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Conference on 'Understanding the role of sex and gender in nutrition research'
Symposium one: Influence of sex and gender in nutrition research

Sex and gender in sports nutrition research: bridging the gap

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The Olympic Games have grown to be the largest, gender-equal sporting event in the world, and the International Olympic Committee is committed to gender equality in sports encouraging and supporting the promotion of women in sports at all levels and in all structures with a view to implementing the principle of equality of men and women (IOC, 2023). Women competed for the first time at the 1900 Olympic Games in Paris, and the number of women competing has grown exponentially over the last 100 years, so an estimated 5494 female athletes (48 %) competed in the Summer Olympic Games 2021 in Tokyo. Supporting women (alongside men) in achieving optimum performance is crucial, and understanding that there are sex and gender gaps in sports nutrition research is important. One reason for this gap is the historical bias in sports and exercise science research towards male participants. This has led to a poor understanding of the unique physiological and nutritional needs of female athletes. In summary, a balanced approach is crucial to address the nutritional needs of both male and female athletes. Researchers should continue exploring this important area to optimise performance and health for all athletes. The aim of this review is to summarise current sports nutrition literature and highlight research that seeks to understand and address where the gaps are with respect to several key areas in sports nutrition recommendations that can impact advice and practice with both males and females.

Keywords: Sports nutrition: Research gaps: Sex and gender

One of the most inspiring stories of the past century is the increased participation of women in sports. The Summer Games comes around every 4 years and unlike other sports competitions men and women compete together. Over the last 100 years, the number of women competing in the Olympic Games has grown exponentially. Women competed for the first time at the 1900 Games in Paris. Of a total of 997 athletes, 22 women competed in 5 sports: tennis, sailing, croquet, equestrianism and golf. An estimated 5059 female athletes competed in the Summer Olympic Games 2016 in Brazil. The International Olympic Committee (IOC) is committed to gender equality in sports encouraging and *supporting the promotion of women in sports at all levels and in all structures to implement the principle of equality of men and women*[1]. The addition of women's boxing to the 2012 Games in London ensured that women competed in all the sports at the games. Since 1991, any new sport seeking to join the Olympic programme must have women's competitions.

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Supporting these women in achieving optimum performance is crucial and understanding that there are sex and gender gaps in sports nutrition research is an important gap to bridge. One of the reasons for this gap is the historical bias in sports and exercise science research towards male participants. Male athletes have traditionally been seen as the norm, with female athletes often considered an afterthought. This has led to a lack of understanding of the unique physiological and nutritional needs of female athletes. Women's bodies differ from men's in a myriad of ways, requiring different nutrition approaches to fuel them. Ensuring sex and gender-specific sports nutrition research in the future will ensure that women and girls as well as men and boys have the best possible nutrition strategies to help them perform and stay injury-free.

This review aims to summarise current sports nutrition literature and highlight research that seeks to understand and address where the gaps are in several key areas in sports nutrition and make several recommendations that can impact advice and practice for both male and female athletes.

Defining sports nutrition

Sports Nutrition or Sport and Exercise Nutrition Science is the application of nutrition principles to improve training, recovery, and performance[2]. Athletes have always consumed food but an academic focus on sports began in the 1930s when human physiology research studies began examining carbohydrate (CHO) and fat metabolism in athletes engaging in endurance exercise[2]. The focus shifted to competitive athletes followed by further research into nutritional needs and nutrient metabolism in the military and astronauts engaged in space travel[2]. The early work focused predominately on CHO metabolism but as understanding of the complex nutritional needs of athletes and trained personnel grew, a greater focus was shifted to protein metabolism and its impact on muscle anabolism and catabolism. In the 1980s, improvements in laboratory-based methodologies provided evidence to inform current sports nutrition guidelines[3] and the first IOC consensus statement which remains relevant in its broadest sense almost 20 years later[4]. With the evolution of science, the emphasis of sports nutrition is increasingly a personalised approach with interventions that aim to optimise training, performance and recovery with a greater focus on the technological advancements of wearables and 'big data'[2].

Sex and gender in sports nutrition research

Over the last decade, the lack of sex and gender diversity in scientific sports nutrition research has become clear. Failure to consider either or both sex and gender in study design and analysis is widespread[5]. A recent review of 2547 original papers, position papers and reviews from 1993 to 2021[5] highlighted that 15 % (*n* 381) failed to report either sex or gender. Moreover, co-conflation of the terms sex and gender was widespread, causing further confusion. Historically, the bias in sports and exercise science research has been towards the study of male participants by male researchers[6]. Male athletes have traditionally been viewed as the norm, with female athletes often considered (if at all) as an afterthought.

Hormonal differences between men and women can significantly influence the physiological response to exercise and nutrition. For example, women exercising at high intensities for relatively long periods may have different nutrient requirements during different phases of the menstrual cycle (MC)[7]. This has only recently been considered in research studies. Previously, male-only athletes have been studied as their physiology remains relatively consistent. Studies involving eumenorrheic women often only test at one-time point to limit hormonal variances which then may impact the application of the findings at other stages of the MC[8]. The limitations of much of the research underpinning these recommendations have been the focus on male subjects. These studies have then been incorporated into systematic reviews or meta-analyses with the assumption that these guidelines can then be applied to female athletes. Numerous anatomical and biological differences exist between the sexes which can influence performance and women's sports may differ from men in terms of shorter duration or distances or lighter equipment[6]. Evidence for the unique physiological and nutritional needs of female athletes is therefore lacking and, hence, poorly understood[9]. This lack of female representation in sports nutrition research can have negative consequences on female athletes. Without a clear understanding of their nutritional needs, female athletes may not be achieving optimal nutrition to support their athletic performance and recovery.

Macronutrients

Energy

For athletes to ensure adequate energy intake for optimal performance, recovery and health, maintaining energy balance is essential[10]. Research on the energy demands of athletes has historically focused on male athletes, leading to significant gaps in understanding the unique physiological and performance needs of female athletes. It has been shown that there are sex differences in the energy expenditure of athletes[10]. Men generally have a higher RMR and energy expenditure compared to women which can have an impact on energy needs during training and competition[11,12]. There may also be differences in energy availability between sexes. Energy availability, which is defined as dietary intake minus exercise energy expenditure, has been identified as low and more of an issue in female athletes causing metabolic disturbances such as menstrual disruption and poor bone health[13,14]. Energy substrate stores play a key role in the regulation of fuel metabolism during exercise and are a determining factor of exercise performance. The relative contribution of these

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fuel sources is determined primarily by the intensity and duration of exercise, but it is also affected by diet, environmental conditions, training status and sex of the participant[15].

Carbohydrate

Although sports performance is dependent on a myriad of factors[16], sex is one of the most important. Sex can influence nutrient requirements and their metabolism[17]. Sex has a significant impact on fuel utilisation with women relying to a greater extent on fat stores during exercise[17,18]. The availability of CHO as a substrate for muscle and the central nervous system is crucial, especially in endurance sports. Sex-based differences in CHO requirements and metabolism arise[16], and it is important to critically review the evidence for timing, amount and type of CHO separately for males and females to establish the populations wherein the evidence was derived[16].

Gluconeogenesis rates are higher in the follicular phase than the luteal phase of the MC at exercise intensities >50 % maximum rate of oxygen consumption uptake during exercise (VO2 max)[19]. As such, a theoretical performance detriment could occur during the luteal phase due to impaired metabolism. Consuming high-CHO snacks/meals 3–4 h before exercise can mitigate these effects during the luteal phase[20]. During exercise, current recommendations are to consume 30–60 g/h CHO for durations of 1–2·5 h and >90 g/h CHO for exercise durations >2·5 h for males and females irrespective of body weight[21]. However, these recommendations are largely based on studies of male athletes[20]. In a 2022 review[16] that documented the representation of females in studies investigating CHO fuelling for exercise highlighted that of 937 studies (11 202 participants), 11 % were female and 89 % were male. There were 740 studies that were exclusively male, and 38 studies were exclusively female. Only 14 studies included methodological design features which specifically compared sex-based responses and 19 studies conducted sex-based comparisons within the statistical procedures. Athlete level (participation/club/elite etc.) was not identified in 53 % of studies and no studies included Tier 5 (elite world class) participants.

External hormone usage by female athletes using combined oral contraceptives (COC) must also be considered. Exogenous hormones can exert greater effects on glucose flux during exercise than those produced endogenously[21]. Given the wide variety of COC formulations available, the response of individual athletes to COC can vary greatly[22]. However, sex-based differences in muscle fibre composition, substrate utilisation during exercise (likely mediated through hormonal differences between males and females) and differences that might also occur within the female cohort, for example, phase of MC or COC usage, could impact requirements and metabolism of CHO[22].

Fat

Fat is an essential macronutrient that is energy dense and allows the body to store and absorb fat-soluble vitamins and maintain sex hormone concentrations[23]. The variations in female sex hormones during the follicular and luteal phases of the MC influence fat metabolism[24]. At rest and during exercise, females rely on fat to a greater extent than males[17,25], which is driven by higher resting energy expenditure during the luteal phase of the MC. Thus, adequate dietary fat intake, particularly during the luteal phase, is essential to cover the costs of upregulated fat metabolism. From a practical standpoint, females should allocate at least 20 % of total energy to dietary fats, not only to meet the demands of sex hormone regulation and fat-soluble vitamin absorption but also to satisfy sex-specific substrate needs. Additional emphasis should be placed on dietary fat intake during the luteal phase of the MC to support the increased reliance on fat metabolism[26]. While not exclusive to female athletes, there exists a ‘fear of fat’ in some athlete contexts. For example, in sports involving physique competitions, athletes are judged based on achieving a symmetrical and well-proportioned body composition with low fat mass and high lean body mass, so achieving these recommendations may be difficult[27].

Protein

Protein requirements can vary for athletes depending on a variety of factors such as training intensity, duration and individual goals; it is essential for muscle repair, growth and recovery and in some circumstances can be used as a fuel source[28]. Evidence suggests that males and females have increased daily protein needs well above the current RDA of 0·8 g/kg per d[29]. The intakes are suggested[30] to be between 1·2 and 2·0g/kg per d, but this recommendation is very broad and does not specifically mention sex differences. In another study[31] it was demonstrated that female athletes performing variable-intensity intermittent exercise had higher protein requirements as compared to non-active males. However, one simple observation is that most male athletes possess a greater quantity of skeletal muscle mass than females[31], and the consequence of this in terms of muscle metabolism during exercise is that females oxidise more fat but less CHO and amino acids compared with males[31].

Currently, no studies have specifically examined the requirements for protein for female athletes across the MC[22]. In eumenorrheic women, protein catabolism is higher at rest following aerobic endurance exercise in the luteal phase compared to the early follicular phase[32,33]. Requirements for protein may differ at different parts of the MC, and again this may be influenced by the individual factors mentioned above such as training load or goals of training. Based on current evidence, it is considered premature to substantiate that female athletes require sex-specific guidelines about protein requirements provided energy needs are met. It is more likely that there is a need for further research using sport-specific competition and training-related exercise protocols that rigorously control for prior exercise, protein/CHO/energy intake, contraceptive use and phase of the MC[34].

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Fluid and electrolytes

In reviewing the development of sports nutrition as a discipline, hydration and its impact on exercise performance are the topic that has been most intensively researched[35]. The fluid requirements for male and female athletes can differ due to physiological and biological factors. The MC can introduce unique physiologic demands for females compared to their male counterparts which may have an impact on fluid regulation. Changes in hormone levels throughout the MC can influence fluid balance, water and electrolyte regulation[36].

Fluid retention during the MC can impact how athletes feel and may have significant impacts in sports where the athlete needs to 'make weight' such as combat sports. In a review by Helm *et al.*[8], hydration interventions involving athletic performance in menstruating women were considered. Of the 11 studies identified that assessed athletic outcomes, only 1 was considered both phases of the MC of the women and 1 only considered the luteal phase, and the other 9 studies measured outcomes in the follicular phase. Despite intra-MC variability not directly influencing markers of dehydration or net fluid balance, certain rehydration therapies did improve athletic performance. They found that interventions were associated with positive changes in urine volume, specific gravity and body weight, indicating improved hydration status. The study also reported significant beneficial effects on exercise performance and cognitive function. However, the authors noted that further research is needed to confirm these findings and determine optimal hydration interventions for females. It appears there is a role for CHO-electrolyte solutions in improving time-trial performance in the follicular phase. However, its application in the luteal phase is less clear. Current evidence supports the role of female sex hormones in influencing thirst and fluid and electrolyte balance. However, studies to date indicate that these do not contribute to whole-body water retention or significantly affect plasma volume at rest or during exercise[37]. Studies are needed to clarify these gaps so that evidence-based guidance for athletes can be developed.

Micronutrients

One area where research in athletes has focused more predominantly on females (than males) is in relation to micronutrient requirements[38]. This may be because micronutrient deficiencies and sub-optimal intakes among female athletes are a concern and are commonly prevented or treated with micronutrient supplements[38]. Several micronutrients receive a great deal of attention when it comes to athletic populations such as iron, calcium and vitamin D. These are crucial in several aspects of performance (the role of iron for the oxygen-carrying capacity of blood and the importance of optimal calcium and vitamin D for bone health). Iron status may be an important aspect to consider when making sex comparisons as it has significant differences between males and females. Women have lower iron stores and higher iron requirements during MC, pregnancy and lactation. Additionally, women are more susceptible to iron deficiency anaemia (IDA) due to blood loss during menstruation. Given the higher prevalence of iron deficiency and IDA in women and findings that poor iron status can alter several physiological systems, it has been suggested that iron status is a critical variable to consider when making sex comparisons in physiology[39].

Ergogenic aids

A plethora of ergogenic aids, defined as a psychological technique(s), mechanical device(s) and nutritional or pharmacological approach that aims to enhance performance, are widely available[40], and their usage within athlete populations has been reported to be between 4 and 87 %[41], with potentially higher rates of use with female athletes. While most intervention studies investigating the effects of ergogenic aids on sports performance have been carried out in males, a recent meta-analysis examined the effectiveness of ergogenic aids in improving physical performance in female athletes[42]. The review included 17 studies and found that ergogenic aids such as caffeine, beta-alanine and creatine kinase improved physical performance in female athletes. Due to the physiological/hormonal differences between males and females, differences in the absorption, distribution and metabolism of these ergogenic aids are likely, and further research into the sex-specific differences in terms of absorption, distribution and metabolism is warranted.

Gender identity, socialisation and culture can influence nutrition in athletes

Whereas sex refers to the biological attributes of males and females, gender refers to the socially constructed roles and behaviours associated with a feminine, masculine or non-binary identity[43]. Young girls' activity and nutrition can be affected by gender norms and feminine ideals through complex negotiations[44]. Girls may be encouraged to eat less or avoid certain foods to maintain a certain body shape or size. Society's concept of how people are expected to look and behave based on societally created norms for masculinity and femininity can influence gender roles in sports. For example, female athletes may traditionally be expected to participate in feminine sports (female boxing was only allowed into the London 2012 Olympics and the first Rugby World Cup for women in 1998), while male athletes may be encouraged to participate in more aggressive or competitive sports.

Although closely associated with male competitive sports, images of female athletes are increasingly employed in the marketing of sports nutrition products. These images can perpetuate unrealistic body ideals and affect female athletes' relationships with food. Although historically considered as something that might impact

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more females, this is now increasingly impacting male athletes[45].

Sociocultural factors such as identity, gender, religion and cultural prohibitions can influence food choices and eating behaviours. Monderrosa *et al.*[46] examined the relationship between food choices and eating behaviours. The article reviewed recent literature on the topic and considered the impact of social and environmental factors on food choices and eating behaviours. For example, certain cultures may have dietary restrictions or preferences that affect the types of foods that athletes consume. Some cultures have only recently allowed females to participate in sports. Ramadan can have a significant impact on the nutritional status of both males and females. The authors conclude that a multidimensional approach is needed to understand and address the complex relationships between food choices and eating behaviours. The article provides valuable insights for policymakers, public health professionals and individuals looking to improve their food choices and eating behaviours.

Limited research exists on the effect of a sports dietitian (SD) on athletes' dietary habits and nutrient periodisation (changes in dietary intake in response to a particular training block)[47]. Male athletes reported consuming fast food or restaurant meals more frequently and had higher weekly (and more frequent) alcohol intake during the competitive season as compared to female athletes. Female athletes were more likely to prepare meals, eat breakfast daily, and have school-provided boxed meals compared to male athletes. However, female athletes had lower energy and micronutrient intakes compared to their male counterparts. It is possible that access to a sports dietitian could help athletes develop a healthier relationship with food and improve their performance in both males and females but for different reasons.

Sex-specific differences in athletes are also seen in behaviours that can impact nutritional status[26]. Men are more susceptible to risky behaviours including performance-enhancing drugs[48] but female athletes are known to be more health conscious[49].

The impact of gender identity on nutrient metabolism, hydration status and athletic performance and links were examined[50]. The authors investigated if there were differences in nutrient metabolism, hydration status and athletic performance between male and female athletes with gender identity congruent with their assigned sex at birth. The study found no significant differences between male and female athletes in these areas, suggesting that gender identity may not have a significant impact on these physiological outcomes.

Athletes, regardless of gender identity, may be at risk of developing eating disorders due to the pressures they face in their sport[51]. Disordered eating and body image concerns are increasingly common among athletes, possibly representing the underpinning of eating disorders (EDs) which may start in adolescence[52]. Research on eating disorders in male athletes *v.* female athletes is still limited.

For those athletes from the transgender population nutritional considerations can be both clinical and psychosocial. Changes in body composition, weight, altered bone and lipid profiles, and rates of disordered eating are factors that need to be considered[53].

Current gaps in the findings and future directions

While there is a plethora of information available regarding the impact of nutrition on exercise performance, most of this is based on research derived from male subjects. Even minor differences between males and females in physical, psychological and physiological characteristics could have considerable impacts on their nutritional needs[54]. Despite the growing body of research on gender differences in sports nutrition, there are still gaps and limitations in the current understanding of this field.

Addressing some of these gaps in sports nutrition research will require a multifaceted approach that involves increasing diversity, increasing women as participants, controlling for MC and hormone differences and studying the functional impacts of nutrition on athletes in different situations and circumstances such as

Call to Action: current gaps and future directions

1. **Lack of diversity:** Many studies on sports nutrition have focused primarily on male athletes, with few women included in the samples. It is improving but it is slow. This has led to a significant gap in our understanding of the unique nutritional needs of female athletes.
2. **Small sample sizes:** Even when women are included in sports nutrition research, sample sizes are often small, which can limit the generalisability of the findings.
3. **Limited focus on MC:** While there is some research on the impact of MC on sports performance and nutrition, more studies are needed to fully understand how hormonal fluctuations affect nutrient requirements and response to exercise. This can place burdens on athletes and recruitment of athletes, especially at the elite level, could take time. Further work is also required on the impacts of peri and post menopause impacts nutritional requirements as athletes are competing at the master level.
4. **Lack of standardised protocols:** Studies on sports nutrition often use different protocols for measuring nutrient requirements and response to exercise, which can make it difficult to compare results across studies. A standardised audit tool has been proposed that will help to establish comparisons over time as it will facilitate data collection in a systematic way[6].
5. **Lack of long-term studies:** Many sports nutrition studies are short term, which can limit our understanding of how nutrient intake and exercise impact long-term health and performance. More long-term studies are needed to understand how nutrient intake and exercise impact long-term health and performance. Specifically, studies are needed to understand the role of sports nutrition in the prevention of chronic diseases, such as osteoporosis and CVD[55].
6. **Limited focus on non-binary individuals:** There is a lack of research on sports nutrition for non-binary individuals, who may have unique nutrient requirements and responses to exercise. Specifically, studies are needed to understand the impact of gender identity on all aspects of sports nutrition and its application.
7. **Mental health and sports nutrition:** More research is needed on the impact of sports nutrition on mental health in male and female athletes. Specifically, studies are needed to understand the role of nutrient intake on mood, anxiety and depression in athletes[56]. Body image has a significant impact on how athletes consider food, and often food restriction is the first option taken when changes to body composition.

concussion, the impact of heat and altitude. By focusing on these key areas of research, we can develop a more comprehensive understanding of differences in sports nutrition and optimise nutrition plans for all athletes, irrespective of the impact of sex or gender.

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Competing interests

None.

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