RELEVANT TO INJURY	25
A. Height and weight	26
B. Bone and connective tissue strength	26
C. Speed	27
D. Strength/Power	28
E. Throwing and kicking speed	30
VI. ENHANCED FEMALE VULNERABILITY TO CERTAIN INJURIES.....	33
A. Concussions.....	34
B. Anterior Cruciate Ligament injuries	40
VII. TESTOSTERONE SUPPRESSION ALONE AS A MITIGATION STRATEGY WILL NOT PREVENT HARM TO FEMALE ATHLETES	44
A. Bone density.....	52
B. Size, weight and lean mass	52
C. Strength	54
D. Speed	57
Conclusion	58
Bibliography.....	63

INTRODUCTION

Up to the present, the great majority of news, debate, and even scholarship about transgender participation in female athletics has focused on sports such as swimming or track and field, and the debate has largely concerned questions of fairness and inclusion. However, the transgender eligibility policies of many high school athletic associations in the United States apply with equal force to all sports, including sports in which players frequently collide with each other, or can be forcefully struck by balls, or equipment such as hockey or lacrosse sticks. And in fact, biologically male transgender athletes have competed in a wide range of high school, collegiate, and professional girls' or women's sports, including, at least, basketball,¹ soccer,² volleyball,³ softball,⁴ rugby,⁵ and even women's tackle football.⁶

The science of sex-specific differences in physiology, intersecting with the physics of sports injury, leaves little doubt that participation by biological males in

¹https://www.espn.com/espnw/athletes-life/story/_/id/10170842/espnw-gabrielle-ludwig-52-year-old-transgender-women-college-basketball-player-enjoying-best-year-life (accessed 2/17/22)

²https://www.unionleader.com/news/education/nh-bill-limits-women-s-sports-to-girls-born-female/article_d1998ea1-a1b9-5ba4-a48d-51a2aa01b910.html ([accessed 5/24/22](#)); <https://www.outsports.com/2020/1/17/21069390/womens-soccer-mara-gomez-transgender-player-argentina-primera-division-villa-san-marcos> (accessed 6/20/21)

³<https://news.ucsc.edu/2016/09/challenging-assumptions.html> (accessed 6/20/21); <https://www.outsports.com/2017/3/20/14987924/trans-athlete-volleyball-tia-thompson> (accessed 6/20/21)

⁴<https://www.foxnews.com/us/californias-transgender-law-allows-male-high-schooler-to-make-girls-softball-team> (accessed 6/20/21)

⁵[Getting hit by a male transitioning to female rugby player similar being hit by a bus | Toronto Sun](#)

⁶<https://www.outsports.com/2017/12/13/16748322/britney-stinson-trans-football-baseball> (accessed 6/20/21); <https://www.mprnews.org/story/2018/12/22/transgender-football-player-prevails-in-lawsuit> (accessed 6/20/21)

these types of girls' or women's sports, based on gender identity, creates significant additional risk of injury for the biologically female participants competing alongside these transgender athletes.

In 2020, after an extensive review of the scientific literature, consultation with experts, and modeling of expected injuries, World Rugby published revised rules governing transgender participation, along with a detailed explanation of how the new policy was supported by current evidence. Previous to this, World Rugby had been using a policy that was amended in 2019 in anticipation of aligning with model rules for International Federations, to be released by the IOC. This 2019 policy required transgender females to maintain a threshold under 5.0 nmol/L for a minimum of twelve consecutive months. When the IOC delayed release of their own amended policy, World Rugby convened a working group under an independent chairman who was both a medical doctor and an international rugby player. This working group consisted of other physicians, exercise physiologists, legal counsel, administrative personnel and players representatives. Among the stated aims of the group was to “facilitate the participation of transgender players in rugby where it is possible to do so safely and fairly.” A two day workshop was convened, where review of evidence, debate and discussion could occur. The sessions from this workshop were recorded and made publicly available. All research cited in the course of the formulation of their updated policy was made publicly available on their website in bibliographic form. The compiled findings of the working group were then prepared as a draft guideline which was then submitted to member unions and associations for input. Direct feedback from players was actively solicited as well.

World Rugby ultimately concluded that “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 biological male advantages persist to a large degree,” and that after puberty, “the lowering of testosterone removes only a small proportion of the documented biological differences.” Hence, World Rugby concluded that biological men should not compete in women’s rugby. (World Rugby Transgender Women Guidelines 2020.) Within their document, World Rugby listed relevant biological advantages from testosterone, resultant performance differences, and most importantly, the rationale of the expert panel for how this translated into a heightened injury risk for biological women. Of note was a reliance on injury modeling to predict injury risk when a retained physiological advantage is a significant possibility. All pronouncements were linked to relevant reference data, including data on injury modeling. The panel also looked at the relative size of male and female elite rugby players and found that in most cases, their weights were bimodal with minimal overlap. All data was included in the body of their guideline. Following this was an extensive discussion of injury modeling risk for collisions at various weight percentiles, looking at head linear and angular acceleration, and neck force and moment. World Rugby has been criticized by some for its new guidelines, but those criticisms have often avoided discussions of medical science entirely or have asserted that modeling scenarios can overstate true risk. What cannot be denied, however, is that World Rugby’s approach is evidence-based, and rooted in concern for athlete safety. As a medical doctor who has spent my career in sports medicine, it is my opinion that World Rugby’s assessment of the evidence is scientifically sound, and

that injury modeling meaningfully predicts that biologically male transgender athletes do constitute a safety risk for the biologically female athlete in women's sports.

In a similar vein, in 2021, the UK Sports Councils' Equality Group released new guidance for transgender inclusion in organized sports. This guidance was formulated after extensive conversations with stakeholders, a review of scientific findings related to transgender athletes in sport through early 2021, and an assessment of the use by some sport national governing bodies of case-by-case assessment to determine eligibility. Noteworthy within these stakeholder consultations was a lack of consensus on any workable solution, as well as concerns related to athlete safety and "adherence to rules which give sport validity." The Literature Review accompanying the guidance document further noted that "[t]here are significant differences between the sexes which render direct competition between males and females . . . unsafe in sports which allow physical contact and collisions." (UK Sports Councils' Equality Group Literature Review 2021 at 1.) Their review of the science "made clear that there are retained differences in strength, stamina and physique between the average woman compared with the average transgender woman....with or without testosterone suppression." (UK Sports Councils' Equality Group Guidance at 3.) This was also reflected in their ten guiding principles, stating that physical differences between the sexes will "impact safety parameters in sports which are combat, collision or contact in nature." (UK Sports Councils' Equality Group Guidance 2021 at 7.) Ultimately, UK Sport concluded that the full inclusion of transgender athletes in women's sports "cannot be reconciled within the current

structure of sport,” stating that “the inclusion of transgender people into female sport cannot be balanced regarding transgender inclusion, fairness and safety in gender-affected sport where there is meaningful competition . . . due to retained differences in strength, stamina and physique between the average woman compared with the average transgender woman..., with or without testosterone suppression.” (UK Sports Councils’ Equality Group Guidance 2021 at 6.) Finally, UK Sport affirmed the use of sex categorization in sport, along with age and disability, as important for the maintenance of safety and fairness. (UK Sports Councils’ Equality Group Guidance 2021 at 7–8.)

Public awareness of the safety issues implicit when biologically female athletes are forced to compete against biological males in the female space is growing. Most recently, this can be seen in the ongoing controversy in 2024 surrounding the San Jose State women’s volleyball team and the multiple teams which have voluntarily forfeited their games against San Jose State in order to avoid potential harm. Other organizations such as USA Boxing have developed eligibility guidelines that are more rigid than their own international sanctioning bodies, (USA Boxing Compliance Guidelines, 2022) and further concerns have been raised by the Association of Ringside Physicians. (Bascharon R, 2024). As a physician who has spent my career caring for athletes, it is my hope to equip and motivate sports leagues and policy makers to give adequate attention to the issue of safety for female athletes when transgender policies are being considered. In this paper, I first explain the nature and causes of common sports injuries. I then review physiological differences between male and female bodies that affect the risk and severity of injuries to females when

biological males compete in the female category, and I explain why testosterone suppression does not eliminate these heightened risks to females. Finally, I explain certain conclusions about those risks.

CREDENTIALS

1. I am a medical doctor practicing Sports Medicine, maintaining an active clinical practice at Stadia Sports Medicine in West Des Moines, Iowa. I received my M.D. from the University of Nebraska College of Medicine in 1994 and completed a residency in family medicine at the University of Michigan in 1997.

2. Following my time in Ann Arbor, I matched to a fellowship in Sports Medicine at Ball Memorial Hospital in Muncie, Indiana, training from 1997 to 1999, with clinical time split between Central Indiana Orthopedics, the Ball State Human Performance Laboratory, and the Ball State University training room. I received my board certification in Sports Medicine in 1999, which I continue to hold. Since residency training, my practice has focused on Sports Medicine—the treatment and prevention of injuries related to sport and physical activity.

3. Since 1997, I have served in several clinical practices and settings as a treating physician, including time as an NCAA Division I team physician for both the University of Illinois and Ball State University, where I provided care to athletes in several sports, including football, ice hockey, basketball, field hockey, softball, gymnastics, soccer, and volleyball. In the course of my career, I have provided coverage for NCAA Power Five Conference championships and NCAA National Championship events in basketball, field hockey and gymnastics, among other sports, as well as provided coverage for national championship events for U.S.A. gymnastics,

and U.S. Swimming and Diving. I have also covered professional soccer in Des Moines.

4. Since 2006, I have been the physician owner of Stadia Sports Medicine in West Des Moines, Iowa. My practice focuses on the treatment of sports and activity-related injury, including concussive injury, as well as problems related to the physiology of sport.

5. I have served in and provided leadership for several professional organizations over the course of my career. In 2004, I was designated a Fellow of the American College of Sports Medicine (ACSM). I have served on ACSM's Health and Science Policy Committee since 2010, and for a time chaired their Clinical Medicine Subcommittee. From 2009 to 2013, I served two elected terms on the Board of Directors of the American Medical Society for Sports Medicine (AMSSM), and during that time served as Chair of that body's Practice and Policy Committee. I was subsequently elected to a four-year term on AMSSM's executive committee in 2017, and from 2019–20, I served as AMSSM's President. AMSSM is the largest organization of sports medicine physicians in the world. I gained fellowship status through AMSSM in 2020—my first year of eligibility. My work for ACSM and AMSSM has brought with it extensive experience in public policy as relates to Sports Medicine. I was the recipient of the AMSSM Founder's Award in 2019. The Founder's Award is the highest honor that AMSSM presents each year. It honors exemplary contributions to AMSSM and to the discipline of sports medicine, and is given annually to the individual, group or organization that "exemplifies the best we can be or do in sports medicine."

6. In 2020, I was named as AMSSM's first board delegate to the newly constituted Physical Activity Alliance. I was a named member of an NCAA advisory group on COVID-19, through which I provided input regarding the cancellation of the basketball tournament in 2020. I also serve as a member of the Iowa Medical Society's Sports Medicine Subcommittee.

7. I have served as a manuscript reviewer for organizational policy pronouncements, and for several professional publications, including sports medicine board review books published in 2021 and 2023. I have published several articles on topics related to musculoskeletal injuries in sports and rehabilitation which have been published in peer-reviewed journals such as Clinical Journal of Sports Medicine, British Journal of Sports Medicine, Current Reviews in Musculoskeletal Medicine, Athletic Therapy Today, and the Journal of Athletic Training. In conjunction with my work in policy advocacy, I have helped write several pieces of legislation, including the initial draft of what became the Sports Medicine Licensure Clarity Act, signed into law by President Trump in 2018, which eases the restrictions on certain practitioners to provide health services to athletes and athletic teams outside of the practitioner's home state.

8. In the past four years, I testified as an expert witness by deposition in *B.P.J. v. West Virginia*, S.D. W.V., No. 2:21-cv-00316, *LE. vs. Lee*, No. 3:21-cv-00835 and *Doe v. Horne*, 4:23-cv-00185-JGZ.

I. OVERVIEW

9. In this statement, I offer information and my own professional opinion on the potential for increased injury risk to females in sports when they compete

against biologically male transgender athletes.⁷ At many points in this statement, I provide citations to published, peer-reviewed articles that provide relevant and supporting information to the points I make.

10. The principal conclusions that I set out in this white paper are as follows:

a. Government and sporting organizations have historically considered the preservation of athlete safety as one component of competitive equity.

b. Injury in sport is somewhat predictable based on modeling assumptions that take into account relevant internal and external risk factors.

c. Males exhibit large average advantages in size, weight, and physical capacity over females—often falling far outside female ranges. Even before puberty, males have a performance advantage over females in most athletic events. Failure to preserve protected female-only categories in contact sports (broadly defined) will ultimately increase both the frequency and severity of injury suffered by female athletes who share playing space with these males.

d. Current research supports the conclusion that suppression of testosterone levels by males who have already begun puberty will not fully reverse the effects of testosterone on skeletal size, strength, or muscle hypertrophy, leading to persistence of sex-based differences in power, speed, and force-generating capacity.

11. In this white paper, I use the term “contact sports” to refer broadly to all sports in which collisions between players, or collisions between equipment such as a stick or ball and the body of a player, occur with some frequency (whether or not permitted by the rules of the game), and are well recognized in the field of sports

⁷ In the body of this paper, I use the terms “male” and “female” according to their ordinary medical meaning—that is to say, to refer to the two biological sexes. I also use the word “man” to refer to a biologically male human, and “woman” to refer to a biologically female human. In the context of this opinion, I include in these categories non-syndromic, biologically-normal males and females who identify as a member of the opposite sex, including those who use endogenous hormone suppression to alter their body habitus. In contexts that are not focused on questions of biology and physiology, terms of gender are sometimes used to refer to subjective identities rather than to biological categories—something I avoid for purposes of a paper focused on sports science.

medicine as causes of sport-related injuries.⁸ The 1975 Title IX implementing regulations (34 CFR § 106.41) say that “for purposes of this [regulation] contact sports include boxing, wrestling, rugby, ice hockey, football, basketball, *and other sports* the purpose or major activity of which involves bodily contact.” Certainly, all of the sports specifically named in the regulation fall within my definition of “contact sport.” Mixed martial arts, field hockey (Barboza 2018), soccer (Kuczinski 2018), rugby (Viviers 2018), lacrosse (Pierpoint 2019), volleyball,⁹ baseball, and softball also involve collisions that can and do result in injuries, and so also fall within my definition.

II. A BRIEF HISTORY OF THE RATIONALE FOR SEPARATION OF SPORT BY SEX

12. World Rugby is correct when it notes that “the women’s category exists to ensure protection, safety, and equality” for women. (World Rugby Transgender Women Guidelines 2020.) To some extent, those in charge of sport governing bodies in the modern era have always recognized the importance of grouping athletes together based on physical attributes, in order to ensure both safety and competitive balance. Weight classifications have existed in wrestling since it reappeared as an Olympic event in 1904. Women and men have participated in separate categories since the advent of intercollegiate sporting clubs early in the 20th century. When Title IX went into effect in 1975, there were just under 300,000 female high school athletes,

⁸ It is common to see, within the medical literature, reference to distinctions between “contact” and “collision” sports. For purposes of clarity, I have combined these terms, since in the context of injury risk modeling, there is no practical distinction between them.

⁹ See <https://www.latimes.com/sports/story/2020-12-08/stanford-volleyball-hayley-hodson-concussions-cte-lawsuit> (accessed 11/11/24).

and fewer than 10,000 female collegiate athletes. With the changes that resulted from Title IX, it was assumed that newly available funds for women in sport would ensure the maintenance of existing, or creation of new, sex-segregated athletic teams that would foster greater participation by women. This has been borne out subsequently; by the first half of the 1980's these numbers had risen to 1.9 million and nearly 100,000 respectively. (Hult 1989.)

13. The rationale for ongoing “separate but equal” status when it came to sex-segregated sports was made clear within the language of the original implementing regulations of Title IX, which, acknowledging real, biologically-driven differences between the sexes, created carve-out exceptions authorizing sex-separation of sport for reasons rooted in the maintenance of competitive equity. Importantly, the effect of these innate sex-based differences on the health and safety of the athlete were acknowledged by the express authorization of sex-separated teams for sports with higher perceived injury risk—i.e., “contact sports.” (Coleman 2020.)

14. In the almost half century since those regulations were adopted, the persistent reality of sex-determined differences in athletic performance and safety has been recognized by the ongoing and nearly universal segregation of men's and women's teams—even those that are not classically defined as being part of a contact or collision sport. Although there are sports where an argument can be made that meaningful competition can occur between the sexes (e.g. shooting, curling, equestrian), in reality even sports such as golf, bowling and fencing are gender-affected to the point that there are few instances of female successes in male

championship events. So sex categories in sport have been shown to serve an important and necessary role.

15. Now, however, many schools and sports leagues in this country are permitting males to compete in female athletics—including in contact sports—based on gender identity. In my view, these policies have been adopted without careful analysis of safety implications. Other researchers and clinicians have addressed questions of the negative impact of such policies on fairness, or equality of athletic experiences for girls and women, in published articles, and in court submissions. One recent review of track and field performances, including sprints, distance races and field events, noted that men surpass the top female performance in each category between 1000 and 10,000 times *each year*, with hundreds or thousands of men surpassing the top women in each event. (Coleman & Shreve.) Although this was not their primary focus, World Rugby well-summarized the point when it observed that in a ranking list of the top thousand performances in most sports, every year, *every one* will have been achieved by a biological male. (World Rugby Transgender Women Guidelines 2020.) Although most easily documented in athletes who have gone through puberty, these differences are not exclusively limited to post-pubescent athletes either (Atkinson 2023). Thus, some national sport governing bodies have tightened their policies recently to restrict some transgender athletes who began transition as early as eleven or twelve years of age from competing in future sanctioned events in their identified gender. (McLarnon 2023; Union Cycliste International 2023; World Athletics 2023; World Aquatics 2023; World Rugby 2022)

16. Global population-based fitness testing over wide geographical regions reveals consistent measurable performance advantages of boys over girls in tests measuring speed, upper and lower body limb strength and power. (Kasovic 2021; De Miguel-Etayo 2014; Tambalis 2016; Catley 2013; Fuhner 2021) A cross-sectional study of 312 Spanish ten year old boys and girls showed boys outperforming girls on every measurement of speed and power, with results of each of seven performance tests bimodal and nonoverlapping. (Marta 2012) Using Catley's data on Australian children, when one looks at performance at the 50th percentile for ten year old boys and girls, running times are approximately 15% faster in boys in the 1.6 km run; boys complete double the number of shuttle stages in a timed shuttle run, perform a standing long jump 7.5% farther, perform 30% more push-ups and demonstrate 10% greater handgrip strength as a group. (Catley 2013) Dohrman looked at the training of eight-year-old boys and girls in kicking and throwing ability shows consistently higher performance of boys over girls at baseline, and similar gains from baseline in both sexes after coaching. Moreover, improvement was similar between the two groups. Retained differences between the sexes after this training were nearly categorical. One important thing to say about this study is that it occurred prior to Title IX, when societal-based differences in sport-related skill sets between boys and girls would be expected to be higher, and yet the rate of improvement between the two groups stayed consistent. In other words, if girls were under-coached, providing them with equivalent access to skill training should have resulted in greater improvement relative to boys; but we don't see that. (Dohrmann 1964.) Competition statistics from elite preadolescent track and field athletes show significant sex-based

difference in performance as well. (Brown 2023) I have reviewed the expert declaration of Gregory A. Brown, Ph.D., FACM of February 23, 2022, provided in West Virginia's case, which includes evidence from a wide variety of sources, including population-based mass testing data, as well as age-stratified competition results, all of which support the idea that prepubertal males run faster, jump higher and farther, exhibit higher aerobic power output, and have greater upper body strength (evidenced by stronger hand grip and better performance with chin-ups or bent arm hang) than comparably aged females. This performance gap is well-documented in population-based physiologic testing data that exists in databases such as the Presidential Fitness Test, the Eurofit Fitness test, and additional mass testing data from the UK and Australia. Collectively, this data reveals that pre-pubertal males outperform comparably aged females in a wide array of athletic tests including but not limited to the countermovement jump test, drop jump test, change of direction test, long jump, timed sit-up test, the 10 X 5 meter shuttle run test, the 20 meter shuttle run test, curl-ups, pull-ups, push-ups, one mile run, standing broad jump, and bent arm hang test. Dr. Brown further references studies showing a significant difference in the body composition of males and females before puberty. In sum, a large and unbridgeable performance gap between the sexes is well-studied and equally well-documented, beginning in many cases before puberty. In this white paper, I focus on some of these differences as they touch on the question of athlete safety.

III. UNDERSTANDING THE CAUSES OF SPORTS INJURIES

17. The causes for injury in sport are multifactorial. In recent decades, medical researchers have provided us an evolving understanding of how sports

injuries occur, as well as the factors that make them more or less probable, and more or less severe. Broadly speaking, there are two ways of modeling injury: the epidemiological model, and the biomechanical model. These models are not mutually exclusive, but provide complementary conceptual frameworks to help us stratify risk in sport.

A. The epidemiological model of injury

18. From a practical standpoint, sports medicine researchers and clinicians often use the “epidemiological model” to explain, prevent and manage sports injuries. Broadly speaking, this model views an injury in sport as the product of internal and external risk factors, triggered by an inciting event. In other words, a given injury is “caused” by a number of different factors that are unique to a given situation. (Meeuwise 1994.) When the interplay of these factors exceeds the injury threshold, injury occurs. One example of how this interplay might work would be a female distance runner in track who develops a tibial stress fracture, with identified risks of low estrogen state from amenorrhea (hypothalamic suppression of menses), an aggressive winter training program on an indoor tile surface, and shoes that have been used for too many miles, and are no longer providing proper shock absorption. Most risk factors ebb and flow, with the overall injury risk at any given time fluctuating as well. Proper attention to risk factor reduction *before* the start of the sports season (including appropriate rule-making) is the best way to reduce actual injury rates *during* the season.

19. As alluded to, the risk factors associated with injury can be broadly categorized as internal or external. Internal risk factors are internal to the athlete.

These include relatively fixed variables, such as the athlete's age, biological sex, bone mineral density (which affects bone strength) and joint laxity, or developmental anomalies such as congenital fusions in the foot. Contrasting this are more mutable variables such as body weight, fitness level, hydration state, current illness, prior injury, or psychosocial factors such as aggression.

20. External risk factors are, as the name suggests, external to the athlete. These include non-human risks such as the condition of the playing surface or equipment, athletic shoe wear, or environmental conditions. Other external risk factors come from opposing competitors, and include such variables as player size, speed, aggressiveness (even from a young age, boys demonstrate higher competitive aggression than girls), and overall adherence to the rules of the game. (Warden 2009) As already mentioned, these risks can be minimized through the proper creation and enforcement of rules, as well as the appropriate grouping of athletes together for purposes of competition. To the latter point, children don't play contact sports with adults and, in the great majority of cases, men and women compete in categories specific to their own biological sex. Certainly these categorical separations are motivated in part by average performance differences and considerations of fairness and opportunity. But they are also motivated by safety concerns. When properly applied, these divisions enhance safety because, when it comes to physical traits such as body size, weight, speed, muscle girth, and bone strength, although a certain

amount of variability exists within each group, the averages and medians differ widely *between* the separated groups.¹⁰

21. Thus, each of these commonly utilized groupings of athletes represents a pool of individuals with predictable commonalities. Epidemiological risk assessment is somewhat predictable and translatable as long as these pools remain intact. But the introduction of outside individuals into a given pool (e.g. an adult onto a youth football team, or males into most women's sports) would change the balance of risk inside that pool. Simply put, when you introduce larger, faster, and stronger athletes from one pool into a second pool of athletes who are *categorically* smaller (whether as a result of age or sex), you have altered the characteristics of the second pool, and, based on known injury modeling, have statistically increased the injury risk for the original athletes in that pool. This, in a nutshell, is the basis for World Rugby's recommendations.

22. Most clinical studies of the epidemiology of sports injuries use a multivariate approach, identifying multiple independent risk factors and examining how these factors might interact, in order to determine their relative contribution to injury risk, and make educated inferences about causation. (Meeuwise 1994.)

¹⁰ In some cases, safety requires even further division or exclusion. A welterweight boxer would not compete against a heavyweight, nor a heavyweight wrestle against a smaller athlete. In the case of youth sports, when children are at an age where growth rates can vary widely, leagues will accommodate for naturally-occurring large discrepancies in body size by limiting larger athletes from playing positions where their size and strength is likely to result in injury to smaller players. Thus, in youth football, players exceeding a certain weight threshold may be temporarily restricted to playing on the line and disallowed from carrying the ball, or playing in the defensive secondary, where they could impose high-velocity hits on smaller players.

23. In applying the multivariate approach, the goal is to keep as many variables as possible the same so as to isolate the potential effect of a single variable (such as age or biological sex) on injury risk, as well as to determine how the isolated variable interacts with the other analyzed variables to affect injury risk. Failure to consider relevant independent variables can lead to error. Researchers focusing on differences between male and female athletes, for example, would not compare concussion rates of a high school girls' soccer team to concussion rates of a professional men's soccer team, because differences in the concussion rate might be due to a number of factors besides sex, such as age, body mass, relative differences in skill, speed, or power, as well as differences in training volume and intensity.

24. As indicated earlier, an injury event is usually the end product of a number of different risk factors coming together. (Bahr 2005.) A collision between two soccer players who both attempt to head the ball, for example, might be the inciting event that causes a concussion. Although the linear and angular forces that occur through sudden deceleration would be the proximate cause of this injury, the epidemiological model of injury would also factor in "upstream" risks, predicting the possibility of an injury outcome for each athlete differently depending on the sum of these risks. If the collision injury described above occurs between two disparately-sized players, the smaller athlete will tend to decelerate more abruptly than the larger athlete, increasing the smaller athlete's risk for injury. Additional discrepancies in factors such as neck strength, running speeds, and muscle force generation capacity all result in differing risks and thus, the potential for differing injury outcomes from the same collision. As I discuss later in this white paper, there

are significant statistical differences between the sexes when it comes to each of these variables, meaning that in a collision sport where skeletally mature males and females are playing against one another, there is a higher statistical likelihood that injury will result when collisions occur, and in particular there is a higher likelihood that a female will suffer injury. This again is the basis for the recent decision by World Rugby to disallow the crossover of men into women's rugby, regardless of gender identity. (World Rugby Transgender Women Guidelines 2020.) The decision-making represented by this policy change is rational and rooted in objective facts and objective risks of harm, because it takes real, acknowledged, and documented physical differences between the sexes (in many cases before adolescence), and models expected injury risk on the basis of the known differences that persist even after hormone manipulation.

B. The biomechanical model of injury

25. Sports medicine researchers and clinicians also consider a biomechanical approach when it comes to understanding sports injuries. In the biomechanical model of injury, injury is considered to be analogous to the failure of a machine or other structure. Every bone, muscle, or connective tissue structure in an athlete's body has a certain load tolerance. Conceptually, when an external "load" exceeds the load tolerance of a given structure in the human body, an injury occurs. (Fung 1993 at 1.) Thus, researchers focus on the mechanical load—the force exerted on a bone, ligament, joint or other body part—and the load tolerance of that impacted or stressed body part, to understand what the typical threshold for injury is, and how predictable this might be. (McIntosh 2005 at 2–3.) Biomechanical models of injury

usually consider forces in isolation. The more consistent the movement pattern of an individual, and the fewer the contributions of unexpected outside forces to the athlete, the more accurate biomechanical predictions of injury will be.

26. Biomechanical modeling can be highly predictive in relatively simple settings. For example, in blunt trauma injury from falls, mortality predictably rises the greater the fall. About 50% of people who fall four stories will survive, while only 10% will survive a fall of seven stories. (Buckman 1991.) As complexity increases, predictability in turn decreases. In sport, the pitching motion is highly reproducible, and strain injury to the ulnar collateral ligament (UCL) of the elbow can be modeled. The load tolerance of the UCL of a pitcher's elbow is about 32 Newton-meters, but the failure threshold of a ligament like this in isolation is not the only determinant of whether injury will occur. During the pitching motion, the valgus force imparted to the elbow (gapping stress across the inner elbow that stretches the UCL) routinely reaches 64 Newtons, which is obviously greater than the failure threshold of the ligament. Since not all pitchers tear their UCLs, other variables innate to an athlete must mitigate force transmission to the ligament and reduce risk. The load tolerance of any particular part of an athlete's body is thus determined by other internal factors such as joint stiffness, total ligament support, muscle strength across the joint, or bone mineral density. Injury load can be self-generated, as in the case of a pitcher's elbow, or externally-generated, as in the case of a linebacker hitting a wide receiver. While load tolerance will vary by individual, as described above, and is often reliant on characteristics innate to a given athlete, external load is determined by outside factors such as the nature of the playing surface or equipment used, in combination

with the weight and speed of other players or objects (such as a batted ball) with which the player collides. (Bahr 2005.)

27. As this suggests, the two “models” of sports injuries described above are not in any sense inconsistent or in tension with each other. Instead, they are complementary ways of thinking about injuries that can provide different insights. But the important point to make regarding these models is that in either model, injury risk (or the threshold for injury) rises and falls depending on the size of an externally-applied force, and the ability of a given athlete to absorb or mitigate that force.

IV. THE PHYSICS OF SPORTS INJURY

28. Sports injuries often result from collisions between players, or between a player and a rapidly moving object (e.g. a ball or hockey puck, a lacrosse or hockey stick). In soccer, for example, most head injuries result from collisions with another player’s head or body, collision with the goal or ground, or from an unanticipated blow from a kicked ball. (Boden 1998; Mooney 2020.) In basketball, players often collide with each other during screens, while diving for a loose ball, or while driving to the basket. In lacrosse or field hockey, player-to-player, or player-to-stick contact is common.

29. But what are the results of those collisions on the human body? Basic principles of physics can cast light on this question from more than one angle. A general understanding of these principles can help us identify factors that will predictably increase or decrease the relative risk, frequency, and severity of sports injuries, given certain assumptions.

30. First, we can consider **energy**. Every collision involves an object or objects that possess energy. The energy embodied in a moving object (whether a human body, a ball, or anything else) is called kinetic energy.

31. Importantly, the kinetic energy of a moving object is expressed as: $E_k = \frac{1}{2}mv^2$. That is, kinetic energy is a function of the mass of the object multiplied by the *square* of its velocity. (Dashnaw 2012.) To illustrate with a simple but extreme example: if athletes A and B are moving at the same speed, but athlete A is twice as heavy, athlete A carries twice as much kinetic energy as athlete B. If the two athletes weigh the same amount, but athlete A is going twice as fast, athlete A carries four times as much kinetic energy as athlete B. But as I have noted, the kinetic energy of a moving object is a function of the mass of the object multiplied by the square of its velocity. Thus, if athlete A is twice as heavy, and moving twice as fast, athlete A will carry eight times the kinetic energy of athlete B into a collision.¹¹

32. The implication of this equation means that what appear to be relatively minor discrepancies in size and speed can result in major differences in energy imparted in a collision, to the point that more frequent and more severe injuries can occur. To use figures that correspond more closely to average differences between men and women, if Player M weighs only 20% more than Player F, and runs only 15% faster, Player M will bring *58% more kinetic energy* into a collision than Player F.¹²

¹¹ $2 \times 2^2 = 8$

¹² $1.2 \times (1.15)^2 = 1.587$

33. The law of conservation of energy tells us that energy is never destroyed or “used up.” If kinetic energy is “lost” by one body in a collision, it is inevitably transferred to another body, or into a different form. In the case of collision between players, or between (e.g.) a ball and a player’s head, some of the energy “lost” by one player, or by the ball, may be transformed into (harmless) sound; some may result in an increase in the kinetic energy of the player who is struck (through acceleration, which I discuss below); but some of it may result in *deformation* of the player’s body—which, depending on its severity, may result in injury. Thus, the greater the kinetic energy brought into a collision, the greater the potential for injury, all other things being equal.

34. Alternately, we can consider force and *acceleration*, which is particularly relevant to concussion injuries.

35. Newton’s third law of motion tells us that when two players collide, their bodies experience equal and opposite forces at the point of impact.

36. Acceleration refers to the rate of change in speed (or velocity). When two athletes collide, their bodies necessarily accelerate (or decelerate) rapidly: stopping abruptly, bouncing back, or being deflected in a different direction. Newton’s second law of motion tells us that: $F = ma$ (that is, force equals mass multiplied by acceleration). From this equation we see that when a larger and a smaller body collide, and (necessarily) experience equal and opposite forces, the smaller body (or smaller player, in sport) will experience more rapid acceleration. We observe this physical principle in action when we watch a bowling ball strike bowling pins: the

heavy bowling ball only slightly changes its course and speed; the lighter pins go flying.

37. This same equation also tells us that if a given player's body or head is hit with a *larger* force (e.g., from a ball that has been thrown or hit faster), it will experience *greater* acceleration, everything else being equal.

38. Of course, sport is by definition somewhat chaotic, and forces are often not purely linear. Many collisions also involve angular velocities, with the production of rotational force, or torque. Torque can be thought of as force that causes rotation around a central point. A different but similar equation of Newtonian physics governs the principles involved.¹³ Torque is relevant to injury in several ways. When torque is applied through joints in directions those joints are not able to accommodate, injury can occur. In addition, rotational force can cause different parts of the body to accelerate at different rates—in some cases, very rapid rates, also leading to injury. For example, a collision where the body is impacted at the waist can result in high torque and acceleration on the neck and head.

39. Sport-related concussion—a common sports injury and one with potentially significant effects—is attributable to linear, angular, or rotational acceleration and deceleration forces that result from impact to the head, or from an impact to the body that results in a whiplash “snap” of the head. (Rowson 2016.) In

¹³ In this equation, $\tau = I\alpha$, torque equals moment of inertia multiplied by angular acceleration, where “moment of inertia” is defined as $I = mr^2$, that is, mass multiplied by the square of the distance to the rotational axis.

the case of a concussive head injury, it is the brain that accelerates or decelerates on impact, colliding with the inner surface of the skull. (Barth 2001 at 255.)

40. None of this is mysterious: each of us, if we had to choose between being hit either by a large, heavy athlete running at full speed, or by a small, lighter athlete, would intuitively choose collision with the small, light athlete as the lesser of the two evils. And we would be right. One author referred to the “increase in kinetic energy, and therefore imparted forces” resulting from collision with larger, faster players as “profound.” (Dashnaw 2012.)

V. GENDER DIFFERENCES RELEVANT TO INJURY

41. It is important to state up front that it is self-evident to most people familiar with sport and sport injuries that if men and women were to consistently participate together in competitive contact sports, there would be higher rates of injury in women. This is one reason that rule modifications often exist in leagues where co-ed participation occurs.¹⁴ Understanding the physics of sports injuries helps provide a theoretical framework for why this is true, but so does common sense and experience. All of us are familiar with basic objective physiological differences between the sexes, some of which exist in childhood, and some of which become apparent after the onset of puberty and persist throughout adulthood. And because of personal experience, all of us also have some intuitive sense of what types of collisions are likely to cause pain or injury. Not surprisingly, our “common sense” on

¹⁴ For example, see <https://www.athleticbusiness.com/college/intramural-coed-basketball-playing-rules-vary-greatly.html> (detailing variety of rule modifications applied in co-ed basketball). Similarly, coed soccer leagues often prohibit so-called “slide tackles,” which are not prohibited in either men’s or women’s soccer. See, e.g., <http://www.premiercoedsports.com/pages/rulesandpolicies/soccer>.

these basic facts about the human condition is also consistent with the observations of medical science. Below, I provide quantifications of some of these well-known differences between the sexes that are relevant to injury risk, as well as some categorical differences that may be less well known.

A. Height and weight

42. It is an inescapable fact of the human species that males as a group are statistically larger and heavier than females. On average, men are 7% to 8% taller than women. (Handelsman 2018 at 818.) According to the most recently available Centers for Disease Control and Prevention (CDC) statistics, the weight of the average U.S. adult male is 17% greater than that of the average U.S. adult female. (CDC 2018.) This disparity persists into the athletic cohort. Researchers find that while athletes tend on average to be lighter than non-athletes, the weight difference between the average adult male and female athlete remains within the same range—between 14% and 23%, depending on the sport analyzed. (Santos 2014; Fields 2018.) Indeed, World Rugby estimates that the typical male rugby player weighs 20% to 40% more than the typical female rugby player. (World Rugby Transgender Women Guidelines 2020.) This size advantage by itself allows men to bring more force to bear in a collision.

B. Bone and connective tissue strength

43. Men have bones in their arms, legs, feet, and hands that are both larger and stronger per unit volume than those of women, due to greater cross-sectional area, greater bone mineral content, and greater bone density. The advantage in bone size (cross-sectional area) holds true in both upper and lower extremities, even when

adjusted for lean body mass. (Handelsman 2018 at 818; Nieves 2005 at 530.) Greater bone size in men is also correlated with stronger tendons that are more adaptable to training (Magnusson 2007), and an increased ability to withstand the forces produced by larger muscles (Morris 2020 at 5). Male bones are not merely larger, they are stronger per unit of volume. Studies of differences in arm and leg bone mineral density—one component of bone strength—find that male bones are denser, with measured advantages of between 5% and 14%. (Gilsanz 2011; Nieves 2005.)

44. Men also have larger ligaments than women (Lin 2019 at 5), and stiffer connective tissue (Hilton 2021 at Table 1), providing greater protection against joint injury.

C. Speed

45. When it comes to acceleration from a static position to a sprint, men are consistently faster than women. World record sprint performance gaps between the sexes remain significant at between 7% and 10.5%, with world record times in women now exhibiting a plateau (no longer rapidly improving with time) similar to the historical trends seen in men. (Cheuvront 2005.) This performance gap has to do with, among other factors, increased skeletal stiffness, greater cross-sectional muscle area, denser muscle fiber composition, higher proportion of type II muscle fibers and greater limb length. (Handelsman 2018; Hunter 2023) Collectively, males, on average, run about 10% faster than females, and accelerate at a faster rate. (Lombardo 2018 at 93; Mirkov 2020) This becomes important as it pertains to injury risk, because males involved in sport will often be travelling at faster speeds than

their female counterparts in comparable settings, with resultant faster speed at impact, and thus greater impact force, in a given collision.

D. Strength/Power

46. In 2014, a male mixed-martial art fighter identifying as female and fighting under the name Fallon Fox fought a woman named Tamikka Brents, and caused significant facial injuries in the course of their bout. Speaking about their fight later, Brents said:

“I’ve fought a lot of women and have never felt the strength that I felt in a fight as I did that night. I can’t answer whether it’s because she was born a man or not because I’m not a doctor. I can only say, I’ve never felt so overpowered ever in my life, and I am an abnormally strong female in my own right.”¹⁵

47. So far as I am aware, mixed martial arts is not a collegiate or high school interscholastic sport. Nevertheless, what Brent experienced in an extreme setting is true and relevant to safety in all sports that involve contact. In absolute terms, males as a group are substantially stronger than women.

48. Compared to women, men have “larger and denser muscle mass, and stiffer connective tissue, with associated capacity to exert greater muscular force more rapidly and efficiently.” (Hilton 2021 at 201.) Research shows that on average, during the prime athletic years (ages 18–29) men have, on average, 54% greater total muscle mass than women (33.7 kg vs. 21.8 kg) including 64% greater muscle mass in the upper body, and 47% greater in the lower body. (Janssen 2000 at Table 1.) The cross-sectional area of muscle in women is only 50% to 60% that of men in the upper

¹⁵ <https://bjj-world.com/transgender-mma-fighter-fallon-fox-breaks-skull-of-her-female-opponent/>

arm, and 65% to 70% of that of men in the thigh. This translates to women having only 50% to 60% of men's upper limb strength and 60% to 80% of men's lower limb strength. (Handelsman 2018 at 812.) Male weightlifters have been shown to be approximately 30% stronger than female weightlifters of equivalent stature and mass. (Hilton 2021 at 203.) But in competitive athletics, since the stature and mass of the average male exceeds that of the average female, actual differences in strength between average body types will, on average, exceed this. The longer limb lengths of males augment strength as well. Statistically, in comparison with women, men also have lower total body fat, differently distributed, and greater lean muscle mass, which increases their power-to-weight ratios and upper-to-lower limb strength ratios as a group. Looking at another common metric of strength, males average 57% greater grip strength (Bohannon 2019) and 54% greater knee extension torque (Neder 1999). Research shows that sex-based discrepancies in lean muscle mass begin to be established from infancy and persist through childhood to adolescence. (Davis 2019; Kirchengast 2001; Taylor 1997; Taylor 2010; McManus 2011.)

49. Using their legs and torso for power generation, men can apply substantially larger forces with their arms and upper body, enabling them to generate more ball velocity through overhead motions, as well as to generate more pushing or punching power. In other words, isolated sex-specific differences in muscle strength in one region (even differences that in isolation seem small) can and do combine to generate even greater sex-specific differences in more complex sport-specific functions. This has applications for disparate sports such as volleyball, fencing and boxing. One study looking at moderately-trained individuals found that males can

generate 162% more punching power than females. (Morris 2020.) Thus, multiple small advantages aggregate into larger ones.

E. Throwing and kicking speed

50. One result of the combined effects of these sex-determined differences in skeletal structure is that men are, on average, able to throw objects faster than women. (Lombardo 2018; Chu 2009; Thomas 1985.) By age seventeen, the *average* male can throw a ball farther than 99% of seventeen-year-old females—which necessarily means at a faster initial speed assuming a similar angle of release—despite the fact that factors such as arm length, muscle mass, and joint stiffness individually don’t come close to exhibiting this degree of sex-defined advantage. One study of elite male and female baseball pitchers showed that men throw baseballs 35% faster than women—81 miles/hour for men vs. 60 miles/hour for women. The authors of this study attribute this to a sex-specific difference in the ability to generate muscle torque and power. (Chu 2009.) A study showing greater throwing velocity in male versus female handball players attributed it to differences in body size, including height, muscle mass, and arm length. (Van Den Tillaar 2012.) Interestingly, significant sex-related difference in throwing ability has been shown to manifest even before puberty (Dorhmann 1964), but the difference increases rapidly during and after puberty. (Thomas 1985 at 266.) These sex-determined differences in throwing speed are not limited to sports where a ball is thrown. Males have repeatedly been shown to throw a javelin more than 30% farther than females. (Lombardo 2018 Table 2; Hilton 2021 at 203.) Even in preadolescent children,

differences exist. International youth records for 5- to 12-year-olds in the javelin show 34–55% greater distance in males vs. females using a 400g javelin.¹⁶

51. Men also serve and spike volleyballs with higher velocity than women, with a performance advantage in the range of 29–34%. (Hilton 2021.) Analysis of first and second tier Belgian national elite male volleyball players shows ball spike speeds of 63 mph and 56 mph respectively. (Forthomme 2005.) NCAA Division I female volleyball players—roughly comparable to the second-tier male elite group referenced above—average a ball spike velocity of approximately 40 mph (18.1 m/s). (Ferris 1995 at Table 2.) Notably, based on the measurements of these studies, male spiking speed in *lower* elite divisions is almost 40% greater than that of NCAA Division I female collegiate players. Separate analyses of serving speed between elite men and women Spanish volleyball players showed that the average power serving speed in men was 54.6 mph (range 45.3–64.6 mph), with maximal speed of 76.4 mph. In women, average power serving speed was 49 mph (range 41–55.3 mph) with maximal speed of 59 mph. This translates to an almost 30% advantage in maximal serve velocity in men. (Palao 2014.)

52. Recall that kinetic energy is dependent on mass and the square of velocity. A volleyball (with fixed mass) struck by a male, and traveling an average 35% faster than one struck by a female, will deliver 82% more energy to a head upon impact.

¹⁶ <http://age-records.125mb.com/>.

53. The greater leg strength and jumping ability of men confer a further large advantage in volleyball that is relevant to injury risk. In volleyball, an “attack jump” is a jump to position a player to spike the ball downward over the net against the opposing team. Research on elite national volleyball players found that on average, males exhibited a 50% greater vertical jump height during an “attack” than did females. (Sattler 2015.) Similar data looking at countermovement jumps (to block a shot) in national basketball players reveals a 35% male advantage in jump height. (Kellis 1999.) In volleyball, this dramatic difference in jump height means that male players who are competing in female divisions will more often be able to successfully perform a spike, and this will be all the more true considering that the women’s net height is seven inches lower than that used in men’s volleyball. Confirming this inference, research also shows that the successful attack percentage (that is, the frequency with which the ball is successfully hit over the net into the opponent’s court in an attempt to score) is so much higher with men than women that someone analyzing game statistics can consistently identify games played by men as opposed to women on the basis of this statistic alone. These enhanced and more consistently successful attacks by men directly correlate to their greater jumping ability and attack velocity at the net. (Kountouris 2015.)

54. The combination of the innate male-female differences cited above, along with the lower net height in women’s volleyball, means that if a reasonably athletic male is permitted to compete against women, the participating female players will likely be exposed to higher ball velocities that are outside the range of what is typically seen in women’s volleyball. When we recall that ball-to-head impact is a

common cause of concussion among women volleyball players, this fact makes it clear that participation in girls' or women's volleyball by biologically male individuals will increase concussion injury risk for participating girls or women.

55. Male sex-based advantages in leg strength also lead to greater kick velocity. In comparison with women, men kick balls harder and faster. A study comparing kicking velocity between university-level male and female soccer players found that males kick the ball with an average 20% greater velocity than females. (Sakamoto 2014.) Applying the same principles of physics we have just used above, we see that a soccer ball kicked by a male, travelling an average 20% faster than a ball kicked by a female, will deliver 44% more energy on head impact. Greater force-generating capacity will thus increase the risk of an impact injury such as concussion.

VI. ENHANCED FEMALE VULNERABILITY TO CERTAIN INJURIES

56. Above, I have reviewed physiological differences that result in the male body bringing greater weight, speed, and force to the athletic field or court, and how these differences can result in a greater risk of injury to females when males compete against them. It is also true that the female body is more vulnerable than the male body to certain types of injury even when subject to comparable forces. This risk appears to extend to the younger age cohorts as well. An analysis of Finnish student athletes from 1987–1991, analyzing over 600,000 person-years of activity exposures, found, in students under fifteen years of age, higher rates of injury in girls than boys in soccer, volleyball, judo and karate. (Kujala 1995.) Another epidemiological study looking specifically at injury rates in over 14,000 middle schoolers over a 20 year period showed that “in sex-matched sports, middle school girls were more likely to

sustain *any* injury (RR = 1.15, 95% CI = 1.1, 1.2) or a time-loss injury (RR = 1.09, 95% CI = 1.0, 1.2) than middle school boys.” In analyzed both-sex sports (i.e., sex-separated sports that both girls and boys play, like soccer), girls sustained higher injury rates, and greater rates of time-loss injury. (Beachy 2014.) Another study of over 2000 middle school students at nine schools showed that the injury rate was higher for girls’ basketball than for football (39.4 v 30.7/1000 AEs), and injury rates for girls’ soccer were nearly double that of boys’ soccer (26.3 v. 14.7/1000 AEs). (Caswell 2017.) In this regard, I will focus on two areas of heightened female vulnerability to collision-related injury which have been extensively studied: concussions, and anterior cruciate ligament injuries.

A. Concussions

57. Females are more likely than males to suffer concussions in comparable sports, and on average suffer more severe and longer lasting disability once a concussion does occur. (Harmon 2013 at 4; Berz 2015; Blumenfeld 2016; Covassin 2003; Rowson 2016.) Females also seem to be at higher risk for post-concussion syndrome than males. (Berz 2015; Blumenfeld 2016; Broshek 2005; Colvin 2009; Covassin 2012; Dick 2009; Marar 2012; Preiss-Farzanegan 2009.)

58. The most widely-accepted definition of sport-related concussion comes from the Consensus Statement on Concussion in Sport (see below).¹⁷ (McCrory 2018.)

¹⁷ “Sport related concussion is a traumatic brain injury induced by biomechanical forces. Several common features that may be utilised in clinically defining the nature of a concussive head injury include:

SRC may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head.

To summarize, concussion is “a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process” that can manifest in a variety of ways. (Harmon 2013 at 1.)

59. Sport-related concussions have undergone a significant increase in societal awareness and concurrent injury reporting since the initial passage of the Zachery Lystedt Concussion Law in Washington State in 2009 (Bompadre 2014), and the subsequent passage of similar legislation governing return-to-play criteria for concussed athletes in most other states in the United States. (Nat’l Cnf. of State Leg’s 2018.) Concussion is now widely recognized as a common sport-related injury, occurring in both male and female athletes. (CDC 2007.) Sport-related concussions can result from player-surface contact or player-equipment contact in virtually any sport. However, sudden impact via a player-to-player collision, with rapid deceleration and the transmission of linear or rotational forces through the brain, is also a common cause of concussion injury. (Covassin 2012; Marar 2012; Barth 2001; Blumenfeld 2016; Boden 1998; Harmon 2013 at 4.)

SRC typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours.

SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.

SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases symptoms may be prolonged.

The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc) or other comorbidities (e.g., psychological factors or coexisting medical conditions).”

60. A large retrospective study of U.S. high school athletes showed a higher rate of female concussions in soccer (79% higher), volleyball (0.6 concussions/10,000 exposures, with 485,000 reported exposures, vs. no concussions in the male cohort), basketball (31% higher), and softball/baseball (320% higher). (Marar 2012.) A similarly-sized, similarly-designed study comparing concussion rates between NCAA male and female collegiate athletes showed, overall, a concussion rate among females 40% higher than that of males. Higher rates of injury were seen across individual sports as well, including ice hockey (10% higher); soccer (54% higher); basketball (40% higher); and softball/baseball (95% higher). (Covassin 2016.) The observations of these authors, my own observations from clinical practice, and the acknowledgment of our own Society's Position Statement (Harmon 2013), all validate the higher frequency and severity of sport-related concussions in women and girls.

61. Most epidemiological studies to date looking at sport-related concussion in middle schoolers show that more boys than girls are concussed. There are fewer studies estimating concussion *rate*. This is, in part, because measuring injury rate is more time and labor-intensive. Researchers at a childrens' hospital, for example, could analyze the number of children presenting to the emergency department with sport-related concussion and publish findings of absolute number. However, to study concussion incidence, athlete exposures also have to be recorded. Generally speaking, an athlete exposure is a single practice or game where an athlete is exposed to playing conditions that could reasonably supply the necessary conditions for an injury to occur. Rates of athletic injury, concussion among them, are then, by convention, expressed in terms of injury rate per 1000 athletic exposures. More recently, some

studies have been published that analyze the rates of concussion in the middle school population. Looking at the evidence, the conclusion can be made that females experience increased susceptibility to concussive injuries before puberty. For example, Ewing-Cobbs, et al. (2018) found elevated post-concussion symptoms in girls across all age ranges studied, including children between the ages of 4 and 8. Kerr's 2017 study of middle school students showed over three times the rate of female vs male concussion in students participating in sex-comparable sports [0.18 v. 0.66/1000 A.E.'s]. (Kerr 2017.) This is the first study I am aware of that mimics the trends seen in adolescent injury epidemiology showing a higher rate of concussion in girls than boys in comparable sports.

62. More recent research looking at the incidence of sport-related concussions in U.S. middle schoolers between 2015 and 2020, found that the rate of concussion was higher in middle school athletes than those in high school. In this study, girls had more than twice the rate of concussion injury (0.49/1000 athletic exposures vs 0.23/1000 AE) in analyzed sports (baseball/softball, basketball, soccer and track), as well as statistically greater time loss. (Hacherl 2021 (Journal of Athletic Training); Hacherl 2021 (Archives of Clinical Neuropsychology).) The authors hypothesized that the increasing incidence of concussion in middle school may relate to “other distinct differences associated with the middle school sport setting itself, such as, the large variations in player size and skill.”¹⁸

¹⁸ [Middle School Sports Have Overall Higher Rate of Concussion Than Reported in High School and Collegiate Settings During the 2015-2016 to 2019-2020 School Years | NATA](#)

63. In addition, females on average suffer materially greater cognitive impairment than males when they do suffer a concussion. Group differences in cognitive impairment between females and males who have suffered concussion have been extensively studied. A study of 2340 high school and collegiate athletes who suffered concussions determined that females had a 170% higher frequency of cognitive impairment following concussions, and that in comparison with males, female athletes had significantly greater declines in simple and complex reaction times relative to their preseason baseline levels. Moreover, the females experienced greater objective and subjective adverse effects from concussion even after adjusting for potentially protective effect of helmets used by some groups of male athletes. (Broshek 2005 at 856, 861; Colvin 2009; Covassin 2012.)

64. This large discrepancy in frequency and severity of concussion injury is consistent with my own observations across many years of clinical practice. The large majority of student athletes who have presented to my practice with severe and long-lasting cognitive disturbance have been adolescent girls. I have seen girls remain symptomatic for over a year, lose ground academically and become isolated from their peer groups due to these ongoing symptoms. For patients who experience these severe effects, post-concussion syndrome can be life-altering.

65. Some of the anatomical and physiological differences that we have considered between males and females help to explain the documented differences in concussion rates and in symptoms between males and females. (Covassin 2016; La Fountaine 2019; Lin 2019; Tierney 2005; Wunderle 2014.) Anatomically, there are significant sex-based differences in head and neck anatomy, with females exhibiting

in the range of 30% to 40% less head-neck segment mass and neck girth, and 49% lower neck isometric strength. This means that when a female athlete's head is subjected to the same load as an analogous male, there will be a greater tendency for head acceleration, and resultant injury. (Tierney 2005 at 276–277.)

66. When modeling the effect of the introduction of male mass, speed, and strength into women's rugby, World Rugby gave particular attention to the resulting increases in forces and acceleration (and injury risk) experienced in the head and neck of female players. Their analysis found that “the magnitude of the known risk factors for head injury are . . . predicted by the size of the disparity in mass between players. The addition of [male] speed as a biomechanical variable further increases these disparities,” and their model showed an increase of up to 50% in neck and head acceleration that would be experienced in a typical tackle scenario in women's rugby. As a result, “a number of tackles that currently lie beneath the threshold for injury would now exceed it, causing head injury.” (World Rugby Transgender Women Guidelines 2020.) While rugby is notoriously contact-intensive, similar increases to risk of head and neck injury to women are predictable in any sport context in which males and females collide at significant speed, as happens from time to time in sports including soccer, softball, and basketball.

67. In addition, even when the heads of female and male athletes are subjected to identical accelerative forces, there are sex-based differences in neural anatomy and physiology, cerebrovascular organization, and cellular response to concussive stimuli that make the female more likely to suffer concussive injury, or more severe concussive injury. For instance, hypothalamic-pituitary disruption is

thought to play a role in post-concussion symptomatology that differentially impacts women. (McGroarty 2020; Broshek 2005 at 861.) Another study found that elevated progesterone levels during one portion of the menstrual cycle were associated with more severe post-concussion symptomatology that differentially impacted women. (Wunderle 2014.)

68. As it stands, when females compete against each other, they already have higher rates of concussive injury than males, across most sports. The addition of biologically male athletes into women's contact sports will inevitably increase the risk of concussive injury to girls and women, for the multiple reasons I have explained above, including, but not limited to, the innate male advantage in speed, strength, power, acceleration and lean muscle mass. Because the effects of concussion can be severe and long-lasting, particularly for biological females, we can predict with some confidence that if participation by biological males in women's contact sports based on gender identity becomes more common, more biological females will suffer substantial concussive injury and the potential for long-term harm as a result.

B. Anterior Cruciate Ligament injuries

69. The Anterior Cruciate Ligament ("ACL") is a key knee stabilizer that prevents anterior translation of the tibia relative to the femur and also provides rotatory and valgus knee stability.¹⁹ (Lin 2019 at 4.) Girls and women are far more vulnerable to ACL injuries than are boys and men. The physics of injury that we have reviewed above makes it inevitable that the introduction of biologically male athletes

¹⁹ Valgus force at the knee is a side-applied force that gaps the medial knee open.

into the female category will increase still further the occurrence of ACL injuries among girls or women who encounter these players on the field.

70. Sports-related injury to the ACL is so common that it is easy to overlook the significance of it. But it is by no means a trivial injury, as it can end sports careers, require surgery, and usually results in early-onset, post-traumatic osteoarthritis, triggering long-term pain and mobility problems later in life. (Wang 2020.)

71. Even in the historic context in which girls and women limit competition to (and so only collide with) other girls and women, the rate of ACL injury is substantially higher among female than male athletes. (Flaxman 2014; Lin 2019; Agel 2005.) One meta-analysis of 58 studies reports that female athletes have a 150% relative risk for ACL injury compared with male athletes, with other estimates suggesting as much as a 300% increased risk. (Montalvo 2019; Sutton 2013.) Particularly in those sports designated as contact sports, or sports with frequent cutting and sharp directional changes (basketball, field hockey, lacrosse, soccer), females are at greater risk of ACL injury. In basketball and soccer, this risk extends across all skill levels, with female athletes between two and eight times more likely to sustain an ACL injury than their male counterparts. (Lin 2019 at 5.) These observations are widely validated, and consistent with the relative frequencies of ACL injuries that I see in my own practice.

72. When the reasons underlying the difference in the incidence of ACL injury between males and females were first studied in the early 1990s, researchers speculated that the difference might be attributable to females' relative inexperience in contact sports, or to their lack of appropriate training. However, a follow-up 2005

study looking at ACL tear disparities reported that, “Despite vast attention to the discrepancy between anterior cruciate ligament injury rates between men and women, these differences continue to exist.” (Agel 2005 at 524.) Inexperience and lack of training do not explain the differences. Sex seems to be an independent predictor of ACL tear risk.

73. In fact, as researchers have continued to study this discrepancy, they have determined that multiple identifiable anatomical and physiological differences between males and females play significant roles in making females more vulnerable to ACL injuries than males. (Flaxman 2014; Lin 2019; Wolf 2015.) Summarizing the findings of a number of separate studies, one researcher recently cited as anatomical risk factors for ACL injury smaller ligament size, decreased femoral notch width, increased posterior-inferior slope of the lateral tibia plateau, increased knee and generalized laxity, and increased body mass index (BMI). With the exception of increased BMI, each of these factors is more likely to occur in female than male athletes. (Lin 2019 at 5.) In addition, female athletes often stand in more knee valgus (that is, in a “knock-kneed” posture) due to wider hips and a medially-oriented femur. Often, this is also associated with a worsening of knee valgus during jump landings. The body types and movement patterns associated with these valgus knee postures are more common in females and increase the risk for ACL tear. (Hewett 2005.)

74. As with concussion, the cyclic fluctuation of sex-specific hormones in women is also thought to be a possible risk factor for ACL injury. Estrogen acts on ligaments to make them more lax, and it is thought that during the ovulatory phase

of menses (when estrogen levels peak), the risk of ACL tear is higher. (Chidi-Ogbolu 2019 at 1; Herzberg 2017.)

75. Whatever the factors that increase the injury risk for ACL tears in women, the fact that a sex-specific difference in the rate of ACL injury exists is well established and widely accepted.

76. Although non-contact mechanisms are the most common reason for ACL tears in females, tears related to contact are also common, with ranges reported across multiple studies of from 20%–36% of all ACL injuries in women. (Kobayashi 2010 at 672.) For example, when a soccer player who is kicking a ball is struck by another player in the lateral knee of the stance leg, medial and rotational forces can tear the medial collateral ligament (MCL), the ACL, and the meniscus. Thus, as participation in the female category based on identity rather than biology becomes more common (entailing the introduction of athletes with characteristics such as greater speed and lean muscle mass), and as collision forces suffered by girls and women across the knee increase accordingly, the risk for orthopedic injury and in particular ACL tears among impacted girls and women will inevitably rise.

77. Of course, there exists variation in all these factors within a given group of males or females. However, it is also true that within sex-specific pools, size differential is somewhat predictable and bounded, even considering outliers. When males are permitted to enter into the pool of female athletes based on gender identity rather than biological sex, there is an increased possibility that a categorical statistical outlier in terms of size, weight, speed, and strength—and potentially an extreme outlier—is now entering the female pool. Although injury is not guaranteed,

risks to female participants will increase. And as I discuss later, the available evidence together suggests that this will be true even with respect to males who have been on testosterone suppression for a year or more. World Rugby relied heavily upon this when they were determining their own policy, and I think it is important to reiterate that this policy, rooted in concern for athlete safety, is justifiable based upon current evidence from medical research and what we know about biology.

VII. TESTOSTERONE SUPPRESSION ALONE AS A MITIGATION STRATEGY WILL NOT PREVENT HARM TO FEMALE ATHLETES

78. A recent editorial in the New England Journal of Medicine opined that policies governing transgender participation in female athletics “must safeguard the rights of all women—whether cisgender or transgender.” (Dolgin 2020.) Unfortunately, the physics and medical science reviewed above tell us that this is not practically possible. If biological males are given a “right” to participate in the female category based on gender identity, then biological women will be denied the right to reasonable expectations of safety and injury risk that have historically been guaranteed by ensuring that females compete (and collide) only with other females. If safety and fairness in women’s sports is to be prioritized, advocates for the crossover of biological males into women’s sports should be able to point to well-designed studies proving that puberty suppression and hormone replacement eliminate the competitive advantage, but they cannot do that.

79. As Dr. Emma Hilton has observed, the fact that there are over 3000 sex-specific differences in skeletal muscle alone makes the hypothesis that sex-linked performance advantages are attributable solely to current circulating testosterone

levels improbable at best. (Hilton 2021 at 200–01.) Indeed, next to breast tissue, there is no tissue in the human body with more sex-differentiated genetic expression than skeletal muscle. (Gershoni 2017)

80. That said, prolonged exposure to elevated levels of serum testosterone is the primary driver of sex-based performance difference. Advocates of unquestioning inclusion based on gender identity often contend that hormonal manipulation of a male athlete can feminize the athlete enough that he is comparable with females for purposes of competition. The NCAA’s Office of Inclusion asserts (still accessible on the NCAA website as of this writing) that “It is also important to know that any strength and endurance advantages a transgender woman arguably may have as a result of her prior testosterone levels dissipate after about one year of estrogen or testosterone suppression therapy.”²⁰ (NCAA 2011 at 8.) Whether or not this is true is a critically important question.

81. At the outset, we should note that while advocates sometimes claim that testosterone suppression *can* eliminate physiological advantages in a biological male, none of the relevant transgender eligibility policies that I am aware of prior to 2021 requires any demonstration that it has *actually* achieved that effect in a particular male who seeks admission into the female category. The Arizona policy that is currently in effect permits admission to the female category without requiring any testosterone suppression at all. (Arizona 2024, Canyon 2023) Under their initial 2010 transgender eligibility policy, the NCAA simply required physician attestation of

²⁰ <https://www.ncaa.org/sports/2016/3/2/lesbian-gay-bisexual-transgender-and-questioning-lgbtq.aspx>
INC TransgenderHandbook.pdf (ncaaorg.s3.amazonaws.com)

twelve months of hormonal therapy without demonstration of any reduction of performance capability, change in weight, or regression of any other physical attribute of the biological male toward female levels. It did not require attainment of any particular baseline serum testosterone level, and did not provide for any monitoring of athletes for compliance. This policy was updated in January, 2022, retaining the requirement for one year of gender-affirming hormone therapy and adding a requirement for periodic measurements of serum testosterone before the start of the regular season, and prior to participation in championship events. The relevant disqualification thresholds for serum testosterone were to be established by a given sport's national governing body, or barring that, the relevant international governing body, or finally, the 2015 IOC threshold of 10.0 nmol/L. Although this policy initially implied that full implementation of national or international governing body policies would be implemented by the 2023-2024 calendar year, presumably incorporating other aspects of rulemaking (e.g. longer sport-specific requirements for length of GAHT, or disqualification if gender transition occurred after the onset of male puberty), this third phase has been largely eliminated from the current policy description (reference to it still exists on some landing pages). In addition, serum testosterone testing for NCAA athletes does not occur through any designated labs, and athletes can simply provide their own documentation, without any designated chain of testing custody or requirements for specific test formats (eg. Immunoassay vs. Mass spectrometry)..

82. Current national and international governing body serum testosterone requirements range from 2.5 to 10.0 nmol/L. The 2015 IOC “fallback” policy for the

NCAA only requires achievement of a testosterone level below 10nmol/liter—a level far above that occurring in normal biological females (0.06 to 1.68 nmol/L).²¹ Even female athletes with polycystic ovarian disorder—a condition that results in elevated testosterone levels—almost never exceed 3.08 nmol/L, (Bermon 2014 at 4334) which was the basis for setting the testing threshold to detect testosterone *doping* in females at 5.0 nmol/L. Thus, males who qualify under the 2015 IOC policy to compete as transgender women may have testosterone levels—even after hormone suppression—*double* the level that would disqualify a biological female for doping with testosterone, and over five times the upper limit of serum testosterone in otherwise healthy biological women.²²

83. Sustained exposure to serum testosterone, most commonly through exposure to male puberty is clearly ergogenic. Phenotypic females with 46XY DSD have been found in the elite track and field population at a rate 140 times higher than expected in the general population. (Bermon S 2014) However even marginally elevated levels of serum androgens in women are probably ergogenic. Women with polycystic ovaries with an average serum testosterone of 2.2 nmol/L have significantly increased axial and appendicular lean muscle mass, (Douchi 2001) and women with PCOS demonstrate increased lower extremity power. (Caliskan Guzelce

²¹ Normal testosterone range in a healthy male averages between 7.7 and 29.4 nmol/L.

²² In November 2021, the IOC released new guidelines, deferring decision-making about a given sport's gender-affectedness to its governing body. The current NCAA policy, however, still utilizes the 2015 IOC policy to determine an athlete's eligibility in event that the sport's national and international governing bodies lack policies to determine eligibility.

2019) Further supporting the idea of a performance effect from low-grade relative elevations of testosterone, the incidence of PCOS is about 4-12% in the general population, but 15-31% in an elite athletic population. (Hagmar 2009)

84. Even assuming that active treatment with gender-affirming therapies actually result in full testosterone suppression – the evidence for which is mixed²³ – (Heather 2022; Liang/Safer 2017) the available evidence strongly indicates that no amount of testosterone suppression can eliminate male physiological advantages relevant to performance and safety. Several recent clinical reviews and meta-analyses of relevant research demonstrate that one year (or more) of testosterone suppression does not substantially eliminate male performance advantages, with an average reduction of about 5%, and with maintenance of muscle strength advantages for three years. (Hilton 2021; DeVarona 2021; Harper 2021; Hunter 2023) This prolonged maintenance of performance makes spot testing for testosterone levels less important than ensuring that a biological male who is desiring to compete with biological females has not experienced male puberty and has maintained a prolonged suppression of testosterone, documented by repeated testing that meets benchmark criteria for validity. (Trost 2016) It should also be noted that in at least one study, 9.4% of biological males attempting transition to female did not change their body composition at all, despite 24 months of hormone therapy, with no correlation to serum testosterone levels. (Van Velzen 2020) Findings like this fly in the face of the IOC’s “no presumption of advantage. (see below)”

²³ It has been reported that this can occur in between 25% to 49% of treated subjects.

85. For purposes of this discussion, I will focus on those specific sex-based characteristics of males who have undergone normal male pubertal skeletal growth and maturation that are relevant to the *safety* of female athletes. Here, too, the available science tells us that testosterone suppression does not eliminate the increased risk to females or solve the safety problem. World Rugby reached this same determination based on the currently available science, concluding that male physiological advantages that “create risks [to female players] appear to be only minimally affected” by testosterone suppression. (World Rugby Transgender Women Guidelines 2020.) Some advocates for the participation of biological males in women’s sports note that prolonged testosterone suppression brings lean body mass and strength into greater conformity with a biological female body type. But at best, research in non-athletic transgender patients indicates that prolonged hormonal manipulation results in lean mass and strength parameters that fall between that of biological males and biological females, with maintenance of statistically significant differences. It is maintained by some that biological males who seek transition towards biological women already exhibit baseline measures of lean mass, strength, etc, that are measurably less than the average biological male. But this is where the discretion of medical experts becomes important. Biological males who are transitioning to become females are not a unique biological category. They are members of the male sex. Assumptions made by evaluating data on sedentary subjects can only go so far in comparison to athletes. There is every reason to think that a biological male athlete who intentionally focuses strength training efforts to mitigate the loss of lean mass during hormonal therapy will in fact be able to mitigate

enough of the negative performance effect of these treatments that their relative performance against biological women will improve. That is exactly what occurred with Lia Thomas, who vaulted from unranked in the NCAA men's 100 freestyle to 13th place in the woman's category, from 551st in the men's 200 to 3rd in the women's event, and from 65th in the men's 500 to winning the NCAA women's championship. (Senefeld 2023) In their recent guidelines, UK Sport determined that, "based upon current evidence, testosterone suppression is unlikely to guarantee fairness between transgender women and natal females in gender-affected sports." (UK Sports Councils' Equality Group Guidance 2021 at 7.) They also warned that migration to a scenario by NGBs where eligibility is determined through case-by-case assessment "is unlikely to be practical nor verifiable for entry into gender-affected sports," in part because "many tests related to sports performance are volitional," and incentives on the part of those tested would align with intentional poor performance. (UK Sports Councils' Equality Group Guidance 2021 at 8.)

86. Despite these concerns, this appears to be exactly the route that the IOC is taking, as reflected in their Framework on Fairness, Inclusion and Non-Discrimination on the Basis of Gender Identity, which was released in November of 2021, and which superseded the IOC's 2015 transgender eligibility policy.²⁴ Rather than require male athletes who identify as women to conform to testosterone levels in the female range, they instead completely changed the goal of their stated

²⁴ The IOC Framework on Fairness, Inclusion and Non-Discrimination on the Basis of Gender Identity and Sex Variations is available at https://stillmed.olympics.com/media/Documents/News/2021/11/IOC-Framework-Fairness-Inclusion-Non-discrimination-2021.pdf?_ga=2.72651665.34591192.1645554375-759350959.1644946978

guidelines from competitive equity to non-discrimination and inclusion. Abandoning any effort at self-regulation, the IOC instead called on international sports governing bodies to formulate their own sport-specific policies, respecting the principles embedded in the IOC's own framework. In this document, the IOC cited ten principles that governing bodies were to consider in the formulation of their policies. These were not science-based goals. One principle was that no transgender athlete should be presumed to have a competitive advantage. Also embedded within the Framework were two disparate goals. First, that “where sports organizations elect to issue eligibility criteria for men’s and women’s categories for a given competition, they should do so with a view to . . . [p]roviding confidence that no athlete within a category has an unfair and disproportionate competitive advantage . . . [and] preventing a risk to the physical safety of other athletes.” (IOC Framework 2021 § 4.1.) At the same time, governing bodies are not to preclude any athlete from competing until evidence exists based upon “robust and peer-reviewed research that . . . demonstrates a consistent, unfair, disproportionate competitive advantage in performance and/or an unpreventable risk to the physical safety of other athletes”—research moreover that “is largely based on data collected *from a demographic group that is consistent in gender and athletic engagement with the group that the eligibility criteria aim to regulate.*” (IOC Framework 2021 § 6.1) Finally, affected athletes may appeal any evidence-based decision-making process through a further “appropriate internal mediation mechanism, such as a Court of Arbitration for Sport.” (IOC Framework 2021 § 6.1.) Rather than cite any of the growing evidence that testosterone suppression cannot mitigate sex-based performance differences, the IOC’s new policy

remains aspirational and opaque, and has come into criticism by other Sports Medicine Federations, many of which, such as World Athletics, FINA, and the International Cyclist Union, have since issued policy changes further restricting biological males from participating against natal females. (Pigozzi 2022; Union Cycliste Internationale 2023; World Athletics 2023; World Aquatics 2023) This is because the research relating to hormonal suppression in transgender athletes, as confirmed by World Rugby and UK Sport, already speaks very clearly to the fact that males retain a competitive advantage over women that cannot be eliminated through testosterone suppression alone. What follows is a brief summary of some of these retained differences as they relate to sport safety.

A. Bone density

87. Bone mass (which includes both size and density) is maintained over *at least* two years of testosterone suppression (Singh-Ospina 2017; Figuera 2019), and one study found it to be preserved even over a median of 12.5 years of suppression (Hilton 2021; Ruetsche 2005).

B. Size, weight and lean mass

88. After the male pubertal growth spurt, suppression of testosterone does not materially *shrink* bones so as to eliminate height, leverage, performance, and weight differences that follow from simply having longer, larger bones, and being subsequently taller.

89. Males are, on average, larger, and heavier. (CDC 2018) As we have seen, these facts alone mean that males bring more kinetic energy into collisions, and

that lighter females will suffer more abrupt deceleration in collisions with larger bodies, creating heightened injury risk for impacted females.

90. Multiple studies have found that testosterone suppression may modestly reduce, but does not come close to eliminating the male advantage in lean body mass. Studies looking at the effect of GAHT on lean mass are generally split between those showing modest decreases, or no statistical change. (Ford 2021.) Researchers looking at transitioning adolescents found that the weight of biological male subjects *increased* rather than decreased after treatment with an antiandrogen testosterone suppressor, with no significant loss of muscle cross-sectional area, and maintenance of grip strength. (Tack 2018.) Adolescent biological male subjects who were exposed to puberty-halting medications prior to institution of testosterone suppression presented with lean body mass 2.5 standard deviations higher than biological girls, and maintained gains of between 1–2 standard deviations at age 22. (Klaver 2018.) In one recent meta-analysis, researchers looking at the musculoskeletal effects of hormonal transition found that even after males had undergone 36 months of therapy, their lean body mass and muscle area remained above those of females. (Harper 2021.) Another group studied the effects in biological men of testosterone suppression to less than 1 nmol/L for one or more years, but still found only a 12% total loss of muscle area by the end of thirty-six months. (Gooren 2004.) Finally, a 2022 study comparing biological males treated for an average of 14.4 years of GAHT to cisgender men and women showed that both skeletal muscle mass and appendicular skeletal mass adjusted for height, as well as handgrip strength, remained statistically greater than cisgender controls. Activity in this study was

controlled for, and did not differ between examined groups. Although there were no statistical differences in serum testosterone between transitioning biological males, and biological females, the levels in the latter group were more consistent with the PCOS range, averaging 3.2 nmol/L and ranging all the way to 22.1 nmol/L, again illustrating the IOC's fallacy of presuming no advantage. (Alvares 2022)

C. Strength

91. A large number of studies have now observed minimal or no reduction in strength in male subjects following testosterone suppression. In one recent meta-analysis, strength loss after twelve months of hormone therapy ranged from negligible to 7%. (Harper 2021.) Given the baseline male strength advantage in various muscle groups of approximately 25% to 100% above female levels that I have noted in section V.D, even a 7% reduction will leave a large retained advantage in strength. Another study looking at handgrip strength—which is a commonly used proxy for general strength—showed a 9% loss of strength after two years of hormonal treatment in males who were transitioning, leaving a 23% retained advantage over the female baseline. (Hilton 2021.) Yet another study which found a 17% retained grip strength advantage noted that this placed the median of the group treated with hormone therapy in the 95th percentile for grip strength among age-matched females. (Scharff 2019.) Researchers looking at transitioning adolescents showed no loss of grip strength after hormone treatment. (Tack 2018.) One recent study on male Air Force service members undergoing transition showed that they retained more than two thirds of pretreatment performance advantage over females in sit-ups and push-ups after one to two years of testosterone-reducing hormonal treatment. (Roberts

2020.) A similar study in 2022 looking at 228 biologically male, transitioning Air Force personnel showed that these individuals retained statistical advantage over cisgender females up to four years for sit-ups, and indefinitely for push-ups, despite the fact that this group started GAHT underperforming to cisgender males in push-ups at baseline. (Chiccarelli 2022) An observational cohort study looked at thigh strength and thigh muscle cross-sectional area in men undergoing hormonal transition to transgender females. After one year of hormonal suppression, this group saw only a 4% decrease in thigh muscle cross-sectional area, and a negligible decrease in thigh muscle strength. (Wiik 2020.) Wiik and colleagues looked at isokinetic strength measurements in individuals who had undergone at least 12 months of hormonal transition and found that muscle strength was comparable to baseline, and torque-generating ability actually increased, leaving transitioned males with a 50% strength advantage over reference females. (Wiik 2020.) Finally, one cross-sectional study that compared men who had undergone transition at least three years prior to analysis, to age-matched, healthy males found that the transgender individuals had retained enough strength that they were still outside normative values for women. This imbalance continued to hold even after *eight* years of hormone suppression. The authors also noted that since males who identify as women often have lower baseline (i.e., before hormone treatment) muscle mass than the general population of males, and since baseline measures for this study were unavailable, the post-transition comparison may actually represent an overestimate of muscle mass regression in transgender females. (Lapauw 2008; Hilton 2021.)

92. World Rugby came to the same conclusion based on its own review of the literature, reporting that testosterone suppression “does not reverse muscle size to female levels,” and in fact that “studies assessing [reductions in] mass, muscle mass, and/or strength suggest that reduction in these variables range between 5% and 10%. Given that the typical male vs female advantages range from 30% to 100%, these reductions are small.” (World Rugby Transgender Women Guidelines 2020.)

93. It is true that most studies of change in physical characteristics or capabilities over time after testosterone suppression involve untrained subjects rather than athletes, or subjects with low to moderate training. It may be assumed that all of the Air Force members who were subjects in the study I mention above were physically fit and engaged in regular physical training. But neither that study nor those studies looking at athletes quantify the volume or type of strength training athletes are undergoing. The important point to make is that the only effect strength training could have on these athletes is to *counteract* and reduce the limited loss of muscle mass and strength that does otherwise occur to some extent over time with testosterone blockade. There appears to be a muscle memory effect related to prior prolonged exposure to testosterone, whereby muscle fibers develop increased myonuclei which enhance muscle hypertrophy and strength gains when resistance training resumes, even in androgen levels have been reduced. (Egner 2013; Hunter 2023) There are studies that illustrate this concept in patients undergoing recent androgen deprivation, measuring strength during a twelve-week period where testosterone was suppressed to levels of 2 nmol/L. During that time, subjects actually increased leg lean mass by 4%, and total lean mass by 2%, and subject performance

on the 10 rep-max leg press improved by 32%, while their bench press performance improved by 17%. (Kvorning 2006.) Evolving data on muscle memory in biological males may underpin this effect (Hunter 2023). Another study of patients on chronic androgen deprivation therapy (mean 1136 days) showed that a 20 week progressive resistance training program moving from concentric toward eccentric load training resulted in 41% improvements in both chest press and seated rows, and a 96% improvement in leg press. (Galvao 2006) More recent meta-analyses looking at resistance training programs in an androgen deprivation state confirms no loss or slight gains in lean mass, and both upper and lower body strength gains. (Chen 2019; Keilani 2017)

94. The point for safety is that superior absolute strength enables a biological male to apply greater force against an opponent's body during body contact, or to throw, hit, or kick a ball at speeds outside the ranges normally encountered in female-only play, with the attendant increased risks of injury that I have already explained.

D. Speed

95. As to speed, the study of transitioning Air Force members found that these males retained a 9% running speed advantage over the female control group after one year of testosterone suppression, and their average speed had not declined significantly farther by the end of the 2.5 year study period. (Roberts 2020.) Again, I have already explained the implications of greater male speed on safety for females on the field and court, particularly in combination with the greater male body weight.

CONCLUSION

Since the average male athlete is larger and exerts greater power than the average female athlete in similar sports, male-female collisions will produce greater energy at impact, and impart greater risk of injury to a female, than would occur in most female-female collisions. Because of the well-documented physiological testing and elite performance differences in speed and strength, as well as differences in lean muscle mass that exist across all age ranges, the conclusions of this paper can apply to a certain extent before, as well as during, and after puberty. We have seen that males who have undergone hormone therapy in transition toward a female body type nevertheless retain musculoskeletal “legacy” advantages in muscle girth, strength, and size. We have also seen that the additive effects of these individual advantages create multiplied advantages in terms of power, force generation and momentum on the field of play. In contact or collision sports, sports involving projectiles, or sports where a stick is used to strike something, the physics and physiology reviewed above tell us that permitting male-bodied athletes to compete against, or on the same team as females—even when undergoing testosterone suppression—must be expected to create predictable, identifiable, substantially increased, and unequal risks of injuries to the participating women.

Based on its independent and extensive analysis of the literature coupled with injury modeling, World Rugby recognized the inadequacy of the International Olympic Committee’s policy to preserve safety for female athletes in their contact sport. Among the explicit findings of the World Rugby working group were the following:

- Forces and inertia faced by a smaller and slower player during collisions are significantly greater when in contact with a larger, faster player.
- Discrepancies in mass and speed (such as between two opponents in a tackle) are significant determinants of various head and other musculoskeletal injury risks.
- The risk of injury to females is increased by biological males' greater ability to exert force (strength and power), and also by females' reduced ability to receive or tolerate that force.
- Testosterone suppression results in only "small" reductions in the male physiological advantages. As a result, heightened injury risks remain for females who share the same field or court with biological males.
- These findings together predict a significant increase in injury rates for females in rugby if males are permitted to participate based on gender identity, *with or without testosterone suppression*, since the magnitude of forces and energy transfer during collisions will increase substantially, directly correlated to the differences in physical attributes that exist between the biological sexes.

Summarizing their work, the authors of the World Rugby Guidelines said that, "World Rugby's number one stated priority is to make the game as safe as possible, and so World Rugby cannot allow the risk to players to be increased to such an extent by allowing people who have the force and power advantages conferred by testosterone to play with and against those who do not." (World Rugby Transgender Guidelines 2020.) As my own analysis above makes clear, I agree with the concerns of UK Sport and the conclusions of World Rugby regarding risk to female athletes. Importantly, I also agree that it must be a high priority for sports governing bodies (and other regulatory or governmental bodies governing sports) to make each sport as safe as reasonably possible. And in my view, medical practitioners with expertise in this area have an obligation to advocate for science-based policies that promote safety.

The *performance* advantages retained by males who participate in women's sports based on gender identity are readily recognized by the public. When an NCAA hurdler who ranked 200th while running in the collegiate male division transitions and immediately leaps to a number one ranking in the women's division;²⁵ when a high school male sprinter who ranked 181st in the state running in the boys' division transitions and likewise takes first place in the girls' division (DeVarona 2021), when a biologically-male collegiate swimmer transitions and moves from 65th place in the men's 500 m event, to NCAA champion in the women's 500 meter race, (Senefeld, JW., 2023) the problem of fairness and equal opportunities for girls and women is immediately apparent, and indeed this problem is being widely discussed today in the media.

The causes of sports injuries are multivariate and not always immediately apparent. And yet, we know that the male advantage in lower extremity explosive movements such as jumping, kicking or throwing averages between 16-22%. That same advantage in upper extremity ballistic activities such as throwing or volleyball spiking average 30% or more. And differences in limb muscle power can be even greater. (Hunter 2023) As indicated above, even suppression with gender-affirming hormone therapy for three years leaves significant retained advantage in muscle strength of between 5 and 9% (Harper 2021; Hilton 2021) In a recently published review, David Handelsman deftly pointed out that there are examples of performance advantages of 2-3.5% conferred by the use of new sports equipment technologies that

²⁵ https://en.wikipedia.org/wiki/Cece_Telfer (accessed 6/20/21)

have resulted in rule changes by various sports governing bodies. Those rulemaking decisions should be viewed in the context of the known categorical male advantage in sport. (Handelsman 2024) And this is potentially a growing problem. While, as I have noted, some biological males have indeed competed in a variety of girls' and women's contact sports, the numbers up till now have been small. But recent studies have reported very large increases in the number of children and young people identifying as transgender compared to historical experience. For example, an extensive survey of 9th and 11th graders in Minnesota found that 2.7% identified as transgender or gender-nonconforming—well over 100 times historical rates (Rider 2018), and many other sources likewise report this trend. (Johns 2017; Herman 2017.)

Faced with this rapid social change, it is my view as a medical doctor that policymakers have an important and pressing duty not to wait while avoidable injuries are inflicted on girls and women, but instead to proactively establish policies governing participation of biological males in female athletics that give proper and scientifically-based priority to safety in sport for these girls and women. Separating participants in contact sports based on biological sex preserves competitive equity, but also promotes the safety of female athletes by protecting them from predictable and preventable injury. Otherwise, the hard science that I have reviewed in this white paper leaves little doubt that eligibility policies based on ideology or gender identity rather than science, will, over time, result in increased, and more serious, injuries to girls and women who are forced to compete against biologically male transgender athletes. When basic science and physiology both predict increased injury, then

leagues, policy-makers, and legislators have a responsibility to act to protect girls and women before they get hurt.

Chad Carlson, M.D., FACSM
West Des Moines, Iowa
Past-President, AMSSM

BIBLIOGRAPHY

- Agel, J. et al., Anterior cruciate ligament injury in National Collegiate Athletic Association basketball and soccer: a 13-year review. *Am. J. Sports Med.* 33(4):524-531 (2005).
- Alvares, L.A.M., Cardiopulmonary capacity and muscle strength in transgender women on long-term gender-affirming hormone therapy: a cross-sectional study. *Br J Sports Med* 56:1292-1299 (2022).
- Arizona Interscholastic Association transgender policy on PDF p. 183 (Section 43.9) of <https://aiaonline.org/files/14046/2024-2025-aia-constitution-bylaws-policies-and-procedures-book.pdf>.
- Athletic Business, "College intramural playing rules vary greatly." <https://www.athleticbusiness.com/college/intramural-coed-basketball-playing-rules-vary-greatly.html>.
- Atkinson MA et al. Sex differences in Track and Field Elite Youth. *Med Sci Sports Exer* 56(8):1390-97 (2024).
- Bahr, R. and T. Krosshaug, Understanding injury mechanisms: a key component of preventing injuries in sport. *Br. J. Sports Med* 39:324-329 (2005).
- Barboza, S.D. et al., Injuries in field hockey players: a systematic review. *Sports Med.* 48:849-66 (2018).
- Barth, J.T. et al., Acceleration-deceleration sport-related concussion: the gravity of it all. *J. Athletic Training* 36(3):253-56 (2001).
- Bascharon R et al., Transgender competition in combat sports: Position statement of the Association of Ringside Physicians. *Phys Sportsmed* 52(4):317-324 (2024).
- Beachy, G. and M. Rauh, Middle school injuries: a 20-year (1988-2008) multisport evaluation. *J. Athl. Train.* 49(4):493-506 (2014).
- Bermon S et al. Serum androgen levels in elite female athletes. *J Clin Endocrinol Metab* 99(11):4328-4335 (2014).
- Berz, K. et al., Sex-specific differences in the severity of symptoms and recovery rate following sports-related concussion in young athletes. *The Physician and Sports Med.* 41(2):58-63 (2015).
- BJJ World, "Transgender MMA Fighter Fallon Fox Breaks Skull of Her Female Opponent." <https://bjj-world.com/transgender-mma-fighter-fallon-fox-breaks-skull-of-her-female-opponent/>.

- Blankenship, M.J. et al., Sex-based analysis of the biomechanics of pitching. 38th International Society of Biomechanics in Sport Conference (July 2020).
- Blumenfeld, R.S. et al., The epidemiology of sports-related head injury and concussion in water polo. *Front. Neurol.* 7(98) (2016).
- Boden, B.P. et al., Concussion incidence in elite college soccer players. *Am. J. Sports Med.* 26(2):238-241 (1998).
- Bohannon, R.W. et al., Handgrip strength: a comparison of values obtained from the NHANES and NIH toolbox studies. *Am. J. Occ. Therapy* 73(2) (March/April 2019).
- Bompadre, V. et al., Washington State's Lystedt Law in concussion documentation in Seattle public high schools. *J. Athletic Training* 49(4):486-92 (2014).
- Broshek, D.K. et al., Sex differences in outcome following sports-related concussion, *J. Neurosurg.* 102:856-63 (May 2005).
- Brown G et al. Sex-based differences in track running distances of 100, 200, 400, 800, and 1500m in the 8 and under and 9–10-year-old age groups. *Eur J Sports Sci.* 24:217-225 (2023).
- Buckman, R. F. and Buckman, P.D., Vertical deceleration trauma: principles of management. *Surg .Clin. N. Am.* 71(2):331–44 (1991).
- Caliskan Guzelce et al. Is muscle mechanical function altered in polycystic ovary syndrome? *Arch Gynecol Obstet* 2019. 300:771-776 (2019).
- Canyon Athletic Association transgender policy Canyon Athletic Association. <https://azcaa.com/about/members/constitution/> at Section 16.13 on Page 4.
- Caswell, S.V., et al., Epidemiology of sports injuries among middle school students. *Brit. J. of Sports Med.* 51(4):305 (2017).
- Catley M., Normative Health-Related Fitness Values for Children: Analysis of 85,437 Test Results on 9-17 Year-Old Australians Since 1985. 47:98-108 (2013).
- Centers for Disease Control, CDC National Health Statistics Report Number 122, 12/20/2018.
- Centers for Disease Control, Nonfatal traumatic brain injuries from sports and recreation activities–United States, 2001-2005, *JAMA* 298(11):1271-72 (Sept 2007).

- Chen Z 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* 10(843):1-11 (2019).
- Cheuvront, S.N. et al., Running performance differences between men and women: an update. *Sports Med.* 35(12):1017-24 (2005).
- Chiccarelli E., Fit transitioning: When can transgender airmen fitness test in their affirmed gender? *Mil Med. Usac*320 (2022).
- Chidi-Ogbolu, N. and K. Baar, Effect of estrogen on musculoskeletal performance and injury risk. *Front. Physiol.* 9:1834 (2019).
- Chu, Y. et al., Biomechanical comparison between elite female and male baseball pitchers. *J. Applied Biomechanics* 25:22-31 (2009).
- Coleman, D.L. and W. Shreve, Comparing athletic performances: the best elite women to boys and [comparingathleticperformances.pdf](#). (Accessed 06/20/21)
- Coleman, D. L. et al., Re-affirming the value of the sports exception to Title IX's general non-discrimination rule. *Duke J. of Gender and Law Policy* 27(69):69-134 (2020).
- Colvin, A.C. et al., The role of concussion history and gender in recovery from soccer-related concussion. *Am. J. Sports Med.* 37(9):1699-1704 (2009).
- Covassin, T. et al., Sex differences and the incidence of concussions among collegiate athletes. *J. Ath. Training* 38(3):238-244 (2003).
- Covassin, T. et al., Sex differences in reported concussion injury rates and time loss from participation: an update of the National Collegiate Athletic Association Injury Surveillance Program from 2004-2005 through 2009-2009. *J. Ath. Training* 51(3):189-194 (2016).
- Covassin, T. et al., The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am. J. Sports Med.* 40(6):1303-1312 (2012).
- Dashnaw, M.L. et al., An overview of the basic science of concussion and subconcussion: where we are and where we are going. *Neurosurg. Focus* 33(6) E5 (2012).
- Davis, S.M., et al., Sex Differences in Infant Body Composition Emerge in First 5 Months of Life. *J. Pediatr. Endocrinol. Metab.* 32(11): 1235–1239 (2019)

- DeVarona, D. et al., Briefing book: a request to Congress and the Administration to preserve girls' and women's sport and accommodate transgender athletes. Women's Sports Policy Working Group (2021).
- Dick, R.W., Is there a gender difference in concussion incidence and outcomes? *Br. J. Sports Med.* 43(Supp 1):i46-i50 (2009).
- DiMiguel-Etayo P., Physical Fitness Reference Standards in European Children: The IDEFICS Study. *Int J Obes (Lond)* 38(2):557-566 (2014).
- Dohrmann P. Throwing and Kicking Ability of 8 Year Old Boys and Girls. *The Research Quarterly* 35(4):464-471 (1964).
- Dolgin, J., Transgender women on college athletic teams – the case of Lindsay Hecox. *NEJM* 383(21):2000-2002 (2020).
- Douci T et al. Relationship of androgens to muscle size and bone mineral density in women with polycystic ovary syndrome. *Obstet Gynecol* 98:445-9 (2001).
- Egner IM et al. A cellular memory mechanism aids overload hypertrophy in muscle long after an episodic exposure to anabolic steroids. *J Physiol* 591(24):6221-6230 (2013).
- Ewing-Cobbs, et al., Persistent postconcussion symptoms after injury. *Pediatrics* 142(5):e20180939 (2018).
- Ferris, D.P. et al., The relationship between physical and physiological variables and volleyball spiking velocity. *J. Strength & Cond. Research* 9(1):32-36 (1995).
- Fields, J.B. et al., Body composition variables by sport and sport-position in elite collegiate athletics. *J. Strength & Cond. Research* 32(11):3153-3159 (Nov 2018).
- Figuera, T.M. et al., Bone mass effects of cross-sex hormone therapy in transgender people: updated systematic review and meta-analysis. *J. Endocrine Soc.* 3(5):943-964 (May 2019).
- Flaxman, T.E. et al., Sex-related differences in neuromuscular control: implications for injury mechanisms or healthy stabilization strategies? *J. Ortho. Research* 310-317 (Feb 2014).
- Ford, K., Characterising body composition and bone health in transgender individuals receiving gender-affirming hormone therapy. *J Hum Nutr Diet.* 35:1105-1114 (2022).
- Forthomme, B. et al., Factors correlated with volleyball spike velocity. *AJSM* 33(10):1513-1519 (2005).

- Fuhner T et al. Age and sex effects in physical fitness components of 108,295 third graders including 515 primary schools and 9 cohorts. *Sci Reports* 11:17566 (2021).
- Fung, Y.C., The application of biomechanics to the understanding of injury and healing. A.M. Nahum et al. (eds), *Accidental Injury*, Springer Science & Business Media: New York (1993).
- Galvao D.A., Resistance Training and Reduction of Treatment Side Effects in Prostate Cancer Patients. *Med Sci Sports Exerc.* 38(12):2045-52.
- Gay, T., *Football physics: the science of the game*. Rodale Books (2004).
- Gershoni, M. The landscape of sex-differential transcriptome and its consequent selection in human adults. *BMC Biology*. 15(7) (2017).
- Gilsanz, V. et al., Age at onset of puberty predicts bone mass in young adulthood. *J. Pediatr.* 158(1):100-105 (Jan 2011).
- Gooren, L.J.G. et al., Transsexuals and competitive sports. *Eur. J. Endocrinol.* 151:425-9 (2004).
- Hacherl, S.L., et al., Concussion rates and sports participation time loss in sex-comparable middle school sports. *Archives of Clinical Neuropsychology* 36:650 (2021).
- Hacherl, S.L., et al., Concussion rates in U.S. middle school athletes from the 2015-16 to 2019-20 school years. *J. Athl. Train.* 56(6s):S-21 (2021).
- Hagmar M et al. Hyperandrogenism may explain reproductive dysfunction in Olympic athletes. *Med Sci Sports Exerc.* 41(6):1241-1248 (2009).
- Handelsman, D.J. et al., Circulating testosterone as the hormonal basis of sex differences in athletic performance. *Endocrine Reviews* 39(5):803-829 (Oct 2018).
- Handelsman DJ. Toward a robust definition of sport sex. *Endocrine Reviews* 45:709-736. (2024).
- Harmon, K.G. et al., American Medical Society for Sports Medicine position statement: concussion in sport. *Br. J. Sports Med.* 47:15-26 (2013).
- Harper, J. et al., 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. *BJSM* 55(15):865-72 (2021).
- Heather A.K. Transwoman Elite Athletes: Their Extra Percentage Relative to Female Physiology. *Int J Environ Res Public Health* 19:9103 (2022)

- Herman, JL et al., Age of Individuals Who Identify As Transgender in the United States. The Williams Institute (2017).
- Herzberg, S.D. et al., The effect of menstrual cycle and contraceptives on ACL injuries and laxity: a systematic review and meta-analysis. *Orthop. J. Sports Med.* 5(7) (2017).
- Hewett, T.E. et al., Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *AJSM* 33(4):492-501 (2005).
- Hilton, E. N. and T.R. Lundberg, Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage. *Sports Medicine* 51:199-214 (2021).
- Hon, W.H.C. and S.H. Kock, Sports related fractures: a review of 113 cases. *J. Orthopaedic Surg.* 9(1):35-38 (2001).
- Howell, D.R. et al., Collision and contact sport participation and quality of life among adolescent athletes. *J. Athletic Training* 55(11):1174-1180 (2020).
- Hult, J.S., Women's struggle for governance in U.S. amateur athletics. *Int. Rev. for Soc. of Sports* 24(3):249-61 (1989).
- Hunter SK et al., The Biological Basis of Sex Differences in Athletic Performance: Consensus Statement for the American College of Sports Medicine. *MSSE.* 55(12):2328-2360 (2023).
- International Olympic Committee. IOC Framework on Fairness, Inclusion and Non-Discrimination on the Basis of Gender Identity and Sex Variations (2021).
- Janssen, I. et al., Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J. Appl. Physiol.* 89:81-88 (2000).
- Johns, M., 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. *MMWR* 2019;68:67-71 (2019).
- Kasovic M et al., Secular Trends in Health-Related Physical Fitness Among 11-14 Year-Old Croatian Children and Adolescents From 1999 to 2014. *Scientific Rep* 11:11039 (2021)
- Keilani M et al. Effects of resistance exercise in prostate cancer patients: a meta-analysis. *Support Care Cancer.* 25:2953-2968 (2017).

- Kellis, S.E. et al., The evaluation of jumping ability of male and female basketball players according to their chronological age and major leagues. *J. Strength and Conditioning Res.* 13(1):40-46 (1999).
- Kerr, Z., et al., Concussion rates in U.S. middle school athletes, 2015-16 school year, *Am. J. Prev. Med.* 53(6):914-18 (2017).
- Kirchengast, S., Sexual dimorphism in body composition, weight status and growth in prepubertal school children from rural areas of eastern Austria. *Collegium Anthropologicum* 25(1):21-30 (2001).
- Klaver M., Early hormonal treatment affects body composition and body shape in young transgender adolescents. *J Sex Med.* 15(2):251-260 (2018).
- Kobayashi, H. et al., Mechanisms of the anterior cruciate ligament injury in sports activities: A twenty-year clinical research of 1700 athletes. *J. Sports Science & Medicine* 9:669-675 (2010).
- Kountouris, P. et al., Evidence for differences in men's and women's volleyball games based on skills effectiveness in four consecutive Olympic tournaments. *Comprehensive Psychology* 4(9) (2015).
- Kuczinski, A. et al., Trends and epidemiologic factors contributing to soccer-related fractures that presented to emergency departments in the United States. *Sports Health* 11(1):27-31 (2018).
- Kujala U.M., et al., Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. *BMJ* 311(7018):1465-68 (1995).
- Kvorning, T. et al., Suppression of endogenous testosterone production attenuates the response to strength training: a randomized, placebo-controlled, and blinded intervention study. *Am. J. Physiol .Metab.* 291:E1325-E1332 (2006).
- La Fountaine, M.F. et al., Preliminary evidence for a window of increased vulnerability to sustain a concussion in females: a brief report. *Front. Neurol.* 10:691 (2019).
- Lapauw, B. et al., Body composition, volumetric and areal bone parameters in male-to-female transsexual persons. *Bone* 43:1016-21 (2008).
- Liang J, Safer J et al. Testosterone levels achieved by medically treated transgender women in a United States endocrinology clinic cohort. *Endocrine Practice* DOI 10.4158/EP-2017-0116. (2017).
- Lin, C. et al., Sex differences in common sports injuries. *PM R* 10(10):1073-1082 (2019).

- Lombardo, M.P. and R. O. Deaner, On the evolution of sex differences in throwing. *Qu. Review of Bio.* 93(2):91-119 (2018).
- Los Angeles Times, "Volleyball star Haley Hodson had it all, until blows to her head changed everything." <https://www.latimes.com/sports/story/2020-12-08/stanford-volleyball-hayley-hodson-concussions-cte-lawsuit>.
- Magnusson, S.P. et al., The adaptability of tendon loading differs in men and women. *Int. J. Exp. Pathol.* 88:237-40 (2007).
- Marar, M. et al., Epidemiology of concussions among United States high school athletes in 20 sports. *Am. J. Sports Med.* 40(4):747-755 (2012).
- Marta CC et al. Physical fitness differences between prepubescent boys and girls. *J Strength Cond Res.* 26(7):1756-1766.
- McCrory, P. et al., Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *BJSM* 51:838-847 (2018).
- McGroarty, N.K. et al., Sport-related concussion in female athletes: a systematic review. *Orthop. J. Sports Med.* 8(7) (2020).
- McIntosh, A.S., Risk compensation, motivation, injuries, and biomechanics in competitive sport, *Br. J. Sports Med* (39):2-3 (2005).
- McLarnon M., A Scoping Review of Transgender Policies in the 15 most commonly played UK Professional Sports. *Int J Environ Res Public Health* 20, 3568 (2023).
- McManus, A. and N. Armstrong, Physiology of elite young female athletes. *J Med & Sport Sci* 56:23-46 (2011).
- Meeuwse, W.H., Assessing causation in sports injury: a multifactorial model. *Clinical J. of Sports Med.* 4(3):166-70 (1994).
- Mirkov D et al. Gender-Related Differences in Mechanics of the Sprint Start and Sprint Acceleration of Top National-Level Sprinters. *Int J Envir Res Public Health.* 17:6447 (2020).
- Montalvo, A.M. et al., Anterior cruciate ligament injury risk in sport: a systematic review and meta-analysis of injury incidence by sex and sport classification. *J. Ath. Training* 54(5):472-482 (2019).
- Montalvo, A.M. et al., "What's my risk of sustaining an ACL injury while playing sports?": a systematic review with meta-analysis. *Br. J. Sports Med.* 53:1003-1012 (2019).

- Mooney, J. et al., Concussion in soccer: a comprehensive review of the literature. *Concussion* 5(3) (2020).
- Morris, J.S. et al., Sexual dimorphism in human arm power and force: implications for sexual selection on fighting ability. *J. Exp. Biol.* 223(Pt 2) (2020).
- National Collegiate Athletic Association, Inclusion of transgender student-athletes. https://ncaaorg.s3.amazonaws.com/inclusion/lgbtq/INC_TransgenderHandbook.pdf (August 2011).
- National Conference of State Legislatures, Report on traumatic brain injury legislation. <https://www.ncsl.org/research/health/traumatic-brain-injury-legislation.aspx#1> (2018).
- Neder, J.A. et al., Reference values for concentric knee isokinetic strength and power in nonathletic men and women from 20 to 80 years old. *J. Orth. & Sports Phys. Therapy* 29(2):116-126 (1999).
- New York Times, “Estimate of U.S. transgender population doubles to 1.4 Million adults.” https://www.nytimes.com/2016/07/01/health/transgender-population.html?mc=aud_dev&ad-keywords=auddevgate&gclid=Cj0KCQjwkZiFBhD9ARIsAGxFX8BV5pozB9LI5Ut57OQzuMhurWThvBMisV9NyN9YTXIzWl7OAnGT6VkaAu0jEALw_wcB&gclid=c=aw.ds. (July 1, 2016).
- Nieves, J.W. et al., Males have larger skeletal size and bone mass than females, despite comparable body size. *J. Bone Mineral Res.* 20(3):529-35 (2005).
- Palao, J.M. et al., Normative profiles for serve speed for the training of the serve and reception in volleyball. *The Sport Journal* (July 2014).
- Pierpoint, L. et al., The first decade of web-based sports injury surveillance: descriptive epidemiology of injuries in US high school boys’ (and girls) lacrosse (2008–2009 Through 2013–2014) and National Collegiate Athletic Association men’s lacrosse (2004–2005 Through 2013–2014). *J. Athl. Training* 54(1):30-41 (2019).
- Pigozzi F et al., Joint Position Statement of the International Federation of Sports Medicine (FIMS) and European Federation of Sports Medicine Associations (EFSMA) on the IOC Framework on Fairness, Inclusion and Non-discrimination Based on Gender Identity and Sex Variations. *BMJ Open Sp Ex Med* 8:e001273 (2022).
- Preiss-Farzanegan, S.J. et al., The relationship between gender and postconcussion symptoms after sport-related mild traumatic brain injury. *PM R* 1(3):245-53 (2009).

- Rider, G.N. et al., Health and care utilization of transgender and gender nonconforming youth: a population-based study. *Pediatrics* 141:3 (March 2018).
- Roberts, T.A. et al., Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organizations and legislators. *BJSM* 0:1-7 (2020).
- Rowson, S. et al., Biomechanical perspectives on concussion in sport, *Sports Med. Arthrosc.* 24(3):100-107 (Sept 2016).
- Ruetsche, A.G. et al., Cortical and trabecular bone mineral density in transsexuals after long-term cross-sex hormonal treatment: a cross-sectional study. *Osteoporos. Int.* 16:791-798 (2005).
- Sakamoto, K. et al., Comparison of kicking speed between female and male soccer players. *Procedia Engineering* 72:50-55 (2014).
- Santos, D.A. et al., Reference values for body composition and anthropometric measurements in athletes. *PLOSOne* 9(5) (May 2014).
- Sattler, T. et al., Vertical jump performance of professional male and female volleyball players: effects of playing position and competition level. *J. Strength and Conditioning Res.* 29(6):1486-93 (2015).
- Scharff, M. et al., Change in grip strength in trans people and its association with lean body mass and bone density. *Endocrine Connections* 8:1020-28 (2019).
- Senefeld, J.W., Case studies in physiology: Male to female transgender swimmer in college athletics. *J Appl Physiol* 134:1032-1037 (2023).
- Singh-Ospina, N. et al., Effect of sex steroids on the bone health of transgender individuals: a systematic review and meta-analysis. *J. Clin. Endocrinol. Metab.* 102(11):3904-13 (Nov 2017).
- Sutton, K.M. et al., Anterior cruciate ligament rupture: differences between males and females. *J. Am. Acad. Orthop. Surg.* 21(1):41-50 (2013).
- Tack, L.J.W. et al., Proandrogenic and antiandrogenic progestins in transgender youth: differential effects on body composition and bone metabolism. *J. Clin. Endocrinol. Metab.* 103(6):2147-56 (2018).
- Tambalis K et al., Physical Fitness Normative Values for 6-18 Year Old Greek Boys and Girls. *Eur J Sport Sci* 16(6):736-46 (2016).
- Taylor, R.W., et al., Gender differences in body fat content are present well before puberty. *Int. J. Obes. Relat. Metab. Disord.* 21(11): 1082-4 (1997).

- Taylor, R.W., et al., Sex differences in regional body fat distribution from pre- to postpuberty. *Obesity* 18(7): 1410-16 (2010).
- Thomas, J.R. and K. E. French, Gender differences across age in motor performance: a meta-analysis. *Psych. Bull.* 98(2):260-282 (1985).
- Tierney, R.T. et al., Gender differences in head-neck segment dynamic stabilization during head acceleration. *Med. and Sci. in Sports and Exercise*, American College of Sports Medicine 37(2):272-9 (2005).
- Trost L et al. Challenges in testosterone measurement, data interpretation and methodological appraisal of interventional trials. *J Sex Med.* 13(7):1029-1046 (2016).
- UK Sports Councils' Equality Group, Guidance for Transgender Inclusion in Domestic Sport, <https://equalityinsport.org/docs/300921/Guidance%20for%20Transgender%20Inclusion%20in%20Domestic%20Sport%202021.pdf> (2021).
- UK Sports Councils' Equality Group, International Research Literature Review, <https://equalityinsport.org/docs/300921/Transgender%20International%20Research%20Literature%20Review%202021.pdf> (2021).
- Union Cycliste Internationale [Transgender athletes | UCI](#) (2023).
- USA Boxing Compliance Guidelines, [USA Boxing | Compliance Policies](#) (2022).
- Van Caenegem E et al., Preservation of Volumetric Bone Density and Geometry in Trans Women During Cross-Sex Hormonal Therapy: A Prospective Observational Study. *Osteoporos Int* 26:35-47 (2015).
- Van Den Tillaar, R. and J. M. H. Cabri, Gender differences in the kinematics and ball velocity of overarm throwing in elite team handball players. *J. Sports Sciences* 30(8):807-813 (2012).
- Van Velzen D et al. Variation in sensitivity and rate of change in body composition: steps toward individualizing transgender care. *Eur J Endocrinol* 183:529-536 (2020).
- Viviers, P. et al., A review of a decade of rugby union injury epidemiology: 2007-2017. *Sports Health* 10(3):223-27 (2018).
- [VolleyballMag.com](#), "Hit by volleyballs: concussions have changed coach Corinne Atchison's life." <https://volleyballmag.com/corinneatchison/> (9/25/16).
- Wang, L. et al., Post-traumatic osteoarthritis following ACL injury. *Arthritis Res. and Therapy* 22(57) (2020)

- Warden KB et al. Comparisons of rates and forms of aggression among members of men's and women's collegiate recreational flag football teams. *J Prev Int Comm.* 37(3):209-215 (2009).
- Wiik, A., T. R Lundberg et al., Muscle strength, size, and composition following 12 months of gender-affirming treatment in transgender individuals. *J. Clinical Endocrin. & Metab.* 105(3):e805-813 (2020).
- Wikipedia, "Cece Telfer." https://en.wikipedia.org/wiki/Cece_Telfer.
- Wolf, J.M. et al., Male and female differences in musculoskeletal disease. *J. Am. Acad. Orthop. Surg.* 23:339-347 (2015).
- World Aquatics [Policy-on-Eligibility-for-the-Men-s-and-Women-s-Competiition-Categrories-Version-on-2023.03.24.pdf](#) (2023).
- World Athletics [Book of Rules | Official Documents](#) (2023).
- World Rugby Transgender Guidelines. <https://www.world.rugby/the-game/player-welfare/guidelines/transgender> (2020).
- World Rugby Transgender Women Guidelines. <https://www.world.rugby/the-game/player-welfare/guidelines/transgender/women> (2020).
- Wunderle, K. et al, Menstrual phase as predictor of outcome after mild traumatic brain injury in women. *J. Head Trauma Rehabil.* 29(5):E1-E8 (2014).