A Review of Fluid and Hydration in Competitive Tennis

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Hypohydration is known to impair performance and increases the risk of heat injury. Therefore, the consumption of appropriate fluid volumes before, during, and after tennis play is important to maintain physiological homeostasis and performance. Tennis is a sport that typically has points lasting fewer than ten seconds, with short-to-moderate rest periods between each work bout. This sequence is repeated over hours. Most fluid and hydration research has focused on continuous aerobic exercise, which provides vastly different physiological strain compared with tennis practice and competition. Consequently, practical recommendations on maintaining hydration status for aerobic continuous exercise may not be appropriate for tennis athletes. Tennis players can sweat more than 2.5 L·h⁻¹ and replace fluids at a slower rate during competition than in practice. In warm and hot environments, electrolyte-enhanced fluid should be consumed at greater than >200 mL per changeover and ideally closer to 400 mL per changeover. Tennis scientists, coaches, and players need to individualize hydration protocols to arrive at the optimal hydration strategy.

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Understanding fluid and hydration status is one aspect in optimizing tennis performance. Tennis is a sport that typically has points lasting fewer than ten seconds, with short-to-moderate rest periods dispersed between each work bout.¹ Tennis is often played in warm-hot environments for multiple hours at a time. This combination of repeated moderate-high intensity activity over a period of hours challenges the tennis athlete to maintain adequate hydration status both for performance enhancement as well as the health and safety of the tennis athlete. Exercise-related hypohydration (less than optimal hydration) can reduce performance and lead to health risks.²⁻⁴ Substantial research has been performed on fluid and hydration in aerobic-focused activities;²⁻⁵⁻⁸ however, tennis players compete in an intermittent, highly anaerobic state, indicated by high maximal oxygen consumption (V̇O₂max) and exercising heart rate (HR) that could classify tennis athletes as highly anaerobically trained athletes.⁹,¹⁰ This may conceivably require different fluid and hydration requirements than traditional aerobic activities (eg, marathon running). In this review, physiological mechanisms leading to performance improvement/decrement will be examined in conjunction with

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practical implications for the player and coach. For a general review of physiological mechanisms related to fluid ingestion and electrolytes, see the work of Sawka and Coyle.\textsuperscript{11}

A MEDLINE database search found 14,423 entries using the search word *hydration*; however, only 8 entries came up when hydration was followed by the word *tennis*. When the same search was performed in the SPORTDiscus database, 1280 entries were found for *hydration*, and when *tennis* was added, 30 responses were found. It is clear that the knowledge and resources are available for in-depth hydration studies in tennis, but little research has been performed. However, the limited research that has been performed provides a clear picture of the fluid and hydration challenges of competitive tennis play. The literature on hydration in tennis was reviewed by using MEDLINE and SPORTDiscus database searches and cross-referencing these articles using the search terms *hydration*, *dehydration*, *fluid consumption*, *hypohydration*, and *tennis*. The purpose of this review was to develop practical recommendations for tennis athletes based upon the evidence-based scientific literature from both controlled laboratory studies as well as field testing in both practice and competitive tennis situations.

**Indicators of Fluid Loss**

The initial drive to drink for most athletes is instigated by the thirst mechanism; however, thirst is not a good indicator of body water status.\textsuperscript{12} Ad libitum (voluntary) drinking typically leads to involuntary hypohydration, as 1.5 L of body water could be lost before thirst is perceived.\textsuperscript{13} A tennis player’s environment and sweat rate both are vital factors in contributing to hypohydration; however, a player’s on-court fluid intake routine is equally important.

The production of sweat will cause an increase in plasma osmolality that increases the drive to drink fluid, owing to the partial plasma retention of Na\textsuperscript{+}.\textsuperscript{14} With the consequent increase in osmotic gradient (fluid moves to equalize solute concentrations) supported by an exercise-induced increase in intravascular albumin and loss of free water,\textsuperscript{15} fluid is mobilized from the intracellular compartment to maintain the extracellular fluid volume.\textsuperscript{14} This relocation of fluid from the cells into the vascular system reduces hypovolemia (an important stimulus for thirst and drinking). Notably, no substantial correlations between postmatch perceived thirst and sweat rate or body weight percentage change were found in tennis players.\textsuperscript{16} This observation supports the notion that thirst is not a sensitive indicator of body water status or a sufficient stimulus to prevent a substantial net body water loss during exercise in a hot environment.\textsuperscript{13}

A player’s thermoregulatory capacity can be diminished if adequate fluid intake is not maintained.\textsuperscript{8,14,17} A fully hydrated, average-sized male tennis player (mass ~80 kg) contains approximately 48 L of water.\textsuperscript{12} Tennis practice and matches can last up to five hours, and players’ sweat rates are often above 1.5 L·h\textsuperscript{-1}. It is not uncommon for athletes to have sweat rates greater than 2.5 L·h\textsuperscript{-1},\textsuperscript{12,18} which may be more than twice that of the gastric emptying rate (1.2 L·hr\textsuperscript{-1}) for beverages.\textsuperscript{19–21} Attempting to keep pace with a sweat rate of greater than 1.5 L·hr\textsuperscript{-1} is a practical and physiological challenge. During a study of collegiate tennis players, the athlete’s voluntary water consumption was approximate 1.0 L·hr\textsuperscript{-1},\textsuperscript{16}
which is close to the typical gastric emptying rate of 1.2 L·hr$^{-1}$. The coupling of voluntary consumption and gastric emptying may be the subconscious desire of the athletes to avoid gastrointestinal discomfort. Another study examining ad libitum fluid intake during tennis competition found that water intake represented only 27% of the total fluid loss. In a more recent study it was found that a sample of tennis players consumed on average 1.6 L·h$^{-1}$ of fluid. Hopefully these observations are evidence that contemporary hydration education is having some effect on tennis players’ fluid consumption habits. These consumption rates, even though improved, still could lead to a body fluid deficit of approximately 1 L·h$^{-1}$ or greater in warm-to-hot environments (assuming a sweat rate > 2.5 L·h$^{-1}$). This level of consumption equates to a 1–2% reduction in bodyweight per hour. In a three hour match this would lead to hypohydration of 3 to 6%. This magnitude of hydration deficit may result in a reduce strength and endurance performance by greater than 30% and severely inhibit temperature regulation, inducing headache, nausea, and other hypohydration-related symptoms.

Competitive factors, such as a close match or highly energized crowds, can inhibit the drive or motivation to consume fluids to a greater extent than during practice. The volume of fluid consumed was less than required for replacement needs, which would, if prolonged, lead to hypohydration. This finding has obvious implications for players preparing for and competing in major tournaments.

### Hypohydration and Tennis Performance

Exercise performance can 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%. Given sweat rates of approximately 2.5 L·h$^{-1}$, some tennis athletes lose greater than 3 L·h$^{-1}$. Clearly, hypohydration is a constant threat to tennis performance as well as health and safety. Apart from lowering body fluid levels, a hypohydrated athlete has a reduced capacity to dissipate heat as a result of reduced blood flow to the skin, which usually results in an increased core body temperature (see Figure 1). The combination of hypohydration and increased core temperature can reduce cardiac stroke volume by ~20% during exercise. This reduction results in an increased heart rate and requires the athlete to work at a greater intensity, which continues the cycle of rising core temperatures. There is evidence that for every 1% of body mass loss due to hypohydration, heart rate increases 5 to 8 beats·min$^{-1}$ and core temperature by 0.2 to 0.3°C (see Figure 1). However, when trying to offset hypohydration, for every 1 L of fluid ingested, core temperature reduces by ~0.3°C and heart rate by 8 beats·min$^{-1}$ (see Figure 2). When hypohydrated, it is clear the cardiovascular demands are increased to maintain performance when fully hydrated.

Even a small reduction in body weight (<3%) due to hypohydration from anaerobic exercise can have a negative effect on tennis players’ 5- and 10-m sprint times. Rehydration (2 mL·kg$^{-1}$ in an initial bolus within 15 minutes of the completion of exercise followed by 9 mL·kg$^{-1}$ in equal volumes every 15 minutes for a total of 90 minutes) during exercise improved sprint times to preexercise levels. Given that it takes between 40 and 60 minutes for ingested fluid to improve physiological symptoms of reduced performance such as heart rate, core temperature,
Figure 1 — Effect of body fluid loss on heart rate and core temperature (information adapted from [9] [12] [18][19]).

Figure 2 — Effect of rehydrated fluids on heart rate and core temperature of hypohydrated athlete (information adapted from [12]).
blood volume, and plasma osmolality, it is more important to prevent hypohydration than trying to rehydrate. This requirement highlights the importance for tennis athletes to have a planned fluid ingestion schedule before and throughout the tennis match to prevent, rather than react to, fluid imbalances.

Apart from the detrimental physiological effects that hypohydration has on tennis athletes, their cognitive function, decision making, and proper execution of complex skills can also be impaired. Tennis is a sport that requires fast reactions and consistent concentration over an extended period of time. Top performance also requires players to choose and execute high percentage tennis strokes over an extended period. Maintaining high cognitive function may be more of a concern in tennis than in some of the sports that have received the majority of hydration research (eg, cycling and running).

During tennis play, as the magnitude of hypohydration increases, there is an accompanying increase in core temperature of between 0.10 and 0.40°C for each percent decrease in body weight (Figure 1). The aim of training programs, ergogenic aids, and recovery time is to optimize training time and performance while limiting the deleterious effects of increased body temperature and hypohydration. A homeostatic explanation for hypohydration is that thermoregulation is sacrificed for cardiovascular stability on the assumption that the hypohydrated athlete will stop playing and move to a cooler environment. 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 their success.

**Electrolytes and Tennis**

Because tennis induces large sweat rates, maintaining electrolyte levels is paramount in order to limit the negative effects of hypohydration. Under typical physiologic conditions for acclimated athletes, potassium (K+) and magnesium (Mg+) concentrations will not be high in sweat. Contrary to the belief of many coaches and athletes that K+ depletion is a major cause of heat-related muscle cramps, some research supports the relationship between heat-related muscle cramps and extracellular Na+ depletion—not K+ depletion. Potassium loss in sweat during exercise is rather small, relative to whole-body K+ stores and, consequently, has minimal physiological or performance consequence. Magnesium is another electrolyte that many health professionals recommend, mainly as a deterrent to heat-related muscle cramps. Magnesium sweat loss is also minimal, but reduced levels of Mg+ have been seen in people who suffer from muscle cramping; therefore, a noncausation link has been made. However, a lower plasma Mg+ level during exercise is more likely due to compartmental fluid redistribution rather than to sweat loss. So supplementing with Mg+ or K+ may not reduce the likelihood of exercise-induced muscle cramping and is not recommended as a beneficial supplement for hydration purposes, but in appropriate doses should be harmless.

Although exercise-induced muscle cramping has multiple causes, the repeated high Na+ losses (due to sweating), which reduce extracellular Na+ content, especially if daily Na+ ingestion (through diet) is low, may partly explain why some
players may cramp in the later rounds of tournaments or toward the end of a strenuous training or match day. Hypohydration and electrolyte loss are not the sole reasons for muscle cramping. Although exercise-induced muscle cramping is still not fully understood, it is plausible that psychological stress may contribute, as anecdotal reports indicate a large number of muscle cramping incidents in tennis players take place during stressful situations in matches.

The combined effect of large sweat Na+ losses with ingestion of a large quantity of hypotonic fluid (eg, unsalted water), could significantly dilute plasma Na+ (hyponatremia). Hyponatremia can have serious consequences, including fatigue, rises in core temperature, muscle cramping, and reduced performance. Hyponatremia is not as common in tennis play as in other sports such as marathon running. More prominent problems are hypohydration-related fatigue, rises in core temperature, muscle cramping, and reduced performance. Gender has a large affect on fluid loss during tennis play. A study evaluating a broad range of fluid-electrolyte responses in males and females to competitive match play in a hot environment found that sweat rates of males were consistently higher than those of females, even when the per-hour sweat rates were expressed relative to estimated body surface area. Males, as would be expected, had larger fluid losses than the female subjects, but the fluid intake was similar. Males have been shown to have greater sweat rates in other, nontennis, exercise research. As a result, fluid consumption guidelines should be different between the genders. Males should attempt to consume greater relative fluid levels during training and competition. At the current time, no gender-specific guidelines for tennis are available for tennis and research in both the laboratory and field settings is needed.

Reduced hydration status, susceptibility to low electrolyte levels, and resultant performance decrements are more commonly experienced by athletes in the later stages of tennis tournaments. During a four-day tournament, more than half the tennis athletes had less-than-acceptable hydration status as measured by urine specific gravity (USG) readings of >1.025. Tennis athletes should have a USG of <1.010 before practice or match play to indicate an appropriate hydration level. Moreover, compared with Na+ (and chloride), the other electrolytes (Mg+ and K+ specifically) have low concentrations in sweat; therefore, it is recommended that if the regular diet is providing an adequate amount of electrolytes, Na+ should be the main electrolyte supplemented in on-court fluid ingestion (20–40 mmol·L⁻¹ of Na+) to help offset the Na+ lost in an athlete’s sweat. This practice is even more important when training or match sessions are long lasting.

**Fluid Intake and Requirements**

**Before a Practice or Match**

A competitive tennis player can practice two or three times throughout the same day. During tournament time, it is not unusual to play three or even four matches in a single day. Therefore, fluid replacement after exercise is not only important from a recovery perspective, but also for match preparations or practice sessions.

In a healthy tennis player, the kidneys excrete excess body water; therefore, consuming excess fluids typically does not induce hyperhydration. Researchers
have tried to develop methods to hyperhydrate athletes to see whether this practice can enhance performance. One method that aids greater fluid retention is supplementing with glycerol, but the numerous side-effects have precluded glycerol supplementation as a practical option. It is important, however, to make sure the tennis athlete is euhydrated before play. The American College of Sports Medicine recommendation that athletes to consume between 400 to 600 mL of water 2 hours before exercise (to allow the kidneys time to regulate total body water volume), should be used as a minimum standard for tennis players to help promote euhydration. This volume would need to be higher if the athlete has lost a substantial amount of fluid in the previous match or practice session on the same day, or if the environmental conditions are hot or humid. Prepractice and match hydration should include some carbohydrate, as well as sodium supplementation. In warm-to-hot conditions, tennis players should consume salty foods (pasta sauces, salted pretzels, soups, etc) and add salt to fluids. Approximately 1.5 g·L\(^{-1}\) of sodium should be included in sports drinks or water in the hours leading to practice or competition.

**Fluid Intake and Requirements During a Practice or Match**

Most hydration education and implementation is focused on fluid, and to a lesser extent electrolyte, ingestion during practice and competition. Despite a favorable osmotic gradient for absorption of water, there is still debate as to which is the best type of fluid to consume, as CHO-electrolyte drink promotes fluid absorption better than plain water.

Fluid volume ingested during practice and play is one area that needs to be individualized for an athlete’s sweat rate, environment, acclimation, and training status. A competitive tennis player who has a normal sweat rate of 2.0 L·hr\(^{-1}\) would need to drink 0.25 L (approximately 8.5 ounces) on each changeover (assuming five changeovers per hour) to replace just 62.5% of the hourly lost fluid. If the player was trying to remain euhydrated (2.0 L·hr\(^{-1}\)), then 0.40 L (approximately 13.5 ounces) is needed on each changeover. Alternatively, 0.30 to 0.40 L of fluid should be consumed every 15 minutes of exercise (1.2 to 1.6 L·hr\(^{-1}\)). These figures are chosen because they are equal to, or slightly higher than the approximate gastric emptying rate 1.2 L·hr\(^{-1}\). Any amounts larger than this would be a physiological challenge for the athletes and may produce gastrointestinal discomfort.

Palatability of the fluid ingested is important in the amount of voluntary fluid an athlete will consume. The greater the palatability, the greater the volume of fluid an athlete consumes. Athletes consume calorie, or calorie-free, flavored liquid during practice and competition to enhance fluid consumption rates to avoid hypohydration.

As voluntary drinking often leads to involuntary hypohydration, a hydration schedules can be developed by the trainer, coach, and athlete by measuring fluid loss. The easiest method is to weigh the athlete before a practice session and then measure how much water is consumed during the session, followed by postexercise weighing of the athlete. After adjusting for any urine losses, the water intake...
is added to the change in body weight providing the approximate sweat rate and fluid volume change for the athlete. Addition of Na⁺ concentrations above 20 mmol·L⁻¹ are recommended since urine production is much lower and more ingested fluid is retained. Hydration protocols should be tested in practice, as a full bladder could hamper concentration during competition. Likewise, a higher osmolality prolongs the thirst and results in greater voluntary hydration.43

**Fluid Intake and Requirements**

**After a Match or Practice**

Postpractice or match hydration is not only important for immediate recovery, but also for performance during play in a subsequent session on the same or the following day. Rehydration after exercise has three major purposes: 1) to replace fluid volume to an equal or greater extent than the volume lost while sweating, 2) to ingest liquid and/or solid carbohydrates to aid in glycogen resynthesis,45 and 3) to replace electrolytes lost during sweating. Water cannot be the only fluid consumed after tennis play because the athlete is typically in a hypohydrated state and an increase in plain water will dilute the lowered electrolyte concentration in the blood and plasma even further. This fall in plasma osmolality and Na⁺ concentration reduces the athlete’s drive to drink and stimulates urine output, which could lead to serious consequences (ie, hypohydration and hyponatremia).43,46 The addition of Na⁺ in postexercise beverages has been supported by multiple position stands.40,47 Sodium supplementation after tennis play should be consumed at a rate of ~1.5 g·L⁻¹.18 Although the incidence of hyponatremia is rare in tennis, it does occur and the consequences are life threatening. Athletes and coaches should be educated on the need to consume sodium-rich fluid and food postmatch to limit the possibility of hyponatremia.

**Conclusions and Practical Applications**

Maintaining appropriate fluid levels before, during, and after tennis practice and competition is vital for performance, as well as health and safety of the athlete. As voluntary fluid ingestion does not provide enough fluid to offset the losses during play, tennis players should employ a structured fluid intake program during practice and match sessions. Tennis players can sweat more than 2.5 L·h⁻¹, yet it is difficult for athletes to comfortably drink substantially more than 1.2 L·h⁻¹. This large difference makes consuming adequate fluids during tennis play difficult. Athletes consume fluids at approximately 1.2 to 1.6 L·h⁻¹, the rate of gastric emptying. Tennis players typically consume fewer fluids during matches than practice. Subsequently, the later stages of matches and tournaments are when athletes are more susceptible to hydration problems. Preventive measures are more effective than reactive responses to hydration-related performance and safety decrements.

Electrolyte balance is an area of interest for tennis, due to the possibility of large electrolyte losses in sweat. The major electrolyte lost during exercise is Na⁺, not K⁺, and this reduction in Na⁺ has been linked to muscle cramping. A typical tennis player who may sweat more than 10 L of sweat with an average sodium concentration (50 mmol·L⁻¹) will need to replace at least 29 g of sodium chloride
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Therefore, Na+ supplementation is recommended in regular diet (eg, sodium-rich foods), or sodium supplementation to fluid ingested before, during, and after tennis play. Tennis athletes should drink more than 200 mL every changeover in mild temperatures, <27°C wet bulb globe temperature (WBGT), but equal to or greater than 400 mL every changeover in hot and humid conditions (>27°C WBGT). Each athlete should employ a specific hydration routine developed through a deliberate and specifically designed program throughout practice and match sessions. A 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. The athlete should consume a CHO-electrolyte drink if matches or practices are longer than 90 minutes, not only for performance enhancement possibilities, but also to aid in fluid palatability. Future research on tennis hydration should investigate methods to increase fluid consumption during matches to limit the losses associated with excess sweat rates, without increasing gastrointestinal distress. It may also be beneficial to monitor changes of ad libitum fluid consumption rates during close matches as opposed to easier matches, and if the hydration rate changes from the beginning to the end of matches. One area of research that should be explored is whether hydration guidelines should be based on gender. Because males typically sweat at a higher rate than females, it would be reasonable to suggest that they consume larger amounts of fluids than females.

References