EXPERT GROUP STATEMENT ON NUTRITION IN HIGH-PERFORMANCE TENNIS. CURRENT EVIDENCE TO INFORM PRACTICAL RECOMMENDATIONS AND GUIDE FUTURE RESEARCH.

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ABSTRACT

The sport of tennis involves unique nutritional demands for the physical and technical aspects of match play and training, as well as the nutritional challenges associated with extensive travel and a lengthy competition calendar. An Expert Group assembled by The International Tennis Federation (ITF), the Women's Tennis Association (WTA) and Association of Tennis Professionals (ATP) has produced a scientific review of current evidence to inform practical recommendations for High Performance Tennis. The narrative summary considers the diversity within the tennis community, including male and female players, youth players and wheelchair players. The Expert Group Statement addresses nine specific topics: (1) introduction to tennis, (2) physiological characteristics of tennis training and match play, (3) training nutrition, (4) body composition, Low Energy Availability (LEA) and Relative Energy Deficiency in Sport (REDs), (5) match day nutrition, (6) dietary supplements for tennis performance, (7) environmental and travel issues, (8) nutrition guidelines during periods of illness and injury rehabilitation, and (9) special population groups. The Statement advocates for an evidence-based approach to nutrition in High Performance Tennis and emphasizes a 'food first' philosophy, prioritizing food over supplements to meet nutrient requirements effectively. In recognition of the benefits of sound nutrition strategies in supporting health and performance over a player's career, academies, national federations and international organizations are encouraged to engage professionals with appropriate nutrition-related qualifications and professional registrations to support players effectively.

1. EXPERT GROUP STATEMENT ON NUTRITION IN HIGH-PERFORMANCE TENNIS: EXECUTIVE SUMMARY.INTRODUCTION

Tennis is a sport undergoing continuous evolution with increasing physical and technical demands during match play. Training programs have become more rigorous to prepare players for these changes and to address individual player requirements. Nutrition plays a crucial role in optimizing the physical and mental performance of elite tennis players during training and matches, as well as maintaining overall health throughout a demanding season filled with travel.

Making appropriate nutrition choices regarding type, quantity, and timing of food, fluids, and supplements can significantly influence a tennis player's performance and recovery between matches. However, the evolving nature of tennis, combined with advancements in sports nutrition knowledge, have led to uncertainty about the best approach for the many varied and unique aspects of training and match play.

The International Tennis Federation (ITF), the global governing body of tennis, along with the Women's Tennis Association (WTA) and the Association of Tennis Professionals (ATP), has convened an Expert Group to produce a scientific review of current evidence. This review aims to provide practical recommendations and guide future research on nutrition in high-performance tennis. This review offers valuable insights to help practitioners understand the practical application of modern sports nutrition in the unique contexts of tennis. We highly recommend reading the full article to gain a deeper understanding of the scientific evidence, critical appraisals, and recommendations.

Our narrative summary considers the diversity within the tennis community, encompassing male and female players, youth players and wheelchair tennis players. Accordingly, the Expert Group Statement addresses nine specific topics: (1) an introduction to tennis, (2) the physiological demands of tennis training and match play, (3) training-day nutrition and overall nutritional goals, (4) body composition, Low Energy Availability (LEA) and Relative Energy Deficiency in Sport (REDs), (5) match-day nutrition, (6) dietary supplements for tennis performance, (7) environmental and travel considerations, (8) nutrition for illness and injury rehabilitation, and (9) special population groups.

Based on these topics, the following work can be summarized in the following key points:

a) *Professional tennis places high physiological and perceptual demands on players, who face frequent international travel and intense competition schedules. To cope with unpredictable match durations, varying recovery times, and diverse environmental conditions, players must carefully manage their nutrition, hydration, and recovery strategies.*

b) *Carbohydrate (CHO) intake provides the key energy source for training and competition, preventing fatigue during play by replenishing body glycogen stores between training sessions and matches. The recommended carbohydrate intake for tennis players varies according to their training/match workloads (duration/frequency and intensity). A daily intake ranging from 3-10 g* $CHO{\cdot}kg^{-1}$ *of body mass (BM) may be suitable, with lower amounts suited for lower-intensity training and higher amounts for more intense on-court sessions and during tournaments.*

c) *Maintaining glycogen stores during tournaments may require daily carbohydrate intakes of 6-10 g* $CHO{\cdot}kg^{-1}$ *BM, including pre-match meals of 1-4 g* $CHO{\cdot}kg^{-1}$ *BM. Meanwhile, carbohydrates should be consumed during matches (30-90 g* $CHO{\cdot}h^{-1}$*) to provide additional muscle fuel, particularly during longer matches, as well as central nervous system stimulation. Of course, the variability and unpredictability of tournament play means that these general strategies must be adapted and individualized depending on match length, recovery needs and court surface.*

d) *Professional tennis players require high protein intakes (1.2–1.8* $g{\cdot}kg^{-1}$ *BM) to support muscle repair, growth, and body composition optimization, with certain scenarios necessitating even higher amounts. These needs can be met through well-*

planned meals and, occasionally, protein supplements, provided attention is given to protein quality and timing.

e) *A well-chosen diet that meets energy, carbohydrate and protein requirements is likely to cover the increased micronutrient needs of professional tennis players. However, particular attention should be given to iron (especially in female and vegetarian/vegan players), vitamin D (for players residing in regions far north of the equator, such as Canada, Russia, and Northern Europe, or far south, such as southern parts of New Zealand and Australia) and calcium (in junior players and females with amenorrhea), as suboptimal intakes may occur in certain players or situations, potentially impairing health and performance. Players at high risk of such deficiencies should have their nutritional status regularly monitored and, if necessary, follow a supervised supplementation plan.*

f) *LEA occurs in tennis players who experience an increase in training/match workload and/or a decrease in energy intake that leaves the body with insufficient energy to support all the human's biological systems to work efficiently, thus avoiding healthy issues. Common scenarios include eating disorders/disordered eating, misguided programs to reduce body mass/fat, intensified training or strenuous competition programs, and poor food availability or nutrition knowledge. Although mild or brief exposure may be adaptable and reversible, chronic and extreme scenarios ("problematic") underpin the syndrome of REDs with a range of health and performance impairments. Strategies to increase awareness and early intervention should be implemented in tennis. Furthermore, players at high risk should be referred to an experienced physician who can make an appropriate diagnosis and manage a multi-disciplinary treatment plan.*

g) *Tennis provides a range of opportunities for players to consume fluids during matches (warm-up, between change of ends and games, etc.). However, the intensity of match play and the environmental conditions may lead to large rates of sweat loss that require planned fluid intakes during the game, and in the period before the next match. All fluid intake guidelines for before, during and between matches should be adapted and individualized depending on match length, individual sweat rates and environmental conditions.*

h) *Recovery after matches and training should focus on addressing the needs incurred by the session. Post-exercise snacks and meals should prioritize carbohydrate according to refueling needs, fluid and electrolytes according to rehydration needs and protein according to the need for myofibrillar muscle protein synthesis and adaptation. Practical strategies must be tailored to ensure these processes are completed as well as possible before the next match or training session, allowing for optimal recovery and performance.*

i) *Although performance supplements are popular among tennis players, only caffeine, creatine monohydrate, and sodium bicarbonate have credible evidence of potential benefits to tennis performance. Further research is needed on supplements that may be useful to tennis players, such as beta-alanine, sodium citrate and citrulline-malate. In all cases, a thorough risk-benefit analysis should be conducted before incorporating them into training or competition as they may enhance performance only with correct application, dosing and timing.*

j) *Players using dietary supplements should purchase products and any other performance-enhancing supplements from reputable companies that guarantee* *(i.e., batch test) the identity, purity, and composition of their products, in order to minimize the risk of contamination with prohibited substances.*

k) *Hot and humid environments increase the physiological and cognitive challenges in tennis, particularly in tournaments, requiring heat acclimatization, proactive hydration and cooling strategies to optimize performance and avoid heat-related illnesses.*

l) *Professional tennis players face unique challenges to their health, including frequent illnesses and injuries. Well-chosen nutrition plays an important role in maintaining a strong immune system and supporting effective recovery. This, in turn, can help prevent injuries and illnesses that might otherwise impact performance.*

m) *Female tennis players have distinct physiological and nutritional needs due to differences in match demands and hormonal fluctuations throughout the menstrual cycle. They are also at a higher risk for conditions like LEA and iron deficiency, necessitating individualized approaches to training, nutrition, and health monitoring.*

n) *High-performance young tennis players face significant nutritional challenges due to intense training schedules, the demands of growth and development, and the irregularities of a touring lifestyle. These factors often lead to energy and nutrient intakes that fall below recommended levels, potentially affecting their performance and long-term health. Young players need both nutritional education and practical skills to optimize their health and performance through proper dietary choices.*

o) *Wheelchair tennis players face distinct physical and energy demands based on their impairments and require tailored nutritional and hydration strategies to optimize performance, health, and recovery.*

p) *The research on which these guidelines are based is largely gathered from a range of exercise and sports scenarios rather than tennis-specific investigations. While there is still confidence in the value of these guidelines, there is a need for further research involving tennis players and tennis-focussed protocols and issues.*

The Expert Group Statement advocates for an evidence-based approach to nutrition and emphasizes a 'food first' philosophy, prioritizing food over supplements to meet nutrient requirements effectively. We highly encourage academies, national federations and international organizations to engage professionals with appropriate nutrition-related qualifications and professional registrations to support players effectively.

1- INTRODUCTION.

Tennis is a game of speed, agility, power and skill, played under mental and physical stress. While talent, coaching and practice are the key ingredients in the making of tennis champions, nutrition plays an important role in the development and achievements of all tennis players. Nutrition potentially optimizes athlete availability, by reducing the days of lost or modified training due to illness and injury, and enables the player to train effectively with maximal adaptation and recovery. A well-chosen eating plan should aim to support a suitable physique without undue psychological stress, to allow the player to enjoy the cultural and social aspects of food, and to optimize match performance in spite of the varying physiological, psychological and environmental challenges of tennis play. The substantial contribution of nutrition to general sporting success has been recognized by consensus statements from various working groups of the International Olympic Committee (Maughan et al., 2018; Maughan & Shirreffs, 2011; Mountjoy et al., 2023). Furthermore, Regional and International Federations including World Athletics (Burke et al., 2019), World Aquatics (‘FINA-Yakult Consensus Statement on Nutrition for the Aquatic Sports’, 2014), International Federation of Association Football (‘Nutrition for Football: The FIFA/F-MARC Consensus Conference’, 2006) and Union of European Football Associations (Collins et al., 2021) have conducted their own initiatives to develop consensus statements on the specific nutritional considerations and applied practices for their events.

Recognizing the special issues required for success in tennis, the ITF, WTA and ATP assembled an expert group to address the nutritional requirements of typical training and competition programs, as well as the lifestyle demands, of elite players. This statement summarizes contemporary guidelines on dietary considerations and eating practices for high-performance tennis players, including male and female athletes, wheelchair tennis players, and both junior and adult divisions. In addition to investigating the evidence for, and practical application of, current sports nutrition recommendations in relation to elite tennis, this statement will identify areas of high priority for future research and education activities.

2- EXPERT GROUP STATEMENT PROCESS.

A coordinating group (NVS, JDC, VMP, DS, JFF, MCC) assembled a group of sports science and medicine professionals with extensive experience and expertise related to high performance tennis. The group (n=25) included sports dietitians (NVS, PL, JLR, SPS, EB, ARCJ and MvR), sports scientists (JDC, VMP, DS, JFF, ALS, MR, RD, OG, SSQ, ASP, SH and MCC) and medical personnel (KS, ARC and TE). Individuals with previous experience in the preparation of consensus statements and positions stands (BH, BMP and LB) were also involved to ensure the integrity of the activity. The majority (n=13) had a background of both research and field-based practice and four were ATP and WTA Medical Committee members.

The activity began in January 2021 by the coordinating group with the identification of the topics to be included, that would provide a framework for the Expert Group Statement, and a compilation of a list of research and field-based experts. Authors from within the coordinating group were nominated to prepare a state-of-the-art summary of each of these topics and subsequently a draft of each topic based on their field was sent to each expert in November 2022. After receiving all the changes and comments from the narrative reviews by each expert, an online meeting was convened in February 2023 with the majority of participants from the Expert Group Statement (n=22). During this meeting, a vote was taken to determine which changes would be retained or eliminated from the draft. Finally, participants experienced in position statements (BMP, BH, and LB) collaborated on the draft to ensure coherence throughout the final document, followed by a comprehensive review by the majority of experts in an online meeting in December 2024.

This narrative synthesis serves to inform the reader of practical recommendations and strategies based on the most up-to-date scientific evidence. The Expert Group notes that much of the evidence on which it is based involves general scenarios of exercise and sport rather than tennis-specific studies. Therefore, an additional aim is to guide applied researchers to focus their future efforts on nutrition research in elite tennis.

3- EXPERT GROUP TOPIC 1: INTRODUCTION TO TENNIS

Tennis is a racket sport, played on a variety of court surfaces, between two (singles) or four (doubles) players who compete to win the match by being the first to win a targeted number of points, games and sets. Professional tennis consists primarily of tournaments in which individual players (and, on occasions, single- and mixed-sex doubles partners) compete not only to win the event, but to accrue points towards their world ranking. Exceptions to this format include the tennis program at the Summer Olympic Games and team events (e.g., Davis, Billie Jean King and World Team Cups) where players compete on behalf of their country of citizenship. The governance of high-performance tennis is overseen by the ITF, WTA, ATP, and the Grand Slam Board, which are responsible for managing the competition circuits and four Grand Slams for professional female and male players, respectively.

Professional tennis (Fernandez et al., 2006; Reid et al., 2008) comprises activity profiles with considerable physiological and perceptual demands that result in reduced neuromuscular function and fatigue (Girard et al., 2006, 2008). The activity profile of the sport traditionally describes a prolonged duration sport (2-4 h), consisting of frequent intermittent high-intensity efforts with periods of low-intensity activity or regular rest periods (Reid et al., 2008). The open-ended nature of professional tennis, however, may lead to matches that extend beyond 5 h (Girard et al., 2008), which can exacerbate physiological, psychological and musculoskeletal stress (Fernandez et al., 2006; Girard et al., 2006, 2008; Reid et al., 2008). When combined with intensive travel, competition, and training schedules across diverse climates and court surfaces, the need for tennis players to address their acute and chronic nutritional and hydration requirements becomes obvious. During the off-season, there is opportunity for a more focused program of conditioning activities and practice. Table I summarizes the features of various formats and levels of tennis competition, highlighting how different factors may influence nutritional requirements for training and competition or pose challenges to a player’s lifestyle.

The demands of singles match-play tennis are well-documented, with players reported to cover 2-3 $m \cdot shot^{-1}$, 8-12 $m \cdot point^{-1}$ and points lasting 6-8 s on average (Ferrauti, Bergeron, et al., 2001; Reid et al., 2008) totaling ~800 $m \cdot set^{-1}$ (Pluim et al., 2023). Within this context, a high proportion of strokes (~80 %) involve movements of less than 2.5 m, though longer movements per stroke (2.5-4.5 m) are not uncommon (~10 %) (Ferrauti et al., 2003). Further, the typical stroke demands on hard courts consist of 6-7 strokes per rally (Torres-Luque et al., 2011) culminating in 200-300 strokes per match (Perri et al., 2018). These demands may vary based on the court surface, with faster surfaces (such as hard and grass) characterized by fewer strokes and shorter point-play durations compared to slower surfaces like clay. Similar findings have been observed in wheelchair tennis players (Sánchez-Pay et al., 2015; Sánchez-Pay & Sanz-Rivas, 2017). These match demands may occur as part of a sequence where matches, each lasting several hours, are played with less than 48 h recovery between them. The combination of uncertain match durations and start times, repeated playing exposures and variable recovery period in tennis match-play can lead to both acute and prolonged fatigue. Even then, these generic accounts of tennis activity may underestimate the demands placed on players at the top of the sport. For example, Reid and Duffield (Reid & Duffield, 2014) reported on the 2012 Australian Open, where elite players performed 12 h of singles tennis across 13 days before competing in a final that lasted almost 6 h. That final then involved >369 points, >6 km of movement and maximum in-point speeds >20 $km \cdot h^{-1}$. More than forty percent of points involved rallies exceeding 8 shots, and over 1100 groundstrokes were hit at speeds greater than 95 $km \cdot h^{-1}$. While arguably an exception to the norm, this type of case report underscores the critical importance of optimal nutritional and hydration intake before, during, and after tennis competition (Reid & Duffield, 2014), particularly for players who participate in multiple matches in a single day, combining singles and doubles. This added workload can significantly impact their physical and nutritional demands, as well as their recovery strategies.

The progression of young tennis players to the professional ranks is achieved via a mixture of national programs, tennis clubs and professional tennis academies. Gifted players are typically fully engaged in such programs by the age of 12 – 14 y. Younger players (i.e., 14

& under [U14]) spend most of their training time to mastering sport-specific skills, with technical/tactical work and physical conditioning activities sometimes exceeding 15–20 hours per week (Crespo & Reid, 2008). However, young tennis players are also subjected to a demanding tournament calendar, which can interfere with an optimal quantity and quality of their training. This may result in an excessive workload, suboptimal recovery, inadequate overall preparation, and an increased risk of injury (Gallo-Salazar et al., 2017; Gescheit et al., 2015). Based on available research, the average age when the athlete first reaches a Top 100 ranking is 22.0 ± 3.0 years for males, and 19.7±1.9 years for females (Kovacs et al., 2015).

As they climb in world rankings, players typically compete in 20-25 tournaments per year, covering 10 – 15 countries on the ITF, WTA and ATP circuits (see Table 1). However, even at the professional level, there may be major differences in the requirements and lifestyle of players. For example, the most successful players who continue to the final rounds typically play from 5 to 7 matches within a tournament (including, sometimes, doubles competition), earning considerable sums from prize money, appearance fees and endorsements, and employing a large entourage to manage their conditioning and lifestyle needs, including nutrition. At this level, the player and his/her coaching team may be able to plan the annual calendar with reasonable control of the workload of tournament matches and intervening training and practice sessions. Meanwhile, lower-ranked players may have a more erratic match schedule, due to uncertain qualifications and early exits from a tournament, as well as less command over resources for training and on-court practice. Most of these players are also likely to have the most limited resources to dedicate to quality nutritional strategies, further complicating their ability to optimize performance and recovery.

The professional tennis circuit entails frequent international travel, with multiple time zone changes, and exposure to different environments (i.e., different altitude elevations, ambient temperatures, and relative humidities); cultures (Western vs. Eastern); and eating patterns (food types and early vs. late meal schedules). Food availability is influenced by a variety of factors including: the provisions of the tournament organizer (e.g., catering supplied at the host accommodation and competition venues); the food culture of the host country, the player's match/practice schedule (which may be unpredictable and include unusual times or a crowded timetable); the player's own resources (which may range from very restricted to an entourage including a chef and/or nutritionist/dietitian) and the weather conditions (e.g., high temperatures and humidity can impact food storage and availability, as well as a player's appetite and hydration needs). Nutrition knowledge and practical nutrition skills vary across players, from poor (e.g., the young player who has left home and school early to invest in the nomadic life on the junior circuit) to excellent (the player who has been supported by wholistic education activities within their tennis program) or outsourced (the player with an extensive entourage including nutrition specialists).

5. EXPERT GROUP TOPIC 2: PHYSIOLOGICAL DEMANDS OF TENNIS TRAINING AND MATCH PLAY

A periodized approach to tennis

From an early age on, tennis players must dedicate significant time to developing physical, technical and tactical capacities in preparation for the professional circuit (Crespo & Miley, 1998). A major challenge in developing aspiring professional players lies in striking a balance between training regimen that enhance technical, tactical and physical skills, while also providing sufficient competitive opportunities (Elferink-Gemser et al., 2011; Unierzyski, 2005). Due to the necessity to accumulate ranking points (Peñalva, 2018; Roetert & Ellenbecker, 2009), tennis players must prioritize competition schedules in their yearly plans (Roetert et al., 2005). Indeed, competitive calendars dictate the periodization of tennis players, with competition engagement often contributing > 60% of annual tennis activities (Reid et al., 2009) and restricting the number of training blocks throughout a calendar year (Kovacs, 2018; Reid et al., 2009).

Although these recommendations often lack supporting evidence, tennis coaching reports suggest that adolescent (i.e., 13-18 years old) players should compete in 18-30 tournaments and 60-100 matches per year (Reid et al., 2010), with younger players (i.e., 13-14 years old) are suggested to engage in no more than 9 annual tournaments, resulting in ~60 matches per year (Unierzyski, 2005). Although expert opinion recommends a maximum of 3 consecutive tournaments in annual plans (Unierzyski, 2005; Perri et al., 2021), results from a recent study (Perri et al., 2021) showed that international competition schedules intensify in their volume and distribution from age 15, with ~5 to 10 consecutive tournaments regularly played throughout late adolescence in future top 100 - 250 players, with a range of 44 to 61 matches per year. Therefore, due to the competitive demands of the annual tournament calendar, tennis players have approximately 20 weeks available each year for training and recovery (Perri et al., 2021; Reid et al., 2003).

Demands of singles match play

Understanding the workload profile during tennis competition is essential for match preparation, and for designing effective physical conditioning programs (Kovalchik & Reid, 2017). Additionally, identifying the physiological, biochemical and psychological factors that limit performance in tennis should guide the development of a competition nutrition plan to mitigate or delay the onset of these limitations. Naturally, the physiological responses to the activity profile and physical demands of tennis vary between individuals and underpin the need for tailored and specific nutritional interventions for players. Most of the research on the demands of tennis play has focussed on singles tennis.

During a singles match, the ball is in play 20 - 30 % of the time, with points lasting 6 - 80 s (Bergeron et al., 1991; Ferrauti, Bergeron, et al., 2001; Girard et al., 2011). Accordingly, the cardiovascular responses to singles match-play approximate 60-80 % of max heart rate (HR) and 60-70 % of maximal oxygen consumption (VO_{2max}) (Ferrauti, Pluim, et al., 2001). A moderate anaerobic energy contribution is inferred from blood lactate concentrations of ≈3 - 7 $mmol \cdot L^{-1}$ (Davey et al., 2002; Ferrauti, Bergeron, et al., 2001). Although cardiac and respiratory responses during tennis seem moderate, they fluctuate in response to the intensity and context of the match (Reilly & Palmer, 1995; Smekal et al., 2001). Additionally, the thermoregulatory responses are often moderate, with core temperatures <39ºC but regularly exacerbated in hot and humid environments (Morante & Brotherhood, 2008) whereby sweat rates are high and fluid loss considerable. Although hormonal responses have been documented in tennis research, their relationship with performance and subsequent recovery remains a topic of ongoing debate. Elevated testosterone and reduced cortisol responses (Ojala & Häkkinen, 2013) have nevertheless been highlighted as evidence of anabolic and catabolic stress, and potential exercise-induced myofibrillar muscle impair (Ojala & Häkkinen, 2013; Reid et al., 2009). Correspondingly, the risk of hypohydration, depletion of muscle and central nervous system carbohydrate stores and increased protein degradation via exercise-induced damage are identified as key challenges for competition nutrition strategies. Strategies involving within-play carbohydrate and fluid intake and post-play nutritional recovery are particularly important following prolonged match-play or consecutive days of high load matches and training (Ojala & Häkkinen, 2013)

Tennis is predominantly played in the summer on outdoor courts, with heat stress leading to exacerbated thermal (i.e., core and skin temperatures), physiologic (e.g., HR and hypervolemia), and perceptual (e.g., perceived exertion and thermal comfort/sensation) strains, which in turn may influence physical performance and match tactics (Périard et al., 2014b). Both players and event organizers should undertake necessary strategies to address such challenges (see Topic 7).

Finally, the mental challenges of high-performance tennis have been extensively described and studied (Harwood, 2016). The individual nature of tennis (apart from doubles competition) exposes players to rigorous psychological scrutiny, placing demands on them that are absent from team sports (Cowden et al., 2014). Recent rule changes now allow coaches some ability to communicate with players during a match, but they still prohibit providing physical support, such as assistance with nutritional strategies. Thus, players are largely on their own on the court and must apply the mental techniques they have learned to navigate the emotional roller coaster of a tennis match (Romero Carrasco et al., 2013). More research is needed to gain further insight into the relationship between nutritional habits and mental skills needed for effective play in high-performance tennis. For instance, studies could investigate if players with adequate nutritional habits show more confidence and positive on- and off-court behaviors during practices and matches compared to players with inappropriate food intake, or if sound nutritional routines have a significant impact on the concentration of players at different stages of their long-term development.

In summary, like athletes in all competitive sports, tennis players strive to optimize their competitive success by identifying and addressing central and peripheral factors that lead to periodic or sustained declines in performance. In tennis, these factors include hyperthermia, hypohydration, and carbohydrate depletion, which are more likely to occur during long matches, in hot environments, or amid a demanding tournament schedule.

Demands of tennis training

The training schedule of elite tennis players, even from the junior stages, usually integrates the on- and off-court practice of technical, tactical, and physical components, as well as psychological skills (Mamassis & Doganis, 2004). Schedules of high-performance tennis players during off-competition cycles are characterized by two daily training sessions (i.e., morning and afternoon), often exceeding 90 minutes. Key psychological skills that underpin the ability to cope with the demands of tennis have also been identified (Weinberg, 2006). Among them, motivation, emotional control, self-confidence, and concentration seem to be crucial (Crespo & Reid, 2007). Psychological strategies can be used to train players both on and off court. These strategies include goal setting, visualization, focusing, routines, breathing, yoga, relaxation, and biofeedback, among others (Lauer et al., 2020).

There is limited evidence to guide the balance and organization of training and competition blocks or even weekly load management. Although there is anecdotal support for the general need to accumulate 2-3 training blocks lasting between 4 to 8 weeks during the year (Reid et al., 2009), the variability of tournament scheduling can constrain training time to ≤ 3 weeks (Brechbuhl et al., 2018; Fernandez-Fernandez et al., 2015; Perri et al., 2023).

A recent study conducted with future top 250 professionally ranked tennis at ages 16-18 years (Perri et al., 2023), showed a typical pattern of three to-four-week training cycles during the year, of ~30 days of duration, with a daily training commitment of ~160 min (i.e., 90-95 min and 45-50 min of, on- and off-court training, respectively). Again, there is limited documentation of the scheduling and periodization of training for competitive tennis players, with most of the available information consisting of anecdotal reports regarding a few successful players. A simplified weekly outline for a 6-day cycle of off-season tennis-specific training is presented in Table 2. Warm-up routines typically focus on a neuromuscular training

(NMT) approach, including a combination of fundamental movements and specific strength and conditioning activities (e.g., dynamic stability, core focused strength, plyometrics, and agility) (Fernandez-Fernandez et al., 2020). Alternatively, they may take a more injury-prevention approach, targeting problematic areas such as the shoulder or hip to improve joint-specific function and address functional deficits when necessary (Abrams et al., 2012). Tennis sessions include different aims, with a more skill-based approach involving on-court conditioning or match play, and depending on the number of sessions per day, a duration of 45-90 min per session. Off-court conditioning typically includes more aerobic-oriented sessions, or sessions focused on movement, speed and change of direction drills, and rarely exceed 40-45 min in duration. Finally, recovery sessions will include the use of different techniques (e.g., water immersions, active recovery, stretching, whole-body cryotherapy, compression garments etc.) according to the training environment of the athlete.

Within tournaments, training processes are challenged by extensive travel, and the lack of access to appropriate facilities, coaches, and professional support (Murphy et al., 2015). Moreover, it is extremely challenging to periodize training against the backdrop of the unpredictable nature of tournament scheduling, the number of matches, characteristics of the opponents, and/or the need to wait for match results. In this scenario, coaches provide supplementary training for players, to reduce the magnitude of the possible fitness decrements when competition no longer provides an adequate physical stimulus (Murphy et al., 2015). Although research on this topic is limited, studies have shown that competitive periods lasting 4 to 6 weeks were associated with significant reductions in speed, agility and muscle mass in junior tennis players, while on other capacities, such as lower-body power and aerobic power, remained unaffected (Luna-Villouta et al., 2023; Murphy et al., 2015). These results highlight the importance of strength and speed/agility-training exposures over tournament weeks.

Physique characteristics of elite tennis players

Despite the published literature on the body composition and biotype of tennis players (Juzwiak et al., 2008; Martinez-Rodriguez et al., 2015; Sánchez-Muñoz et al., 2007; Söğüt et al., 2019; Yáñez-Sepúlveda et al., 2018), there is no single ideal physique for a tennis player. Rather, elite players display a diverse range of physical profiles, including height, body mass and lean mass. They tend to adapt their playing style to suit the strengths and characteristics of their physique, while utilizing conditioning programs to enhance key attributes. Therefore, as players grow older and gain training maturity, they tend to develop certain adaptable characteristics that enhance performance, such as becoming leaner and stronger. Strength and conditioning programs might include modalities such as resistance training and aerobic conditioning, among others that promote beneficial outcomes. However, these should serve as a means to improve as a tennis player, rather than becoming the primary goals themselves.

Since tennis is an asymmetric sport, the dominant arm experiences higher mechanical loading than the non-dominant arm (Chapelle et al., 2021). This was verified both in male and female players using methods such as anthropometric assessment, bioelectrical impedance analysis, and DEXA, among others (Chapelle et al., 2021). These asymmetries include a greater arm and wrist circumference, elbow width, humerus length, bone mineral density and content, and lean body mass in both genders (Calbet et al., 1998; Chapelle et al., 2021; Krahl et al., 1994; Sanchis-Moysi et al., 2010). These aspects would need to be considered when evaluating body composition using anthropometric measures. It is worth highlighting the important relationship that may exist between the management of body composition and the risk of developing the syndrome of Relative Energy Deficiency in Sport (REDs), especially in women (see Topic 4).

6 EXPERT GROUP TOPIC 3: TRAINING-DAY NUTRITION AND OVERALL NUTRITIONAL GOALS

Everyday dietary practices and food choices should provide an athlete with the nutrients needed to fuel exercise, promote recovery and adaptation, reduce the risk of illness and injury, and promote well-being, enjoyment and social interaction. Unlike sports with lengthy and well-defined off-season training periods, tennis may require players to weave training phases within and between tournaments, increasing the importance of understanding how to meet longer-term nutritional needs such as micronutrient support within competition eating, or to integrate special projects such as manipulating body composition or trialing new match strategies into small but available training periods. The guidelines here and throughout this Expert Statement are built from the existing sports nutrition literature, including a small but important number of studies undertaken in tennis players and tennis-specific scenarios.

Energy requirements

Energy intake represents the core of a player's nutrition plan because it addresses its success in supporting all the biological processes required for health and performance, as well as providing the potential for the athlete to consume necessary macronutrients, micronutrients and other food components. Energy needs vary between players and within individual players with major factors contributing to this variability including exercise workload (duration, intensity, and frequency of sessions) and the need for growth, such as deliberate increases in lean mass. Energy intake may fail to meet needs if the player is intentionally trying to alter body composition or if there are unintentional mismatches caused by limited nutrition knowledge, inadequate practical skills, disordered eating behavior, or challenges with food availability and consumption opportunities. The issue of LEA in which there is insufficient energy intake to meet the body's needs for physiological function and health once the energy cost of exercise is subtracted will be discussed separately (Topic 4). However, challenges that can lead to overconsumption of energy intake by tennis players should also be considered, noting factors that occur particularly during the extended tournament season in players with unpredictable schedules. These challenges include a disorganized lifestyle and poor control of the food environment, often linked to constant travel and repeated aggressive fueling strategies for matches or competitions that conclude prematurely with a lower actual energy requirement. Individual work with a sports dietitian or nutritionist can help players address these issues. Ideally, the relative stability of the pre-season period provides an opportunity for players to develop appropriate knowledge, tools and eating behaviors.

A feature of tennis, particularly during life on the circuit in general, or during tournament play in particular, is the unpredictability of exercise energy expenditure. There have been several studies of energy expenditure in high level players, using comprehensive (activity sensors and individualized measures of metabolic rate) or specialized (doubly labelled water) protocols. Applying the first protocol during periods of training involving 1-2 sessions per day, male and female players (ATP rankings: 287 ± 187) were reported to expend 4,708 ± 583 $\text{kcal}\cdot\text{day}^{-1}$ (males) and 3,639 ± 305 $\text{kcal}\cdot\text{day}^{-1}$ (females, $p < .001$), with the associated hourly energy cost of training being ~615 kcal and ~455 kcal, respectively (Ellis et al., 2024). Meanwhile, doubly labeled water protocols can only provide a mean value for energy expenditure over a period of days. Using this method, a case study reported that a female player (ranked in the top 15 in their tour) averaged a total daily energy expenditure (TDEE) of ~3380 kcal during a 3-match international tournament and ~3820 kcal during 5-Grand Slam matches (Ellis et al., 2021). In addition, a similarly ranked male player recorded a TDEE of ~3710 kcal during a phase involving mostly training and one ATP tournament match, and ~5520 kcal during a phase that included training and 5 International/Grand Slam matches (Ellis et al., 2021). Further case observations using this methodology identified a male doubles player with a TDEE of ~4500 kcal across 10 days of Wimbledon, and two female players with substantial differences in TDEE (~4000 and ~3400 kcal), despite similar match play times (Ellis et al., 2023). While the sample size is small and the players are of elite caliber, these findings provide valuable insights into the fluctuating energy costs of tennis play.

There is an absence of robust information on the dietary practices of high-performance tennis players, but the available dietary surveys on adolescent and lower-level players suggest that some fail to meet their nutritional energy requirements as well as intakes of macronutrients and micronutrients (see Topic 8). However, such studies face the specific limitation of no adequately representing the target population of primary interest, along with the broader inherent limitation of dietary survey methods, which often fail to provide valid and reliable data on energy and nutrient intake. Indeed, careful review of dietary surveys of athletes against doubly-labeled water gold standard measures of energy expenditure finds that energy intake is typically under-reported by ~20%, with significant errors in nutrient intakes also presumed (Capling et al., 2017). While such results are generally unsuited to the diagnosis of nutritional deficiencies, they may nevertheless identify dietary behaviors that are either supportive or unlikely to meet nutritional goals (Fleming et al., 2018).

Carbohydrate requirements

Nutrition during training periods must provide fuel for practice sessions, both in the meals consumed over the day, and snacks/drinks consumed during the session. The accumulation of high-intensity efforts (i.e., >90 % of maximum HR) during training sessions and the importance of maintaining stroke quality and decision-making underpins the critical role of CHO availability during these sessions, just as it does in matches (Vergauwen et al., 1998; Kovacs, 2006b; McRae & Galloway, 2012; Ranchordas et al., 2013). This includes dietary strategies to replenish muscle and liver glycogen stores between sessions, as well as to maintain blood glucose availability during exercise, thus offsetting the onset of fatigue.

Sports nutrition guidelines for daily CHO intake have evolved markedly over the last 30 years, moving away from universal recommendations for a high CHO intake to personalized and periodized recommendations that match CHO intake to the fuel cost of the day's training program (= high-CHO availability), depending on the importance of supporting training intensity and quality (Burke et al., 2018). As is the case for energy, CHO intake should vary between and within tennis players according to the general and specific phases of a tennis preseason, training goals and additional considerations such as strategies to manipulate body composition. Table 3 summarizes the current range of suggested CHO intakes for athletes, integrated into tennis scenarios. Such recommendations represent a starting point which should be fine-tuned by the individual athlete according to their overall goals, food preferences/available food supply and feedback from training performance. It is likely that pre-season training provides the tennis player with the most stable period, albeit short in high performance players, to plan and fuel their workload appropriately. Although changes in CHO intake can be achieved simply by changing the type and quantity of CHO-rich foods at meals, it is also useful to implement CHO intake strategies pre, during and between practice sessions. Such tactics help to ensure that total CHO intake meets fuel needs, and that targeted sessions are completed with optimal fuel support and/or opportunities to trial potential match fueling strategies. Specific recommendations for acute CHO intake to enhance CHO availability around on-court practice sessions and match simulation are provided in Table 3 and are discussed in more detail in Topic 5.

It is also noted that high absolute intakes of CHO are not necessary every day or for every player. Among endurance athletes at least, there is interest in the occasional and deliberate implementation of strategies that achieve low CHO availability for targeted sessions of low-moderate intensity aerobic exercise (e.g., training in a fasting state, training with low muscle glycogen content) to increase the cellular signaling responses to the exercise stimulus (Burke et al., 2018; Impey et al., 2018). While such strategies may have a role in conditioning sessions undertaken by tennis players, they should not be confused with diets of reduced or restricted CHO intake (e.g., ketogenic low CHO high fat – LCHF) that have become popular within some groups of athletes (Burke, 2021). While such diets substantially increase the contribution of fat as an exercise substrate, they impair capacity for CHO utilization and decrease performance during high-intensity aerobic demanding exercise (Burke, 2021).

Protein recommendations

While the World Health Organization recommends a protein intake of 0.8 g·kg^{-1} body mass/day for sedentary people (*Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*, 2005), it is now widely recognized that athletes require higher protein levels to support the additional turnover of protein for exercise-induced skeletal muscle remodeling and repair, facilitate injury rehabilitation, and optimize body composition (Jäger et al., 2017; Tipton, 2015; Witard et al., 2019). Those who have reviewed the sports nutrition literature through the lens of tennis have recommended that high performance players achieve daily protein intakes of ~1.2–1.8 g·kg^{-1} body mass (Domínguez et al., 2021; Ranchordas et al., 2013). Meanwhile, recent summaries by experts in protein metabolism in sport recognize that intakes in this range are needed to address the contribution of protein breakdown to exercise fuel needs and an upregulation in myofibrillar muscle protein synthesis in response to strenuous training or a resistance training program aimed at increasing lean body mass (Jäger et al., 2017; Witard et al., 2019). Furthermore, although the evidence is less clear, optimal protein intakes may be even higher (up to 2.2-2.4 g·kg^{-1} body mass/day) in specific scenarios. These include maintaining lean body mass during periods of energy restriction or injury disuse/rehabilitation (Jäger et al., 2017; Tipton, 2015; Witard et al., 2019), or supporting periods of particularly strenuous growth of lean body mass or high exercise demands (Jäger et al., 2017). Such recommendations are in line with the protein intake guidelines for high performance football (soccer) players within the UEFA expert group statement on nutrition in elite football (Collins et al., 2021). Although there are few contemporary studies of protein intakes among highly competitive tennis players, the consensus from reports on highly supported elite athletes such as soccer players is that targets are typically met via high energy intakes and well-chosen dietary practices (Collins et al., 2021).

There have been many studies of the effect of the type, form, timing and frequency of intake of protein to optimize acute myofibrillar protein synthesis or chronic outcomes such as body composition changes and performance (for review see (Hartono et al., 2022; Schoenfeld & Aragon, 2018)). In general, the goal is to consume high-quality protein throughout the day, ensuring blood leucine concentrations reach the threshold needed to optimally activates myofibrillar protein synthesis, while supplying the full range of amino acids required to build new proteins (Burd et al., 2019)(Antonio et al., 2020). Protein intakes at the higher end of the recommended range typically optimize muscle remodeling and recovery outcomes. However, during periods of lower protein or energy intake or during strenuous workloads, spreading protein consumption across 4-6 meals or snacks per day, with portions of 20-40 g, may offer additional benefits. Key opportunities include post-exercise and pre-sleep meals, which can enhance myofibrillar protein synthesis, improve functional outcomes, and contribute to total daily protein intake (for review, see (Antonio et al., 2020)).

Animal sources of protein, such as meats, poultry, fish, eggs, and dairy products, are considered high-quality and are well-suited to meeting protein intake goals. The recent popularity of vegetarian and vegan eating patterns for athletes has increased the interest in the digestibility and amino acid differences of plant-based protein sources. While acute studies of muscle protein synthesis following the intake of isolated proteins have shown superior outcomes with animal sources (e.g., whey, egg) than plant-based (e.g., soy, pea, wheat), this appears to be largely overcome by consuming protein intakes at the higher end of the recommended range in mixed meal scenarios (Hevia-Larraín et al., 2021; Pinckaers et al., 2021). Although food sources, including whole foods with an intact food matrix, can meet a player's protein targets, practical and lifestyle challenges include consuming foods while experiencing a suppressed appetite or risk of gastrointestinal upset, or having access to suitable food choices at an exercise site or over a busy day. In these circumstances, protein supplements and liquid meals may represent a useful option, provided the player manages the risk of contamination, including the potential for substances on the World Anti-Doping Agency Prohibited List, by choosing products made by reputable companies, especially those that have undergone batch testing via third-party auditors (Walpurgis et al., 2020).

Fat requirements

Dietary fat provides a substantial source of energy, with health authorities recommending it constitute 20-35% of total energy intake. This range is designed to exceed the minimum required for essential fatty acids and support the absorption of fat-soluble vitamins, while also limiting saturated fats intake to address cardiovascular health concerns (Liu et al., 2017). Dietary fat intake can be manipulated to balance the athlete's goals for total energy intake without sacrificing protein and carbohydrate intake targets, and is typically reduced during periods of focused body mass/body fat loss. Preferred sources of fats include omega-3 fatty acids (e.g., α-linolenic, eicosapentaenoic, and docosahexaenoic acid) found in fatty fish and some plant, seed and nut oils, due to the potential general health benefits associated with their intake, as well specific benefits to on-court performance associated with anti-inflammatory, anti-oxidant and immunomodulatory effects (Seferoglu et al., 2012; Calder, 2013; Gammone et al., 2018).

Essential micronutrients for training periods

It is generally assumed that demands for micronutrients are elevated in tennis players to support increased metabolic needs and to counter increased turnover and losses (Peeling et al., 2023). Due to the high energy intake required for practice, however, the demands for micronutrients should be covered in the diet if the food sources are of good quality and include a high nutrient density. Nevertheless, deficiencies or suboptimal nutrient status may occur in certain players, as discussed below. Key risk factors include reduced energy intake during periods focused on body composition, limited dietary variety, and an over-reliance on ultra-processed foods, including sports foods (Peeling et al., 2023)

Iron

Iron is important for athletic performance because of its involvement with oxygen transport in the blood (hemoglobin) and muscle (myoglobin) and the function of iron-dependent enzymes which include mitochondrial enzymes and cytochromes underpinning energy metabolism (for review, see (Peeling et al., 2021; Sim et al., 2019)). Iron deficiency is considered to occur as a spectrum, with the first stage involving depletion of iron body stores (represented by a reduction in serum ferritin concentrations), while Stage 2 affects erythropoiesis (represented by a reduction in blood hemoglobin) before reaching Stage 3 anemia (microcytic, hypochromic red blood cells with hemoglobin concentrations below a threshold) (for review, see (Peeling et al., 2021)). Iron deficiency anemia is associated with fatigue, reduced capacity for training and performance, limited erythropoietic mechanisms and, impairments of the immune system and neural/cognitive function (for review, see (Larson-Meyer et al., 2018; Okazaki et al., 2019; Peeling et al., 2021). While there is dispute about whether all these symptoms occur with iron depletion/non-anemic deficiency, it is recommended that sub-optimal iron status be prevented and/or treated in athletes before it progresses to iron deficiency anemia (Peeling et al., 2021; Sim et al., 2019)

As reviewed by Peeling and colleagues (Peeling et al., 2021), athletes can be at greater risk of iron deficiency due to increased iron turnover and losses (e.g., foot strike hemolysis, sweat iron losses, gastrointestinal bleeding) as well as the reduction in iron absorption/recycling associated with the iron-regulatory hormone, hepcidin, which is increased in the hours following strenuous exercise (Larsuphrom & Latunde-Dada, 2021; Peeling et al., 2014). High performance tennis players are likely to carry such risks, with extra focus on females (extra requirements to cover menstrual blood loss), vegetarians/vegans (lower intake of bioavailable iron), and others who are exposed to low energy and/or low CHO availability (increased hepcidin response) (Badenhorst et al., 2019; McKay et al., 2020; Petkus et al., 2019; Snyder et al., 1989). Although recommendations for daily iron intakes have not been specifically established for athletes, the US Institute of Medicine has noted that the Estimated Average Requirement (EAR) for athletes might be increased by 30-70% above those of sedentary individuals, while vegetarians have an 80% increase in EAR (Dietary Reference Intakes, 2001). Limited data is available on the iron status of high-performance tennis players. Studies examining iron intakes in young female players (Gropper et al., 2006) and ferritin concentrations in young and senior male players (Kozłowska et al., 2021; Ziemann et al., 2013) report lower levels compared to control groups. However, these findings may be influenced by under-reporting in dietary surveys and the potential for ferritin levels to be falsely elevated as an acute-phase reactant in response to strenuous training loads (Sim et al., 2019), respectively.

Regular screening of iron status, especially of those at risk of greater losses and/or sub-optimal intake, should be part of the routing monitoring of high-performance athletes including tennis players (Larson-Meyer et al., 2018; Sim et al., 2019).

Dietary iron exists in two forms: the more bioavailable heme iron, found in red meat, poultry, and fish (particularly darker cuts), and non-heme iron, which must be reduced to Fe^{3+} for absorption in the gut. Non-heme iron is present in both animal-based-foods and plant-based sources, such as fortified cereals, legumes, and green leafy vegetables (Hurrell & Egli, 2010). The bioavailability of non-heme iron can be manipulated by the presence of other components of the meal in which it is included. This includes increased iron absorption when consumed with foods rich in vitamin C, peptides from partially digested muscle tissue, fermented foods, or organic acids (e.g., malate or citrate). Conversely, absorption may be reduced when consumed with phytates, oxalates, and polyphenols (found in tea or coffee), peptides from partially digested vegetable proteins, or calcium (Hurrell & Egli, 2010; Monsen, 1988). Exercise also affects the bioavailability of dietary iron, as hepcidin concentrations typically increase during the recovery period 3-6 hours after strenuous activity. However, this dampening effect on iron absorption and recycling is down-regulated when iron status, indicated by ferritin levels is low (Peeling et al., 2014). Players who are at risk of iron deficiency may need expert advice from a sports dietitian to integrate strategies regarding the timing, source and meal combinations of iron-rich foods in their diets to maximize iron absorption (Sim et al., 2019). This may be difficult during competition season when considerations for match nutrition take priority. Advice regarding iron supplementation is covered in greater detail in Topic 6.

Vitamin D

Vitamin D is considered a vitamin and is found in the diet from natural sources (e.g., fatty fish) as well as some fortified foods. However, the food supply of vitamin D is small and inconsistent across countries, and human requirements can be fully met by skin synthesis arising from UVB sunlight exposure. vitamin D is found in two forms: D_2 (ergocalciferol) found in sun-exposed plant foods (e.g., mushrooms) and D_3 (cholecalciferol) found in animal sources and from direct sunlight conversion (Holick et al., 2011; Ramasamy, 2020). Within the body, Vitamin D acts as a hormone, with a wide range of physiologic functions, including calcium and phosphate homeostasis, bone metabolism, immunomodulation, skeletal muscle health, and gene expression (Holick et al., 2011). There is some debate around the assessment of, and recommendations for, optimal vitamin D status. At present, vitamin D status is generally assessed via circulating blood concentrations of total 25-hydroxyvitamin D (25(OH)D). However, there is current investigation of whether free or bioavailable 25(OH)D (which represents ~10–15% of total serum vitamin D) provides a more meaningful marker (Kerr & Larson-Meyer, 2021).

The US Institute of Medicine (IOM) guidelines for the classification of vitamin D status identify > 50, 30-50 and < 30 nmol·L^{-1} of total 25-hydroxyvitamin D (25(OH)D) as being adequate, insufficient and deficient, respectively (*Dietary Reference Intakes for Calcium and Vitamin D*, 2011) [for conversion to ng/ml, divide by 2.5]. Meanwhile, the Endocrine Society Practice Guidelines (Holick et al., 2007) has set the ranges at >75 and <50 nmol·L^{-1} for sufficiency and deficiency, with the optimal range being 100-250 nmol·L^{-1}. Levels above 180 nmol·L^{-1} and 375 nmol·L^{-1} are considered toxic by the IOM and Endocrine Society, respectively (*Dietary Reference Intakes for Calcium and Vitamin D*, 2011; Holick et al., 2007). The inconsistency in these recommendations has been attributed to differences in the focus of the guidelines (Owens et al., 2018). The historical interest in vitamin D has been on support for bone health, and the IOM guidelines target vitamin D concentrations in which effects on bone, for example, an increase in blood levels of parathyroid hormone are absent (Owens et al., 2018). Meanwhile the Endocrine Society places the optimal range (100–250 nmol·L^{-1}) to incorporate the historical concentrations likely experienced in a hunter gatherer lifestyle where high sun exposure was normal (Kerr & Larson-Meyer, 2021). Examples of support for higher ("optimal") levels of vitamin D status, particularly in athletes, focus on vitamin D's role in skeletal muscle proliferation and repair. In summarizing the results of cross-sectional studies of correlations between vitamin D status and sports performance, or outcomes of supplementation studies in athletes, Wiciński et al. (Wiciński et al., 2019) note that there is some, but inconsistent, evidence that higher vitamin D status is associated with benefits to jump, strength or sprint performance in team and intermittent sport players. Further high-quality studies are needed, but in the meantime, there is some justification for at least setting the cutoff for deficiency at a higher value (e.g., 25(OH)D of 50 mmol·L^{-1}).

Although tennis is mainly an outdoor sport, players who spend large amounts of time in regions far north of the equator, such as Canada, Russia, and Northern Europe, or far south, such as southern parts of New Zealand and Australia will experience very low or absent vitamin D_3 synthesis in the skin during winter months (Holick et al., 2007). Even in regions with adequate sunlight, sensible habits like wearing sunscreen or exercising early or late in the day to avoid heat, can reduce natural vitamin D production. Studies of athletes (Kerr & Larson-Meyer, 2021; Owens et al., 2015), including tennis players (Kozłowska et al., 2021), show that many record vitamin D levels in the insufficient and deficient range, especially at the end of winter. Therefore, there is value in identifying players at risk of inadequate vitamin D status for routine screening and potential supplementation. For detailed protocols on vitamin D supplementation, including dosage recommendations and treatment of deficiency, please refer to the section on calcium and vitamin D (Topic 6).

Calcium

Calcium is one of the most abundant minerals in the human body and controls a wide range of physiologic processes such as muscle contraction, nerve transmission, hormone secretion, vascular function, intracellular signaling and cell growth (*Dietary Reference Intakes for Calcium and Vitamin D*, 2011; Emkey & Emkey, 2012). However, it is most associated with the formation, strength and metabolism of bone. Indeed, over 99% of total body calcium is found in bones and teeth, with the remodeling of bone tissue providing a reservoir for the provision of calcium for critical body needs (Emkey & Emkey, 2012). Bone health is a major concern for athletes, with stress fractures being a common and serious injury in many populations, including tennis players (Maquirriain & Ghisi, 2006). Inadequate intake of calcium can contribute to poor bone health, but poor vitamin D status and LEA (Topic 4) are the key factors to avoid or treat. The recommended dietary intake for calcium varies between countries and between population groups (700 mg-1300 $mg \cdot d^{-1}$) with the lower end of the range targeting adults, while the higher end of the range notes the additional needs of adolescents and post-menopausal females. Female athletes with functional hypothalamic amenorrhea should follow the same guidelines as the latter group to compensate for their hormonal disturbances while treating the underlying causes. The major dietary source of calcium in Western diets is dairy foods (e.g., milk, cheese, yoghurt) with fish eaten with bones (e.g., canned sardines and salmon), green leafy vegetables (e.g., kale, broccoli, spinach) and calcium-fortified dairy substitutes providing alternatives. Advice regarding calcium supplementation is covered in greater detail in Topic 6.

7. EXPERT GROUP TOPIC 4: BODY COMPOSITION, LEA AND REDS

Conceptually, energy availability represents the amount of energy that the body can allocate to the functions it requires to stay healthy. Operationally, it is calculated by subtracting the energy cost of an athlete’s exercise program from their dietary energy intake, and normalizing it to their fat free mass, which represents the body’s most active tissues (Loucks, 2013):

EA [Energy Availability] = EI [Energy Intake (kcal)] - EEE [Exercise Energy Expenditure (kcal)] / FFM [Fat-Free Mass (kg) per day].

Energy mismatches, caused by an increase in exercise energy expenditure and/or a decrease in energy intake, are termed LEA. They can occur via a range of scenarios commonly seen in sport (Burke et al., 2021) of pathological (e.g., eating disorder), deliberate but potentially misguided (e.g., fat/weight loss programs, intensified training or strenuous competition programs) or unintentional origin (e.g., reduced appetite, poor food availability, poor nutrition knowledge). Some scenarios of LEA represent normal human resilience ("adaptable LEA"), with small and reversible adaptations to metabolism in response to energy scarcity. Indeed, manipulation of body composition and high training volumes are normal and valuable activities in many sports. However, other scenarios of lengthy and/or extreme LEA ("problematic LEA") underpin the REDs syndrome, a syndrome of exclusion, in which a mismatch between energy intake and the energy cost of training/competition leads to inadequate support for the energy cost of maintaining health and body functions. In turn, this can lead to a variety of impairments of health and performance in athletes, across sex, caliber and sporting event (Mountjoy et al., 2023). Figure 1 summarizes the range of body systems and performance metrics that may be impaired by REDs, highlighting additional issues beyond the well-established disruptions to reproductive and bone health identified in the Female Athlete (Nattiv et al., 2007) and Male Athlete Triad (Fredericson et al., 2021; Nattiv et al., 2021). The IOC's 2023 Consensus Statement on REDs (Mountjoy et al., 2023) provided an update to the science behind this syndrome to better position the complexities and nuances of the effects of LEA on athlete health and performance, and to provide standardized guidelines for methodologies for future research. Systematic investigations of LEA and REDs in tennis are lacking; however, there is evidence of underlying risk factors such as disordered eating and scenarios of inadequate energy intake in individual players and special populations (see Topic 9). Sporting organizations and the player’s entourage and health/performance team all play a role in protecting player well-being, by promoting awareness of REDs and providing an environment that supports the prevention, early detection and treatment of problematic LEA (Torstveit et al., 2023). This includes recognising risk factors and achieving an early diagnosis of issues with the use of an updated and validated Clinical Assessment Tool (REDs CAT2) (Stellingwerff et al., 2023). Further work may help to evolve our understanding of problematic LEA, including identifying the characteristics of EA changes that impair various body systems, and moderating factors such as age, sex, training, genetics, stress and dietary factors that may either amplify or attenuate the effects of LEA exposure (Burke et al., 2023). It is noted that although female players are likely to be of greater risk of experiencing LEA and its effects (see Topic 9), the problem should not be overlooked in male players.

The manipulation of body composition to achieve an “ideal” body mass and body fat level is a major topic in many sports, including tennis. Although maturation and conditioning may allow individual players to gradually achieve lean and fat mass characteristics associated with long term health and performance goals over the course of their careers, Topic 2 identified that a broad range of physiques can be observed among successful players. However, for some players, particularly females, there is considerable stress involved with body composition assessments (public commentary as well as official assessments) and manipulation (Ingle, 2014). This may reflect sex differences in body composition and body image, as well as the shorter match (and lower energy requirements) of women’s tennis that may make it more difficult to manage energy balance.

The 2023 IOC REDs Working Group raised concern whether overemphasis on the effect of being lighter and leaner on sports performance, and practices around body composition assessments, potentially increase the risk of REDs via their contribution to unsafe weight loss practices and disordered eating (Mathisen et al., 2023). An analysis of the current literature on physique and sports performance observed a negative relationship between body fat and performance in endurance sports. However, it found that this effect was less significant than the impact of training variables and experience. Overall, the study concluded that gaining muscle mass rather than reducing body fat, is more likely to lead to performance benefits (Mathisen et al., 2023). It recommended a multi-disciplinary approach to body composition assessment and management, emphasizing that assessments should be conducted by qualified professionals using standardized protocols, performed at justifiable intervals, and treated as confidential medical information. Additionally, appropriate measures should be in place to safeguard athlete privacy and facilitate sensitive, effective communication with the athlete. Furthermore, any adjustments to body composition should be carefully justified and achieved under expert guidance, following an individualized program tailored to specific goals (Mathisen et al., 2023).

8. EXPERT GROUP TOPIC 5: MATCH-DAY NUTRITION

Nutrition and hydration in the days before a match

Given the physiological demands of match play and the incentives for being successful, it is not surprising that nutrition for match play has received considerable attention (Kovacs, 2006a; Ranchordas et al., 2013). Because of the nature of tournament play, it is often difficult to differentiate recovery from one match with preparation for the next (Table 1). Indeed, it can be assumed that in some scenarios, the player will be preparing from a sub-optimal nutritional status and may not have adequate time or opportunity to fully achieve hydration and fueling goals. Nevertheless, the following principles and strategies should be integrated into the specific routine as well as possible, with extra care around within-match nutrition being used to address residual issues.

Pre-match fueling is achieved by the meals consumed in the 24 hours pre-match, including the pre-match meal. Although muscle glycogen usage patterns have not been assessed over the course of a single match or tennis tournament, overall or fiber-specific and location-specific glycogen depletion may contribute to various forms of neuromuscular fatigue and performance declines (Vigh-Larsen et al., 2022). Therefore, muscle glycogen stores should be prepared with consideration of the likely needs of the match, including in men's Grand Slam matches, the potential for 5 set matches lasting >4 h. Playing in hot weather may also increase carbohydrate requirements since, as under certain exercise conditions, hyperthermia is associated with higher rates of muscle glycogen utilization (Fernández-Elías et al., 2015). As summarized in Table 3, muscle glycogen stores can typically be optimized by 24 hours of carbohydrate intakes of 6-10 $g \cdot kg^{-1}$ body mass and a reduced training load (Burke et al., 2017; Thomas et al., 2016). If there is the need and opportunity to extend this fueling period to 48, loading/ supercompensation of muscle glycogen stores may be achieved (Burke et al., 2017; Bussau et al., 2002).

In addition, coaches should educate players on the importance of staying well hydrated throughout the match preparation phase, whether this involves training or an earlier match. It is difficult to judge daily fluid losses and hydration status, especially in tournament scenarios when match duration and intensity are difficult to predict, and environmental conditions around each match (i.e., heat stress) cannot be chosen (Bergeron, 2014). Monitoring fluid status through daily body weight measurements or urine testing (e.g., using a urine color chart or urine-specific gravity measures) can be a valuable practice (Barley et al., 2020), especially for players or situations with a high risk of fluid imbalance. Additionally, and in a more accurate way to estimate the ideal player fluids intake during a match with specific environmental conditions, there can be estimated the hydric balance with an equation including variables such pre- and post- training BM, total fluid intake during training and urine production (Armstrong et al., 2015). Indeed, studies of professional players that have assessed pre-match hydration status at the commencement or within ITF tournaments have reported urine-specific gravity values indicative of hypohydration (Hornery et al., 2007; López-Samanes et al., 2018). Presentation with poor hydration status to training sessions or matches is a consistent finding across different levels of tennis play and can be improved with a personalized fluid plan within and around exercise sessions (Bergeron, 2014; Périard et al., 2014a)

Pre-match nutrition and hydration

Foods and fluids consumed in the 4 hours prior to the match have the potential to contribute to the general fuel and hydration plan. They may play a greater role when the recovery time between successive matches is short and/or muscle glycogen stores or fluid status has been substantially affected by the previous match, or in the case of morning matches, where liver glycogen content has been substantially reduced by the overnight fast (for review, see (Hargreaves, 2001)). Because it is also important that the pre-match meal maintain gastrointestinal comfort, it should be based on familiar foods and adjusted according to the specific conditions of each match and the players' previous experiences. In general, a carbohydrate intake of 1-4 $g \cdot kg^{-1}$ is recommended within the 1-4 hours pre-match (Table 3). However, the type, timing and size of the pre-event meal is likely to vary between players and matches, according to the need for continued recovery, individual tolerance, and the degree of certainty over match timetables. Unlike most sports, the tennis player is often faced with unpredictable competition starting times and must often adopt a flexible pre-match routine. This might include a more substantial meal when there is certainty of several hours until match start, with continued light and easily digestible carbohydrate-rich snacks or fluid "top ups" until the actual commencement. Menu choices that are low in fat and fiber are generally recommended to minimize gastrointestinal issues in players prone to such problems.

The maintenance of blood glucose concentrations during prolonged exercise reflects complex control by several physiological systems, including the sympathetic nervous system and the endocrine system, with characteristics of diet and exercise also affecting the balance between muscle glucose uptake and gut/liver release (for review, see (Suh et al., 2007)). Hypoglycemia is often proposed as a cause of fatigue or performance decrements during tennis (Ferrauti et al., 2003; Hornery et al., 2007; Kovacs, 2008), although cases of frank hypoglycemia are likely to be rare. Furthermore, there is an apparent disconnect between the symptoms attributed to hypoglycemia by athletes and their true blood glucose concentrations (A. E. Jeukendrup & Killer, 2010). Nevertheless, decreases in blood glucose, causing sensations or performance issues in individual players, may occur in two scenarios: at the commencement of exercise due to the rebound effect of the insulinemic response to carbohydrate consumed in the 30-60 min pre-exercise, or the response to prolonged tennis play when carbohydrate availability is becoming low (Ferrauti et al., 2003). Players who experience concerns related to the first issue have a number of options regarding pre-exercise carbohydrate intake within the window of apparent risk: choose CHO-rich foods with lower glycemic index or reduce the glycemic response to their intake by consuming them with added protein, fat or fiber (if tolerated); or wait until the warm-up to consume pre-match carbohydrates where the sympathetic response to higher-intensity exercise can counteract the decline in blood glucose (Jeukendrup & Killer, 2010).

Opportunities to consume fluid to address hydration status are also important, particularly given the reports of poor hydration at the commencement of matches (Hornery et al., 2007; López-Samanes et al., 2018). An individualized fluid intake plan should be constructed that accounts for the predicted fluid deficits and the player's tolerance of pre-exercise fluid intake (Périard et al., 2014a). Typically, a bolus (e.g., 5 – 7 mL·kg^{-1} body mass) of fluid can be consumed up to 4 hours pre-match (American College of Sports Medicine et al., 2007) allowing time for fluid equilibration and excretion of urine production. Other more aggressive protocols might be needed to reverse significant hypohydration from a previous match, including further intake of smaller amounts of fluid until closer to the game and during/after the warm-up (Kovacs, 2008). The choice of fluids may consider other match nutrition goals (e.g., provide carbohydrates towards fueling plans) and/or contain electrolytes to aid in fluid retention (Maughan et al., 2016).

Nutrition and hydration during matches

Official breaks in play at the change of ends within and between sets provide an opportunity for players to consume food and fluids within a match. The importance of this will depend on match characteristics which determine hydration and fuel requirements, as well as the carryover effect of inadequate recovery of these factors from previous matches. General guidelines for carbohydrate intake, summarized in Table 3, identify an intake of 30-60 g·h^{-1} as a suitable starting point for intermittent sports similar to tennis (Baker et al., 2015) and tennis *per se* (Kovacs, 2006b). This may not be necessary in short matches, where addressing hydration needs may be the priority, and small amounts of carbohydrate, including simple mouth rinsing may be an adequate approach. Conversely, in longer matches (>2 – 3 hours), which mainly occur during Grand Slam and Davis Cup competitions, increased carbohydrate intakes of 60 – 90 g·h^{-1} even at the onset of matches may help to address greater fuel requirements. Fueling practices could be adjusted for matches played on clay and hard courts, noting the greater physical/physiologic requirements of longer matches on these surfaces (Ferrauti et al., 2003; Martin et al., 2011). Similarly, programs where entries in singles and doubles competitions, or other formats with shorter recovery between matches, restrict refueling between matches, additional focus on carbohydrate intake during matches could be trialed.

Various studies have investigated the benefits of carbohydrate ingestion during tennis activity. Some have reported improvements in tennis-specific running speed (Ferrauti et al., 1997), serve and return success (McRae & Galloway, 2012), and higher stroke frequency during play (Peltier et al., 2013). However, other studies have failed to detect benefits with carbohydrates compared to placebo (Gomes et al., 2013; Hornery et al., 2007). This may reflect the lack of sensitivity of performance measures, or the adequacy of fuel availability without additional carbohydrate intake under the conditions of the control trial. Players should therefore trial match fueling strategies to determine the most suitable practice for their specific competition scenarios. Carbohydrate intake during tennis competition can be achieved via the use of sports drinks (4-8% carbohydrate-electrolyte solutions), or by the use of semi-liquids (sports gels) and solids (sports bars or bananas); indeed, all have been reported in studies of match nutrition strategies of tennis players (Fleming et al., 2018; López-Samanes et al., 2017).

Fluid intake, whether via sports drinks or water, is necessary to address individual sweat losses incurred during the match as well as the larger fluid deficit that may accrue over a tournament. Sweat rates vary according to metabolic heat production (i.e., playing intensity), environmental conditions and heat acclimatization status. The high variability (e.g., from 1.0 – 3.5 $L \cdot h^{-1}$) (Bergeron et al., 2006, 2007; López-Samanes et al., 2018) means that it can be useful to establish a fluid plan that is adapted to each scenario or individual (Bergeron, 2014; Kovacs, 2008; Périard et al., 2014a). Each player should become aware of their typical sweat rates in different conditions and whether "ad libitum" fluid intake during breaks can successfully keep pace to keep the overall fluid deficit to acceptable levels. This can be assessed by monitoring changes in body mass in training sessions simulating match play.

Although the plentiful breaks during play allow for a regular fluid intake, the variability in the self-chosen hydration practices of individual players (Bergeron, 2014; López-Samanes et al., 2018) means that some scenarios might benefit from a more targeted approach to increase intake. Indeed, modest hypohydration (~3% loss of body mass) has been shown to reduce sprint running performance during tennis play (Magal et al., 2003) and it is noted that there are greater risks of performance impairment, via effects on skills and concentration, than seen in the literature involving running or cycling on which the hydration literature is reliant (Kovacs, 2008). Indeed, even when a fluid plan does not appear to alter performance during a match, there is evidence of reduced thermal strain and perception of effort which may assist with longer term benefits within a tournament (Périard et al., 2014a). Fluid replacement during match may include other features, including replacement of electrolytes lost in sweat and manipulation of the temperature of beverages to assist palatability, gastric emptying and support thermoregulation. These are covered in more detail in Topic 7: Travel and Environmental issues.

Recovery nutrition and hydration

Nutrition to support post-match recovery includes the same principles as in training situation: rehydration, refueling and support for muscle tissue repair and adaptation. However, the player is often challenged by the greater degree of depletion and physiological stress incurred in particularly strenuous matches, as well as an unplanned or unpredictable recovery period until the next match. Furthermore, late-night matches can lead to reduced sleep duration, which not only impairs recovery by disrupting physical and cognitive processes but may also negatively affect appetite, making it more difficult for players to adequately refuel. In addition, there may be a need to accommodate other activities, such as the integration of other recovery modalities (e.g., water immersion and massage), or doping control and media commitments, within the recovery period. Therefore, there is interest in practical strategies that can optimize rates of recovery within the available time frame (Gescheit et al., 2015; Kovacs & Baker, 2014; Maraga et al., 2018; Poignard et al., 2020; Reid & Duffield, 2014).

Carbohydrate and protein intakes that replenish liver and muscle glycogen and promote muscle protein synthesis represent key aspects of recovery nutrition. When refueling needs to be maximized, post-match meals and snacks within the first 4 hours of recovery should target an intake of 1.0 – 1.5 g·kg^{-1} body mass/hour towards the total daily targets summarized in Table 3 (Burke et al., 2017). Protein intakes of 20-40 g (0.3-0.6 g·kg^{-1} body mass) are generally promoted as a goal for the period immediately after exercise, with the larger value reflecting the results of more recent studies which suggest that higher protein intakes may contribute to greater protein synthesis (Trommelen et al., 2023), particularly after strenuous whole-body exercise (Macnaughton et al., 2016). Although a range of different protein sources may be able to contribute to these targets, it is noted that liquid sources of protein commonly used by athletes (e.g., protein-powders or dairy-based drinks) are quickly consumed and absorbed when the recovery period is brief. A range of different protocols of meals and snacks can be arranged within the recovery period according to appetite, food availability and overall nutrient targets.

Following significant sweat losses, replacement of water and electrolytes (particularly sodium), is needed to support full body fluid balance status over the next 2-5 hours. When losses are significant and the recovery period is short, a targeted fluid plan will expedite this process. A volume of fluid equal to 125-150% of the residual water deficit is needed to cover ongoing sweat and urine losses during the recovery period (Maughan & Shirreffs, 1997; Shirreffs et al., 1996). Furthermore, sodium should either be included in rehydration beverages in concentrations equivalent to oral rehydration solutions (40-50 mmol·L^{-1}) rather than conventional sports drinks (~20 mmol·L^{-1}) to replace plasma volume and osmolality in tandem

(Maughan & Shirreffs, 1997; Shirreffs et al., 1996). Alternatively, sodium can be replaced by added salt or high-rich salt foods consumed in recovery meals accompanied by lower-sodium beverages. The fluid plan can be adjusted according to the level of the fluid deficit and the period of time before the next match

9. EXPERT GROUP TOPIC 6: DIETARY SUPPLEMENTS FOR TENNIS PERFORMANCE

Use among tennis players

Surveys of elite and high-level tennis players have found that that 80-100% report using at least one dietary supplement during the season (Kondric et al., 2013; López-Samanes et al., 2017). Although such studies are confounded by inconsistencies in the definition of "supplement", they are in agreement with the widespread use of supplements and sports foods among sporting populations (Garthe & Maughan, 2018). Commonly used products by tennis players include sports drinks, protein supplements, iron, caffeine, creatine, and multivitamins (Kondric et al., 2013; López-Samanes et al., 2017), with the most common reasons for use including enhanced recovery and increased energy levels (López-Samanes et al., 2017). Although the evidence-based use of these products differs between individual players, a shared concern is the risk of an anti-doping rule violation (ADRV) due to the ingestion of prohibited substances contained as declared ingredients or contaminants within these products (Garthe & Maughan, 2018; Martínez-Sanz et al., 2017; Mathews, 2018). Because of individual needs and responsibilities regarding ADRV outcomes, each tennis player should make an informed decision about their use of supplements and sports foods, based on advice from qualified professionals such as sports nutritionists, dietitians and physicians. Furthermore, to reduce the risk of an inadvertent ADRV due to contamination, the player should ensure that all products have been batch-tested by accredited third-party programs such as Informed Sports®, the Cologne List® or NSF Certified for Sport® (Garthe & Maughan, 2018; Martínez-Sanz et al., 2017; Mathews, 2018).

Dietary Supplements

Multivitamins and minerals

There are no official Recommended Dietary Intakes/Allowances for vitamins and minerals in athletes (Larson-Meyer et al., 2018). Although athletes may have increased requirements for various micronutrients, a well-chosen food plan that meets their higher energy demands is likely to meet additional needs for vitamins and minerals. An accredited sports nutritionist or dietitian can assist with an assessment of dietary quality or nutritional status and provide guidance to address micronutrients of concern (Larson-Meyer et al., 2018). This is especially directed at players with restricted energy intake or food variety, including those following vegan or vegetarian diets who may be at particular risk of sub-optimal micronutrient intakes and deficiencies.

During a tournament, there may be some risk of inadequate micronutrient intake due to the limited availability of fresh and high-quality food associated with travel, reliance on external catering and competition eating practices. Multivitamin and mineral supplementation may be appropriate in this context depending on the individual (Ranchordas et al., 2013). For players who consume vegetarian or vegan diets, cyanocobalamin supplementation (50 – 100 $\mu g \cdot d^{-1}$ or 2000 μg per week divided into two doses) is safe and essential to prevent deficiencies that could affect health (Rizzo et al., 2016).

Iron

Risk factors and assessment of iron deficiency are discussed in detail in Topic 3 in the paragraph on iron. Athletes, including tennis players, are at increased risk of iron deficiency due to factors such as increased iron turnover, losses from sweat and gastrointestinal bleeding, and reduced absorption related to the regulatory hormone hepcidin (McCormick et al., 2019; McKay et al., 2024).

For the prevention and treatment of sub-optimal iron status, dietary strategies should focus on increasing the intake of bioavailable iron, with emphasis on combining iron-rich foods with vitamin C to enhance absorption (for review, see Sim et al., 2019) (See Topic 3 for dietary recommendations). When dietary changes are insufficient, iron supplements may be required. Standard protocols involve daily oral intake of ~100 mg of elemental iron in the form of ferrous salts (e.g., sulphate, fumarate, gluconate), with supplementation guided by ferritin reassessment over 1-3 months. For those experiencing gastrointestinal side-effects, alternate day dosing or newer formulations, such as sustained release supplements, may be more suitable (Hall et al., 2019;Sim et al., 2019; Stoffel et al., 2017).

In cases of severe deficiency or when oral iron is ineffective, intravenous iron may be considered as a time-sensitive alternative, though it requires medical supervision and a Therapeutic Use Exemption under World Anti-Doping Regulations (Auerbach et al., 2020; Australian Institute of Sport Sports Supplement Framework, n.d.; Fensham et al., 2024). These treatments are typically reserved for specialized scenarios where rapid correction of iron status is essential. For further information on iron supplementation strategies, including detailed dosing protocols and considerations for managing side effects, refer to Topic 3**.**

Calcium and Vitamin D

Adequate calcium intake and vitamin D status are critical for maintaining bone health, as previously discussed in Topic 3. Athletes unable to meet the recommended calcium intake of

700-1300 mg·day^{-1} through dietary means should consider supplementation, particularly those with functional hypothalamic amenorrhea, problematic LEA/REDs, or osteopenia/osteoporosis, who may require 1300-1500 mg per day (for review, see (Kerr & Larson-Meyer, 2021)).

Calcium supplements typically providing 500-600 mg of elemental calcium (e.g., calcium carbonate, although calcium citrate, phosphate and gluconate are also available) are well-tolerated and effectively when dietary intake is insufficient. However, the long-term effects of calcium supplements on bone health in athletes remain unclear due to a lack of randomized controlled trials (for review, see (Kerr & Larson-Meyer, 2021)). For detailed information on dietary sources of calcium and broader considerations for bone health, refer to the Calcium section in Topic 3.

Prevention and treatment of sub-optimal vitamin D status may be assisted by vitamin D supplements. There are two isoforms of vitamin D, with the D3 form (cholecalciferol) being the preferred form for supplementation due to its higher efficacy in raising and maintaining vitamin D levels (Kerr & Larson-Meyer, 2021; Owens et al., 2015). There is no standard protocol for vitamin D supplementation in the case of insufficiency or deficiency. Some guidelines suggest a sliding scale depending on baseline 25(OH)D concentrations, with vitamin D deficiency being treated with short-term, high-dosage vitamin D3 supplements (e.g., 50 000–100,000 IU D3·day^{-1} for 8–10 weeks) to rapidly replenish stores (Holick et al., 2011). Meanwhile vitamin D insufficiency can be treated or prevented in high-risk scenarios with a daily dose of 2000-4000 IU·day^{-1} for 1-2 months to restore status, with further use guided by assessment of blood vitamin D concentrations (Australian Institute of Sport Sports Supplement Framework, n.d.; Owens et al., 2018). Further details on the role of vitamin D in athlete health, including its physiological functions and factors influencing synthesis, can be found in the section on vitamin D (Topic 3),

Ergogenic (performance) supplements

Caffeine

Caffeine is consumed by most adults via food, drinks, supplements and medications and is one of the best-studied and most effective performance aids (Burke, 2008; Grgic et al., 2020; Guest et al., 2021). It enhances performance across various types of sporting activities, primarily by reducing the perception of effort, pain or fatigue through adenosine antagonism. This allows athletes to maintain optimal workload or skill outputs for longer durations (Burke, 2008; Grgic et al., 2020; Guest et al., 2021). It has been identified as the most reliable performance aid for racket sports (Vicente-Salar et al., 2020). Among the studies of sport-specific benefits of caffeine, tennis players who ingested caffeine, pre- and/or during the match, have been shown to increase the numbers of games won during match play (Ferrauti et al., 1997), better maintain serve speed in the last phases of a ~3 h simulated tennis match (Hornery et al., 2007), improve sprint running during a simulated tennis match (Gallo-Salazar et al., 2015; Poire et al., 2019) and achieve a greater number of successful shots during a tennis skill test (Klein et al., 2012).

Typically, an acute dose of 3 – 6 $\text{mg}\cdot\text{kg}^{-1}$ body mass is considered optimal, with opportunities to consume caffeine prior to the onset of a match and/or throughout longer matches. There has been recent interest in the benefits of low caffeine doses (3 $\text{mg}\cdot\text{kg}^{-1}$), particularly when taken just before the onset of fatigue (Spriet, 2014). Although it is often important to consider sex- or menstrual-phase differences, studies have found a similar ergogenic response to caffeine intake in male and female athletes (Lara et al., 2021; Skinner et al., 2019). Sources of caffeine for competition use include anhydrous capsules/tablets, caffeinated-variants of sports gels and other sports foods, and the more quickly absorbed caffeinated gums (Guest et al., 2021; Wickham & Spriet, 2018). Coffee is a widely used lifestyle caffeine source, but the variability of its content makes it less suitable as a targeted performance aid (Pickering & Grgic, 2020). Products such as pre-workouts and some energy drinks are less desirable because of large or undeclared amounts of caffeine and other stimulants.

Side-effects of caffeine use have been reported among athletes, including tennis players, when taken in doses at the higher end of the recommended range (Poire et al., 2019). These include gastrointestinal distress and nervousness (Poire et al., 2019), and an impairment of sleep quality, including reduced total sleep time and sleep efficiency, and an increase in sleep onset latency and wake after sleep onset (Gardiner et al., 2023). The effect of caffeine on sleep is particularly important in multi-day events such as tennis tournaments where recovery is key to overall success, and players should consider the benefit/risk ratio of caffeine supplementation for afternoon and evening matches when there is consecutive day competition. Conversely, the use of caffeine to enhance cognitive and physical performance after sleep deprivation may be useful to address next-day activities following late-night matches. Although the general literature on sleep deprivation and subsequent performance is supportive of this effect (Guest et al., 2021), it is noted that the single study in tennis players, albeit involving only a small caffeine dose (80 mg), failed to detect an attenuation of the impairment of service accuracy following reduced sleep (Reyner & Horne, 2013).

Habitual consumption of caffeine may promote tolerance to its ergogenic effects (Lara et al., 2019), although the benefits of caffeine are well demonstrated in many studies in which participants did not undertake a caffeine withdrawal (Pickering & Grgic, 2021). Nevertheless, some periodization of caffeine use as a match and training aid may be beneficial (Pickering & Grgic, 2021). Individual differences in response to acute caffeine intake are noted, and although polymorphisms of genes that affect caffeine's metabolism and excretion (CYP1A2) and adenosine receptor activity (ADORA2A) have been suggested as an underlying cause, these do not seem to fully explain interindividual reactions to caffeine (Guest et al., 2021). For this reason, responses to caffeine should be tested during training or simulated competition to undertake a risk-benefit analysis of caffeine use and to develop a personalized plan.

The American College of Sports Medicine (ACSM) (*ACSM Announces New Recommendations and Warnings Regarding Safety of Energy Drinks*, 2018) has provided recommendations for athletes on energy drink consumption. These recommendations include limiting marketing directly to children, given their smaller body size and greater risk of complications from naïve ingestion of high levels of caffeine, as well as specifically recommending that these energy drinks are not consumed “before, during, or after strenuous exercise”. International tennis organizations and federations have included this specific message, cautioning players against the consumption of high-caffeine drinks before, during, or after competition and training activities.

Creatine monohydrate

Creatine was found to be the most commonly used performance supplement in a survey of practices among the top 100 ATP-ranked players (López-Samanes et al., 2017). When used in appropriate protocols to increase muscle phosphocreatine stores, creatine supplementation may increase performance in single and repeated sprints (Antonio et al., 2021), enhance lean body mass and adaptations to strength training (Lanhers et al., 2015), and improve recovery and training tolerance (Rawson et al., 2018). Creatine loading can be achieved acutely with a 5-7 d protocol involving split doses (4 x 5 g), preferably consumed with carbohydrate-rich or carbohydrate-protein-rich foods to enhance muscle uptake (for review, see (Kreider et al., 2017)). A daily dose of 3-5 g will maintain elevated creatine/phosphocreatine stores and/or achieve a slower loading protocol after a month (Kreider et al., 2017). Creatine monohydrate remains the preferred supplement form, and such supplementation protocols have found to have no adverse events for up to 5 years (Kreider et al., 2017). Men and women appear to equally respond to creatine supplementation protocols (Tarnopolsky & MacLennan, 2000).

Despite the larger literature on benefits of creatine supplementation on performance of intermittent high-intensity sports (Wax et al., 2021), an analysis of tennis-specific research has shown minimal evidence of direct benefits to tennis play such as changes in service characteristics or movement velocity (Vicente-Salar et al., 2020). For example, an acute creatine loading protocol failed to enhance stroke power or precision, or high-intensity sprint velocity during simulated match characteristics (Op 't Eijnde et al., 2001). Another study involving creatine loading and one month of maintenance found that neither offered any benefits to serve velocity, arm and leg strength or intermittent running speed in a group of tennis players (Pluim et al., 2006).

Nevertheless, the popularity of creatine among elite tennis players may be explained by its use to provide more chronic and/or periodized support for training quality and adaptations. It may be especially recommended during the pre-season, where there is a greater focus on obtaining gains in muscle mass and strength (Vicente-Salar et al., 2020). Creatine supplementation may be also recommended for elite tennis players during injury recovery to reduce the loss of lean body mass (Kreider et al., 2017). Lastly, creatine supplementation may be especially helpful in tennis players with vegan or vegetarian diets, since they habitually have lower creatine stores due to the lack of dietary sources of creatine (Kaviani et al., 2020).

Sodium bicarbonate and buffering agents

Acute supplementation with bicarbonate or citrate can enhance extracellular buffering capacity to help maintain blood and muscle pH during repeated high-intensity exercise, with potential benefits to sports performance (Carr et al., 2011; Grgic et al., 2021). Chronic B-alanine supplementation may enhance intracellular buffering capacity (Carr et al., 2023) with similar effects. Several tennis-specific studies of buffering agents have been undertaken. In one, acute ingestion of sodium bicarbonate (0.3 g·kg^{-1} body mass) before a simulated match, and additional supplementation of 0.1 g·kg^{-1} body mass after the third game, attenuated the decline in groundstroke consistency during a tennis-specific test in tennis players (Wu et al., 2010). In another, those who received 0.5 g·kg^{-1} of sodium citrate 2 hours before a battery of tennis-specific tests and 1 hour of simulated match play won more games during the match (Cunha et al., 2019). Despite these reports, the acute use of buffering supplements is rarely reported by elite tennis players (López-Samanes et al., 2017). This may reflect the risk of gastrointestinal side-effects, especially with bicarbonate supplements, or the challenges of choosing the ideal timing of intake for a tennis match. Typically, bicarbonate and citrate, when taken in doses of 0.3 and 0.5 g·kg^{-1} respectively, achieve peak concentrations and effects on blood buffering within ~3 hours, explaining the pre-event protocols used by athletes who compete in brief sustained high-intensity exercise (e.g., rowers, swimmers, middle distance runners) (Carr et al., 2023; Grgic et al., 2021). However, the timing or scenarios within a tennis match in which acid-base balance might become limiting for performance is less certain, and longer matches might require a later intake or a “top up” during the match to align the strategy with the time of required support. Further research is needed if strategies which are of sufficient benefit to tennis players are practical to achieve. Although sodium citrate is sometimes promoted as the buffering supplement of choice due to the lower prevalence of some gastrointestinal effects, smaller effects on extracellular buffering capacity are noted (Peacock et al., 2021).

10. EXPERT GROUP TOPIC 7: ENVIRONMENTAL AND TRAVEL CONSIDERATIONS

Tennis is played all around the world, including in naturally hot environments and in summer months, with many tennis players moving to compete in these environments from cooler locations. Travel provides a range of challenges, including jet lag, as well as the changes in the food environment previously identified. Hot weather competitions provide challenges, not only for players, but for umpires and spectators, with specific mitigation strategies such as Extreme Heat Policies now being promoted to event organizers (Racinais et al., 2015). Players should adequately prepare for competing in hot conditions by heat acclimatizing and by implementing individualized cooling strategies (e.g., ice towels and fanning) based on the type of environment they will encounter (e.g., hot/dry versus hot/wet) (Schranner et al., 2017). Other countermeasures including appropriate nutrition and hydration strategies are also useful (Girard, 2015; Girard & Millet, 2009; Kovacs, 2006c).

Strategies to optimize thermoregulation

Hot and humid environments can exacerbate physiologic and cognitive challenges of tennis, especially during Grand Slam events (Morante & Brotherhood, 2008). Thermoregulation is essential, not only to achieve better performance in sports, but also to avoid injuries, dehydration, or even death (Périard et al., 2015; Racinais et al., 2015). The Australian Open is the first Grand Slam tournament of the year and players often encounter high temperatures that are further increased by solar radiation and reflection off hard court surfaces. These conditions can result in health problems for the players, even leading to increased courtside medical calls and withdrawals (Smith et al., 2018). The Australian Open Extreme Heat Policy (Australian Open Extreme Heat Policy, 2019) in 1998 and updated most recently in 2019, provides a number of strategies to safeguard player health and welfare, based on a bespoke heat scale that accounts for four climate factors – air temperature, radiant heat or the strength of the sun, humidity and wind speed. Actions range from encouraging fluid intake and cooling strategies, through to allowing breaks in play or suspending play entirely. The stadium roof can also be closed at the discretion of the umpire.

Heat acclimatization

Although regular exercise in hot conditions elicits partial heat acclimatization, consecutive days of training in the heat is more beneficial. Heat acclimatization improves thermal comfort and submaximal as well as maximal aerobic exercise performance in warm to hot conditions. The benefits of heat acclimatization are achieved via increased sweating and skin hyperemia, plasma volume expansion, and hence improved cardiovascular stability and fluid-electrolyte balance. Exercise-related heat acclimatization is therefore essential for athletes preparing for competitions in warm to hot environments (Nassis et al., 2015). Sessions should last at least 60 min per day inducing an increase in core body (e.g., rectal temperature ≥38.5° C) and skin temperatures, in addition to stimulating sweating. Adaptations begin with-in the first few days, but the main effects are not fully realized until approximately 1 week. Ideally, the heat acclimatization period should last 2 weeks to maximize all benefits (Racinais et al., 2015).

Hydration and electrolyte replacement

Topic 5 introduced the concept of a fluid plan, including pre-match hydration and drinking during the match, suited to the individual and the conditions. Under hot conditions, and particularly in extreme heat, it can be difficult to keep pace with high rates of sweat loss. Large volumes of fluid intake during high-intensity sports involving frequent changes in pace and direction may exacerbate the risk of gastrointestinal issues, including vomiting, particularly in some individuals. Practicing with drinking during training and match play can help players build tolerance for higher intake rates (Lambert et al., 2008) and reduce the magnitude of the likely fluid deficit and its contribution to the physiological challenges of exercise in hyperthermic conditions. Nevertheless, each player's plan needs to be tweaked to suit their gastrointestinal tolerance, and some players may need to focus on greater pre- and post-match rehydration to address a lower capacity to match fluid losses during play. Given that electrolytes are also lost in sweat, hydration plans should be pro-active with electrolyte replacement, especially sodium ("salt"). This has been covered in relation to post-match recovery (Topic 5. Match day Nutrition) and becomes even more important in tournament scenarios where losses may be amplified (Racinais et al., 2015). Sodium replacement between matches via electrolyte supplements and salt-rich foods is encouraged. Electrolyte intake during matches can be achieved by the use of sports drinks and other sport foods, including those with higher electrolyte concentrations that are produced for scenarios with higher sweat rates/electrolyte losses (often called "endurance" formula). Whole body muscle cramps, called exertional cramps to distinguish them from muscle-specific conditioning-related cramps, have been associated, not without controversy (Schwellnus, 2009), with high rates of sweat and electrolyte loss (Bergeron, 2008). However, even if this is not a universal issue, it makes sense to take a more pro-active approach to sodium intake during scenarios of greater loss.

However, even with a pro-active approach to fluid intake during play, hot weather play may be associated with significant fluid deficit in each match, that can accumulate over the tournament. Topic 5 noted the frequency with which tennis players begin a match with an existing fluid deficit (Bergeron, 2014; Périard et al., 2014b, 2014a). Therefore, strategies that monitor hydration status and target rehydration between matches are valuable. Hydration parameters include daily body mass changes <1 %, plasma osmolality <290 $\text{mmol}\cdot\text{kg}^{-1}$, and urine specific gravity <1.020 (Racinais et al., 2015). Pre-exercise hyperhydration involves the intake of large amounts of fluid (e.g. 25 $\text{ml}\cdot\text{kg}^{-1}$) in the hours prior to exercise in the heat, with the co-ingestion of an osmolyte such as sodium (e.g.7-8 g·L^{-1}) and/or glycerol (e.g. 1-1.2 g·kg^{-1}) to aid in fluid retention and sufficient time (e.g. 120-150 min) for excess fluid to be excreted as urine (Jardine et al., 2023; McCubbin & Irwin, 2024). Such strategies have been trialed with running and cycling protocols and found to achieve an improvement in hydration status (retention of an extra ~ 600 ml) to provide a buffer against subsequent unmatched sweat losses (Jardine et al., 2023; McCubbin & Irwin, 2024). Although improvements in plasma volume, and the thermoregulatory and perceptual responses to exercise have been noted, the available literature on performance outcomes is sparse. In particular, studies on high performance athletes, especially female athletes, are warranted. Such investigations should address issues such as the risk of gastrointestinal discomfort and the impact of increased body mass on sports that require running with frequent changes in pace and direction (Jardine et al., 2023; McCubbin & Irwin, 2024). A practical consideration for tennis is that such strategies may only apply to matches with a suitable preparation period and a fixed starting time.

Cooling strategies

Cooling strategies can significantly improve exercise performance in the heat if they improve thermal comfort and reduce cardiovascular strain. These interventions include external (e.g., application of iced garments, towels, water immersion, or fanning) and internal (e.g., ingestion of cold fluids or ice-slurry) methods. In the latter case, the benefits are attributed to perceptual cooling and a reduction in internal heat storage, primarily due to the enthalpy effect when ice-slurries ("slushies") undergo phase change within the body (Jay & Morris, 2018). The application of both external and internal cooling strategies results in a higher cooling capacity than the same techniques used in isolation (e.g., ingestion of ice-slurry, wearing cooling vests, and providing fanning). The logistics of tennis may allow a combination of cooling before and during the match, providing superior outcomes for improving exercise performance in the heat than one strategy in isolation (Bongers et al., 2015). A range of strategies are observed in play and require targeted study according to the conditions they are trying to address and the practicalities of implementation. Most importantly, cooling strategies should be individualized for each player and well-practiced (Duffield et al., 2011; Wiewelhove et al., 2021).

Jet lag and Travel Fatigue

Tennis players usually travel across multiple time zones every season. As a result, many attempt to adjust to jet lag or manage travel fatigue, which can have deleterious effects on cognitive and physical performance (Silva et al., 2019). Jet lag is caused by rapid travel across time zones (>3) and results in desynchronization of the circadian system to the destinations new environment (Janse van Rensburg et al., 2021). Travel fatigue is often experienced following travel and can occur regardless of the mode of travel or changes in time zones (Janse van Rensburg et al., 2021). It also typically accumulates over time and is likely experienced by tennis players due to the significant travel these athletes undertake.

The circadian system regulates physiological, psychological and behavioural functions that occur diurnally and cyclically and is regulated by a central "master clock" and peripheral clocks located in almost every cell of the body (Janse van Rensburg et al., 2020). Both the master and peripheral clocks are synchronised through *zeitgebers* or time-givers, with light, sleep/wake, physical activity, social cues and meals being the most common (Janse van Rensburg et al., 2020). These effects may occur to a greater degree when athletes travel eastward, as the "body clock" is slightly longer than 24 h. This requires the body to phase *advance* as the body clock is behind (i.e., at an earlier time of day) compared to the destination time zone and must advance or move forward (to a later time of day) to become synchronised (Janse van Rensburg et al., 2020). When traveling westward a phase *delay*: is required as the body clock is ahead of time (i.e., at a later time of day) compared to the destination time zone and has to delay or move backward (to an earlier time of day) to become synchronised. Therefore, jet-lag symptoms can persist for longer when traveling eastward (approximately one day per time zone crossed) than westwards (approximately a half-day per time zone crossed) (Janse van Rensburg et al., 2020).

Jet lag is associated with a range of negative effects including disturbances in mood (e.g., tension, anxiety), impaired sleep and daytime sleepiness, gastrointestinal symptoms (e.g., nausea, vomiting, and appetite loss), and impaired cognitive and physical performance (Janse van Rensburg et al., 2020). A range of strategies can be implemented around travel to minimize the effects of jet lag, as well as mitigate other challenges associated with long haul travel, including travel fatigue. In the days prior to travel, it may be possible to start to adjust sleep habits to the new time zone (Ranchordas et al., 2013; Silva et al., 2016). However, while theoretically advantageous, it is often very impractical due to timing of training and lifestyle activities and altering sleep patterns prior to travel may result in reduced sleep durations. On board the flight, it is often recommended that travelers reset their watches and phones to the destination time to get used to the new schedule in advance (Vitale et al., 2019). However, others suggest keeping the sleep schedule of the city of departure (Fowler et al., 2021). Keeping on the departure time zone may result in additional sleep on the flight as the players circadian rhythm will be synchronized to the departure time zone. However, this decision is likely dependent on duration of flight and number of flights.

Food provision on flights should be considered, with options to provide or supplement the existing catering with the special meals provided by some airlines or foods and drinks taken on board by the player. The latter needs to be carefully chosen in relation to food hygiene and the logistics of safe storage and consumption. In some cases, flight or customs regulations around fluid and food supplies may create further limitations, with solutions include carriage of empty bottles and containers to fill with post-security purchases or supplies on the aircraft.

Airplanes have low humidity leading to greater than usual respiratory fluid losses as well as changes in fluid availability when compared to usual options (e.g., smaller drink serves and container sizes, restricted movements on board that make it difficult to obtain drinks). Indeed, travelling athletes tend to consume less fluids and less food rich in water than normal (Silva et al., 2016). Although quantitative guidelines for fluid intake are often provided for long haul travel (e.g. drink ~ 100 to 300 $\text{mL}\cdot\text{hour}^{-1}$) behavioral recommendations can also be useful in improving hydration status. These include having access to personal fluid supplies rather than relying on airline catering schedules, and choosing drinks that promote better fluid retention, such as drinks containing electrolytes rather than water (Zubac et al., 2020) or fluids consumed at the same time as meals or snacks (containing salt). Although travelers are generally warned that that alcoholic beverages or drinks containing caffeine promote diuresis (increased urine losses), the effects of these, particularly caffeinated drinks, are generally overstated (Zhang et al., 2015) and it is often forgotten that they contribute to total fluid intake. Generally, they should be consumed with caution, if at all, with regard to their effects on sleep quality and quantity (Ranchordas et al., 2013; Silva et al., 2016).

Light exposure is considered the most effective *zeitgeber,* with light exposure during the 0-to-3-hour period on either side of the core body temperature minimum resulting in the maximum phase shift (Bin et al., 2019). The wavelength (shorter blue light, 400–495 nm) and intensity of bright light (≥ 2500 lx) and the duration of exposure (longer) will determine the degree of phase shift (Janse van Rensburg et al., 2020).

Melatonin supplementation has been studied for its ability to aid resynchronization following long-haul travel. Although results of a meta-analysis were positive, they were based on only a few poor-quality studies (Chan et al., 2021). The use of melatonin at the new destination may assist circadian re-alignment however incorrect timing of administration may be counterproductive and cause detrimental side effects (Janse van Rensburg et al., 2020). This is due to the pattern of endogenous melatonin secretion being inversely related to body temperature and peak melatonin release corresponding to the timing of lowest core body temperature (Atkinson et al., 2003). Therefore, melatonin is recommended to be provided at time points relative to the nadir in core body temperature, which is typically unknown or estimated. For a thorough description of the role of both endogenous and exogenous melatonin in jetlag as well as methods to calculate timing of exposure, please see (Janse van Rensburg et al., 2020).

When possible, it is recommended to arrive with sufficient time before the tournament to adjust the new environment. Maintaining regular habits such as waking up at the same time, going to bed at the same time and doing similar evening routines may be useful (Vitale et al., 2019). Players should optimize light exposure and avoid light exposure at specific times (Fowler et al., 2021; Vitale et al., 2019), based on direction of travel and number of time zones crossed (Janse van Rensburg et al., 2020). Following basic sleep hygiene guidelines including a cool, dark and quiet bedroom environment, where possible, is important (Walsh et al., 2021). The use of earplugs and eye makes can be helpful (Walsh et al., 2021).

Exercise can promote sleep post-flight however excessive volume, number of hours, and frequency per week of training sessions could negatively affect sleep and recovery from long-haul travel. Players should also avoid excessive intake of fluids in the evening since the need to urinate could disrupt sleep (Ranchordas et al., 2013). Caffeine and alcohol consumption in the evening also may interfere with sleep, but in the morning, caffeine can help players to readjust their “body clock” (Ranchordas et al., 2013; Silva et al., 2016).

11. EXPERT GROUP TOPIC 8: NUTRITION FOR ILLNESS AND INJURY REHABILITATION

Immune Health

One of the biggest challenges facing tennis players throughout the season is staying healthy, with interruptions due to upper respiratory infections and gastrointestinal disturbances often clustering around intensified training periods (Williams et al., 2019). Additional factors that stress athletes' immune systems include frequent travel, poor sleep quality, and LEA (Colbey et al., 2018). The importance of adequate nutrients such as glucose, amino acids, and fatty acids, as well as micronutrients (including vitamin C, vitamin D, zinc, iron, magnesium) and microorganisms like probiotics, are all recognized in promoting a robust immune system (Walsh, 2019). It is outside the scope of this paper to thoroughly review current research on immune health of athletes, but extensive work has been conducted on this topic (Bermon et al., 2017; Colbey et al., 2018; Jäger et al., 2019; Pyne et al., 2015; Sivamaruthi et al., 2019; Walsh, 2018, 2019; Williams et al., 2019). Nutritional supplements with the strongest support for immune function will be briefly discussed here – probiotics, vitamin C, and zinc.

Probiotics are supplements containing live microbes that may have beneficial effects on intestinal microbial balance and health. The two main species used in commercial preparations are lactobacillus and bifidobacterium, but products vary according to the number of strains (single or multiple), the number of bacterial units (an effective dose requires at least 1 billion - 10^9 - with some products providing 25-50 billion per dose) as well as the form (shelf stable or requiring refrigeration) (Australian Institute of Sport Sports Supplement Framework, n.d.). Probiotics can also be consumed in fermented foods such as yogurt, cultured milk products, and fermented drinks (e.g., kombucha or kefir). The results of studies of direct effects on sports performance are mixed and may be complicated by the variability in the doses, strains and duration of supplementation protocols (for review, see (Calero et al., 2020; Jäger et al., 2019; Wosinska et al., 2019). However, reviews of the general sports nutrition literature conclude that probiotic supplements can assist with gut health and immune function, especially periods of travel or strenuous training/competition (Jäger et al., 2019). Further research is needed on probiotics, in both supplement and food forms, and other variants that may alter gut health to identify products and protocols that may enhance player health. This includes pre-biotics (sources of soluble fiber for the maintenance of the intestinal flora), symbiotics (products that provide bacterial strains and soluble fiber at the same time) and post-biotics (sources that directly provide the products and metabolites produced by the flora). At the present time, a proactive stance that may achieve the potential benefits of probiotic use, in tennis players who have had stomach health problems in the past during travel and extended stays in other countries, is to commence supplementation 2 weeks prior to the event to allow for adequate colonisation of the gut (Australian Institute of Sport Sports Supplement Framework, n.d.; Jäger et al., 2019).

Specific benefits of interest to high performance athletes may include a protective effect on gut health, particularly when compromised by strenuous exercise in the heat or the risk of traveler's diarrhea (McFarland, 2007). However, further research is needed to confirm optimal supplementation protocols and applications for use. The area of greatest research involves the role of probiotics in reducing the number of episodes, severity, and duration of upper respiratory tract infections (Pyne et al., 2015; Zhao et al., 2022). Here the commensal microbial community may interact with an athlete's immune function via a common mucosal immune system, protecting it against the reduction in immune function often seen with periods of strenuous exercise. The literature on probiotic supplementation and upper respiratory tract infections is mixed, due to differences in methodologies and supplementation protocols (for review, see (Jäger et al., 2019)). However, the most recent Cochrane Review of probiotic supplementation in the general community reported that they may reduce incidence of upper respiratory tract infections by ~24% and reduce the mean duration of an illness episode by ~ 1.2 days (Zhao et al., 2022).

Vitamin C is a water-soluble antioxidant vitamin that has been studied extensively for its role in enhancing immune cell function and preventing and treating upper respiratory infections and the common cold (Hemilä & Chalker, 2013). Vitamin C is found naturally in a variety of foods, including citrus fruits, berries, kiwi fruit, broccoli, bell peppers, and potatoes. While routine vitamin C supplementation does not seem to reduce incidence of the common cold in the general population, regular vitamin C supplementation (250-1000 mg) may reduce the risk of upper respiratory infections in athletes undertaking strenuous exercise (Hemilä & Chalker, 2013). Meanwhile zinc is a trace element that acts as a cofactor for immune cells (Walsh, 2019), with zinc deficiency being linked to increased susceptibility to infections (Bermon et al., 2017). A meta-analysis of studies of zinc supplementation and the common cold found that zinc acetate and zinc gluconate lozenges containing 80-92 mg·d^{-1} of elemental zinc reduced the duration of a common cold by 33% (Hemilä, 2017). It appears that a specific supplementation protocol is required, with multiple uses of the zinc lozenges (6-10 times over the day) at the first onset of symptoms. There is little support for the prophylactic use of zinc supplements. However, in the management of a common cold, athletes should consider a total dose of 75 – 100 mg·d^{-1} of elemental zinc for 5 days, started as soon as possible (preferably within 24 hours) after the onset of symptoms (Hemilä, 2017). In all cases, of prevention and/or management of illnesses, decisions re supplementation should be made and managed by the medical team. Furthermore, players should practice good hygiene measures which reduce their risk of exposure to pathogens and of spreading these to other athletes.

Nutrition for injury prevention and rehabilitation

High-level tennis players regularly participate in numerous training sessions and/or competitive matches on consecutive days (Gescheit et al., 2015). Moreover, the high-intensity efforts that characterize tennis involve repetitive manoeuvres (i.e., strokes, accelerations, decelerations, and changes of direction) for lengthy periods (on average 90 min), which place stress on the upper and lower limbs (Fernandez et al., 2006). Incidence of injury among elite tennis players ranges between 1.0 – 2.8 injuries per 1000 games played and 1.3 injuries per 1000 hours of training (Gescheit et al., 2019; Moreno-Pérez et al., 2019). In tennis, most injuries occur in the lower limbs and trunk, mostly affecting muscles and tendons (Moreno-Pérez et al., 2019). Elite-level tennis players tend to have more acute injuries in the lower body, while upper-extremity injuries involve more chronic, overuse injuries (Ellenbecker et al., 2009).

Although few studies have examined nutritional strategies to reduce the risk of injuries in sport, it is judicious to ensure adequate energy availability, with a focus on nutrient-rich foods that meet macro/micronutrient needs and avoid suboptimal status of key nutrients such as protein, vitamins C and D, copper, n-3 PUFA, and calcium(Close et al., 2019). There is also particular interest in supplements that might have potential to reduce injury risk (Close et al., 2019). Tendinopathy is one of the most common musculoskeletal issues in tennis players (Moreno-Pérez et al., 2019). Tendons are dynamic tissues that respond to load (Magnusson et al., 2010) by increasing the content of directionally oriented collagen and the density of cross-links within the protein to increase the tensile strength of the tendon (Susilo et al., 2016). The combination of tendon loading with nutritional interventions that may support collagen synthesis, specifically supplementation with collagen and vitamin C is being actively investigated (Shaw et al., 2017). However, the current literature is premature in providing high-level evidence for the use of collagen supplements for either injury prevention or treatment. Although certain reviews of this literature have reported that long-term supplementation with collagen (15 g/d) and vitamin C may assist with improvements in tendon morphology and mechanical properties (Turnagöl et al., 2021), there is no unanimity on the more efficient doses to be used (Noriega-González et al., 2022). Further research in high-performance athletes is needed before firm recommendations can be made.

Bone injuries are also common in athletes, especially stress fractures (Fredericson et al., 2006). Although previous studies have identified several factors related to increased risk of stress fracture (Fredericson et al., 2007), nutritional inadequacies may also be a risk factor (Moran et al., 2012). However, the available evidence does not support any specific nutritional strategies that might prevent injury other than to maintain adequate energy availability (Topic 4) and match day/training fueling. Strategies such as load control can be more beneficial for this purpose.

When injuries occur, they result in the cessation, or at least reduction, in the practice of tennis (Pluim et al., 2009). Additionally, depending on the type and severity of the injury, limb immobilization may be involved (Tipton, 2015). Such severe injuries are generally considered to involve two phases. During the acute injury phase, immobilization/inactivity leads to rapid muscle atrophy due to a reduction in muscle protein synthesis and anabolic resistance to protein intake (Mettler et al., 2010; Wall et al., 2013, 2015). Higher protein intakes (1.6 to 2.5 $g \cdot kg^{-1}$ body mass/day), spread equally at meals over the day, may help to mitigate muscle loss and counter the anabolic resistance, during recovery (Tipton, 2015; Wall et al., 2015). While some experts have recommended the use of creatine and omega-3 fatty acid supplements to mitigate muscle loss (Wall et al., 2015), others have suggested that the anti-inflammatory effects of omega-3 fatty acids may be counteractive to the healing process and that creatine supplements may only be effective for “responsive” individuals during this acute phase (D. Pyne et al., 2021). However, in the second phase, injury rehabilitation, such supplements may have been beneficial in supporting repair and hypertrophic responses to the exercise program. Adequate energy availability is also important in supporting both the acute and recovery phases of injury but is often at risk in the injured athletes (Burke & Maughan, 2012). Here, LEA may occur as a deliberate (but misguided) attempt to reduce body fat gain during periods of lower activity, or as a failure to understand the energy cost of ambulation with crutches or rehabilitation programs. Inadequate intake may also occur due to interference with domestic routines, food preparation or resources. This is a time in which expert guidance around nutrition support is needed.

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12. EXPERT GROUP TOPIC 9: SPECIAL POPULATION GROUPS

Female players

Across the past decades, there has been improvement in the professionalism, commercial interest and participation in women's sport in many arenas (Thompson, 2019) with tennis leading some initiatives including equal pay for major tournaments (Cepeda, 2021; Mercer & Edwards, 2020). Despite achieving parity with men in some areas, however, there are a number of ways in which female tennis players have different needs and considerations than their male counterparts. Difference in game characteristics include not only the distinction of the match length (3 sets vs 5 sets) at the Grand Slam tournaments, but differences in the technical, tactical and physical workloads of playing styles (Reid et al., 2016; Whiteside & Reid, 2017). These differences have implications for training and conditioning practices and for match day nutritional strategies.

The physiology of a female athlete is complicated by her menstrual status, which involves a range of interchanging versions including pre-menarche, natural menstrual cycle (with distinct phases), various menstrual cycle disruptions or absence, the use of hormonal contraception, peri-menopause and menopause (Elliott-Sale et al., 2021). Each of these is distinguished by changes in the concentration and ratio of female reproductive hormones, with the most well-known being estrogen, progesterone, follicle-stimulating hormone and luteinizing hormone (for reviews, see (Carmichael et al., 2021; D’Souza et al., 2023; Elliott-Sale et al., 2020; McNulty et al., 2020)). Recognition that these hormones have a range of effects on body systems, including cardiovascular, respiratory, metabolic and neuromuscular parameters, has led to a range of questions: Is there a difference in performance, injury risk, nutritional needs or other characteristics between and within female players according to changes in menstrual status and phase? Should female tennis players change their training or nutritional practices according to menstrual status or phase? Do female tennis players require difference nutritional guidelines or approaches to their nutrition goals than male players?

Systematic reviews and meta-analyses of the literature, while noting that the low quality of many studies in terms of verifying menstrual status/phase, that differences in attributes or functional performance across the menstrual cycle or between naturally menstruating women and those using hormonal contraceptives are unclear or likely trivial (Carmichael et al., 2021; D’Souza et al., 2023; Elliott-Sale et al., 2020; McNulty et al., 2020). In tennis, one specific study showed a decrease in serve accuracy during bleed days (early follicular phase) without affecting serve velocity or strength measures (i.e., hip and quadriceps) (Otaka et al., 2018). All have recommended that an individualized approach regarding training programs and nutrition plans is required when coaching female players, attending to subjective effects and individual experiences of menstrual cycle phase on women´s performance. An improvement in the quality and quantity of the literature on the effects of menstrual status and phase on exercise and nutrition is of high priority.

Of equal importance is the effect of nutrition and exercise on menstrual health. Disturbances of the menstrual cycle include irregularity in observable characteristics such as the frequency, duration, and features (e.g., blood flow, pain) of menses, as well as a number of less obvious disruptions such as anovulatory cycles (Elliott-Sale et al., 2021). Meta-analyses of studies of menstrual disturbances in athletes (Gimunová et al., 2022; Taim et al., 2023) are hindered by differences in the methodologies (e.g., protocols used to define, collect and verify menstrual disturbances as well as the period over which the observation applied). Nevertheless, across studies with acceptable quality, the mean prevalence of the most common problems was reported as: primary amenorrhea (failure to commence menses by 15 y: 7%); secondary amenorrhea (loss of 3 consecutive periods once menses is established: 16%); oligomenorrhea (cycle length of > 35 d: 23.5%) and dysmenorrhea (painful periods: 32%) (Taim et al., 2023). Wide ranges in prevalence of these conditions are reported between sports and studies of the same sports. Within this literature, specific investigation of tennis players is limited to two studies involving small sample sizes of youth (~14 y) and collegiate (~20 y) players, conducted by questionnaire (Coelho et al., 2013) and pre-participation exam (Tenforde et al., 2017), respectively. These found a prevalence of reported irregularities (oligomenorrhea and secondary amenorrhea) in approximately third to a half of the groups (Coelho et al., 2013; Tenforde et al., 2017).

Disruption of eumenorrhea can have many causes of which endocrine disorders (Saei Ghare Naz et al., 2020) and problematic LEA are among the most important (Elliott-Sale et al., 2018; Mountjoy et al., 2023). Female players and their entourage should recognize that menstrual dysfunction is both a health issue *per se* and a potential signal of underlying nutrition- and/or exercise-related problems. It is likely that female athletes are at higher risk of problematic LEA (Topic 4), due to their typically greater prevalence of disordered eating/eating disorders and concern around optimal body mass and its management (Mountjoy et al., 2023; Nattiv et al., 2007). However, differential diagnoses regarding the underpinning causes of menstrual disorders (and indeed, all other health impairments associated with REDs) should always be considered (Mountjoy et al., 2023; Torstveit et al., 2023). Furthermore, direct treatment of functional impairments as well as attention to problematic dietary practices and/or exercise commitments remain the goal. Special attention is focused on tennis players who use hormonal contraception, since this masks but does not treat the underlying menstrual disorder (Tenforde et al., 2017). Separate assessment of LEA status and menstrual function is needed for such players.

Special nutritional needs for female tennis players include an increase in iron requirements to counter iron losses due to menstruation in addition to the sport-related increase in iron needs (Topic 3). Female players should be regularly screened for their iron status since increased requirements in addition to a lower energy (and therefore dietary iron) intake compared to their male counterparts places them at higher risk of iron deficiency. In addition to advice regarding iron-rich dietary practices (Topic 3), iron supplementation may be needed to prevent or treat iron deficiency. General recommendations regarding supplementation are provided in Topic 6. Although systematic study of the practical outcome of this observation advice is lacking, there may be some benefits from focusing on supplementation during the early and late follicular phases of the menstrual cycle, since levels of hepcidin tend to be lower during those phases (Badenhorst et al., 2021).

The question regarding the need for separate guidelines for female athletes across the range of sports nutrition themes is topical but remains largely unanswered. Unfortunately, despite the increase in other aspects of the involvement of females in sport, a significant under-representation of female participants across the sports science/medicine literature is recognized (Smith et al., 2022), with many areas of sports nutrition and performance being identified as the most unbalanced in terms of female participation (Kuikman, McKay, et al., 2023; Kuikman, Smith, et al., 2023; Smith, McKay, et al., 2022). Some sources have started to make separate recommendations for female athletes, or changes in recommendations for female athletes across menstrual phase or with the use of hormonal contraceptive (e.g., CHO intake in the daily diet or immediately around exercise sessions) (Sims et al., 2023). Although some differences in substrate utilization during exercise with changes in circulating estrogen and progesterone concentrations are noted (Sims et al., 2023), audits of the literature in which the efficacy of guidelines for acute and chronic intakes of CHO have been tested show that the poor quality and quantity of the available studies on female athletes, or differences between male and female athletes, fails to provide actionable information (Kuikman, McKay, et al., 2023; Kuikman, Smith, et al., 2023). Until better evidence is collected, female tennis players should follow the general recommendations for macronutrient intake in the training diet (Topic 3), and competition nutrition strategies (Topic 5), noting that these guidelines include the principles of tweaking according to individualized needs and experiences.

Youth players

Previous sections have identified the potential for young tennis players to undertake considerable training and competition commitments, as well as an altered lifestyle (Topic 1). Both aspects contribute to nutritional challenges; increasing nutritional requirements and/or affecting the player's capacity to meet these needs. For this reason, there has been interest in investigating the eating habits of youth tennis players across ages, competitive levels, and continents. A caveat to the interpretation of all such studies involves the limitations of dietary surveys and their tendency to underestimate true intake and to fail to capture habitual practices. Nevertheless, the consistency of some findings using a range of different methodological approaches, often supported by additional information, warrant comment.

An early abstract described an extensive study of 62 elite youth tennis players involving food frequency and food recalls, an eating attitudes (eating disorder) questionnaire and resting metabolic rate measurements (Page & Johnson, 1993). Attention was drawn from these data to differences between predicted requirements and apparent intake of these players for energy and macronutrients, as well as sex differences between the gaps. A more recent dietary survey of male tennis players (10-13 years old and 14-18 years old) reported that significant numbers of players reported intakes of energy, macronutrients and micronutrients that were below population recommendations (Juzwiak et al., 2008). Meanwhile studies of self-reported habitual training and competition intakes of 12 to 16-year-old players, as well as a more closely assessed group of 14-years-old during a training camp, found through various methodologies and techniques that energy intakes were below projected or recommended levels (Fleming et al., 2022). Factors that may contribute to real rather than artefactual mismatches include poor nutrition knowledge and practical nutrition skills, lack of awareness of requirements, and a food environment that may not provide stable or sufficient access to suitable food choices. In one specific scenario, it was noted that the organized living environment provided meals for the players but no support for between-meal or exercise-focused snacks (Fleming et al., 2022). While catering limitations, and constantly changing environments associated with touring undoubtedly contribute to sub-optimal food intake, the commitment and skill set of the players around eating practices should also be considered. Indeed, in extension of the focus on nutrition practices, one study also reported on poor sleep quality and quantity which was attributed to exposure to new sleep environments as well as personal sleep hygiene practices (Fleming et al., 2022).

Other investigations of youth players have focused on nutritional strategies around competition and recovery. One survey of 70 youth tennis players found that players reported following a match nutrition plan, with water (94%), banana(s) (86%), and sports drinks (50%) most commonly chosen, and an increased used of carbohydrate-rich sport foods, including sports drinks (80%) and energy gels (26%), being applied to matches lasting >2 hours (Fleming et al., 2018). Another online questionnaire administrated to 45 male and female tennis players (~16 years old) reported strategies such as consuming a CHO-rich pre-match meal (29%) and using water (98%), sports drinks (73%), granola or protein bars (42%), and bananas during match play. Matches >2 hours were again targeted for increased use of CHO-rich fluids and foods. With regard to fluid intake during matches, 87% of players reported not having a specific fluid intake goal with 69% determining their needs according to thirst (Truax et al., 2022).

In summary, youth tennis players may have special needs for their own growth and maturation onto which the nutritional requirements for energy-demanding training competition and the irregular lifestyle around touring are superimposed. There is evidence that young players may fail to meet the energy, macro- and micronutrient demands associated with this combination, both as a result of their own deficiencies of knowledge, practical skills and readiness, as well as a failure of their environment to provide the necessary resources and opportunity. The outcome of the mismatches between nutrient intake and nutrient need includes the concerns associated with LEA (Topic 4), and the failure to optimize training (Topic 3) and match (Topic 5) goals.

It is difficult to provide generic recommendations for energy and nutrient targets for youth players since they may vary markedly in biological age and maturity in their sporting pathway. Guidance for training and match demands is provided in Topics 3 and 5 of this statement and should be tweaked according to the level of play and appreciation of the growth and development needs of adolescence, as well as social and cultural needs (Desbrow, 2021; Desbrow et al., 2014). At the global level, more investigation is warranted to identify the specific factors that underpin situations of poor nutritional practices or nutritional status, and strategies by which they can be addressed. This is likely to include increased knowledge and practical skills around targeted nutrition issues, and better infrastructure around the touring lifestyle. At the individual level, specialized advice by a sports dietitian may be needed to help assess the player's needs and develop an appropriate plan. Coaches and parents, as well as the player's tennis organization or developing entourage are likely to play an active role in these activities. In addition to targeted catering and the provision of nutrition support for training and matches, the player's environment should provide a safe space around growth, body image and management of physique (Mathisen et al., 2023). Some studies have found that coaches' knowledge of the nutritional needs of youth tennis, including body composition issues, is very limited and may contribute to the risk of players developing inadvertent and pathological (e.g., disordered eating) practices underpinning LEA (Reagan, 2018). Ongoing efforts are being made by major governing bodies of tennis and other sports, to improve coaching education in sports nutrition, to prevent safe environments around physique management, with the ultimate goal of helping youth tennis players better meet their growth, development, and performance nutrition needs (Mathisen et al., 2023).

Wheelchair tennis

Wheelchair tennis is one of the fastest growing wheelchair sports in the world, with more than 150 international tournaments and over $3 million in prizes available (Sánchez-Pay et al., 2020). Unlike other racquet sports such as table tennis or badminton, where participants may compete in a seated or standing position, wheelchair tennis involves the use of a sport-specific wheelchair. Wheelchair tennis shares the same court size, scoring system and rules as able-bodied tennis, with the exception of permitting 2 bounces of the ball (Mason et al., 2013). Athletes with a permanent lower limb impairment (e.g., lower limb amputation or spinal cord injury at thoracic (T1) level or lower [paraplegia]) are eligible to compete in the Open division, which has separate categories for men and women. Athletes with a permanent lower and upper limb impairment (e.g., cerebral palsy; spinal cord injury at cervical 6 (C6) or C7 level [quadriplegia], and sometimes quadriplegic players using power chairs) compete in the Quad division, where men and women compete together (*ITF Rules and Regulations*, 2024).

Wheelchair tennis shares the characteristics of able-bodied tennis in being an intermittent, multidirectional sport that is predominantly aerobic with short periods of high-intensity activity (Croft et al., 2010; Roy et al., 2006). Wheelchair tennis matches can be affected by performance level, impairment type and level, sex, or even the playing surface (Croft et al., 2010; Roy et al., 2006; Sánchez-Pay et al., 2015; Sánchez-Pay & Sanz-Rivas, 2017, 2021; Williamson et al., 2024). High-level wheelchair tennis matches can last 60 – 70 minutes, with effective playing time about 15 – 20% of that duration, equivalent to a ratio of working time to resting time of around 1:4 with rallies of 5 – 7 seconds (Sánchez-Pay et al., 2015; Sánchez-Pay & Sanz-Rivas, 2017), and three strokes per rally (Mason et al., 2020; Sánchez-Pay et al., 2015; Sánchez-Pay & Sanz-Rivas, 2017). Wheelchair tennis players typically cover distances of 2816 ± 844 m at a mean speed of 0.7 ± 0.2 m·s^{-1} and reach peak speeds of 3.4 ± 0.4 m·s^{-1} (Sindall et al., 2013), with an average HR equivalent to 66 – 75 % of peak HR during singles match play (Croft et al., 2010; Roy et al., 2006; Sánchez-Pay et al., 2016). In addition, players usually hit the ball after the first bounce and volleys represent less than 5% of total shots (Mason et al., 2020; Sánchez-Pay et al., 2020). Although these characteristics are global for wheelchair tennis matches, there are some differences in physical and technical demands among the male, female, and Quad categories (Mason et al., 2020) as well as between playing surfaces (Sánchez-Pay & Sanz-Rivas, 2021).

Energy demands

Energy demands in wheelchair tennis players, especially those with spinal cord injuries, differ from those of their able-bodied counterparts. Differences accrue from the smaller working muscle mass, the smaller size of muscles used during wheelchair displacements, and stroke action (Glaser, 1985; Sanz, 2003). Each player’s daily energy requirements require evaluation based on the nature of their impairment, mode of ambulation outside of training, training levels, and physique. Only one study has assessed the energy requirements of 10 wheelchair tennis players (5 males, 5 females) using doubly labelled water and reported mean daily energy expenditures of 65.2 kcal·kg^{-1} fat free mass (Weijer et al., 2024). This group included a range of impairments and modes of daily ambulation, so the standard deviation was 8.9 kcal·kg^{-1} fat free mass per day, indicating a wide degree of individual variance. Until more research is available, practitioners are encouraged to watch wheelchair tennis players in training and during games to make appropriate nutrition recommendations based on a better understanding of the demands of their sport. Evidence-based nutrition programs for wheelchair tennis players are needed to: i) ensure their nutrient intake is optimal, ii) seek to enhance their training capacity and competitive performance, iii) facilitate their energy availability, especially throughout heavy training periods, iv) support training adaptations, and v) optimize their health.

Research about nutritional habits or strategies in wheelchair tennis is scarce and suffers from the same issues of poor reliability and validity as that of the literature on able bodied players. Studies include a report by Goosey-Tolfrey and Crosland (Goosey-Tolfrey & Crosland, 2010) on nutritional habits in a sample of wheelchair tennis players combined with wheelchair basketball players, while characteristics around energy balance and availability have been assessed in other wheel-chair athletes, with differing outcomes (Egger & Flueck, 2020; Pritchett et al., 2021). Such discrepancies can be at least partly attributed to methodological issues around assessing energy intake and exercise expenditure, as well as a lack of appropriate EA targets for athletes with different physical impairments (Figel et al., 2018). It is likely that risk factors that underpin LEA such as disordered eating and weight loss practices are found among wheelchair tennis players (Egger & Flueck, 2020; Pritchett et al., 2021). However, it is also important to recognize that qualitative and quantitative measures used to screen for LEA or REDs risks may lack sensitivity for wheelchair tennis use; for example, low bone mineral density may reflect a spinal cord injury rather than problematic REDs (Jonvik et al., 2022; Pritchett et al., 2021). Therefore, there is a need to develop para-specific REDs assessment tools (Pritchett et al., 2021).

Macronutrients

Energy intake must ensure a sufficient intake of all macro- and micronutrient needs, including appropriate fueling for training and games. Individualized nutrition recommendations should align with the amount of active muscle, the likely daily energy requirements, and the need to optimize body composition. This likely will require a more conservative application of current macronutrient recommendations for able-bodied athletes, particularly carbohydrate recommendations, together with a pragmatic use of nutrient-rich whole-food sources of nutrients through well-planned timing of meals and snacks relative to training sessions and games. Wheelchair tennis players with lower energy requirements (e.g., athletes with a thoracic or cervical spinal cord injury) might benefit from a periodized approach to carbohydrate intake that focusses on key training sessions (Egger & Flueck, 2020). This strategy would maximize training intensity and facilitate recovery (i.e., protein turnover or glycogen resynthesis) while managing energy balance and body composition goals.

While the average duration of a wheelchair tennis game is 60–70 min, an actual playing time of only 20–30 minutes means that fueling requirements for competition may differ from those of training. Although muscle glycogen usage in wheelchair tennis players has not been studied, it is likely different from those of able-bodied players since movement is predominantly from upper body muscles. Consequently, carbohydrate intake during matches or training may be more important for maintenance of blood glucose levels at optimal concentrations, for which intakes of up to 30 $g \cdot h^{-1}$ should be sufficient (American College of Sports Medicine et al., 2007). In matches lasting less than an hour, smaller amounts of carbohydrates or a mouth rinse should prevent hypoglycemia and its subsequent decrease in performance (A. Jeukendrup, 2014).

When multiple games are to be played in one day, players should optimize glucose availability across the day by consuming sufficient carbohydrate-rich sources between each match. Requirements will vary according to the duration of each game and the overall energy requirements of the athletes, noting that following recovery eating guidelines for able-bodied athletes for lengthier or total day periods (Table 3) are likely to exceed the daily energy requirements of a wheelchair tennis player. Instead, the wheelchair tennis player might focus their recovery strategies to key periods (Ranchordas et al., 2013). Optimizing immediate recovery remains important in a busy training/match schedule; hence, a post-game intake of 1 $g \cdot kg^{-1}$ body mass of carbohydrates and 20-30 g protein is likely to be appropriate for all wheelchair tennis players.

Guidelines for protein and fat intake are covered above (Topic 3) and can generally be adapted to the wheelchair tennis player by using strategies that recognize a lower energy intake. In the case of protein, daily amounts of up to 1.8 $g \cdot kg^{-1}$ should be possible within the energy budget of a wheelchair tennis player without the need for specific supplementation. However, as outlined for players with lower protein intakes and/or energy requirements, there may be benefits in distributing this protein evenly throughout the day and post-exercise to optimize post-training or game recovery. Food choices and protein portion sizes at main meals may require some adjustment to achieve this goal.

Hydration

Fluid requirements are likely different in wheelchair athletes, particularly those with spinal cord injury, who have a limited sweating response below the anatomic location of their injury (Price, 2006). Assessing individual sweat rates and hydration practices in wheelchair tennis players is essential to individualize their daily fluid intake recommendations, especially in relation to training or matches. In some instances, particularly in wheelchair tennis athletes with quadriplegia, it may be necessary to reduce fluid intake to avoid bladder distension and the induction of autonomic dysreflexia (Griggs et al., 2020) a high-risk hypertensive response (Blackmer, 2003).

Coaches and sport scientists have access to a range of tools to help protect the safety of wheelchair tennis players, especially when competing in the heat (Topic 7). Heat acclimatization protocols can be effectively implemented in wheelchair tennis players, with care to monitor individual responses and modify protocols as necessary (Castle et al., 2013; Stephenson et al., 2019). Furthermore, experimenting with a combination of different cooling strategies (i.e., access to shade, ice vests, ice slurries, wet towels) can minimize increases in core temperature and enhance performance, even in thermoneutral conditions (Girard, 2015; Griggs et al., 2017; Pritchett et al., 2020). For top-ranked wheelchair tennis players, monitoring core temperatures using ingestible capsules and assessing skin temperature with high-resolution thermal images (Racinais et al., 2021) could help minimize the risk of hyperthermia (>38.5° C).

Micronutrients and ergogenic aids

Many wheelchair tennis players are considered within the high-risk group for iron deficiency, with reduced energy requirements posing the main risk for inadequate dietary iron intake. Accordingly, iron status should be assessed at least once a year in wheelchair tennis players.

Treatment for iron deficiency is covered in Topic 6 with the caveat that gastrointestinal tolerance and effectiveness of supplementation must be assessed in wheelchair tennis players, especially those with a spinal cord injury. Gradual introduction of supplementation is recommended, and dosing strategies may require modification (e.g., every other day). Specific studies of the iron needs of wheelchair athletes are limited, but one case report found that a daily intake of 105 mg of ferrous iron was sufficient to maintain body iron stores (ferritin) during training at both sea level and high-altitude environments (~4000 m elevation) (Sanz-Quinto et al., 2019).

a) Vitamin D

Athletes who compete in wheelchairs, even outdoors, have a relatively high incidence of low vitamin D status, ranging from 50 – 100% (Flueck, Hartmann, et al., 2016; Flueck, Schlaepfer, et al., 2016; Magee et al., 2013; Pritchett et al., 2016). While tennis is predominantly played outdoors, wheelchair tennis players, especially those with spinal cord injuries, may be at risk of low vitamin D. Risk factors include a smaller amount of skin surface area that is exposed to sunlight, either because of limb loss or the selection of clothes that cover all limbs. In addition, wheelchair tennis players may wish to avoid hotter parts of the day with greater UVB exposure, due to their diminished thermoregulatory capacity (Flueck, Hartmann, et al., 2016; Pritchett et al., 2016). Plasma 25(OH)D status in wheelchair tennis players should be measured at least once a year (preferably in autumn) and supplementation provided if needed, not only to support training capacity and performance, but also for optimal immune function and bone health. While Topic 6 summarizes general supplementation strategies for Vitamin D, protocols recommended to wheelchair tennis players include a set dose (5000 – 6000 IU·day^{-1} for 10 - 12 weeks) (Flueck, Schlaepfer, et al., 2016; Magee et al., 2013). Doses determined by initial plasma 25(OH)D status include 50000 IU·week^{-1} for 8 weeks and then 15000 IU·week^{-1} if deficient, 35000 IU·week^{-1} for 4 weeks followed by 15000 IU·week^{-1} for 8 weeks if insufficient, or 15000 IU·week^{-1} if sufficient (Pritchett et al., 2019).

b) Caffeine

Caffeine is considered an evidence-based performance aid for many sports (Topic 6) but the limited research involving wheelchair athletes has produced mixed results. Performance of a 1500 m race was not significantly changed in a group of wheelchair racers following pre-race (60 min) supplementation with caffeine (6 mg·kg^{-1} body mass), although individuals (3 of 9) may have seen a benefit (Flueck et al., 2014). Meanwhile, a 20 km handcycle time trial improved by 1.5-2.7% in a male triathlete with a spinal cord injury T7 in a dose-response trial involving 2–6 mg·kg^{-1} body mass caffeine (T. Graham-Paulson et al., 2018). More relevant to wheelchair tennis players, caffeine supplementation of 4 mg·kg^{-1} body mass in wheelchair rugby players improved 20 m sprint time and a one-off bout of endurance performance (T. S. Graham-Paulson et al., 2016). Determining individualized dose and timing of caffeine supplementation in training may be critical for wheelchair tennis players, since there are large inter-individual variations in plasma response (peak and duration) to a 3 mg·kg^{-1} dose of caffeine dose at rest in individuals with a spinal cord injury (T. S. Graham-Paulson et al., 2017). In particular, athletes with quadriplegia may require lower doses of caffeine, and athletes with paraplegia may respond better to a longer delay between dose and exercise (up to 90 minutes).

c) Creatine

Creatine supplementation might be useful for improving performance in wheelchair tennis, since rallies are often comprised of several short sprints with limited recovery (Sindall et al., 2013). Experienced wheelchair tennis players who have already optimized other aspects of their training and nutrition, might consider creatine supplementation using the same protocols as recommended for able-bodied athletes (Topic 6): ~0.3 $g \cdot kg^{-1}$ body mass·day^{-1} during 5 – 7 days followed by 3 – 5 $g \cdot d^{-1}$ thereafter, to maintain elevated muscle creatine storage (Kreider et al., 2017). Additionally, after 4-week supplementation, several tests (i.e., stroke ball speed, repeated-sprint ability) should be done to confirm if any benefits have resulted. As is the case for able-bodied players, creatine supplementation is not recommended for junior players due to the lack of evidence around safety and efficacy in athletes under 18 years of age (Topic 6)

13. CONCLUSIONS

Tennis is a complex sport that involves short bursts of intense activity over matches of variable and unpredictable duration. Players are required to move efficiently around the court, hitting powerful shots with great accuracy and tactical intent, while maintaining high levels of mental concentration. Nutrition plays an important role across the lifespan of the high-performance player, supporting the fuel and nutrient needs of a demanding training schedule which often commences during adolescence. Early access to sports nutrition expertise will help the player develop sound eating practices that meet their special nutrition requirements within the lifestyle challenges of travel and tournament play. Increased requirements for energy, carbohydrate, protein and micronutrients vary with the training load and should be adjusted accordingly. LEA may occur due to inappropriate activities related to the challenge of managing variable energy requirements within the changing food environment associated with frequent travel. Meanwhile, the tournament style of competition presents added challenges with matches of unknown duration, and often, unknown starting times, with the player advancing through several draws (singles, doubles) until they are eliminated. Fuel and hydration needs can be substantial, particularly when matches are lengthy and/or played in hot environments. The player and their entourage need pro-active and individualized plans for fluid and carbohydrate during and between matches, as well as nutrition strategies that promote recovery between matches. A few supplements are evidence-based and may be used to support sports nutrition goals or directly enhance performance, but players should take care to only use batch-tested sports foods and supplement products to reduce the risk of inadvertent consumption of substances that are banned in sport. Some populations, including female players and wheelchair players have special needs related to their physiology and match requirements. The Expert Group Statement advocates for an evidence-based approach to nutrition with emphasizes a 'food first' philosophy. Academies, national federations and international organizations are encouraged to engage professionals with appropriate nutrition-related qualifications and professional registrations to support players effectively. Finally, in acknowledging that these guidelines are built largely on an extensive literature involving a range of exercise and sports scenarios, a need for further tennis-specific research is identified.

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Table 1: Characteristics of key competition formats for high performance tennis.

Organization	Competition	Format	Unique Characteristics	Opportunities for the Nutrition Plan
International Tennis Federation	World Tennis Tour	• Best of 3 sets for Men and Women´s Singles (32 competitors) and Doubles (16)	• Full calendar season length—tournaments scheduled from January-December • One-week tournaments held on different court surfaces (hard, clay and grass) • Heavy and unpredictable match schedule. • Sometimes multiple matches in one day (singles and doubles) with potential for short recovery period (as little as 60 minutes between). This is now less common for the top ranked players • 10-point tie-breaker rule change implemented in 2022 • Frequent trans-continental travel with minimal acclimatization to new environment. • Frequent air travel and communal venue eating environments. • Variable environmental conditions • Media pressures, match clothing choices, and time spent away from home support networks. • In women, longevity of career, from teens to 40s, including pregnancy and parenthood.	• Year-round calendar may mean that work on “big picture” nutrition strategies/goals such as physique modification or trialing new match nutrition strategies need to be carefully integrated into strategic periods • Typical 3 set match length is ~1.5-2 h: Nutrition strategies should meet fuel and hydration needs during matches, and in recovery between matches. • Nutritional recovery strategies may become more important with increased match load (e.g. participation in singles and doubles competitions). • Sudden transition to environments with different thermal characteristics may not allow for full acclimatization. Players should quickly adjust to new match needs around hydration, cooling etc. • Players should be aware of increased risk of illness due to frequent travel, group environments, and reliance on local food environments. A proactive nutrition plan should include hygiene considerations as well as strategies to optimize the availability of suitable foods. • Heightened body image awareness and emotional eating susceptibility for female tennis players is recognized. • Differing nutrition needs throughout the life stages should be met within nutrition plan.
	World Tennis Tour Juniors			
	Wheelchair Tennis Tour			
	Team Competitions	• Best of 3 sets for Men (Davis Cup) and Women (Billie Jean King Cup) • 3-4 Singles matches and 1 Doubles		
Association of Tennis Professionals	ATP Tour	• Tournaments of 250, 500 and Masters 1000 • Best of 3 sets for Singles (32-64 competitors) and Doubles (48-64)		
	ATP Challenger Tour	• Best of 3 sets for Singles (32 competitors) and Doubles (32)		
Women’s Tennis Association	WTA Tour	• Tournaments of 125, 250, 500 and 1000 • Best of 3 sets for Singles (32-96		

		competitors) and Doubles (32)		
International Olympic Committee	Olympic Games	• Best of 3 sets for Singles, Doubles and Mixed Doubles (64 competitors)	• Only played every 4 years, players represent their country • Disruption to regular tournament schedule. • Olympic/Paralympic Village provides communal living with national teammates, usually sharing rooms • Olympic/Paralympic Village offers large-scale food provisions and communal dining.	• The infrequent and unique nature of each Olympic/Paralympic Games presents a novel experience for the tennis player. Although some may fully embrace the Olympic experience and try to integrate their specific nutrition plans within the Village environment, other players choose to live externally while competing then join their larger national teams once they have finished.
International Paralympic Committee	Paralympic Games	• Best of 3 sets for Singles, Doubles (95 competitors)		
Grand Slam Board	Grand Slams • Australian Open (January) • Roland-Garros (May/June) • Wimbledon (June/July) • US Open (August/ September)	• Best of 5 sets Men's Singles (128 competitors) • Best of 3 sets for Women's Singles (128 competitors), Doubles (64), Mixed Doubles (32), Juniors (32), Wheelchair (8)	• Two-week tournaments held on different court surfaces (hard, clay and grass) • 10-point tie-breaker rule change implemented in 2022 • AO and US Open can involve hot weather conditions. Others have variable environmental conditions • Players may enter several competitions (singles, double, mixed doubles) leading to a heavy and unpredictable match schedule. This is now less common for the top ranked players	• Typical length of 5 set match is ~2:45 h but (particularly prior to change in tie break rule), the duration of men's singles matches can be > 5 h and include finishes after midnight. Longer and more frequent matches within a tighter schedule increase the demands for fuel and hydration strategies during matches, and in recovery between matches. • Each tournament may call for novel and specific nutrition plans. For example, hot weather conditions at AO will benefit from more aggressive hydration and cooling strategies. Different surfaces may predispose different match characteristics with concomitant effects on nutrition strategies: for example, clay court matches tend to be longer and may need greater nutrition support

Table 2: Example of a 6-day training week during the off-season.

Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
Morning Practice					
Warm-Up (NMT[a])	Warm-Up (NMT)	Warm-Up (Injury Prevention)	Warm-Up (NMT)	Warm-Up (NMT)	Warm-Up (Injury Prevention)
TENNIS	**TENNIS**	**TENNIS**	**TENNIS**	**TENNIS**	**TENNIS**
Afternoon Practice					
Strength	Off-court conditioning	Strength	Physiotherapy	Strength	Off-court conditioning
TENNIS		**TENNIS**		**TENNIS**	
Recovery	Recovery	Recovery	Recovery	Recovery	Recovery

[a] NMT: neuromuscular training

Table 3: Summary of guidelines for carbohydrate intake adapted to tennis players (from Thomas et al 2016; Burke et al. 2018).

	Situation	Carbohydrate targets	Comments on type and timing of carbohydrate intake
DAILY TRAINING NEEDS TO FUEL PRACTICE AND RECOVERY 1. High intensity and high quality/skill sessions (e.g. on court practice) are best undertaken with high CHO[a] availability (i.e., CHO intake to meet the fuel needs of the muscle and central nervous system) 2. When exercise quality or intensity is less important, CHO intake can be more flexible. 3. Some players might choose to take advantage of new insights around enhanced training responses to moderate intensity exercise (e.g. conditioning sessions) undertaken with low CHO availability (e.g., training in a fasted state, undertaking a second workout without refuelling after the first session).			
Light training load	• Lower intensity conditioning work (up to 60-90 min)	3-5 g/kg of athlete's body mass/day	• Targets for high CHO availability are general and should be tweaked according to individual feedback (performance outcomes, hunger, body composition goals). • Timing of CHO intake over the day can target fuelling for a specific session by consuming CHO before or during the session, or by refuelling from a previous session. • Players should focus on nutrient-rich CHO foods to allow overall health needs to be met. • Practice sessions offer opportunities to trial new strategies of pre- and during match intake
Moderate	• 1-3 hours of activity (e.g. one on court + conditioning session)	5-7 g/kg/day	
High	• Double sessions of on-court practice or games (3+ hours)	6-10 g/kg/day	
ACUTE FUELLING STRATEGIES FOR MATCHES			
Day before match	• General match preparation	6-10 g/kg per 24 h as for daily fuel needs	• Players may choose CHO-rich foods in match fuelling meals that are low in fibre and easily consumed to ensure that fuel targets are met and gut comfort is maintained • In many tournaments, the player may be in continual match fuelling/recovery • Since the duration of the upcoming match is unknown, the player may need to make an educated guess about anticipated needs and readjust for subsequent matches
CHO Loading	• Potential preparation for 5 set matches (if practical)	36-48 h of up to 10-12 g/kg per 24 h	
Pre-match meal	• 1-4 hours prior to match	1-4 g/kg	• The player may not always know the exact time of their match or be able to optimize meal timing • The amount and type of CHO-rich foods and drinks can be tweaked by the player according to practicality and individual preferences/experiences.

			• Choices high in fat/fibre may need to be avoided to reduce risk of gastrointestinal issues during the event.
Match fuelling	• Short matches (45-75 min)	Small amounts including mouth rinse	• Frequent mouth contact with CHO (e.g. change of ends, between sets) can stimulate brain/ central nervous system, reducing perception of effort and increasing self-paced efforts • Benefits of fuelling during a match (and mouth sensing) may increase when there has been inadequate refuelling from a previous match
	• 90 min to 3-hour matches	30-60 g/hour	• CHO intake provides additional muscle and brain fuel to supplement glycogen stores. • Breaks (change of ends and between sets) provide opportunities to consume drinks, sports foods and "everyday" goods according to preference and experience • The player should develop a refuelling plan that suits their individual goals including hydration needs and gut comfort • Unpredictable nature of match (duration, intensity) may require player to be aggressive with fuel intake in anticipation of fuel stress, or to address inability to fully refuel from previous match.
	• 5-set/5-hour matches	60-90 g/hour	• Higher intakes of carbohydrate are associated with better performance in events involving prolonged strenuous exercise • Sports products (e.g. sports drinks, gels, chews) containing "multiple transportable CHO" (Glucose:fructose mixtures) achieve higher rates of oxidation of CHO consumed during exercise.
Rapid refuelling	• < 8 h recovery between 2 fuel demanding sessions or matches	1-1.2 g/kg/h for first 4 h then resume daily fuel needs	• There may be benefits in refuelling via smaller frequent snacks than a single large meal. This may also be practical for gastro-intestinal considerations when the timing of the next match is uncertain • CHO-rich drinks may help to ensure that rehydration targets are addressed while refuelling • Protein consumed with recovery snacks may enhance refuelling when it is difficult to meet CHO targets, as well as address other recovery needs

[a] CHO: carbohydrate

Figure 1: The REDs 2023 Conceptual Models for Health (A) and Performance (B) (Mountjoy et al., 2023)**.**