

## Review article

# HYDRATION AND TEMPERATURE IN TENNIS – A PRACTICAL REVIEW

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### ABSTRACT

Competitive tennis is typically played in warm and hot environments. Because hypohydration will impair tennis performance and increases the risk of heat injury, consumption of appropriate fluid levels is necessary to prevent dehydration and enhance performance. The majority of research in this area has focused on continuous aerobic activity - unlike tennis, which has average points lasting less than ten seconds with rest periods dispersed between each work period. For this reason, hydration and temperature regulation methods need to be specific to the activity. Tennis players can sweat more than  $2.5 \text{ L}\cdot\text{h}^{-1}$  and replace fluids at a slower rate during matches than in practice. Latter stages of matches and tournaments are when tennis players are more susceptible to temperature and hydration related problems. Sodium ( $\text{Na}^+$ ) depletion, not potassium ( $\text{K}^+$ ), is a key electrolyte in tennis related muscle cramps. However, psychological and competitive factors also contribute. CHO drinks have been shown to promote fluid absorption to a greater degree than water alone, but no performance benefits have been shown in tennis players in short matches. It is advisable to consume a CHO beverage if practice or matches are scheduled longer than 90-120 minutes.

**KEY WORDS:** Dehydration, heat stress, body temperature, electrolytes.

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### INTRODUCTION

As tennis is a sport that is typically played outdoors in warm and hot environments, there is a need for tennis researchers, coaches and medical staff to understand the effects of temperature and hydration status on the health and performance of tennis players. Exercise-related hypohydration (less than optimal hydration) and hyperthermia (increased body temperature) have been shown to limit performance (Costill and Miller, 1980; Magal et al., 2003; Saltin and Costill, 1988) and this is an area that needs greater investigation into the causes and preventative measures needed to maintain positive hydration and temperature levels.

Tennis is often played in hot, humid environments, and it has been shown that tennis players can sweat approximately  $2.5 \text{ L}\cdot\text{h}^{-1}$  (Bergeron

et al., 1995a), and some players have been recorded with sweat rates greater than  $3.0 \text{ L}\cdot\text{h}^{-1}$  (Bergeron, 2003). However, the gastric emptying rate for beverages rarely exceeds  $1.2 \text{ L}\cdot\text{hr}^{-1}$  (Armstrong et al., 1985a; Coyle and Montain, 1992a). Attempting to keep pace with a sweat rate of greater than about  $1.5 \text{ L}\cdot\text{hr}^{-1}$  is a practical and physiological challenge. Players who ingest more than  $1.25 \text{ L}\cdot\text{hr}^{-1}$  may feel gastrointestinal discomfort as they compete (Coyle and Montain, 1992a; 1992b; Neuffer et al., 1989). During a study looking at collegiate tennis players, the athlete's water consumption was at an approximate rate of  $1.0 \text{ L}\cdot\text{hr}^{-1}$  (Bergeron et al., 1995b), which may be due to this subconscious need to avoid gastrointestinal discomfort.

Exercise performance has been shown to be impaired when an individual is hypohydrated by as little as 2% of body mass, and a loss of 5% can

decrease work capacity by about 30% (Armstrong et al., 1985b; Saltin and Costill, 1988). During exercise, as the magnitude of hypohydration increases, there is an accompanying increase in core temperature — between 0.10°C and 0.40°C — for each percent decrease in body weight (Armstrong et al., 1985a; 1985b; Buono and Wall, 2000; Sawka, 1992). The aim of training programs, ergogenic aids and recovery is to optimize training time and performance while limiting the deleterious effects of increased body temperature and hypohydration.

The purpose of this review is to provide relevant information of the tennis literature on hydration and temperature regulation in an attempt to assist coaches, trainers and medical staff to prepare tennis athletes to perform at a high level.

### **WHY THIRST IS NOT A GOOD GUIDE TO BODY WATER STATUS**

Thirst is not a good indicator of body water status or a sufficient stimulus to prevent a net body water loss during exercise in a hot environment (Bergeron et al., 1995a; Hubbard et al., 1984; Wilmore and Costill, 2004). Ad libitum drinking typically leads to involuntary dehydration. One reason for involuntary dehydration is that 1.5L of body water could be lost before thirst is perceived (Armstrong et al., 1985b; Greenleaf, 1992; Wilmore and Costill, 2004). By this time, impaired exercise thermoregulation has already begun (Greenleaf, 1992). A tennis player's environment and sweat rate are both vital factors in contributing to hypohydration; however, a player's on-court fluid intake pattern is equally important.

A study looking at ad libitum water intake during tennis practice match conditions found that only 27% of the total fluid lost was consumed during play (Dawson et al., 1985). This figure should be of concern to coaches and scientists, and a structured hydration program during competition must be implemented.

The production of sweat will cause an increase in plasma osmolality (an increase solute concentration) that increases the drive to drink fluid owing to the partial plasma retention of Na<sup>+</sup>. With the consequent increase in osmotic gradient (fluid moves to equalize solute concentrations) that is supported by an exercise-induced increase in intravascular albumin (Nagashima et al., 1999), fluid is mobilized from the intracellular compartment to maintain the extracellular fluid volume (Nagashima et al., 1999). This relocation of fluid from the cells reduces an important stimulus for thirst and drinking – extracellular dehydration (hypovolemia). Notably, one study found there were no correlations between postmatch perceived thirst and sweat rate or body

weight percentage change (Bergeron et al., 1995b). This supports the notion that thirst is not a rapid enough indicator of body water status or a sufficient stimulus to prevent a substantial net body water loss during exercise in a hot environment (Greenleaf, 1992).

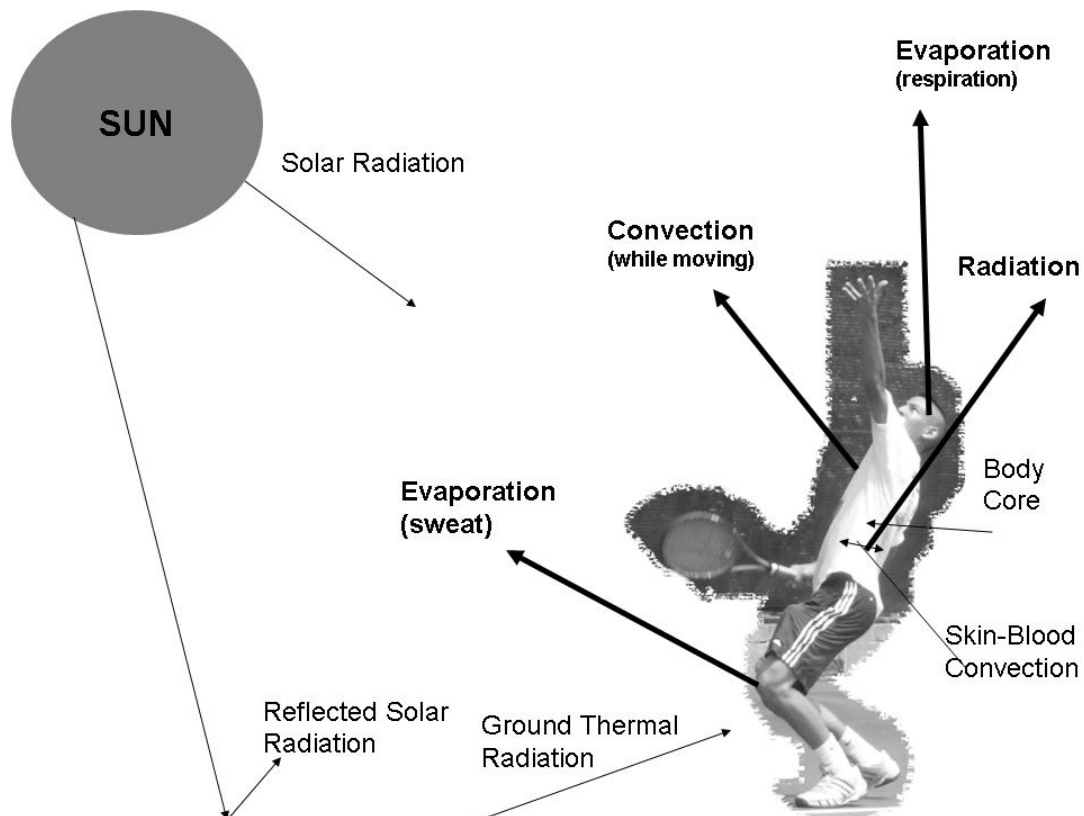
Even a small reduction in body weight (<3%) due to dehydration from anaerobic exercise has been shown to have a negative effect on 5 and 10 meter sprint times (Magal et al., 2003). Also, rehydration during exercise improved sprint times to pre-exercise levels. It has been suggested that a possible mechanism for the reduction in performance due to hypohydration may be associated with the inability or unwillingness of the participants to maintain sufficient central nervous system drive to the working muscles (Montain et al., 1998). The reason for this suggestion is that during a hypohydrated state that induced a 14% reduction in muscular endurance, absolute force (as measured by a maximal voluntary contraction) was comparable to a euhydrated state (Montain et al., 1998).

Plasma volume changes associated with postural changes can impact hydration status. When players are seated (an example may be during changeovers) the postural position increases plasma volume relative to standing (Harrison, 1985). Therefore, the stimulus to drink is possibly further reduced (Bergeron et al., 1995a). This is another reason that athletes should consume more fluid than comfortable on changeovers.

### **TEMPERATURE REGULATION AND TENNIS PERFORMANCE**

Tennis is a complex sport due to the intermittent nature and unpredictable length of matches. The short bursts of high intensity exercise followed by repeated rest periods that can total over four hours makes it challenging, but necessary, to maintain optimum body temperature. The large majority of points in tennis last less than 10 seconds with rest periods lasting no more than 25 seconds (Bergeron et al., 1991; Chandler, 1991; Christmass et al., 1994; 1998; Dawson et al., 1985; Elliott et al., 1985; Ferrauti et al., 2001; Hughes and Clark, 1995; König et al., 2001; Kovacs, 2004; Kovacs et al., 2004; Morgan et al., 1987; O'Donoghue and Ingram, 2001; Richers, 1995; Seliger et al., 1973; Smekal et al., 2001; Therminarias et al., 1991; Yoneyama et al., 1999). This work/rest ratio (like other forms of exercise) can cause large changes in body temperature, but it does allow for ample periods for fluid replacement.

During tennis competition and practice, a player's metabolic rate increases substantially



**Figure 1.** Methods of heat exchange during tennis play.

compared to resting values (Bergeron et al., 1991). Most of the energy released does not contribute to hitting the tennis ball or even moving around the court, since about 80% is released as heat (Bergeron et al., 1995a). Thermoregulation is largely accomplished through evaporative heat loss through sweating, and is typically the most effective on-court mechanism. On-court conductive heat loss (i.e. heat transfer due to contact) from the body is negligible and in many circumstances the court surface is warmer than the athlete's skin temperature, which causes the conductive heat transfer from the court to the athlete and thus increases skin and core temperature. Radiative heat exchange (non-contact transfer of electromagnetic energy) is often weighted in favor of heat gain from absorption of solar energy. Convective heat exchange (heat transfer due to gas or fluid motion) can be a factor, especially on windy days, and as a player moves on court. Convective cooling is not as productive as evaporative cooling for maintaining an appropriate body temperature (Bergeron et al., 1995a) (Figure 1). When the ambient temperature is cool or cold (i.e. less than skin temperature) the metabolic heat produced during exercise can be dissipated from the body through radiation and convection as well as by evaporation of sweat. However, when the temperature of the air and surroundings equals, or is greater than, the skin temperature radiative and convective heat loss are compromised, leaving

evaporation as the only significant avenue of heat loss (Dawson et al., 1985).

If adequate fluid intake is not maintained, a player's thermoregulatory capacity is diminished (Brooks et al., 2000; Jung et al., 2005; Murray, 1992; Murray et al., 1987; Sawka, 1992). A fully hydrated, average-sized, male tennis player (80kg) contains approximately 48L of water (Bergeron et al., 1995a). Muscle tissue is about 75%-80% water, whereas adipose tissue is considerably less (about 10%) (Greenleaf, 1992; Sawka, 1992). Female tennis players have less total body water than their male counterparts of similar weight, because females have less lean body mass and proportionally more adipose tissue. Male and female tennis players can lose between 0.5 and 3.0 L of water per each hour of play, depending on environment, intensity of play, sweat rate, acclimatization, aerobic fitness, hydration status, age and gender (Bergeron, 2003; Bergeron et al., 1995a).

A fluid loss as little as 1% of body weight has been associated with a significant increase in rectal temperature compared to the same exercise performed with normal hydration (Claremont et al., 1975). Heart rates are usually higher when exercising in hot conditions than cool conditions, due, in part, to the large removal of fluid from the blood to replace that lost through sweating (Dill and Costill, 1974) and the need for increased cutaneous blood flow to facilitate heat removal (McCord and

Minson, 2005). Both these functions reduce the central blood volume, which reduces the stroke volume (Powers and Howley, 2001), thus requiring a higher heart rate to maintain the required total blood flow.

It has been proposed that the human strategy behind hypohydration is that thermoregulation is sacrificed for cardiovascular stability with the assumption that, for example, a dehydrating athlete will stop playing and move to a cooler environment (Sawka, 1992). This strategy may be effective for typical individuals; however, it would not be effective in competitive situations, wherein the inherent desire of athletes to deal with adversity and push through physiological barriers is at the core of all successful athletes, but these attributes may also compromise safe human physiological conditions.

## ACCLIMATIZATION

When playing in hot and humid environments, it is important that the athlete becomes acclimatized to perform at optimum levels. The acclimatized athlete will begin to sweat earlier, will have a higher sweat rate for a given core temperature and can maintain a higher sweat rate for a longer period (Hue et al., 2004; Kirby and Convertino, 1986; Yanagimoto et al., 2002). An acclimatized player also loses fewer electrolytes in sweat than a player who is not acclimated (Allan and Wilson, 1971; Kirby and Convertino, 1986). As international level junior and professional tennis players play the majority of tournaments in warm/hot environments, or in indoor environments, acclimatization is not as big a factor in tennis as some other sports.

## ELECTROLYTE BALANCE

Electrolyte balance is important to help limit the likelihood of dehydration, fatigue and possible muscle cramping. Under normal physiologic conditions for acclimated athletes, potassium ( $K^+$ ) and magnesium ( $Mg^{2+}$ ) concentrations will not be high in sweat (Bergeron et al., 1995a). Contrary to the belief of many coaches and athletes that  $K^+$  depletion is major cause in heat related muscle cramps, the clinical evidence supports the relationship between heat-related muscle cramps and extracellular  $Na^+$  depletion—not  $K^+$  depletion (Bergeron et al., 1995a). The total amount of  $K^+$  lost, via sweat during play, should be rather small, relative to whole-body  $K^+$  stores, and of little physiologic or performance consequence (Pivarnik and Palmer, 1994). It would be appropriate, therefore, for tennis players to supplement with  $Na^+$  to help prevent electrolyte imbalances.

In a tennis tournament or repeated days of practice in a hot and humid environment, the cumulative effect of repeated high  $Na^+$  losses over several days may result in a low extracellular  $Na^+$ , especially if daily  $Na^+$  ingestion (through diet) is low. This is a reason why some players may cramp in the latter rounds of tournaments or toward the end of a strenuous training or match day. Exercise induced muscle cramping has multiple factors, and it has been shown that dehydration and electrolyte loss are not the sole reasons for muscle cramping (Jung et al., 2005). These other reasons have still not fully been determined, but psychological stress in competitive situations is a plausible contributor to the onset of muscle cramping during play.

Although unlikely, the combined effect of large sweat  $Na^+$  losses, with ingestion of a large quantity of hypotonic fluid (e.g., unsalted water), could lead to significantly diluted plasma  $Na^+$  (hyponatremia) (Bergeron, 2003; Bergeron et al., 1995b). Even though extensive  $Na^+$  loss during play is possible, the greater concern for a tennis player is the threat of dehydration versus acute electrolyte losses while training or competing.

The rationale for the inclusion of  $Na^+$  in the practice and match fluid intake is related to maintaining plasma osmolality and  $Na^+$  concentration, thereby conserving the drive to drink. Drinking plain water can lead to hemodilution and enhanced urine production, followed by a reduced drive to drink (MacLaren, 1998).

A major study to evaluate a broad range of single- and multiple-match fluid-electrolyte responses in males and females to successive, multi-day, competitive match play in a hot environment was conducted and the results showed that sweat rates of males were consistently higher than females, even when the per hour sweat rates were expressed relative to estimated body surface area (males  $0.9 \pm 0.2 \text{ L}\cdot\text{m}^{-2}$ , females  $0.6 \pm 0.1 \text{ L}\cdot\text{m}^{-2}$ ,  $p < 0.001$ ) (Bergeron et al., 1995b). Accordingly, the male subjects had larger fluid losses than the female subjects. However, fluid intake was similar. This could predispose males to dehydration related problems. The observation of a greater average sweat rate for the male players is consistent with previous, non-tennis specific findings (Avellini et al., 1980; Haymes, 1984). Even though males and females do not ingest enough fluid to replace fluids lost during play, it would be advisable for male tennis players to consume more fluids during practice and matches than females.

Latter stages of tournaments are when athletes are more susceptible to electrolyte imbalances, dehydration and heat related performance decrements. In a study looking at hydration status, it

was shown that more than half the tennis athletes during a four day tournament had less than optimal hydration status as measured by urine specific gravity (USG) readings  $>1.025$  (Bergeron et al., 1995b). Tennis athletes should have a USG  $<1.010$  to indicate an appropriate hydration level (Bergeron et al., 1995b).

## FLUID CONSUMPTION DURING AND AFTER MATCHES

During tennis practices and match situations it is important for athletes to consume adequate fluid and electrolytes. There is some debate as to the best types of fluid to be ingested while on court. Despite water's favorable osmotic gradient for absorption (the majority from the small intestine), most investigators have shown that a carbohydrate (CHO)-electrolyte drink promotes fluid absorption better than plain water (Bergeron et al., 1995a; Gisolfi and Duchman, 1992; Murray, 1992; Murray et al., 1987). The two major reasons for this are: without active solute transport, the intestine cannot transport water effectively and in the presence of glucose, the water transport is enhanced. However, too great an ingestion of glucose can have a negative effect on transport and gastrointestinal comfort ( $>60-90 \text{ g}\cdot\text{h}^{-1}$  or concentrations  $>7-8\%$ ) (Febbraio et al., 1996; Galloway and Maughan, 2000; Wagenmakers et al., 1993). The optimal amount of fluid consumption to maintain hydration is individualized dependant upon environment, intensity level, body mass and sweat rate.

An example of the difficulty tennis players have with replacing fluids has been explained by Bergeron et al. (1995a), using the example of a player who has a  $2.0 \text{ L}\cdot\text{hr}^{-1}$  sweat rate and drinks  $0.25\text{L}$  (approximately 8.5 ounces) of fluid on each changeover (assuming five changeovers per hour). This drinking schedule would replace just 62.5% of the hourly lost fluid (Bergeron et al., 1995a).

It has also been suggested that  $200\text{ml}$  of fluid every 15 minutes is an adequate rate to maintain body fluid balance at a warm environment (WBGT  $27^\circ\text{C}$ ) (MacLaren, 1998). This level of fluid should be increased in conditions that are greater than  $27^\circ\text{C}$  WBGT. This recommendation is equal to  $0.80\text{L}\cdot\text{hr}^{-1}$ , which is less than half the amount of fluid that can be lost due to sweating in hot conditions (Bergeron et al., 1995a; 1995b). Although fluid intake should be individualized per player, if situations do not support this individualization, it would be appropriate, from the research, to recommend a fluid intake guide equal or greater than  $400\text{mL}$  of fluid every 15 minutes ( $1.6 \text{ L}\cdot\text{hr}^{-1}$ ). This figure is chosen because it is slightly higher than the gastric emptying rate (Armstrong et al., 1985a; Coyle and

Montain, 1992a) which will limit the amount of body fluid losses during hot and humid conditions.

Carbohydrate supplementation has been utilized in other sports with varied results. The ingestion of a carbohydrate solution did not improve performance in a three-hour tennis match (under practice conditions) (Mitchell et al., 1992). This result is contrary to previous results (performed in non-tennis exercise studies) (Coyle et al., 1983; Hargreaves et al., 1984; Mitchell et al., 1988). These previous studies were all done on aerobic cycling performances, which differed substantially from the tennis performance tests which were primarily anaerobic tasks, and the cycling tasks are time-to-exhaustion and performance-ride methods.

No performance benefit has been shown with CHO ingestion during tennis play with sessions lasting less than three (Mitchell et al., 1992) and four (Ferrauti et al., 1997) hours, even though ACSM guidelines recommend CHO supplementation ( $30-60 \text{ g}\cdot\text{h}^{-1}$ ) for "intense exercise lasting longer than one hour" (Convertino et al., 1996). Therefore, a general recommendation could be made that there is no apparent benefit in including CHO's in fluid-replacement drinks during less than approximately two hours of tennis play. However, when athletes need to play or practice two or three different sessions during the same day, it is vital to replenish glucose levels. Negative disturbances of glucose levels have particularly occurred after the rest period between a first and second match during live tournament study (Ferrauti et al., 2003). Then while the players warm-up for the subsequent match, there was a sudden drop in glucose levels. In that study (Ferrauti et al., 2003), it did not seem to affect competitiveness; however, in highly competitive situations this could have a large bearing on the players' attitude and readiness to compete at the highest level (Ferrauti et al., 2003). A commercially available CHO-electrolyte (6% CHO) sports drink has been shown, in long duration activities, to help delay the onset of exercise induced muscle cramps, but has not been shown to prevent the cramps (Jung et al., 2005).

Recovery and rehydration after a strenuous practice or match session is vital for health and subsequent tennis performance. After a tennis match or practice, the player's concern should be with replacing lost fluid, carbohydrate ingestion of either liquid and/or solid to aid in glycogen resynthesis and electrolyte replacement (Sherman, 1992). Glycogen synthesis rates are the highest immediately after exercise (Bonen et al., 1985). If CHOs are withheld for two hours post exercise, it can reduce the rate of glycogen synthesis by 47%, compared with feeding CHO immediately after exercise (Ivy et al., 1988). This accelerated rate of glycogen resynthesis is

likely due to the insulin-like effect of exercise on skeletal muscle (Ploug et al., 1987). The specific type of CHO ingested has been shown to be important. Ingestion of high glycaemic-index CHOs resulted in a 48% greater rate of muscle glycogen resynthesis than the ingestion of low-glycaemic index CHOs at 24 hours after ingestion (Burke et al., 1993). It is recommended that players consume 1.5 g·kg<sup>-1</sup> of CHO during the first hour post-exercise, but no greater benefit has been seen on muscle glycogen resynthesis when >1.5 g·kg<sup>-1</sup> of CHO was ingested (Ivy et al., 1988). For example a 75kg tennis player should consume approximately 113g of CHO within the first hour post-exercise. The addition of protein to the CHO has resulted in a 27% greater rate of muscle glycogen accumulation over 4 hours than the same fuel source without 28g of protein (80g CHO and 6g fat) (Ivy et al., 2002).

If a tennis player has to follow up with a practice session or match within one to two hours, it is recommended that a CHO-electrolyte beverage be consumed that contains Na<sup>+</sup> and Cl<sup>-</sup> concentrations of 30 to 40 mmol·L<sup>-1</sup> (Gisolfi and Duchman, 1992).

As ad libitum drinking often leads to involuntary dehydration (Greenleaf, 1992), it would be recommended to have tennis athletes on a specific hydration schedule during match changeovers and practice sessions. Hydration schedule can be developed by the trainer, coach and athlete by measuring fluid loss—practically. The easiest method is to weigh (kg) the athlete before a practice (match) session and then subtract the athletes post-exercise weight (kg) and amount of fluid ingested (L) during play (Equation 1). This will determine the athlete's fluid volume loss for that particular session. This value can be divided by time (hourly, 15 minutes etc) to determine the athlete's approximate fluid loss (sweat rate) per unit of time. From this value an individualized practical hydration routine can be established.

$$\text{Total Fluid Loss} = \text{BW (pre-exercise, kg)} - [\text{BW (post-exercise, kg)} - \text{Fluid ingested (L)}] \quad (1)$$

The following example demonstrates the practicality of equation 1. A tennis player who has a pre-exercise weight of 80kg and who plays for 2 hours while ingesting 2 L of fluid with a measured post-exercise weight of 77kg, will have an approximate fluid loss of 5 L in two hours or 2.5 L·h<sup>-1</sup>. This equation does not account for fluid lost due to urination. If the athlete must urinate it needs to be accounted for in the equation.

## CONCLUSIONS

- Maintaining appropriate fluid levels is vital for performance and temperature regulation. Tennis players need to be on a structured fluid intake program during practice and match sessions.

- Most tennis players sweat more than 2.5 L·h<sup>-1</sup>, yet it is difficult for athletes to comfortably drink more than 1.2 L·h<sup>-1</sup>. This discrepancy makes consuming adequate fluids during play a physiological challenge.

- Thirst is a bad indicator of body water status.

- Tennis players consume less fluids during matches than practice.

- Approximately 80% of a tennis player's energy is released as heat.

- Na<sup>+</sup> depletion, not K<sup>+</sup> depletion is a key electrolyte in heat related muscle cramps.

- Latter stages of matches and tournaments are when athletes are more susceptible to temperature and hydration related problems.

- Recommend athletes drink more than 200ml every changeover in mild temperatures (<27°C WBGT), and it would be highly recommended that each athlete is on a specific hydration routine that has been developed through a monitoring period of sweat changes throughout practice and match sessions.

- Recommend athletes drink more than 400ml every changeover in hot and humid conditions (>27°C WBGT).

- CHO and electrolyte drink promotes fluid absorption to a greater degree than water alone. However, water consumption has been shown to be sufficient for tennis practice and matches lasting less than 90 minutes. As hydration guidelines must be individualized, it is appropriate from the research to recommend that the tennis athletes consume a CHO and water drink if matches or practices are longer than 90-120 minutes.

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### KEY POINTS

- Although substantial research has been performed on temperature and hydration concerns in aerobic activities, there is little information with regard to tennis performance and safety
- Tennis athletes should be on an individualized hydration schedule, consuming greater than 200ml of fluid every changeover (approximately 15 minutes).
- Optimum hydration and temperature regulation will reduce the chance of tennis related muscle cramps and performance decrements.

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