

5-5-2012

Examination of Preseason Hydration Strategy of NCAA Division I Men's Soccer Athletes

Lesley Willis

Lesley Willis, lesley.willis@uconn.edu

Recommended Citation

Willis, Lesley, "Examination of Preseason Hydration Strategy of NCAA Division I Men's Soccer Athletes" (2012). *Master's Theses*. 286.
https://opencommons.uconn.edu/gs_theses/286

This work is brought to you for free and open access by the University of Connecticut Graduate School at OpenCommons@UConn. It has been accepted for inclusion in Master's Theses by an authorized administrator of OpenCommons@UConn. For more information, please contact opencommons@uconn.edu.

Examination of Preseason Hydration Strategy of NCAA Division I Men's Soccer
Athletes

Lesley Rachael Willis

B.S. in Athletic Training, California University of Pennsylvania, 2010

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

2012

COPYRIGHT

© 2012
Lesley Rachael Willis
ALL RIGHTS RESERVED

APPROVAL PAGE

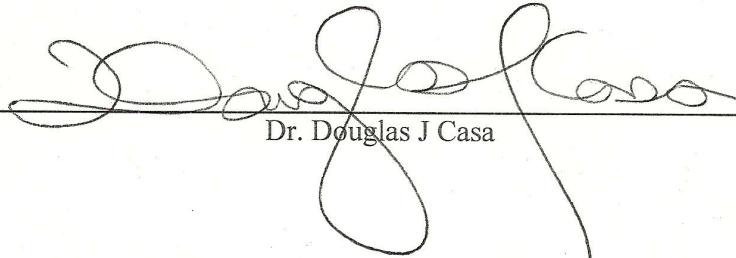
Master of Science Thesis

Examination of Preseason Hydration Strategy of NCAA Division I Men's Soccer
Athletes

Presented by

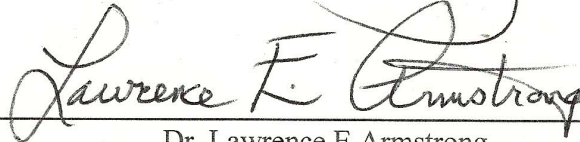
Lesley Rachael Willis, B.S.

Major Advisor



Dr. Douglas J Casa

Associate Advisor



Dr. Lawrence E Armstrong

Associate Advisor



Dr. Carl M Maresh

University of Connecticut

2012

ACKNOWLEDGEMENTS

Dr. Casa- There is no way to thank a person for changing my life as much as you have these past two years. Your constant encouragement and belief in me gave me a kind of confidence I never had. Thank you for inspiring me with your incredible drive and passion.

Dr. Maresh- Thank you for taking time to be a part of my thesis committee. The time and dedication you put into the programs at UConn is truly inspiring. Thank you for making possibilities into realities for me and other lucky students who pass through this department.

Dr. Armstrong- I have enjoyed learning from you. You have pushed me harder than you know to be a better researcher and more perceptive learner. Thank you for your time and attention to my master's thesis.

I could never have done this without the positive and patient support from my family and friends. You are each inspirational to me in your own unique ways. And to David Vandermark, thank you for being the living example of my wildest dreams. They cannot be possible without you.

TABLE OF CONTENTS

I.	Review of Literature	1
	a. Physical Demands of Soccer	1
	b. Body Temperature During Exertion	9
	c. Fluid Balance During Soccer	20
	d. Body Temperature and Hydration Status	28
	e. Conclusion	33
II.	Introduction	35
III.	Methods	37
IV.	Results	45
V.	Discussion	60
VI.	Applicability	78
VII.	Future Directions	79
VIII.	References	80

TABLES AND FIGURES

Tables

1. Distance covered according to activity type and player position	4
2. Reported core temperatures in soccer athletes	10
3. Factors affecting sweat rate	22
4. Reported measures of hydration in soccer athletes from current research	24
5. Mean values for hydration variables	47
6. Mean values for performance variables	49
7. Means for speed zone percentages of time and distance; mean efforts in each zone..	51
8. Mean blood values for markers of hydration and intensity.....	54
9. Means for perceptual measures of mood	55

Figures

1. Energy costs associated with dribbling a soccer ball at different running speeds	8
2. Change in core temperature from rest to full time in recreational and professional soccer matches	11
3. Relationships between skin temperature and air temperature, and absolute and relative humidity	15
4. Intestinal temperature readings during the simulated soccer exercise in fluid and no-fluid trials	29
5. Effects of increased core temperature and dehydration on soccer performance	31
6. Study timeline with session date, identifying number, and location.....	38
7. Timeline of procedures during preseason training and scrimmages	40
8. Overall percent body mass loss	45
9. Urine specific gravity change.....	46
10. Pre and post practice urine color	46
11. Overall average and maximum heart rates.....	48
12. Percentage of total distance by speed zone	50
13. Percentage of time spent in each speed zone.....	50
14. Average T_{gi} by overall and by player year	52
15. Perceptual measures of thirst and thermal sensation	55
16. Hierarchy of themes from post-hoc interviews.....	56

ABSTRACT

Examination of Preseason Hydration Strategy of NCAA Division I Men's Soccer Athletes

Lesley R. Willis, University of Connecticut

Context: Dehydration can have negative effects on performance and mood during intense exercise.

Objective: To examine a soccer program to determine the effectiveness of their hydration protocol during preseason training.

Design: 9-day mixed methods study of preseason training sessions (97.3 ± 21.3 min) and scrimmages (123 ± 14.1 min) for men's soccer athletes on an NCAA division I soccer team with post-hoc interviews of staff members.

Setting: Outdoor soccer field and indoor training facility.

Participants: 21 male NCAA division I soccer athletes (age 20 ± 1 years, height 187.5 ± 2 cm).

Main Outcome Measures: Hydration (BML, U_{col} , USG, U_{osmo}), Mood (thirst, thermal, ESQ, POMS), Performance (distance covered, total efforts, max velocity, T_{gi} , HR_{avg} , HR_{max}), and interview.

Results: No differences between first year players vs. returning players or training sessions vs. scrimmages for BML, U_{col} , USG, or T_{gi} ($p < 0.05$). No effect of time on dehydration (%BML 0.99 ± 0.28 ; post-practice U_{col} 5 ± 1 ; post-practice USG 1.021 ± 0.001 ; pre-practice U_{osmo} 746 ± 159.8). Performance was lower than professional male soccer players (distance 5463.32 ± 1088.26 m; HR_{avg} 132.39 ± 14.18 bpm; HR_{max} 183.6 ± 5.99 bpm; total efforts 250 ± 58 ; max velocity 25.51 ± 1.84 km/h; average T_{gi} 38.11 ± 0.35 °C). Mood

did not significantly change over the preseason period (pre-practice thirst 3 ± 0.1 ; pre-practice thermal 3.8 ± 0.4 ; pre-practice POMS_{TMD} 5 ± 4 ; pre-practice ESQ 5 ± 1). The interview revealed major themes: education and importance placed on hydration, with minor themes: testing, during practice, and outside of practice.

Conclusions: Mild dehydration occurred during intense preseason training. Performance and mood did not decline over the preseason period. This is likely due to emphasis placed on hydration by staff.

Key Words: dehydration, training, recovery, core temperature, mood, perceptual, performance

Review of Literature

During exercise in the heat, the body is constantly trying to make adjustments to most efficiently dissipate heat and maintain homeostasis. The system that performs this task is the thermoregulatory system. The physical demands of soccer put stress on the athlete's thermoregulatory system. Additional stress comes from external factors, such as environmental stress from temperature and humidity, and internal factors like hydration status, diet, and sleep patterns. It has been shown that when the thermoregulatory system is heavily taxed, it may not be able to function appropriately and by these factors, it is theorized that performance decrements will follow.

Physical Demands of Soccer

The physical demands of soccer are high for every level of soccer player, from adolescent to professional. An elite level soccer game is 90 minutes in duration. During two 45 minute periods, teams are allowed a small number of substitutions; three substitutions per Major League Soccer competition, for example. Since substitutions are so limited, most athletes play the entire 90 minutes of each match. Athletes rely heavily on aerobic energy for adequate endurance performance throughout the match. The intermittent nature of soccer requires anaerobic energy also, as changes in activity happen frequently. Several factors play into the high physical stress level for soccer players, such as intensity, time, distance covered, and types of activity. Demands also vary by player position and level of play. By analyzing the physical demands of soccer, the fatigue that results from play can be further understood and implications for more effective training strategies can be drawn. The demands are very high for some field

positions, specifically field players who are defined as all those players who are not the goalie. The game tasks of a goalie are anaerobic in nature and have a much different effect on thermoregulation and hydration during match play.

Intensity

Soccer is an intense, intermittent sport dominated by aerobic activity with brief periods of high-intensity anaerobic activity. The physical demands placed on a soccer player can be categorized in several ways, one is intensity. By analyzing the mean heart rate (HR) and maximum heart rate (HR_{max}), as well as the maximal pulmonary oxygen uptake (VO_{2max}) of players during soccer exercise, we can more accurately gauge how hard the players are working during soccer-type exercise.

Several studies have measured heart rate and VO_{2max} and are compiled in a review by Stølen *et al.*, 2005. For males, it describes a range of VO_{2max} for field players of 50-75 mL/kg/min. Also, a mean HR range at 157-176 beats per minute (bpm) and 80-93% of HR_{max} were reported for these athletes. HR_{max} was only reported in seven of the studies reviewed, so the numbers may be misrepresentative of the population. Females were not similar in any capacity, however very few studies have reported VO_{2max} and heart rate values for females which calls into question the true representation of a large population of soccer players. VO_{2max} values were reported at 38.6-57.6 mL/kg/min, which is considerably lower than males.¹ Contrastingly, heart rate and HR_{max} were very similar to males, at 170-175 bpm and 89-91% respectively. Since only two studies reported on females, only one of which provided HR_{max} data, no conclusive evidence exists to support the notion that male soccer athletes are more able to perform intense exercise than female soccer athletes. However, Worthington, 1980 suggests that the match

requirements of men and women do not significantly differ.² An unpublished study, reported in the same review, found that seven elite Swedish women soccer players covered an average distance of 8.47 ± 2.2 km during a match. This, along with other values, correlates easily to those reported for male soccer athletes, indicating that if gender plays a role in match play, it is minimal at most.

Females specifically were observed by Krustup *et al.*, 2005 to examine the effect of physical capacity on match performance. The mean HR of the 14 subjects was 167 bpm and the athletes reached as high as 97% of their HR_{max} . The examiners found that the VO_{2max} of the players was very comparable to other similar studies, at 28.9 mL/kg/min. The examiners concluded that the mean HR and HR_{max} were not entirely indicative of physical capacity.³ All players participated in activities that require high aerobic endurance and bouts of activity that caused a peak in percentage of HR_{max} . But these measures were consistent across all players independent of distance, indicating that total physical capacity is not entirely reliant upon the aerobic endurance of each athlete.

It has been suggested that it is difficult to obtain an accurate VO_{2max} while participating in match or practice soccer play.⁴ The intrusiveness of the equipment may interfere with the level of intensity, making the reading inaccurate and not useful in the field. Castagna *et al.*, (2011) ventured to quantify training intensity of elite male Italian soccer athletes by involving treadmill running at selected speeds and not evaluate VO_{2max} . Intensity was assessed by observing speed at three target heart rate zones. However, treadmill running was performed as continuous endurance exercise. As soccer is intermittent in nature, continuous running does not nearly describe the energy demand

that a soccer player experiences during match play. That acknowledged, other factors must be assessed to grasp the full energy demand for soccer athletes.⁵

Table 1. Distance covered according to activity type and player position. Modified from Stolen <i>et al.</i> , 2005. ¹								
Study	Level/Country	Position	N	Distance covered (m) according to mode of movement (numbers/text in parentheses indicate speed)				
				Walk	Jog	Stride/ Cruise	Sprint	Back
Bangsbo et al.	Division 1 and 2/Denmark		14	3600 ^a	5200 ^b	2100	300	
Castagna et al.	Young/Italy		11	1144 ^a	3200	986	468	114
Knowles and Brooke	Professional/England		40	1703	2610		520	
Mohr et al.	Division 1/Denmark Top team/Italy Combining both teams		24			1900	410	
			18			2430	650	
		FB	9			2460	640	
		CD	11			1690	440	
		M	13			2230	440	
Ohashi et al.	League/Japan	A	9			2280	690	
			4	7790 (0-4 m/sec)		2035 (4-6 m/sec)	589 (6-10 m/sec)	
		FB	8	2292	2902	1583	783	668
		CB	7	1777	2910	1598	830	651
Reilly and Thomas	Division 1/England	M	11	2029	4040	2159	1059	510
		A	14	2309	2771	1755	1066	495
			17	3251 ^a	4119 ^b	923	345	
			6	3068 ^a	6111 ^b	887	268	
Rienzi et al.	International/SA EPL/England International/EPL	D	9	3256 ^a	4507 ^b	701	231	
		M	10	3023 ^a	5511 ^b	1110	316	
		A	4	3533 ^a	2746 ^b	900	557	
			5	2340	5880		2880	
Saltin	Non-elite/Sweden		5				2880	
Thatcher and Batterham	EPL first team/England	D	4				253	
	EPL first team/England	M	4				387	
		A	4				306	
		D	4	2572	3956		360	1114 ^c
		M	4	2442	5243		247	1301 ^c
Van Gool et al.	EPL U-19/England	A	4	2961	4993		222	803 ^c
		D	2	4449 (low)	4859 (medium)		595 (high)	
		M	3	4182 (low)	5704 (medium)		823 (high)	
		A	2	4621 (low)	4333 (medium)		867 (high)	
Wade	Professional/England			1372-3652		229-1829 ^d		
Whitehead	Division 1/England	M	1	2150	4604	2281	1894	
		D	1	2593	3545	2753	2593	
	Division 2/England	M	1	4910	4183	1096	1007	
		D	1	4190	2966	2079	1591	
	Top Amateur/England	M	1	3824	3397	945	908	
		D	1	4104	2575	1820	1181	
	College/England	M	1	3563	2968	1348	875	
		D	1	3133	1870	1071	529	
Winterbottom	Professional/England			2347		1015 ^d		
Withers et al.	National League/Australia	FB	5	2839	5391	1737	946	1066
		CB	5	3081	3854	1271	397	1556
		M	5	2670	6085	1841	646	951
		A	5	3506	5224	1177	682	1188

a Including backwards walking; b Including sideways and backwards jogging; c Including sideways jogging; d Speed running.
A = attacker; CB = central-back; CD = central defender; D = defender; EPL = English Premier League; FB = full-back; M = midfield player; SA = South America; U = under.

Different activity types and game-related skills during soccer are anaerobic events.

The energy it takes to perform these events comes from a different system than the long duration running. Studies that have attempted to examine the physical demands of soccer

through treadmill running alone do not adequately estimate the intensity of match play. During a match, athlete activity can be quantified by total distance covered. This distance, however, is made up of different running intensities as well as anaerobic events. These anaerobic events are not assessed well during treadmill running, therefore total intensity of soccer play is not easily assessed off the field, or in studies that require only aerobic activity. Total intensity should be made up of all types of activity and game-related skills. However, it has been observed that heart rates during treadmill running are similar to those observed during match play. This suggests that while not a direct indicator, mean HR during treadmill running does approximately estimate work intensity during soccer match play.⁴

It should also be noted that performance during match play and performance during practice conditions will vary. A vast majority of current research investigates solely match play, however the intensity at which athletes train can certainly reflect on the characteristics of match play. The motivation behind practice is very different from that of match play. Specifically this could impact overall match play intensity if the expectations of practice performance are not nearly equal to the demands placed on the athletes during matches.

Distance Covered

The current literature identifies that field players cover a total distance of between eight and thirteen kilometers per match.^{1,6-9} The total distance is comprised of all player activities, and includes both forward and backward running, as well as movement at several speeds. Table 1 exhibits the findings of several studies that describe the distance

covered by elite soccer players, broken down by player position and type of activity. As the player position is separated, it is evident that midfielders cover the longest distance, more than all other field players.^{6,7,10} Defensive players, excluding the goalie, move the shortest total distance during match play.¹ It has been suggested that player position plays a role in total distance covered. However, Mohr *et al.*, 2008 described no significant difference in total distance by position for elite female soccer players. In total, 10.33 ± 0.15 km was travelled by all players during a single match. A significant positional difference was observed for different activity types.⁷

One topic of discrepancy between total distances covered is in reference to nationality of the players being studied.¹⁰⁻¹² Ekblom, 1986 discusses the differences between elite athletes based on nationality or region. He described a minimal difference between professional Swedish divisions in the distance covered during sprint activities. It is possible that the West German elite athletes play in more intense game situations and therefore must have a higher absolute speed to maintain a high level of play. In depth analysis of regional differences in soccer match play are outside the scope of this review.

Several studies are in agreement with Ekblom (1986); that there are differences in match play between nations or regions. One study¹⁰ found that while Danish and Swedish elite soccer athletes travel approximately the same average distance per game, English elites travel between 8.7 and 13.5 km per game. English elite soccer athletes also tended to engage in more high-intensity in longer periods than their counterparts from other nations.¹¹ The total distance covered fluctuates for each player, depending upon the requirements of the specific match. However, the amount of high intensity running tends to be similar in match to match comparisons.¹² Rienzi *et al.*, (2000) found that male

English Premier League players covered significantly more distance than South American players, 10.1 versus 8.6 km respectively.¹³ That would place the South American players in the same distance category as the Danish and Swedish players. The English players may lay outside the norm for several reasons, including differences in type of game strategy, level of competition, playing conditions.

Activity Types

Although total distance and activity types are important for analysis of the physical demands placed on soccer athletes, these are not totally representative of the sport. Soccer athletes execute types of activity during match play that can be classified into locomotion categories. For the purposes of this review, they will be separated as: standing; walking; low-intensity running, including jogging, low-speed, and backwards running; and high-intensity running, including moderate-speed and high-speed running, and sprinting.¹⁴

Changes in activity happen very frequently during match play. Mohr *et al.* (2003) identified ~1200 changes in activity in a single match for elite female soccer players. This corresponded to one change in activity every three to five seconds of match play. This places even more emphasis on the intermittent nature of soccer, rather than simply an endurance, or aerobic, activity. These changes in activity are usually unplanned and frequently change the depending on the athlete's proximity to ball play.

A significant rift exists between levels of players in reference to intensity of running. Top-class, or elite, athletes tend to engage in more high-intensity running and cover a larger distance than their moderate or low-level counterparts.^{7,9} A study by Mohr et al,

2003 examined the differences between the types of movement for moderate soccer athletes and elite soccer athletes. Elite soccer athletes covered 5% more total distance ($10.86 \pm 0.18 \text{ km}$) than moderate soccer athletes. But the greatest difference was in regards to high-intensity running. The elite group performed 28% more high-intensity running than the moderate group.⁹

Independent of player level, a majority of activity performed during match play is sub-maximal activity.⁶ The match activities of elite Danish male soccer players were

analyzed in regards to percentage of total match play time that was spent performing each activity.¹⁰ On average, players spent a majority of their time performing low-intensity activity; 17.1% spent standing, 40.4% spent walking, and 35.1% of the time was spent performing low-intensity running. Only 8.1% of match time was spent with high-intensity running. No significant differences for high-intensity running were found

between each position, which indicates that the larger total distance that is covered by midfielders is spent

mostly on sub-maximal activity. Midfielders travel a longer distance performing low-intensity running than both defenders and forwards, which accounts for the discrepancy in total distance versus activity.¹⁰

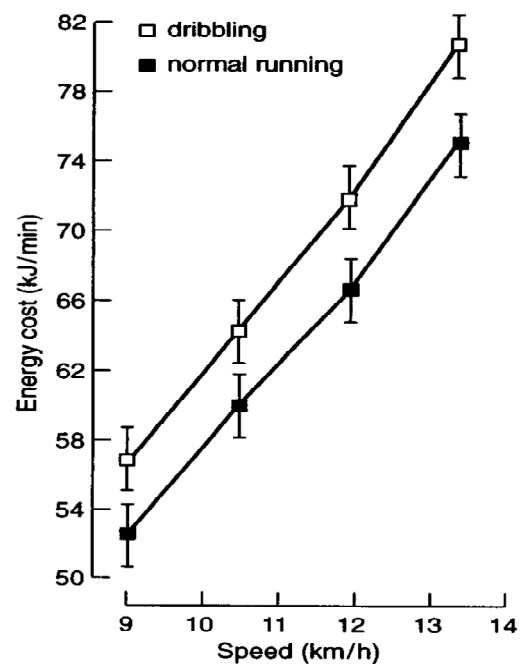


Figure 1. Energy costs associated with dribbling a soccer ball at different running speeds. From Reilly, 1997.⁶

Game-Related Activities

Game-related activities alter the energy expenditure of players, but are not considered types of movement, as they are mostly skills and are not performed independently of the game activities previously discussed. One common game-related activity is dribbling the ball. One study examined the energy cost of dribbling a soccer ball versus the cost of running, both at different speeds. As described in Figure 1, speed was irrelevant, as energy cost while dribbling was consistently higher than the energy cost of running at all speeds.⁶

Tackles and headers are also considered game-related activities that require a significant additional amount of energy above that which is needed for intermittent running. During a women's soccer match, 11 and 8 headers were performed by elite and high-level players respectively. The athletes performed a large number of tackles during the game as well; 16 by elite players and 14 by high-level players.⁷ Other game-related activities that are prevalent are kicking and jumping, as well as sideways and diagonal movement. Future research should be performed to evaluate the increased energy demand for such activities. While running is a good representation of the aerobic activity that makes up a majority of soccer match activity, the game-related activities are mostly anaerobic and the energy required to perform these tasks are not evaluated adequately by examining running alone.

Body Temperature During Exertion

As discussed by Brotherhood *et al.* (2008), body heat loss is a complex mixture of metabolic heat production variables, methods of heat loss, and environmental factors. Exercise in itself creates heat production due to an increase in metabolism, which is not

harmful to the body unless it is excessive and not adequately dissipated.¹⁵ The following equation is used to anticipate the amount of heat storage that will occur when examining metabolic heat production and environmental condition.

$$S = M \pm R \pm K \pm C_v - E$$

This equation takes heat storage (S) and breaks it up into the environmental factors that influence it: metabolic heat production (M), radiative heat loss (R), conductive heat loss (K), convective heat loss (C_v), and evaporative heat loss (E). Excessive heat production or storage indicates that the thermoregulatory system is no longer able to dissipate heat appropriately. This stress to the thermoregulatory system is often a result of environmental conditions which do not allow heat transfer to occur. Acclimatization aids the thermoregulatory system by allowing the body to adapt to the

Table 2. Reported core temperatures in soccer athletes

Study	Study Conditions			Climate		Demographics		Core Temperature (°C)					
	Performance Level	Type of Performance	Hydration Status	Ambient Temp	Relative Humidity	Gender	Age	Site	Pre	Half	Post	Avg	Change
Eklblom, 1986 ¹¹	Professional					Male		Rectal				39.5	
	Semi-Professional					Male		Rectal				39.1	
Edwards and Clark, 2006 ¹⁶	Recreational	Recreational Match	Voluntary	16°C	47%	Male	20	Intestinal	37.1	38.5	39.3		2.2
	Professional	Friendly Match	Voluntary	19°C	53%	Male	24	Intestinal	36.9	38.2	38.7		1.8
Ozgunen et al., 2010 ¹⁷	Semi-professional	Competitive	Voluntary	34°C	38%	Male	20.4	Intestinal	37.6	38.2	38.8		1.2
	Semi-professional	Competitive	Voluntary	36°C	61%	Male	20.4	Intestinal	37.7	38.7	39.2		1.5
Rico-Sanz et al., 1996 ¹⁸	Elite	Recreational Match	Hyper-hydrated	26.8°C	81%	Male	17	Rectal					1.17
	Elite	Recreational Match	Voluntary	26.8°C	81%	Male	17	Rectal					2.04

environment over a period of time and decreases the amount of heat stress an athlete will endure during exercise.

Effects of Exercise

Naturally, the body relies on several mechanisms to regulate heat stored during exercise. The sweating response is one of the most effective and outwardly noticeable responses, but cardiovascular changes occur as well. Blood flow is shunted to the skin and vasodilation occurs to aid in heat dissipation by radiation, heart rate increases to aid in circulatory efforts to dissipate heat, and an increase in respiratory rate follows.¹⁹ Up to 25% of cardiac output may be shunted to the skin in an effort to provide heat dissipation during exercise.²⁰ A study

by Bangsbo *et al.* (2007) describes oxygen uptake and average heart rate of soccer players during match play. They make reference to the effects of certain

factors (dehydration, hyperthermia, and mental stress) and how they can alter exercise intensity as

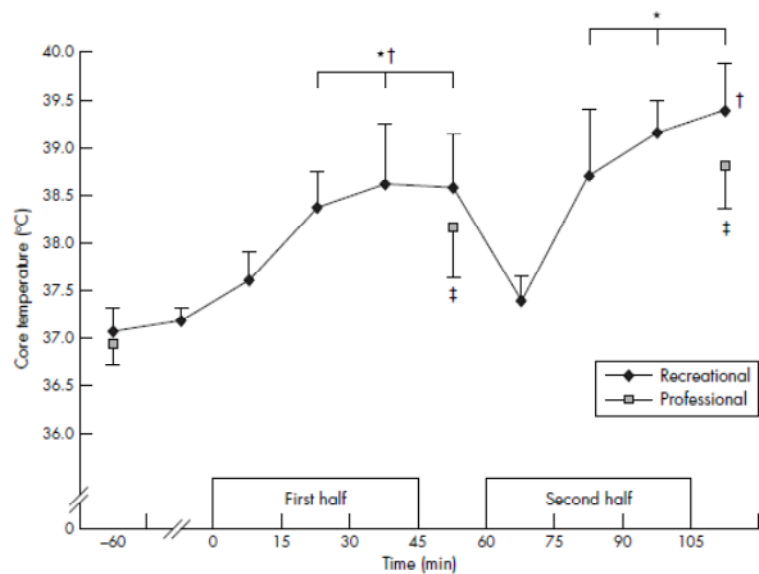


Figure 2. Change in core temperature from rest to full time in recreational and professional soccer matches. *Significant difference between resting core temperature and match play measurements in the recreational players ($p<0.01$). †Significant difference between first and second half core temperature measurements in the recreational players ($p<0.05$). ‡Significant difference from resting core temperature in the professional players ($p<0.01$). From Edwards and Clark. 2006.¹⁶

viewed through heart rate and VO_{2max} .⁴ Examination of cardiovascular factors in relation specifically to hyperthermia is important for performance, in that if athletes can control hyperthermia during exercise and place less stress on their thermoregulatory systems, they will be able to train at a higher intensity and improve performance.

Exercise Type and Intensity

Elite and high-level athletes exercise at higher intensities and would theoretically have a higher metabolic energy production, which leads to more heat storage.¹¹ From a thermoregulatory standpoint, however, elite and high-level athletes may be more capable of handling the resulting hyperthermic conditions. It was shown in one study¹⁶ that body temperature in all subjects, as measured by ingestible thermistor, increased as the match went on. The highest body temperature in the match was measured in the second half, primarily within the last 10 minutes of match play. Interestingly, the study compared recreational athletes and professional athletes. As illustrated in figure 2, the recreational athletes had significantly increased body temperatures after the second half vs. the first half; contrastingly the professional athletes did not have a significantly increased body temperature. While the professional athletes experienced hyperthermia to some degree, it was not nearly as elevated as the recreational athletes performing under the same conditions. There was some discussion of the training influence and experience of professional soccer athletes attribute to a markedly less significant increase in body temperature during match play. This can be related back to the discussion on training intensity and differences between levels of play. Table 2 describes studies that have examined the core temperature of multiple levels of soccer athletes during different types of match play.

Regardless of athlete performance level, athletes who exercise in the heat have a higher cardiac output and heart rate, and overall higher skin temperatures; as well as marked increases in core temperature. Exercise intensity seems to have little effect on these physiological changes during exercise, as it occurs despite exercise intensity, but

rather the degree of change is directly related to exercise intensity.²⁰ Physiological changes occur at an increased rate as exercise intensifies. A study by Havenith *et al.* (1998) specifically examined personal characteristics in relation to rectal temperature at varying exercise intensities performed in different environments.²¹ The subjects cycled at two intensities, fixed absolute and relative based on individual $\text{VO}_{2\text{max}}$. Each level of exercise intensity was performed in two environments, either hot and dry, or warm and humid. Interestingly, the subjects' with higher $\text{VO}_{2\text{max}}$ cycling at a higher relative intensity than other subjects had lower rectal temperatures. Although the high $\text{VO}_{2\text{max}}$ subjects would have been producing more metabolic heat, they were also better at dissipating heat than the other subjects. The differences between groups were independent of exercise environment, which made an even more significant correlation between $\text{VO}_{2\text{max}}$ and thermoregulation. Figure 2 describes this in soccer athletes participating in soccer match play. Subject's core temperatures were measured via ingestible thermistor and measured at time points throughout match play. Recreational soccer athletes tended to have an increase in core temperature earlier in match play and finished the match with higher core temperatures than the professional athletes. Professional athletes participate at higher intensities, and tend to have higher $\text{VO}_{2\text{max}}$ values and lower resting heart rates¹⁶ than recreational athletes. From this, it is evident that level of fitness as it relates to intensity of match play is an important factor in core temperature changes during match play.

This prompts some discussion on the theorized reaction of the athlete to alter exercise intensity based on thermoregulatory stress. A brief review by Cheuvront *et al.* (2010) reports that self-pacing is frequently observed in athletes exercising in a hot

environment. Observed performance decrements may be contributed to self-pacing during exercise, rather than the inability to continue at a high intensity.²² Sawka and Wenger, (1988) describes a thermoregulatory response to exertion in the heat as preceding any significant change in core temperature. It is described as an anticipatory response to high ambient temperatures or high humidity.²³ An increase in thermal sensation and discomfort serve as an early warning for the athlete that behavioral changes may need to occur to prevent significant exertional hyperthermia. Ozgüven *et al.* (2010) suggests similar reactions due to altered body temperature during exertion. They describe a “voluntary cessation of effort” influenced by a change, specifically, in brain temperature.¹⁷ Self-pacing may be a significant factor in decreased intensity during exercise in the heat,²⁴ but it is precipitated by a response of the thermoregulatory system anticipating a gross change in core temperature.

Duration of Exercise

Typical soccer matches consist of two 45-minute halves. Since substitutions are minimal in most leagues, usually no more than 3 per game, most players are participating for the entire 90 minutes. Even the intermittent nature of soccer lends itself more to being classified as aerobic activity than anaerobic activity. Long duration aerobic activity creates a much more conducive environment for dehydration to occur than short, anaerobic activity.

Figure 2 shows the progressive increase of core temperature during one regular-time soccer match. Match play is at least 90 minutes, but may be extended by the need for overtime as the result of a tie. Overtime periods vary according to league rules but are usually at least 5 minutes in duration. So during overtime, soccer athletes are

required to play an additional 18% of a normal match. The additional time means more aerobic and anaerobic activity, which in turn will further increase dehydration. While there is a short rest period prior to the start of overtime, it is not long enough to replenish a high percentage of body water lost during regular match time. As match play continues, core temperature continues to increase.

Another factor that may play into dehydration as it relates to exercise duration is the participation in multiple matches on the same day. This happens most often in youth leagues and tournaments, where many matches will be played in a short time period. If rapid rehydration can occur, then the athlete may start with no body water deficit in the following matches; but if the athlete does not adequately replace lost fluids from the first match, fluid deficit will continue to increase with each subsequent match played. As the athlete incurs increased levels of dehydration, performance and physiological declines will occur.

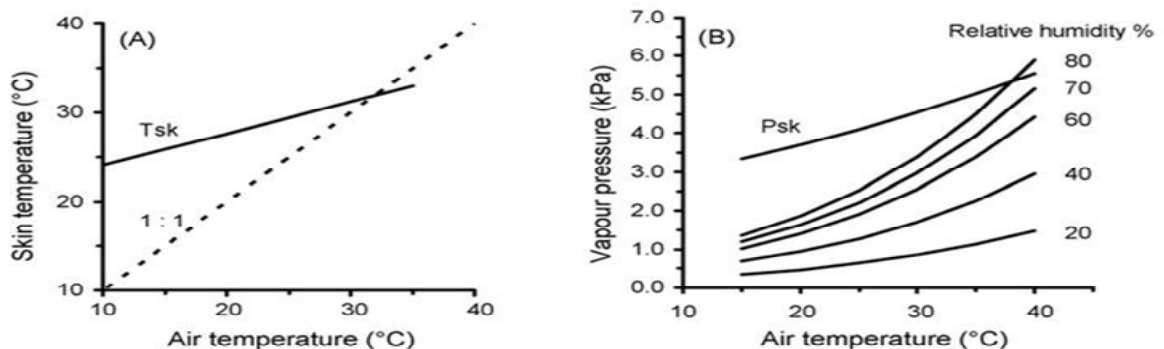


Figure 3. Relationships between skin temperature and air temperature (A), and absolute and relative humidity(B). (A) 1:1, skin temperature = air temperature. (A) The skin to air temperature difference determines the potential for convective heat exchange. (B) P_{sk} is the saturated vapour pressure at skin temperature. Vapour pressure indicates absolute water content of air. At a fixed relative humidity, e.g. 70%, vapour pressure varies with air temperature as the water holding capacity (saturated vapour pressure) varies with air temperature. P_{sk} varies with skin temperature. The skin to air vapour pressure gradient determines potential for evaporation of sweat. From Brotherhood, 2008.¹⁵

The differences between soccer match play and practice situations can be vastly different. Practices may go through periods of high intensity and low intensity exercise,

while game situations are most commonly high intensity due to the nature of the competition. No studies have examined the effects of practice on core temperature versus core temperature during match play. Further examination of the types of drills and conditioning efforts during practice may give information regarding training strategies that adequately prepare soccer athletes for match play. As previously suggested, higher level athletes who play and train at higher intensities are more able to handle the thermoregulatory stresses of match play.

Effects of Environment

Stored body heat can be dissipated in four basic ways: radiation, convection, conduction, and evaporation. Most commonly in athletes, evaporation is the primary method of heat dissipation. The environment can either enhance or hinder evaporative heat loss by not allowing sweat to be evaporated from the skin surface. This equation can be used to determine the requirements of evaporative cooling (E), given the rate of metabolic heat production (M) and also the rates of radiative (R) and convective (Cv) heat transfer.

$$E = M \pm R \pm C_v$$

The equation for requirements of evaporative cooling accounts for the heat lost by both radiation and convection, singling out the amount of evaporative cooling that is required to dissipate heat produced by exertion and environmental stress. The rate of radiative heat transfer is dependent on the gradient between skin temperature and radiant temperature. A relatively small difference between temperatures results in a relatively small rate of radiative heat transfer. A similar relationship exists for convective heat

transfer, with the addition of the thermal properties of air and the flow of air over the body surface. Convection can work either for or against heat dissipation, in that if air temperature is higher than skin temperature, the air temperature will add to the body's heat load.¹⁵

Ambient Temperature

Sawka and Wenger, (1988) describes the impact of ambient temperature on heat dissipation mechanisms. Figure 3 refers to a positive relationship between higher ambient temperatures and higher sweat rates. The body's dependence on sweat for evaporative cooling is initiated when entering the hot environment, and continues to rise as core temperature increases. Ozgunen *et al.* (2010) describes a significant relationship between environmental temperature and match performance. Matches were observed on two occasions, without acclimatization; one moderate heat day (34°C), and one high heat day (36°). All subjects showed similar trending; on both days, subject intestinal temperatures rose dramatically and plateaued in the first half without a significant rise in the second half. However, on the high heat day, subjects increased body temperature in the first half of match play correlated with a decrease in total distance covered.¹⁷ It is important to note that the high heat day was not only a high ambient temperature, but also a high relative humidity, creating an intense environment for match play.

Humidity

In the study by Ozgunen *et al.* (2010) previously mentioned, the environmental stress was calculated from not only ambient temperature, but also relative humidity. On the high heat day, for example, the relative humidity was 61%. The reported heat index calculation for high heat day then becomes 49°C (120°F) when relative humidity is

included. Relative humidity can considerably alter playing conditions, and therefore increase the physical stress on the body. It has the greatest environmental effect on evaporative cooling in relation to thermoregulation. In order for evaporation to happen, there must be a pressure gradient between the water vapor in the air and that which is to be evaporated from the skin. Figure 3 gives values for the vapor pressure at the skin's surface. The higher the vapor pressure, the more water is saturated in the air. When more water is in the air, evaporative cooling is less effective because it requires a higher air temperature for the sweat to evaporate. Since evaporative cooling is the most relied upon and efficient method of cooling during exertion, suppression of this method can have extreme consequences in regards to the total heat stress on the body. A high gradient results in more effective evaporation.

Wind speed

Wind speed has also been suggested as an environmental factor for heat dissipation and thermoregulation. Generally, a high wind speed encourages evaporative cooling, and therefore bolsters thermoregulation. Low or no wind, however, attenuates the body's ability to dissipate heat appropriately. Specifically for soccer athletes, the amount of running they perform during match play is supportive of air rushing past the skin surface, thus naturally creating their own wind. Absolute humidity and wind speed should be included when calculating a rate of evaporative cooling, as heat energy can be transferred more effectively through evaporation with these factors.^{15,25} However, few studies have generated data which suggest that wind speed is a significant factor in evaporative heat loss. Such data could be useful in determining more effective hydration and core temperature regulation strategies during exercise in the heat.

Acclimatization

Physiological adaptation via acclimatization is an effective strategy for reducing heat related illness by adequately preparing the body for exercising while incurring heat stress. Some speculated benefits from acclimatization include decreased resting core body temperature, decreased heart rate during exercise, increased sweat rate, decreased sodium losses, and expanded plasma volume. These adaptations are beneficial in preventing heat related illnesses and it is speculated that there are positive effects on performance as well.²⁶

By decreasing resting core body temperature, a dramatic rise in exercising core body temperature is attenuated.²⁶ A study by Nybo *et al.* (2001) demonstrated that exercise-induced hyperthermia increases central fatigue. When exercise core body temperature is decreased prior to exercise, the exercising individual is less likely to experience a high degree of hyperthermia and can attenuate central fatigue.²⁷

Decreasing exercise heart rate is also beneficial to athletes, by creating a more physiologically efficient playing environment. Elite soccer players have a typical resting heart rate of 48-52 bpm,²⁸ which is reasonably below the average human. By decreasing the resting heart rate, it takes a higher intensity to reach the HR_{max} . Expanded plasma volume is also cardiac-related. An increased plasma volume allows the athlete to also have an increased stroke volume, which again creates a more efficient physical environment for the athlete to perform optimally. Expanded plasma volume also assists the body in avoiding dehydration by allowing subsequent storage of body water in the blood stream.

Sweat rate has been shown to increase as an athlete becomes acclimatized. This has been considered a physiological method of thermoregulatory control. As sweat rate

increases, the body is more capable of evaporative cooling; and therefore more effective at dissipating heat and controlling core temperature. Decreased sodium loss through sweat and expanded plasma volume are also beneficial. By more effectively preserving sodium in the body, an electrolyte imbalance is less likely to occur, preventing hyponatremia.²⁸

Acclimatization is about balancing the body's needs with the environmental conditions. Decreased resting body temperature allows the athlete to start the exercise session cooler and decreased exercise heart rate allows the athlete to exercise at a higher intensity than an athlete who is not acclimatized. An increased sweat rate promotes evaporative cooling, but expanded plasma volume staves off dehydration with an increased storage of body water. An athlete who is hydrating appropriately can maintain sufficient electrolyte balance by increased sodium retention.

Fluid Balance During Soccer

Hydration is an important part of all exercise. Adequate amounts of body water promote efficient cooling, encourage adequate blood flow, and mitigate drastic changes in blood pressure.²⁹ Many performance deficits have been observed in dehydrated athletes, specifically cardiovascular and thermoregulatory strain. Athletes who practice adequate hydration strategies during exercise have a less significant reduction in performance than dehydrated athletes.³⁰

Dehydration During Exercise

Dehydration usually occurs during exercise due to fluid lost through sweat. Dehydration has been shown to cause impairments to aerobic performance, but has little

effect on anaerobic performance.^{26,31} The aerobic effects come from the cardiovascular strain that is proportional to the amount of water loss. Decreased stroke volume, increased heart rate, increased systemic vascular resistance, decreased cardiac output, and lower mean arterial pressure are all cardiovascular effects of dehydration that impair performance.³⁰ Dehydration has been known to cause a decrease in cardiac output. More specifically, a decrease in blood volume has been found to be the main factor in decline of cardiac output regardless of environment.²⁹ Hydration status prior to the beginning of practice is an important factor in determining the aggressiveness of rehydration during and after practice. An athlete who begins practice dehydrated is likely to develop a more significant deficit in total body water than an athlete who begins the practice adequately hydrated. Performance decrements have been seen at less than 2% body mass loss.³²

Body Mass and Sweat Rate

Body mass loss is a simple and effective measure of change in hydration over a period of exertion. By examining body mass prior to the start of exertion, and again after exertion is complete, a loss of mass attributed to sweat lost during exertion¹¹ can be calculated. Changes in body mass during exercise are consistent with other measures of dehydration, such as plasma osmolality, hematocrit, urine color, urine osmolality, and urine specific gravity.³³ In that way, changes in body mass can be directly associated with performance decrements observed during exercise. Urine samples are easier to collect than blood samples, and body mass is easier still which makes it a useful clinical tool.

An extension of the use of pre-post exercise body mass is in the calculation of sweat rate. Sweat rate is influenced by several factors and can be calculated with the following formula:

$$SR = \text{Pre-ex BM} - \text{Post-ex BM} + \text{Fluid intake} - \text{Urine volume} / \text{Hours of exercise}$$

where sweat rate (SR) is the combination of the difference between pre-exercise body mass (BM) and post-exercise body mass plus the fluid taken in during practice, minus the urine volume accumulated during practice, all divided by the amount of time the exercise was performed in hours.

Table 3. Factors Affecting Sweat Rate³⁴⁻³⁷

Intrinsic	Extrinsic
Body mass	Type of exercise
Body surface area	Exercise intensity
Heat acclimatization	Clothing/uniform
Genetic predisposition	Ambient temperature
Metabolic efficiency	Humidity
Gender	Sky conditions (sunny, cloudy, etc.)
Age	
Diet	

Several factors affects sweat rate, both intrinsic and extrinsic, which are included in Table 3. Female soccer players have lower sweat rates than male soccer players.³⁴

Female athletes also have a tendency to drink a smaller volume of water, but this can be simply attributed to lower overall body mass. An athlete with a smaller, or lower body mass, does not have to maintain the same total body water volume as a larger athlete.

Dehydration in essence lowers sweat rate, creating a shift in evaporative heat loss which affects the balance of heat storage.³⁸ Dehydration appears to increase the temperature threshold at which sweating begins.³⁹ This would indicate a linear relationship between sweat threshold and dehydration. But the longer it takes for sweating to begin, the more heat storage is allowed to occur. As heat storage increases, heat dissipation methods would need to be more effective to mitigate a dramatic rise in

core temperature. As dehydration and core temperature increase, sweat rate declines. So it is even more difficult for the body to dissipate heat effectively and core temperature continues to rise.

Types of Exercise

It appears in the literature that the type of exercise, anaerobic or aerobic, is important in determining the effect of dehydration on performance. Studies that focused on anaerobic performance, especially in soccer athletes, found that hydration status was not markedly important in task-related performance. While the amount of body mass lost seems to differ by gender under similar conditions, no performance decrements have been observed during anaerobic exercise.⁴⁰ Supportively, a lesser level of dehydration is incurred during anaerobic exercise.

Exercise intensity and dehydration are significantly correlated. As exercise intensity increases, sweating sensitivity also increases. Sweating sensitivity is the change in sweat rate from the level at which sweating was initiated, or the sweat threshold.⁴¹ Although an increase in sweat sensitivity is seen with increased intensity, a decrease in sweat sensitivity is seen as the level of dehydration increases.³⁹ Body mass loss of 3% has been associated with a graded sweating sensitivity decrease over a single exercise bout.³⁹ Logically from a physiological standpoint, decreased sweating sensitivity with dehydration is consistent with the body's drive to maintain homeostasis. As total body water level decreases, more serious physiological effects are evident. So in an effort to deflect life-threatening changes, it makes an attempt at maintaining a suitable body water balance by decreasing sweat rate after sweating has begun.

Study	Study Conditions		Climate				Demographics		Average Body Mass (kg)		USG		Plasma Volume	Sweat Analysis	
	Performance Level	Type of Performance	Hydration Status	Ambient Temp (°C)	% Humidity	Wind speed (m/s)	Gender	Age	Change	% Change	Pre	End	% Change	Sweat Rate (L/hr)	Volume Loss (L)
Mohr et al., 2010 ⁴²	Professional	Friendly Match	Voluntary				M	19	1.5	2		1.024			
Edwards and Clark, 2006 ¹⁶	Recreational	Recreational Match	Voluntary	16	47		M	20	1.3	1.6			7.2		
	Professional	Friendly Match	Voluntary	19	53		M	24	1.5	1.9			11.6		
Ozgunen et al., 2010 ¹⁷	Semi-professional	Competition	Voluntary	34	38		M	20.4	2.3	3.4		1.024		1.9	
	Semi-professional	Competition	Voluntary	36	61		M	20.4	2.1	3.1		1.03		2.0	
Al-Jaser et al., 2006 ⁴³	Elite	Friendly Match	Voluntary	45.4	23.6		M	24		2.7	1.019	1.026			
Broad et al., 1996 ³²		Practice/Training	Voluntary	> 20			M	16-18		1.2				0.985	
		Practice/Training	Voluntary	< 10			M	16-18		0.8				0.746	
		Practice/Training	Voluntary	> 20			F	16-28		0.9				0.814	
		Competition	Voluntary	> 20			M	16-18		1.4				1.209	
		Competition	Voluntary	< 10			M	16-18		1.4				1.027	
		Competition	Voluntary	> 20			F	16-28		1.2				0.761	
Kilding et al., 2009 ²⁰	Elite	Practice/Training	Voluntary	14.1	71	1.2	F	23	0.38	0.6	1.014			0.49	0.73
	Elite	Practice/Training	Voluntary	6.2	74	0.9	F	23	0.28	0.49	1.011			0.44	0.66
Maughan et al., 2004 ⁴⁴	Professional	Practice/Training	Voluntary	26.5	55		M	27	1.10	1.37				2.033	
Rico-Sanz et al., 1996 ¹⁸	Elite	Recreational Match	Hyper-hydrated	26.8	81		M	17	1.89	3			2.7		
	Elite	Recreational Match	Voluntary	26.8	81		M	17	1.77	2.81			1.7		

Dehydration not only effects athletes physically, but shows changes in behavioral patterns as well. The theory of voluntary pacing recurs with dehydration. As percent dehydration increases, so do ratings of perceived exertion and thirst ratings.²⁴ It has been suggested that these changes in behavior, such as avoidance of high intensity activity, while dehydrated produce the decreases in performance that are evident in soccer athletes who are dehydrated. While not the sole cause, the psychological aspect of dehydration and self pacing may be partially responsible for decreased soccer performance.

Environmental Conditions

The largest effect of the environment in relation to hydration status is the effect on to sweat rate. Higher environmental temperatures cause athletes to sweat more during exertion as a thermoregulation method. Higher sweat rate encourages loss of total body water and dehydration during exertion. Dehydrated athletes exercising in a neutral environment suffered relatively less significant cardiovascular effects than dehydrated athletes exercising in moderate and high heat stress environments.³⁸

Hydration During Exercise

The need for hydration during exercise is lower when sweat losses are minor. But the relationship between sweat rate and need for fluid replacement is parallel. As sweat rate increases during heavy activity or stressful environmental conditions, the body loses its water storage and needs replenishment. Soccer athletes tend to have high sweat rates, which only increase with acclimatization, so fluid replacement is important. Table 4 shows some studies that have examined hydration measures in soccer athletes at different levels of performance. It can also be difficult for soccer athletes to adequately hydrate during match play. By practicing effective and efficient hydration strategies during match play, soccer athletes can stave off the negative aerobic effects of dehydration.

Unique Challenges for Soccer Athletes

There are my unique challenges that soccer athletes incur during match play. Matches are continuous, allowing few substitutions and one break at half time. This presents infrequent opportunities to hydrate during match play.²⁴ The type of exercise, intermittent, rather than continuous exertion is very different from most other sports.

Continuous exercise, such as distance running or cycling, usually has planned water stations or break areas. Only one planned break exists in soccer, which is half time, so opportunities to hydrate are infrequent at best.²⁰ If athletes consume too much fluid during half time, gastric upset and decreased performance can result, so athletes tend not to consume enough fluid to adequately replace their lost fluids and continue playing with an increasing fluid deficit.²⁰

Playing season is also a unique challenge for soccer athletes. Often, soccer is played in the summer and fall, during the hottest parts of the calendar year. Although some areas of the world have warmer climates than others, most commonly soccer is played in warm climates under hot conditions. This presents a challenge unique to soccer, in that few other sports have the same physical requirements as well as stressful environmental conditions.¹⁸

Trends and Strategies

Hyperhydration has been suggested as an effective method for soccer athletes to stave off dehydration and quell the associated performance decrements. A study by Rico-Sanz *et al*, (1996) describes a cross-over protocol for half of the subjects to intake 4.6 ± 0.2 L per day (65 mL/kg/day) and the other half of subjects to intake fluid ad libitum, for one week prior to playing a soccer match. The study found that the hyperhydration protocol increased the subject's total body water storage and reduced thermal stress incurred during match play. However, they found no significant difference in post-match soccer specific skill performance between the hyperhydrated and ad libitum groups. The soccer specific skill was an anaerobic activity, so the insignificance of hydration in skill performance is well supported by other studies.⁴⁰ However, this study by Rico-Sanz *et al*,

(1996) did not examine aerobic performance in relation to hydration status, so no conclusions can be drawn about the effects of hyperhydration on aerobic performance.³⁸ Hyperhydration can also lead to dilution of plasma sodium levels and predispose the athlete to hyponatremia.^{36,45} Planned intake of dietary sodium before or during exercise may assist in proper hydration by stimulating thirst and water retention.³⁶

Hydration beverage content, of carbohydrate, electrolyte or glycerol, may be more effective than plain water under specified exercise conditions. It has been suggested that during exercise when sweat rate is high, beverages containing small amounts of carbohydrate and sodium,³⁴ or glycerol⁴⁶ can be more effective in preventing significant dehydration. A beverage containing carbohydrates and electrolytes slows the rate of gastric emptying.⁴⁷ If the ingested fluid takes longer to enter the blood stream from the gastrointestinal tract, rehydration may be delayed and thus, is more ineffective in situations where rapid rehydration is necessary. If appropriate hydration strategies are maintained, the slower rate of gastric emptying is minute in the grand scheme of hydration during exercise. It may also be a more effective strategy to incorporate carbohydrate/electrolyte into the hydration strategy of a soccer athlete specifically.

Pre-exercise ingestion of glycerol for hyperhydration has been explored as a method of increasing total body water before exercise begins. Studies show marginal effectiveness, as it does serve to increase total body water and reduce resultant dehydration, but performance differences are insignificant.⁴⁶ Rehydration with glycerol has also been studied as a subsequent performance enhancer. While time to exhaustion increased in the glycerol trials, no thermoregulatory or cardiovascular advantages were observed over plain water.⁴⁸

The current trend in hydration for all athletes is adequate preparation prior to beginning exercise, adequate hydration during exercise, and rehydration after the completion of exercise.^{36,49,50} Athletes should practice pre-exercise hydration strategies, using urine output and volume to gauge hydration status, then intake an appropriate volume of water hours prior to practice. This strategy allows the athlete to recognize any lingering dehydration that may have been incurred over the previous day, and prepares the body for practice. During exercise, the goal is to maintain less than 2% body mass loss,^{30,32} so approximating sweat loss by calculating sweat rate is useful. Once sweat rate is calculated, the athlete may take in smaller, more frequent drinks to avoid nausea or gastric upset.

After exercise, rehydration should be complete within 2 hours after exercise. Rehydration beverages that contain both carbohydrates and electrolytes restore depleted muscle glycogen and aid in water retention and prevent a sharp decrease in plasma sodium levels.^{45,46,48} The volume of fluid to be ingested post exercise should approximate sweat loss during exercise, with one exception: if rehydration must occur rapidly, sweat losses should be overcompensated by 25-50%. By increasing the fluid ingested, the athlete will offset for probable urine and enduring sweat output.

Body Temperature and Hydration Status

There exists a very close relationship between body temperature and hydration status in relation to exercise. As is evident by the current literature, separately each topic has a significant effect on factors relating to performance in soccer. In combination, their effects on performance are even more considerable. Current research presents a wealth

of knowledge on each topic and the combination of effects can assist in better strategies to combat negative effects, which will subsequently enhance performance and decrease thermoregulatory strain.

Hyperthermia and Hydration

Body temperature and hydration status have influence on and by each other, giving them a close relationship.

Figure 4 shows the relationship between fluid ingestion as a

method of preventing

dehydration, and no fluid

ingestion. It shows that core

temperature steadily increased and remained higher in subjects who did not ingest fluid

during the trial. It is clear that the negative effects of dehydration are inflated while

exercising in the heat.⁵¹ Exercise induced hyperthermia has a direct effect on hydration

status due to an increase in thermoregulatory sweating. Higher body temperature is

naturally induced during exercise, but as dehydration increases, so does core body

temperature on a graded scale. Sawka, Montain, and Latzka (2001) describe the

commencement of core temperature elevation at only 1% decrease in body mass from

dehydration; and core temperature elevates at a rate of 0.1°C to 0.25°C per percent of

body mass lost to sweat.³⁵ For example: at 5% body mass loss, core temperature is

elevated between 0.5°-1.25°C from dehydration alone. That calculation does not figure

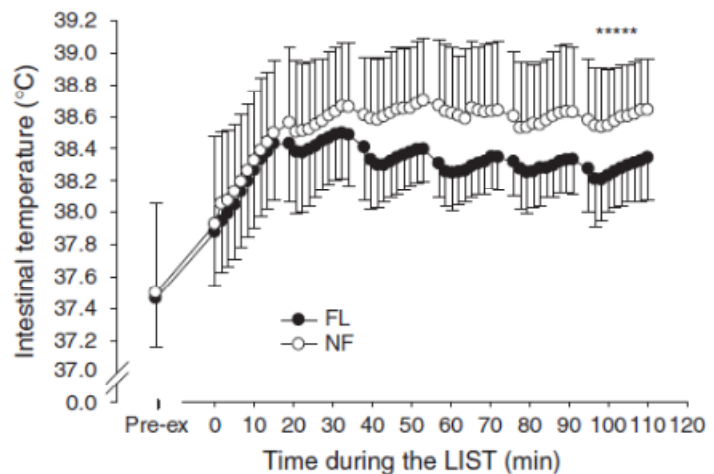


Figure 4. Intestinal temperature readings during the simulated soccer exercise in fluid (FL) and no-fluid (NF) trials (NB the time scale on the x-axis includes 4-min rest periods between exercise time during the exercise; *significantly higher than FL; $P < 0.05$). From Ali *et al.*, 2010.⁴⁰

in the amount of metabolic heat produced from exercise, which elevates core temperature significantly more.

The cardiovascular effects of dehydration and hyperthermia are very similar when isolated during exercise. Each produces a decrease in stroke volume of approximately 7-8%²⁹ and increases heart rate, but does not have a large impact on cardiac output. When dehydration is the primary cause of hyperthermia, stroke volume decreases much more drastically (20%) and cardiac output is subsequently decreased.²⁹

Effects on Soccer Performance

A study by Sawka *et al.* (1992) examined the effect of a large percentage of dehydration on thermoregulation by examining rectal temperature, skin temperature, and heart rate. Theoretically, if the thermoregulatory system was taxed, the temperature needed to produce exhaustion would decrease. The study showed that during exercise in the heat, at a dehydrated level of 8% total body mass deficit, core temperature rises and time to exhaustion decreases.⁵² In a sport like soccer, which lasts no less than 90 minutes, a decrease in time to exhaustion could mean that exhaustion occurs prior to the end of match play. This would be an extremely negative effect on performance, especially when it is easily reduced with proper preparation before match play commences.

It was discussed earlier that pacing is fairly prevalent in elite soccer athletes, and may provide an effective strategy for increasing endurance performance during match play. Supportive evidence exists for endurance sports, which may be relevant for soccer

Figure 5. Effects of increased core temperature and dehydration on soccer performance.^{15-17,20,22-24,30,38,52}

Sweat Rate: A contrast exists between core temperature and dehydration's effects on sweat rate. An elevated core temperature inspires increased sweat rate as a cooling mechanism. However, dehydration markedly decreases sweat rate in an effort to conserve body water. In the end, the effects of dehydration tend to win out and sweating decreases as core temperature rises.

VO_{2max}: Heat stress and decreased plasma volume from dehydration alter VO_{2max}, which is profoundly detrimental to aerobic performance. As soccer is essentially an intermittent endurance sport, a decrease in VO_{2max} can severely decrease soccer match performance.

Cardiac Output: Both increased core temperature and dehydration have a negative effect on cardiac output. During exercise, blood flow is shunted to the skin to stimulate heat dissipation by convection. This, along with an increased demand by the muscles, creates increased cardiovascular strain. Decreased blood volume from dehydration decreases stroke volume, which in turn decreases cardiac output.

Intensity: Increased core temperature in combination with dehydration decreases overall exercise intensity in soccer athletes, meaning they cover less distance and participate in lower intensity activities. Athletes also tend to feel like they are working harder in hotter conditions.

Skin Temperature: The environmental factors that affect soccer athletes are ambient temperature, relative humidity, and wind speed. As skin temperature increases, the body's response is to sweat, to produce evaporative cooling, which is enhanced by any wind that is created naturally or by the athlete running. As sweating increases to attempt to maintain a lower core temperature, dehydration increases, which in turn increases core temperature.

Distance Covered: Distance covered during soccer is one way of quantifying intensity. As core temperature and dehydration increase, total distance travelled decreases. This may be due to subconscious self-pacing responses to stressful environmental conditions.



given the long duration of match play, which suggests that hydration status effects overall pacing effectiveness. Stearns *et al.* (2009) describe the ability of long distance trail runners to adequately pace themselves, in both hydrated and dehydrated conditions, to complete a total of 12 km. Average total distance covered for soccer athletes is very similar, which correlates well to this study. It is important to note that the pacing strategy differed between groups. Hydrated runners tended to perform at an even pace, while dehydrated runners performed at a positive pace,⁵³ meaning that they started slower and increased speed as the task continued. The even pacing strategy is more energy efficient, and led to better overall times. It was suggested that the difference in overall time between groups was probably because the dehydrated group over-estimated the amount of energy it would take to complete the task, so as the run continued they were able to increase speed. However, this strategy is inefficient, consequently placing a higher energy demand on athletes later in competition, which may hinder performance.

Figure 5 captures the most pronounced effects of dehydration and increased core temperature on soccer performance. Heat stress has an effect on performance variables measured during soccer such as VO_{2max} , and cardiac output. Heat stress degrades VO_{2max} ,²² which negatively effects aerobic performance. As described earlier, aerobic exercise makes up the majority of action during soccer match play. Decreased VO_{2max} is a consequence of altered cardiac output. During exercise in the heat, the pattern of blood flow changes to enhance skin blood flow to encourage heat dissipation by radiation and evaporation. During milder environmental conditions, normal muscle blood flow is usually maintained, which gives evidence for the change in blood flow pattern being due to elevated core temperature.²² Heart rate also increases, creating a smaller time interval

for cardiac filling and decreased stroke volume. For a primarily aerobic soccer athlete, this is definitely a hindrance to performance.

Negative psychological responses are associated with decreased performance in soccer match play for dehydrated athletes. Edwards, *et al.* (2007) describes moderate dehydration, defined as 1.5-2% body mass loss, did have negative impacts on soccer performance and increased core temperature. There were also psychological implications for the dehydrated subjects, including increased ratings of perceived exertion. The author concludes that dehydration does decrease performance; but the cause is indistinct between the physiological and psychological factors.⁵⁴ It would be difficult to accurately distinguish between the psychological and physiological factors that decrease performance, but generally both are viewed as important mechanisms of dehydrated performance decreases.

Conclusion

The thermoregulatory system is extremely important for performance implications for soccer athletes. Hyperthermia and dehydration effect performance both independently and in conjunction. Physiological alterations are seen from both; however negative effects are not usually noticed before core temperature reaches a critical level and dehydration reaches 2% body mass loss. Negative cardiovascular implications from a combination of hyperthermia and dehydration lead to deficits in aerobic performance during match play. Alterations of heart rate, stroke volume, and blood flow change $\text{VO}_{2\text{max}}$ secondary to decreased overall cardiac output. These alterations provide a decrease in aerobic performance, which is of utmost importance to soccer athletes who

rely heavily on aerobic power to cover large distances. Alternatively, the many changes in activity and sport specific skills are anaerobic in nature, and therefore are not altered by either high body temperature or dehydration.

Overall the implications of hyperthermia and dehydration have been extensively researched in relation to cardiovascular effects on performance. More research should be performed on the effects of those factors in relation to total distance and the distance covered at different intensities. As soccer athletes spend a majority of their time at moderate and high-intensity running, a closer look at the effects of those specific intensities on thermoregulation could be helpful to individualize practice strategies that will enhance match play. This could be achieved by examining each position individually. As each position differs significantly in the demands of match play, positional examination could provide more thorough thermoregulatory information for soccer athletes.

Introduction

The physical demands of professional men's soccer have been extensively studied during elite match play. They cover 10-12 km in a match, depending on player position, with average heart rate at 80-93% heart rate max.¹ Player position creates a discrepancy in distance covered, with midfielders covering the most distance.^{6,7,10} It appears that all players spend a majority of their time doing low-intensity running, with bouts of high-intensity running and sprinting.⁶ Those demands are what qualifies soccer as an intense, intermittent type of aerobic activity, as it requires high a $\text{VO}_{2\text{max}}$ as well as a propensity to perform repeated bouts of sprint and skill performances.^{3,5} However, it has also been suggested that performance and intensity are dictated mainly by player level, professional athletes participating at a higher intensity than semi-professional athletes.^{7,9} More information on the demands of all levels of soccer is necessary to say conclusively that performance is directly related to player level. However, no studies exist which clearly define the physical demands of elite collegiate soccer.

The average body mass loss during professional match play is $<2\%$,^{8,11,32} likely stemming from the high intensity exercise and limited fluid availability. Dehydration of $<2\%$ during exercise has been associated with performance decreases.³² Cardiac output decreases, which limits aerobic power and increases cardiovascular strain.³⁰ If dehydration is present prior to beginning exercise, it likely increases, putting athletes starting dehydrated behind from the start. And replacing during a soccer match is unlikely, since fluid replacement is commonly limited to the 15 minute half time period in collegiate and professional sports.

The decrease in performance due to dehydration is likely a protective mechanism. As exercise intensity increases, sweat rate and sweat sensitivity increase.^{39,41} Without fluid replacement, this leads to dehydration. Dehydration also decreases sweat rate during exercise, which leads to increased heat storage.³⁸ Core temperature rises with metabolic energy production for exercise,¹¹ and the rate of rise depends on the intensity of exercise. More intense exercise creates more heat production. However, it appears that higher level soccer athletes may be better at handling the increased heat production than lower level soccer athletes.¹⁶ But this has not been researched in the collegiate population, which may not dissipate heat as well.

The unique nature of soccer can also affect both hydration status and core temperature. Typical collegiate and professional soccer matches consist of two 45-minute halves with a 15 minute half time. Most players participate for the entire game, as in these upper level leagues substitutions are limited. This presents a challenge for athletes to hydrate or get rest during a match. If breaks are limited, pre-match hydration status would need to be excellent to prevent significant dehydration and possibly performance deficits. Players must also attempt to replenish lost fluid in a short half time period. No researchers have previously examined the hydration strategy that is used by players before or during match play.

The purpose of the present study was to examine the hydration strategy of a collegiate men's soccer team to describe dehydration which occurs during preseason training. Collegiate male soccer athletes have previously not been studied during preseason training. We hypothesized that core temperatures will rise during training sessions, players will incur significant dehydration during training sessions, cumulative

dehydration will occur over the course of preseason training, and mood will decline as preseason continues.

Methods

Participants

Volunteers were recruited from the University of Connecticut men's soccer team for a 9-day observational field study. Demographic information is presented in Table 1. Volunteers were included as subjects if they: 21 males (age 20 ± 1 years, height 187.5 ± 2 cm, body mass 76.2 ± 5.6 kg) were members of the men's soccer team, and had passed a pre-participation physical examination, as required by the university for athletic participation. Subjects were excluded if they met any of the following criteria: current musculoskeletal injury, history of cold sensitivity, took sleep altering medications, suspected to have obstructive disease of the gastrointestinal (GI) tract, impaired gag reflex, previous GI surgery, might undergo Nuclear Magnetic Resonance scanning, or had hypomotility disorder of the GI tract. All subjects agreed to participate by their own free will and signed an informed consent form approved by the University of Connecticut Institutional Review Board. Participation in the research study had no effect on playing status and was minimally intrusive.

Procedures

On the first day of soccer practice during the second week of August 2011 (WBGT: 21.57 ± 1.70 °C, ambient: 23.54 ± 2.33 °C, relative humidity: $60.57 \pm 10.70\%$, wind speed: 2.54 ± 1.25 m/s), subjects were asked to complete a short demographic questionnaire, which included information about current medical conditions, exercise variables, and past

heat illnesses. This questionnaire was used as descriptive data about each subject and verified that no exclusionary criteria were present. Subject height and initial body mass were recorded.

Figure 6 describes the timing of the preseason period and location of each session. Practice sessions are labeled in order from 1 to 9 (97.3 ± 21.3 min). Some practice sessions happened on the same testing day; sessions 1 and 2, 3 and 4, and 6 and 7. All other testing days had single sessions. Two interscholastic scrimmages (SC1 and SC2) occurred during the study (123 ± 14.1 min); SC1 between sessions 5 and 6, and SC2 after session 9. All Scrimmages took place on separate days from any training session and were in the evening. Subjects had one day with no practice session (OFF1), which was between SC1 and 6. Sessions SC1, 6, 7 and 8 took place in an indoor turf training facility; all other sessions took place on an outdoor, natural grass playing field.

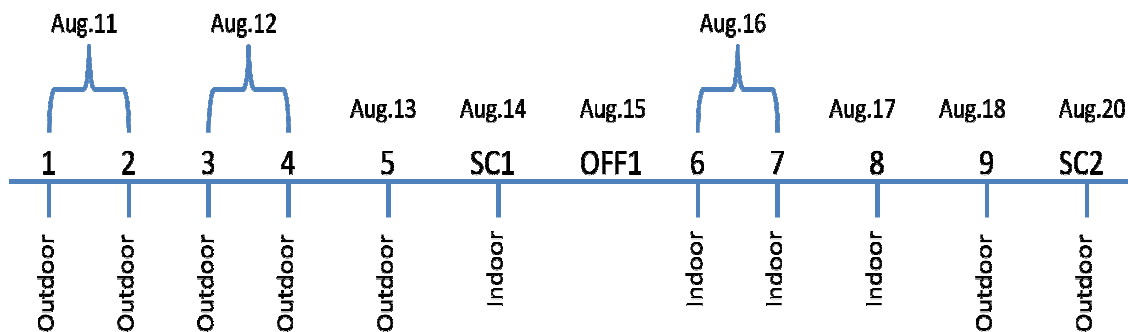


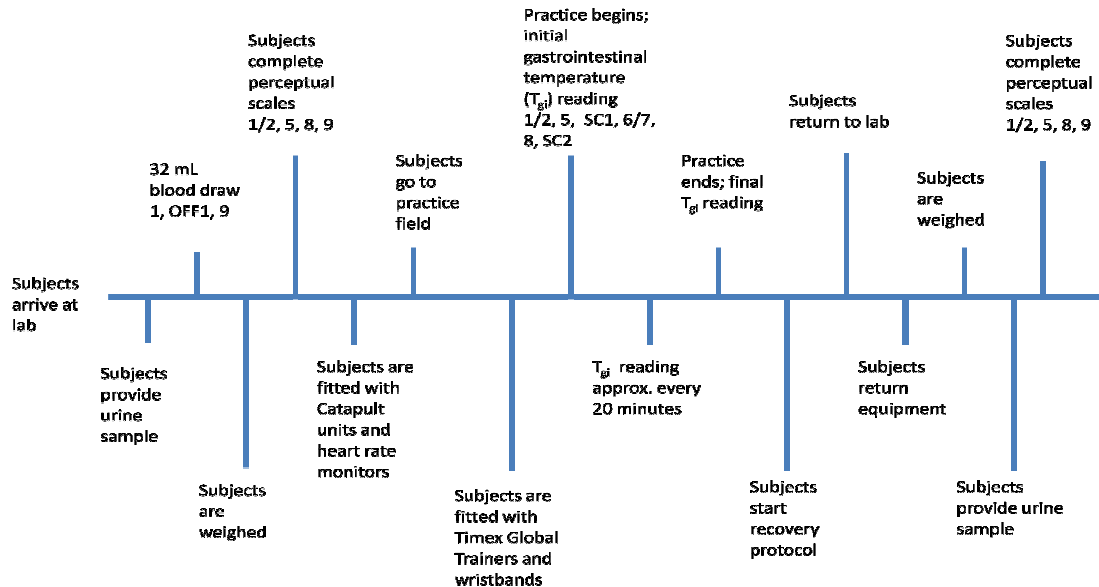
Figure 6. Study timeline with session date, identifying number, and location.

Subjects were provided an ingestible thermistor the day prior to testing sessions 1/2, 5, SC1, 6/7, 8, and SC2, if no previously ingested thermistor was present. Subjects ingested the ingestible thermistor directly before going to sleep the night before. Diet and sleep logs were provided to record their diet and sleep over the course of the next 24

hours. These were used to examine possible influences from dietary intake and recovery techniques post-practice.

Figure 7 describes the timeline for each training and scrimmage session. Subjects arrived at the lab approximately 1 hour prior to each practice session. At that time subjects provided a small urine sample. Urine samples were analyzed for urine color (U_{col})⁵⁵, urine specific gravity (USG), and urine osmolality (U_{osmo}). The urinalysis provided data regarding hydration status. Body mass while wearing shorts was recorded. Body mass provided information regarding volume change during exercise by comparing pre-practice body mass to post-practice body mass. On day 1, OFF1, and 9, a blood draw of 32mL was performed by trained phlebotomists using universal precautions with subjects standing. Blood was used to measure plasma osmolality (P_{osmo}), and testosterone, cortisol, testosterone-cortisol ratio (T:C), and creatine kinase (CK). Subjects completed several psychological questionnaires for sessions 1, 2, 5, 8, and 9. Psychological questionnaires included Profile of Mood States (POMS),⁵⁶ and thirst⁵⁷ and thermal⁵⁷ scales. Subjects were fitted with two GPS units and a heart rate monitor. Subjects were given a Catapult GPS unit which consists of a light neoprene vest with one small GPS unit attached to the back, between the shoulder blades. These tracked the subjects' movement during practice, and were used as a way of observing performance. The Catapult GPS unit continuously collected data during practice and stored it for later analysis. The other GPS device was a Timex Global Trainer and heart rate monitor, which consisted of a watch worn on the wrist with a soft covering and strap worn around the chest. This unit continuously monitored heart rate and stored this

information for later analysis. Subjects were blinded to their heart rate during all sessions by wearing a wrist band over the face of the Global Trainer.



During practice, data collection was limited to natural breaks to limit interference. Upon arrival at the practice field, intestinal temperature (T_{gi}) was recorded as a baseline measure and to ensure the ingestible thermistor was functioning properly. If the thermistor was not functioning properly or the thermistor from the previous testing day was still in the GI tract, the subject was excluded for that testing day. WBGT, ambient temperature, relative humidity, and wind speed were measured daily every 15 minutes during practice with a portable heat stress monitor. (Quest technologies, inc.) Subjects were encouraged to participate in practice as normally as possible, making no changes in regards to hydration or exercise intensity for the duration of the study.

Immediately after each session, subjects T_{gi} was recorded as a final temperature. Subjects cooled in large ice baths for 10 minutes, and consumed 1 energy bar and supplemental protein beverage, then returned to the lab. GPS units and heart rate monitor

were removed. Body mass was recorded wearing shorts, then subjects provided a small urine sample. Subjects completed psychological questionnaires on days 1, 2, 5, 8, and 9. Subjects were encouraged to eat and sleep as they normally would for the duration of the study.

After the soccer season, interviews of the head athletic trainer and strength and conditioning coach were conducted for information regarding their beliefs on hydration and details on any hydration strategy the team follows. Questions were guided and open-ended so that the staff could provide descriptive answers.

Outcome measures

Hydration

Hydration status was assessed in several ways: U_{col} , USG, U_{osmo} , and percent body mass loss (%BML). U_{col} was evaluated via the urine color scale described by Armstrong *et al.*, (1994). USG was measured using a calibrated refractometer (Atago, A300CL, Japan) to provide measurement of the weight of the urine as compared to distilled water. U_{osmo} was measured using an osmometer to describe the concentration of particles in the urine. U_{col} , USG, and U_{osmo} are different methods of quantifying concentration of the urine. The change for these variables was assessed within session, subtracting pre-session values from post-session values. P_{osmo} was measured using an osmometer to describe the concentration of particles in the blood. %BML was assessed (Tanita scale 800S, Arlington Heights, IL), while wearing shorts, before and after each session to compare changes in body mass per practice and also across the nine day research period.

Mood

A battery of psychological tests, which have been shown to accurately gauge exercise-related factors affecting mood, was used to gain information regarding psychological state. These included the POMS, thirst, and thermal scales. These scales accounted for factors related to environmental conditions and feelings related to exertion that provide an indication of the psychological reactions incurred during soccer play. Thirst was evaluated via a likert scale from 1-9, 1 meaning not thirsty at all and 9 meaning very, very thirsty. Thermal was evaluated via a likert scale from 0.0-8.0, with 0.0 meaning unbearably cold and 8.0 meaning unbearably hot. ESQ was measured via a likert scale from 0-70, with lower values indicating fewer symptoms. The possible range for POMS total mood disturbance (POMS_{TMD}) is -32-232, lower values indicating more positive mood. POMS_{TMD} is a composite score of the other 6 scores which evaluate tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment.

Performance

Performance was measured by recording total distance covered, activity types, heart rate, and rest time. Distance was recorded and stored by the Catapult unit (Catapult innovations, Melbourne, Australia) and the Timex unit (Timex Group USA Inc, Middlebury, CT) during practice and held for analysis via computer software. Eleven sensors in the Catapult unit measured practice activity, including a 5 Hz GPS and multi-axis accelerometers. Measurement of total distance commenced when practice began and concluded when practice ended. It was comprised of all activity types in the following speed zones: standing (0.0-0.7 km/h), walking (0.7-7.2 km/h), low intensity running

(7.2-14.4 km/h), moderate intensity running (14.4-19.8 km/h), high intensity running (19.8-25.2 km/h), and sprinting (>25.2 km/h); and included backward and sideways running, as well as maximum velocity¹⁴. To measure work, efforts were counted in each speed zone. An effort is operationally defined as 2 seconds spent in a speed zone. Efforts are not counted if speed increases or decreases to a different speed zone, nor in the first speed zone (standing). For example, if an athlete starts from walking, and continues to increase speed until he reaches high intensity running, an effort will only be counted if he continues high intensity running for at least 2 seconds. Also, % distance and % time in each speed zone were spliced out and used to describe exercise intensity.

T_{gi} was measured via ingestible thermistor (HQ Inc, Palmetto, FL). Ingestible thermistors transmit constant radio signals that can be picked up by a receiver pointed at the abdomen. In the current literature, ingestible thermistors have been found to be a valid and reliable method of accurately measuring gastrointestinal temperature, which relates directly to what is referred to as core temperature. During exercise, ingestible thermistors are easily checked and require very little disturbance in activity.

Heart rate was recorded and stored in the Timex heart rate monitor (Timex Group USA Inc, Middlebury, CT) for the entirety of practice. It recorded heart rate via a chest strap and stored it for analysis. Heart rate was analyzed for heart rate max (HR_{max}) and average heart rate (HR_{avg}).

Blood samples were collected before three morning practices, all between 6:00-7:00am. Blood was analyzed for testosterone, cortisol, and CK. T:C ratio was also constructed during the statistical analysis. These were used as physiological markers of intensity or physiological stress during soccer training.

Hydration strategy

In-person, individual interviews of two of the most involved staff provided information regarding hydration protocols regarding pre-practice, during practice, and post-practice strategy, as well as recovery. Each interview was brief, less than 30 minutes, and included the head athletic trainer (ATC) and head strength and conditioning coach (SCC).

Statistical Analyses

A one-way MANOVA was used to determine the effect of expertise, first year player (FY) vs. returning player (RP) during practice sessions vs. scrimmages. And session type on U_{col} , USG, T_{gi} , and BML. A repeated measures ANOVA with Bonferroni corrections evaluated differences over time during practice sessions 1, 2, 3, 4, 5, SC1, 6, 7, 8, 9, and SC2 for dependent variables: average T_{gi} , HR_{avg} , HR_{max} , %BML, distance covered, % distance, % time, and efforts in each speed zone, total efforts, maximum velocity, USG, U_{col} , U_{osmo} , P_{osmo} , testosterone, cortisol, T:C, CK, thirst, thermal, POMS_{TMD}, and ESQ. A repeated measures ANOVA with Bonferroni corrections evaluated differences over time during practice sessions 1, OFF1, and 9 for dependent variables: plasma osmolality, creatine kinase, testosterone, cortisol, and testosterone-cortisol ratio. Greenhouse-geisser corrections were used when sphericity was violated. An *a priori* alpha level of 0.05 was set.

Results

T_{gi} was not significantly different between FY and RP during practices vs. scrimmages ($p=0.34$). BML during practices ($0.98\pm0.45\text{kg}$) was not significantly different than scrimmages ($1.11\pm0.39\text{kg}$), regardless of player year ($p=0.265$). Pre-practice U_{col} (4 ± 1) and post-post practice U_{col} (4 ± 1) as well as pre-practice USG (1.019 ± 0.005) and post-practice USG (1.021 ± 0.004) were not significantly different between FY and RP during practices vs. scrimmages ($p<0.05$).

Hydration

%BML (Figure 8) differed significantly between all practice and scrimmage sessions ($p<0.001$). Practice 3 was significantly lower than SC1, 6, 9, and SC2 ($p<0.05$); 6 was significantly higher than 3 and 8 ($p<0.05$); 7 was significantly lower than SC1

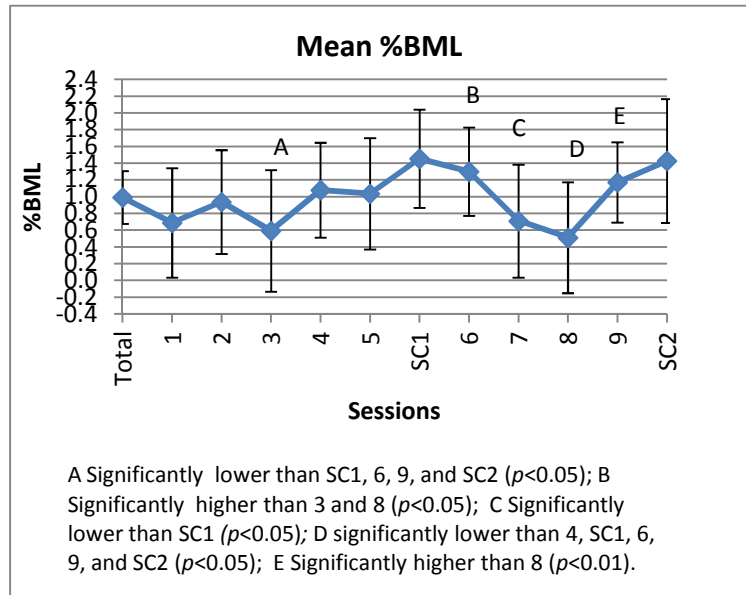


Figure 8. Overall percent body mass loss

($p=0.047$); 8 was significantly lower than 4, SC1, 6, 9, and SC2 ($p<0.05$); and 9 was significantly higher than 8 ($p=0.002$). Means for all hydration variables can be found in Table 5.

Pre-practice USG differed significantly between all practices ($p<0.001$). Practice 1 was significantly lower than 5 and 9 ($p<0.01$); 2 was significantly lower than 3, 5, 6, and 9 ($p<0.01$); 5 was

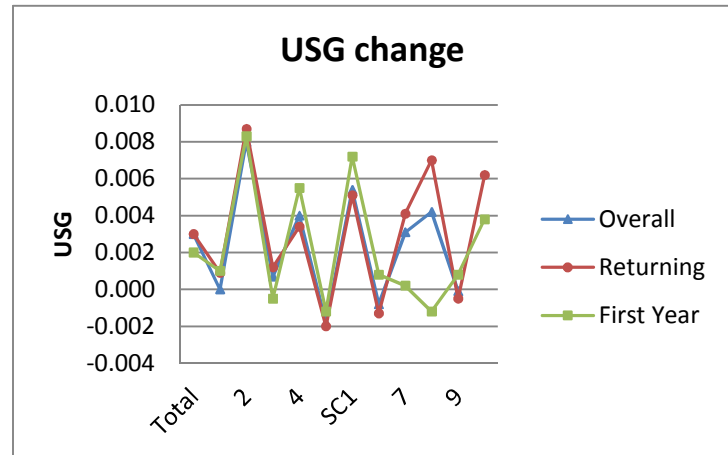


Figure 9. Urine Specific Gravity change

significantly higher than 1, 2, 4, SC1, 7, and 8 ($p<0.05$); 6 was significantly higher than 2 and 8 ($p<0.01$), but lower than 9 ($p=0.009$); 9 was significantly higher than 1, 2, 6, 7, and 8 ($p<0.01$). Post-practice USG differed significantly between all practices ($p<0.001$).

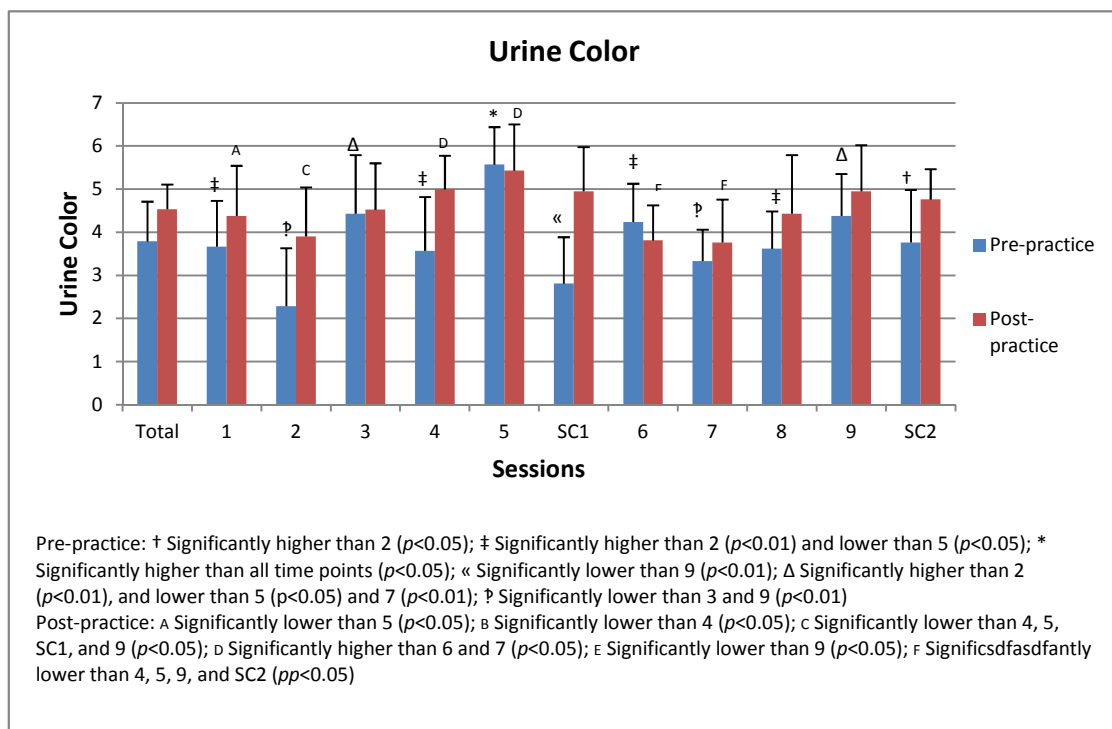


Figure 10. Pre and post practice urine color

Practice 1 was significantly lower than 9 and SC2 ($p<0.05$); and 6 was significantly lower than SC2 ($p=0.005$). USG change (Figure 9) differed significantly between all practices and scrimmages ($p<0.001$). Practice 2 was significantly higher than 1, 3, 5, 6, and 9

Preseason Session	BML (%)	Urine color pre	Urine color post	Urine color change	USG pre	USG post	USG change	Urine osmolality
1	0.69±0.65	4±1	4±1	1±1	1.018±0.006	1.019±0.006	0±0.004	715.6±210.1
2	0.938±0.62	2±1	4±1	2±1	1.011±0.008	1.019±0.005	0.008±0.008	443.3±325.9
3	0.593±0.73	4±1	5±1	0±1	1.022±0.008	1.022±0.005	0.001±0.006	785.7±256.1
4	1.08±0.57	4±1	5±1	1±1	1.018±0.008	1.022±0.004	0.004±0.008	x
5	1.037±0.67	6±1	5±1	0±1	1.024±0.004	1.022±0.005	-0.002±0.004	871±161.3
SC1	1.5±0.6	3±1	5±1	2±1	1.017±0.007	1.022±0.006	0.005±0.006	x
6	1.3±0.53	4±1	4±1	-1±1	1.021±0.002	1.02±0.003	-0.001±0.003	834±143.0
7	0.711±0.67	3±1	4±1	0±1	1.018±0.005	1.021±0.004	0.003±0.004	x
8	0.512±0.66	4±1	4±1	1±1	1.016±0.004	1.02±0.006	0.004±0.007	658.8±190.4
9	1.173±0.48	4±1	5±1	1±1	1.023±0.003	1.023±0.003	0.00±0.002	913.7±95.0
SC2	1.4±0.7	4±1	5±1	1±1	1.019±0.007	1.025±0.004	0.006±0.006	x
Mean	0.99±0.28	4±1	5±1	1±1	1.019±0.004	1.021±0.001	0.003±0.003	746±159.8
(Mean±SD)								

($p<0.01$); 5 was significantly lower than 2, SC1, 7, and SC2 ($p<0.05$); 6 was significantly lower than 2 and SC1 ($p<0.05$).

Pre-practice U_{col} (Figure 10) differed significantly between all practices ($p<0.001$). Practice 5 was significantly higher than all time points ($p<0.05$); 1 was significantly higher than 2 ($p<0.01$), but lower than 5 ($p<0.05$); 2 was significantly lower than 1, 3, 4, 5, 6, 8, 9, and SC2 ($p<0.05$); 3 was significantly higher than 2, SC1, 7

($p < 0.01$), but lower than 5 ($p = 0.022$); 4 was significantly higher than 2 ($p < 0.01$), lower than 5 ($p < 0.001$); 6 was significantly higher 2 and SC1 ($p < 0.01$), but lower than 5 ($p = 0.02$); 7 was significantly lower than 3, 5, and 9 ($p < 0.01$); 8 was significantly higher than 2 ($p = 0.009$), but lower than 5 ($p < 0.01$); 9 was significantly higher than 2, SC1, 7 ($p < 0.01$), but lower than 5 ($p < 0.01$). Post-practice U_{col} (Figure 10) differed significantly between all practices ($p < 0.001$). Practice 1 was significantly lower than 5 ($p = 0.04$); 2 was significantly lower than 4, 5, and SC1 ($p < 0.05$); 4 was significantly higher than 2, 6, and 7 ($p < 0.05$); 5 was significantly higher than 1, 2, 6, and 7, ($p < 0.05$); 6 and 7 were significantly lower than 4, 5, SC1, 9, and SC2 ($p < 0.05$). U_{col} change differed significantly between practices ($p < 0.001$).

Practice 1 was significantly higher than 6 ($p = 0.012$); 2 was significantly higher than 3, 5, 6, and 7 ($p < 0.01$); 4 was significantly higher than 3 and 6 ($p < 0.01$); 5 and 7 were significantly lower than 2 and SC1 ($p < 0.01$); 6 was significantly lower

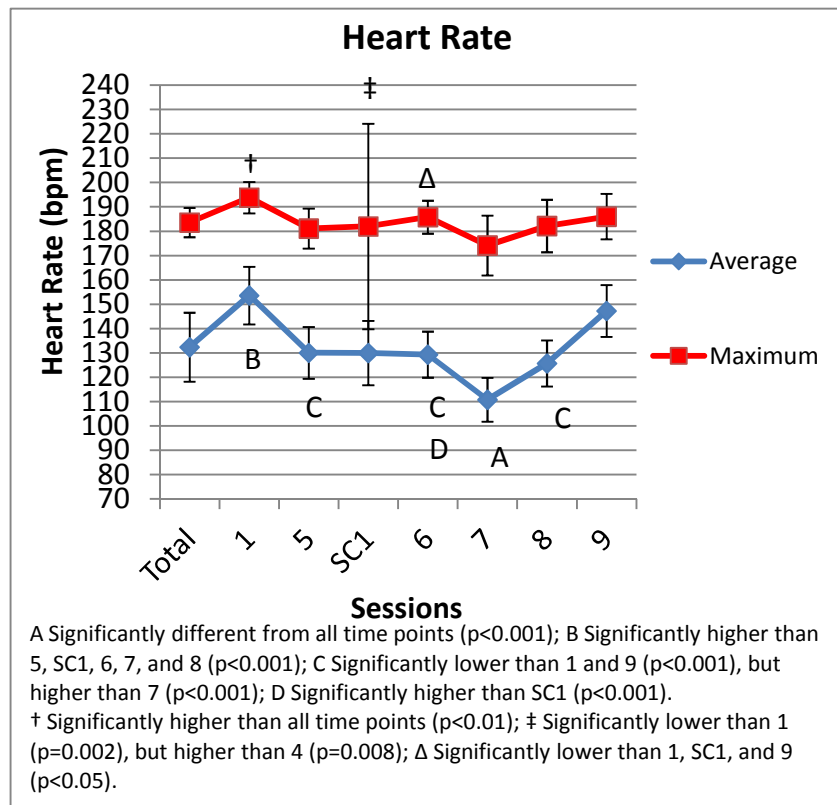


Figure 11. Overall average and maximum heart rates

than 1, 2, 4, SC1, 8, 9, and SC2 ($p<0.05$); SC1 was significantly higher than 3, 5, 6, 7, and 9 ($p<0.01$).

Preseason Session	Hravg (bpm)	Hrmax (bpm)	Distance Covered (m)	Total Efforts	Max Velocity (km/h)	Average Tgi (°C)
1	153.62±11.83	193.86±6.45	x	x	x	38.6386±0.46
2	x	x	4578.62±905.51	225±75	25.94±3.35	x
3	x	x	5767.15±558.6	279±44	26.56±1.81	x
4	x	x	5450.374±759.95	236±59	26.61±2.38	x
5	130.05±10.67	181.14±8.24	5204.542±1024.17	295±79	26.16±2.96	37.9271±0.32
SC1	130±13.25	182±42.2	x	x	x	x
6	129.33±9.47	185.81±6.78	4370.413±1968.77	153±122	x	37.9719±0.29
7	110.76±9.01	174.19±12.26	x	x	x	x
8	125.71±9.51	182.19±10.78	x	x	x	37.9062±0.26
9	147.29±10.67	186.05±9.34	7408.809±728.19	310±153	22.24±7.68	x
SC2	x	x	x	x	x	x
Mean	132.39±14.18	183.6±5.99	5463.32±1088.26	250±58	25.51±1.84	38.11±0.35
(Mean±SD)						

U_{osmo} was differed significantly between practices 1, 2, 3, 5, 6, 8, and 9 ($p<0.001$).

Practice 1 was significantly higher than 2 ($p=0.017$), but lower than 9 ($p=0.001$); 2 was significantly lower than 1, 3, 5, 6, and 9 ($p<0.05$); 5 and 6 were significantly higher than 2 and 8 ($p<0.01$); and 8 was significantly lower than 5, 6, and 9 ($p<0.01$).

P_{osmo} differed significantly between time points 1, OFF1, and 9 ($p<0.001$). Practice 9 was significantly higher than both 1 and OFF1 ($p<0.05$).

Performance

HR_{avg} (Figure 11) differed significantly between practices 1, 5, SC1, 6, 7, 8, and 9 ($p<0.001$). Practice 7 was significantly different from all time points ($p<0.001$); 1 was significantly higher than 5, SC1, 6, 7, and 8 ($p<0.001$); 5, 6, and 8 were significantly lower than 1 and 9 ($p<0.001$), but higher than 7 ($p<0.001$); 6 was also significantly higher than SC1 ($p<0.001$). HR_{max} differed significantly between practices 1, 5, SC1, 6, 7, 8, and 9 ($p<0.001$). Practice 1

was significantly higher than all time points ($p<0.01$); SC1 was significantly lower than 1 ($p=0.002$), but higher than 4 ($p=0.008$); and 6 was significantly lower than 1, SC1, and 9 ($p<0.05$).

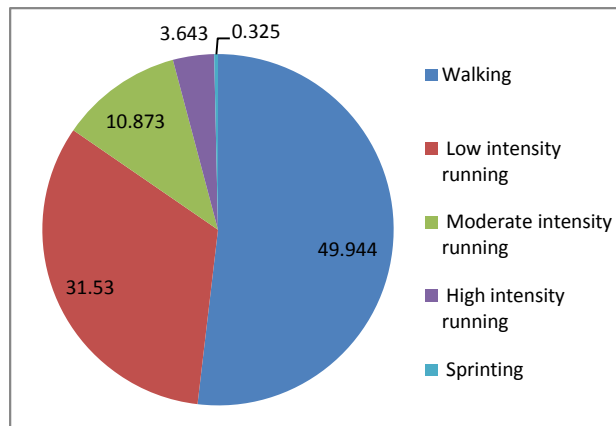


Figure 12. Percentage of total distance by speed zone

higher than 2, 3, 4, 5, and 6 ($p<0.001$). Mean values for percentages of time and distance by speed zone are provided in Table 7. Percent of total distance are presented in Figures 12 and 13. Percent of total walking distance was significantly different between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 6 ($p<0.001$), but higher than 4 ($p=0.033$); 4 was significantly lower than 2, 5, and 6 ($p<0.05$).

Percent of total low intensity running distance differed significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly higher than 3 and 6 ($p<0.001$); 3 was significantly lower than 2, 4, 5, and 9 ($p\leq 0.001$); 4 was significantly higher than 3 and 5 ($p<0.05$),

Distance covered was significantly different between practices 2, 3, 4, 5, 6, and 9 ($p<0.001$). Practice 2 was significantly lower than 3, 4, and 9 ($p<0.01$); 3 and 4 were significantly higher than 2 ($p<0.001$), but lower than 9 ($p<0.001$); and 9 was significantly

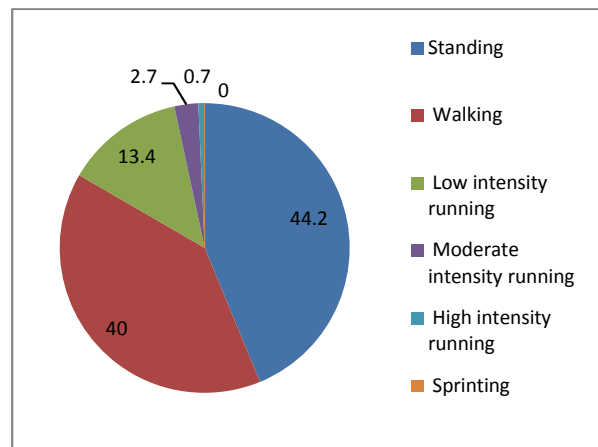


Figure 13. Percentage of time spent in each speed zone

but lower than 6 ($p<0.001$); 5 was significantly higher than 3 and 6 ($p<0.001$), but lower than 4 ($p=0.018$). Percent of total moderate intensity running distance differed

Preseason Session	% Time						% Distance						Efforts					
	Standing (0.0-0.7 km/h)	Walking (0.7-7.2 km/h)	Low Intensity Running (7.2-14.4 km/h)	Moderate Intensity Running (14.4-19.8 km/h)	High Intensity Running (19.8-25.2 km/h)	Sprinting (>25.2 km/h)	Standing (0.0-0.7 km/h)	Walking (0.7-7.2 km/h)	Low Intensity Running (7.2-14.4 km/h)	Moderate Intensity Running (14.4-19.8 km/h)	High Intensity Running (19.8-25.2 km/h)	Sprinting (>25.2 km/h)	Standing (0.0-0.7 km/h)	Walking (0.7-7.2 km/h)	Low Intensity Running (7.2-14.4 km/h)	Moderate Intensity Running (14.4-19.8 km/h)	High Intensity Running (19.8-25.2 km/h)	Sprinting (>25.2 km/h)
2	42.7 ±11.8	38.3±9.5	15.9±3	2.5±0.7	0.5±0.5	0±0	x	41.3±6.2	42.8±4.6	10.7±2.8	3.1±1.5	0.6±0.7	x	141±33	66±18	23±7	6±4	1±1
3	52.3 ±6	33.1±4.6	5.3±1.2	3.9±0.6	1.5±0.6	0±0	x	46±4.4	18.5±3.6	23.4±3.4	10.3±3.8	0.2±0.4	x	180±36	54±10	29±7	16±6	1±1
4	30.8 ±6.6	43.1±5.3	19.9±4.4	3.4±0.9	0.9±0.5	0±0	x	39.6±6	43±4.9	11.9±2.5	3.7±1.7	0.6±0.7	x	126±32	68±21	33±9	8±5	1±1
5	50.5 ±8.5	47.6±6.9	10.8±3.3	1.5±0.8	0±0	0±0	x	47±6.9	39.1±5.5	9.4±3.4	2.1±1.1	0.4±0.6	x	202±57	64±20	25±12	4±3	1±1
9	44.6 ±23.1	37.7±15.8	15±6.9	2.3±1.2	0.5±0.5	0±0	x	49.7±17.2	35.7±15.6	8.9±4.4	2.3±1.9	0.1±0.4	x	198±81	85±38	35±18	7±5	1±1
Mean	44.2 ±8.5	40±5.5	13.4±5.6	2.7±0.9	0.7±0.6	0±0	x	49.9±3.3	31.5±3.9	10.9±7.3	3.6±3.6	0.3±0.2	x	166±32	61±18	25±10	7±5	1±1

(Mean±SD)

significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 ($p<0.001$), but higher than 6 ($p<0.001$); 3 was significantly higher than all time points ($p<0.001$); 4 was significantly higher than 5, 6, and 9 ($p<0.05$), but lower than 3 ($p<0.001$); 5 was significantly lower than all time points ($p<0.001$). Percent of total high intensity running distance differed significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 ($p<0.001$), but higher than 6 ($p<0.001$); 3 was significantly higher than all time points ($p<0.001$); 4 was significantly lower than 3 ($p<0.001$), but higher than 5 and 6 ($p<0.01$); 5 was significantly lower than 3 and 4 ($p<0.01$), but higher than 6 ($p<0.001$); 6 was significantly lower than all time points ($p\leq 0.001$). Percent of total sprinting distance differed significantly between 2, 3, 4, 5, and 9 ($p=0.001$). Practice 6 was significantly lower than 2 and 4 ($p<0.05$).

Percentage of time spent standing differed significantly between practices 2, 3, 4, 5, and 9 ($p=0.001$). Practice 2 was significantly lower than 3 and 5 ($p<0.05$), but higher than 4 ($p=0.001$); 3 was significantly higher than 2 and 4 ($p<0.05$); 4 was significantly lower than 2, 3, and 5 ($p\leq 0.001$); and 5 was significantly higher than 2 and 4 ($p<0.05$).

Percentage of time spent walking did not significantly differ over time between practices 2, 3, 4, 5, and 9 ($p=0.440$). Percentage of time spent low intensity running differed significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly higher than 3 and 5 ($p<0.001$), but lower than 4 ($p=0.001$); 3 was significantly lower than

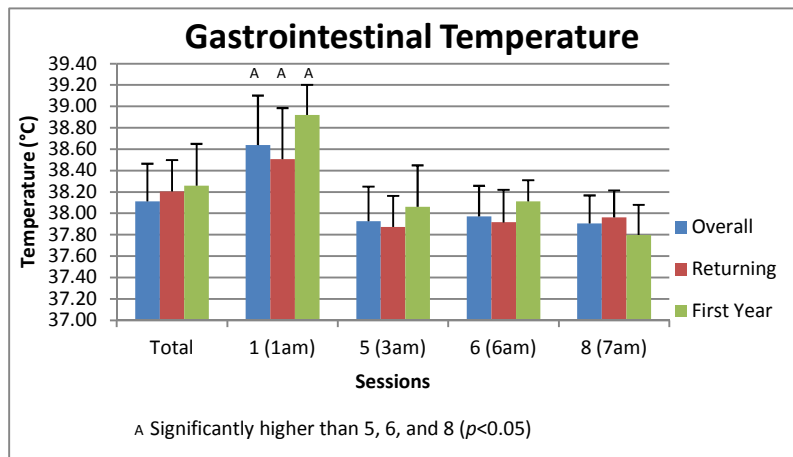


Figure 14. Average T_{gi} by overall and by player year

performing moderate intensity running differed significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 and 4 ($p<0.001$), but higher than 5 ($p=0.001$); and 3 and 4 were significantly higher than 2, 5, and 9 ($p<0.001$).

Percentage of time spent performing high intensity running differed significantly between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 and 4 ($p<0.05$), but higher than 5 ($p<0.001$); 3 was significantly higher than all practices ($p<0.001$); 5 was significantly lower than all practices ($p<0.01$); and 4 was significantly

all practices ($p<0.001$); 4 was significantly higher than 2, 3, and 5 ($p\leq 0.001$); and 5 was significantly lower than 2 and 4 ($p<0.001$), but higher than 3 ($p<0.001$).

Percentage of time spent

higher than 2 and 5 ($p<0.05$), but lower than 3 ($p<0.001$). Percentage of time spent sprinting was zero for every practice session and did not differ.

Total efforts were significantly different between practices 2, 3, 4, 5, 6, and 9 ($p<0.001$). Practice 2 was significantly lower than 5 ($p=0.012$); 3 was significantly higher than 6 ($p=0.008$); 5 was significantly higher than 2 and 6 ($p<0.05$); 6 was significantly lower than 3, 5, and 9 ($p<0.05$). Walking efforts were significantly different between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 and 5 ($p<0.05$); 3 was significantly higher than 2 and 4 ($p<0.05$); and 4 was significantly lower than 3, 5, and 9 ($p<0.05$). Low intensity running efforts were significantly different between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly higher than 6 ($p<0.001$); 3 was significantly higher than 6 ($p=0.015$), but lower than 9 ($p=0.028$); and 6 was significantly lower than all practices ($p<0.05$). Moderate intensity running efforts were significantly different between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 ($p=0.001$), but higher than 6 ($p<0.001$); 4 was significantly higher than 2 and 6 ($p<0.01$); and 6 was significantly lower than all practices ($p<0.001$). High intensity running efforts were significantly different between practices 2, 3, 4, 5, and 9 ($p<0.001$). Practice 2 was significantly lower than 3 and 4 ($p<0.05$), but higher than 9 ($p=0.004$); 3 was significantly higher than all practices ($p<0.001$); 4 was significantly higher than 2, 5, and 6 ($p<0.05$), but lower than 3 ($p<0.001$); 6 was significantly lower than 2, 3, 4, and 9 ($p<0.01$). Sprinting efforts were significantly different between practices 2, 3, 4, 5, and 9 ($p=0.006$). Post hoc testing revealed no significant differences between days.

Max velocity differed significantly between practices 2, 3, 4, 5, and 9 ($p=0.018$). Post hoc tests using Bonferroni correction determined that no pairs were significantly different.

Average T_{gi} (Figure 14) differed significantly between practices 1, 5, 6, and 8 ($p<0.001$). Practice 1 was significantly higher than 5, 6, and 8 ($p<0.001$), but there were no other significant differences between practices. Means for all variables of intensity are presented in table 6.

Testosterone did not differ significantly between time points 1, OFF1, and 9 ($p=0.157$). Cortisol did not differ significantly between time points 1, OFF1, and 9 ($p=0.120$). T-C

ratio differed significantly between time points 1, OFF1, and 9

Preseason Session	Plasma Osmolality	Creatine Kinase	Testosterone	Cortisol	T:C Ratio
1	298±4	206.9±145.7	19.26±12.62	697±297	0.02±0.01
OFF1	297±4	675.8±404.9	20.2±12.23	588±254	0.03±0.02
9	303±4	460.2±365.8	17.95±11.08	589±374	0.02±0.01
Mean	300±3	447.6±234.7	19.29±1.17	625±63	0.03±0.01
(Mean±SD)					

($p=0.009$). Practice 9 was significantly lower than OFF1 ($p=0.036$). Creatine kinase differed significantly between time points 1, OFF1, and 9 ($p<0.001$). Practice 1 was significantly lower than OFF1 and 9 ($p<0.01$). Means for all blood values are presented in Table 8.

Mood

Pre-practice Thirst differed significantly between practices 1, 2, 5, 8, and 9 ($p<0.001$). Practices 1 and 2 were significantly lower than 8 and 9 ($p<0.05$). Post-practice Thirst differed significantly between practices 1, 2, 5, 8, and 9 ($p<0.026$). Post hoc tests using

Bonferroni correction revealed that no pairs were significantly different. Thirst change was not significantly different between practices 1, 2, 5, 8, and 9 ($p=0.516$).

Practice session	Thirst pre	Thirst post	Thirst change	Thermal pre	Thermal post	Thermal change	POMS TMD pre	POMS TMD post	POMS TMD change	ESQ pre	ESQ post	ESQ change
1	3±1	4±0	1±1	4±0.6	4±1.2	-0±1	7±16	5±15	-2±11	4±1	4±1	3±3
2	3±1	4±1	1±2	3.3±0.6	3.3±1	-1±1	0±9	6±19	6±14	4±2	7±3	10±6
5	3±1	4±1	1±1	3.6±0.6	3.6±0.7	-1±1	9±10	10±16	1±15	7±3	9±4	2±4
8	4±1	4±1	0±2	4.4±0.5	4.4±0.8	0±1	3±8	7±10	4±15	5±3	6±4	0±2
9	4±1	4±2	1±1	3.8±0.4	3.8±0.6	0±1	5±11	10±12	4±10	5±3	7±4	2±2
Mean	3±0	5±2	1±0	3.8±0.4	3.8±0.4	-1±1	5±4	8±2	3±3	5±1	6±2	3±4
(Mean±SD)												

Pre-practice Thermal did not differ significantly between practices 1, 2, 5, 8, and 9 ($p=0.052$). Post-practice Thermal differed significantly between practices 1, 2, 5, 8, and 9 ($p=0.010$). Practice 8 was significantly higher than 2 and 5 ($p<0.05$). Thermal change differed significantly between practices 1, 2, 5, 8, and 9 ($p=0.004$). Practice 8 was significantly higher than 2 and 5 ($p<0.05$). Pre and post-practice measures of Thirst and Thermal are presented in Figure15.

Pre-practice ESQ was significantly different between practices 1, 2, 5, 8, and 9 ($p<0.001$).

Practice 5 was

significantly

higher than 1 and 2 ($p<0.01$). Post-practice ESQ was significantly different between practices 1, 2, 5, 8, and 9 ($p<0.001$). Practice 1 was significantly lower than 2, 5, and 9

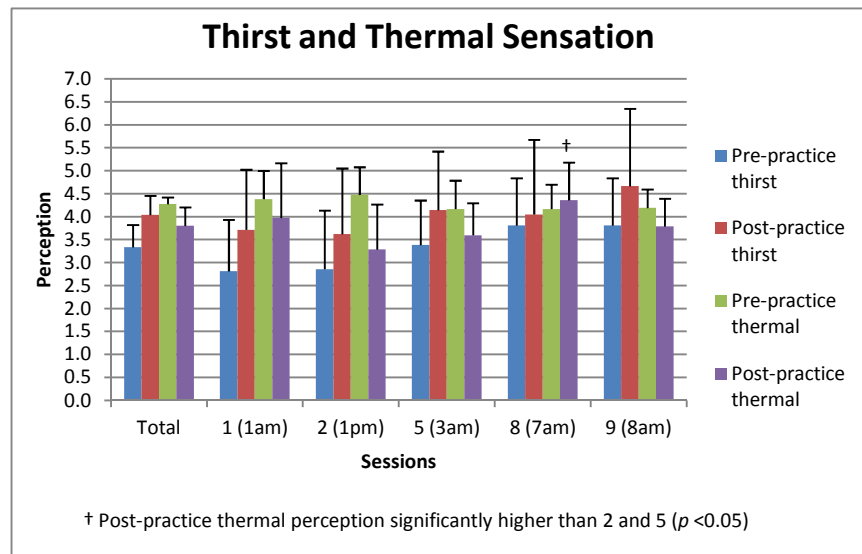


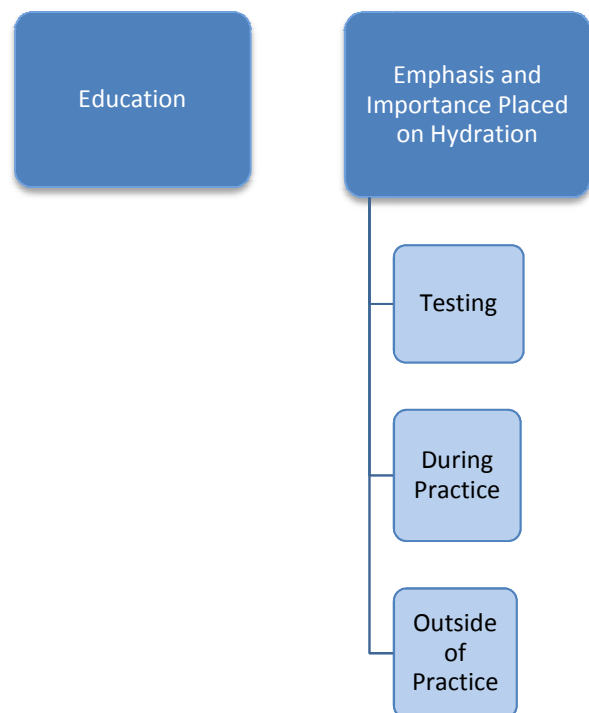
Figure15. Perceptual measures of thirst and thermal sensation

($p<0.05$). ESQ change differed significantly between practices 1, 2, 5, 8, and 9 ($p<0.001$).

Pre-practice POMS_{TMD} differed significantly between practices 1, 2, 5, 8, and 9 ($p=0.017$). Practice 2 was significantly lower than 1 and 5 ($p<0.05$). Post-practice POMS_{TMD} did not differ significantly between practices 1, 2, 5, 8, and 9 ($p=0.343$). POMS_{TMD} change did not differ significantly between practices 1, 2, 5, 8, and 9 ($p=0.199$). Practice 1 was significantly lower than 2 and 8 ($p<0.05$); and 2 was significantly higher than all practices ($p<0.01$). Mean values for all mood variables are presented in Table 9.

Post-hoc interviews

The certified athletic trainer (ATC) and head strength and conditioning coach (SC) for the men's soccer team was interviewed in regards to the hydration strategy followed by the team. Two themes emerged in the interview: education, and emphasis and importance placed on hydration. Emphasis and importance of hydration could then be broken up into three subthemes: testing, during practice, and outside of practice time (Figure 16).



ost-hoc interviews

In reference to the education theme, when asked about pre-practice hydration, the ATC responded: "I do educate the athletes about staying hydrated throughout the day." To the same question, the SC responded: "We talk to them in preseason about, jokingly about some of the urine color. I don't know if you've seen they have these little laminated boards that have the urine color and there were some funny comments that would come up with that." When asked about post-practice rehydration, the ATC responded: "I will remind them if not every day, every other day, make sure we hydrate, make sure we hydrate." To the same question, the SC responded: "But I tell them that when they go to the next level, you may not always have someone there who is going to take you through this process. You have to be able to take yourself through this process." When asked about education athletes on hydration in reference to performance, the ATC responded: "I will say 'Stay hydrated, you should rehydrate.' But if I see someone who's really not buying in, I'll talk with them 1 on 1 to get them to do it. 'If we do this, change this in your diet, or this hydration-wise, it'll affect A B and C, then you'll be better off in the long run.'" When asked about how the athletes respond to the education they're given, the SC responded: "I think that process, talking about the kind of the culture of what it sounds like we've been able to develop, because in the end sometimes we don't necessarily, when it becomes part of the culture it's difficult to point to, here is the thing. But I think that each time we do that to someone who says 'no, I don't need a drink' and we say 'no, drink something' I think that becomes part of an understanding that they have."

In reference to the emphasis and importance of hydration, when asked about pre-practice hydration testing, the ATC responded: "They weigh in before every practice. I

don't really do a weigh out because I don't think they're losing as much weight as a football player would during like an August practice session. So I'll do a weigh in before every practice session and if they kind of have regained similar weight."

In reference to hydration strategy during practice, when asked about the flexibility of their hydration protocol, the ATC responded: "If it's really hot, I'll remind coach to make sure they're getting enough water and get hydration breaks in. He's really good with that." When asked about the availability of water during each training session, the ATC responded: "They can come to me during a drill or something like that to get some water. If there is a team break, I will go out there and hydrate them like you guys saw. But if someone is like thirsty, I don't mind them coming up to me or I'll go and find them and get them water as needed." To the same question, the SC responded: "Really between each period they're given an opportunity to get water. So, and not only that, but if it's a drill per se, there's water readily available in the water bottles right behind them. So, if it's something where it's I go, you go, you have the opportunity to get something to drink there as well. And there have been, as we talk it kind of brings it up more thoughts to the surface, but certainly there are times when we have a break and we'll go out with the water bottles. And a guy will be like, 'no, I'm good', you'll say 'no, you know what, drink something.'" When asked about the length of each break between drills, the ATC responded: "I will purposely take my time with some of the breaks and get more rest recovery slash more hydration. So I would say goal, average it's probably like 3-5 minutes, but sometimes I'll lag it out to like 5 or 6. There is no set stopwatch time, it's really about trying to drag it out as much as I can."

In reference to hydration strategy outside of practice time, when asked about pre-practice hydration, the ATC responded: “The day of their physical, whatever day that is, I give them a water bottle. And obviously they have water bottles at practice, but this is for them to use outside of practice, outside of when they’re at meetings or when they’re in their dorms to kind of fill up in the cafeteria or in the hallways with water or Powerade, whatever it might be.” To the same question, the SC responded: “But we have Gatorades like they’re going to stop selling them and we need to stock up. We buy Gatorades by the dozens. And guys will literally leave meals with bags that weigh 40 pounds because there’s extra Gatorades left over and they’ll take them.” When asked about rehydration and recovery, the ATC responded: “Generally they would go to meals right afterward, so it’s just hydrate, hydrate as much as they can. I’ll see the guys eating up in the cafeteria and they’re going straight for the Powerade or the juices, they probably get enough water from me so they don’t go for too much of that.” To the same question, the SC responded: “Making sure that we plan practice around the fact that they’re able to get breakfast at some point in there. And that’s something that maybe in the past 4-5 years is relatively new, in that I’m looking at the guys and we’ve got an 8 o’clock practice and I say ‘what did you have to eat before this?’ And they say ‘we didn’t have anything before this because it’s 8 o’clock practice.’ So we’ve kind of been able to modify those practice times, expressing to coach the importance of getting those meals in there.” When asked how the coaching staff is able to implement their program, the SC responded: “When the structure is there, it’s very easy to make little things happen along the way. But without that structure it can be very difficult, borderline impossible, as I can tell you with experience with another team I work with.”

Discussion

The present study examined the first 9 days of soccer preseason training in reference to physical demands, hydration status, core temperature, and mood. There was no significant relationship between BML and T_{gi} , likely due to the low levels of dehydration experienced by subjects. During the preseason, subjects experienced mild dehydration of $\leq 1\%$ BML, with no significant loss over the entire preseason period. Urine color, USG, urine osmolality, and plasma osmolality all indicated good hydration before each practice; both urine color and USG agree with mild dehydration after each training session. Average core temperatures during the study were moderate for individuals performing intense exercise in a warm environment; and only a few subjects ever reached 40°C , but not consistently across practices. The perceptual measures before and after practice indicated that mood was not significantly affected by the environment or training sessions. There also was not a cumulative effect on mood over the preseason period.

Performance

Few studies have looked at preseason training over the course of several days. No studies to date have examined collegiate preseason soccer training, including practice sessions and scrimmages. A majority of the literature that discusses soccer performance focuses on professional athletes participating in mid-season match play. Coaches, athletes, and athletic trainers place great emphasis on this time of the season for different reasons. Coaches and athletes may view it as a determining time for the success or failure of a team during their regular season, while athletic trainers consider the risk of injuries/illnesses commonly associated with unacclimatized exercise during a normally warm or hot time of the year. Athletes perform intense conditioning to prepare for their

season during this time, which increases risk of EHI. Maintaining adequate hydration throughout preseason training can optimize heat acclimatization and may reduce fatigue, which would only serve to enhance the benefits of the intense conditioning.

No quantifiable data is available which examines the physical demands of preseason soccer training. Neither physical demands such as distance or velocity, nor physiological and psychological demands, such as core temperature, hydration, or mood, have been studied in reference to collegiate men's soccer. The goal of preseason training is to adequately prepare for the demands of match play during the season. However, no conclusive data on collegiate match play exists, which makes deriving a connection between past and present research difficult. Based on the trend that higher level professional athletes perform at higher intensities than semi-professionals would support that collegiate athletes perform even less intense exercise, however no research on collegiate soccer exists to substantiate that assumption.

Soccer match performance has been extensively studied in professional soccer, however not so in the collegiate population. Several studies have reported that the physical demands of the game decrease as the performance level of the athletes decrease (professional vs. semi-professional). This would seem to predict that collegiate athletes would have reduced physical demands compared to professional athletes, which is true of the present study. Ekblom (1986) reviewed the match activities of professional soccer athletes. Players reportedly covered in excess of 12 km during a match, with a wide range of velocities. Heart rates were reported as >85% heart rate maximum for a majority of the match. BML also reportedly ranged from 1-5 kg during match activities, with the higher values occurring with extreme environmental conditions.¹¹ Mohr et al.

(2010) reports heart rates for professional athletes. Average HR and maximum HR were higher than the present study, suggesting that the professional athletes have a higher intensity overall than the collegiate athletes. However, higher heart rates may be noted with dehydration, as dehydration decreases stroke volume, but increases heart rate as an attempt to keep up with the high circulatory demand during exercise. The higher heart rates observed in Mohr et al (2010) could have been associated with dehydration since subjects lost > 2% body mass, started the match with USG indicating slight dehydration (1024 ± 1).⁴² Maximum velocity during the match was 32.1 ± 0.5 km/h, which is slightly higher than the maximum velocity of the subjects in the present study, which supports the theory that performance level impacts intensity. The authors concluded that decrements in sprint performance as well as distance covered during the latter portions of the match were correlated with increased dehydration during the match and high environmental stress (30°C).⁴² In the present study, subjects began exercise well hydrated and maintained relatively good hydration during practice, which likely lead to less demand for increased heart rate as stroke volume would not have drastically decreased.

In several studies, a decrease in distance covered during the second half of match play in professional soccer is reported.^{1,8,10,42} Stolen et al. (2005) describes match distance covered as 10-12 km for field players with a 5-10% decrease in distance covered occurring in the second half. Sprint performance decreased in the second half as well. Only heart rate had a significant trend across days (Figure 11). It appeared that in the current study, average heart rate decreased during the first half of the preseason, but started to increase during the second half of the preseason. As reported by other research, this could be due to dehydration. But since dehydration was mild and did not

have a similar trend, it is more likely that the training sessions required different amounts of intensity or fatigue became a factor. Bangsbo et al. (2006) describes dehydration and hyperthermia as factors which contribute to the decreased performance in the second half of soccer match play. Fatigue was pointed to as the culprit, derived from decreased velocity and distance covered as compared to the first half of match play.⁸ In the present study, it is apparent from the T:C ratio decrease and CK increase, that the athletes were participating in intense exercise. But this doesn't necessarily describe development of cumulative fatigue, as much as it describes the intensity of the previous practices. Development of fatigue is vague in the literature, and is thought to be caused by a combination of accumulated dehydration and bouts of intense exercise without adequate recovery. An ideal scenario to examine fatigue in soccer athletes is during preseason training, where intensity is high and recovery may be limited to a few hours between sessions in one day. But unlike a soccer matches, the high intensity training occurs over consecutive days. If fatigue is related to dehydration, and decreased performance is a result of fatigue, then limiting dehydration would theoretically also limit fatigue. The findings of the present study support this notion, in that although recovery periods were short, performance did not significantly decrease over the 9 day preseason period. As shown in table 6, total distance covered and total efforts increased on the final practice day as compared to every other day, although maximum velocity decreased. Athletes completed more work, which may explain the increase in average heart rate. In the present study, practice 1 had higher heart rates than any other day and higher average T_{gi} than any other day, however distance data is not available. However, from observation, the drills performed during that session were not significantly different from other

training sessions during the study, and measures of dehydration were not significantly higher than other days. So the higher heart rates and T_{gi} could be explained by lack of heat acclimatization, fitness level, or stress, as it was the first day of preseason training.

Dehydration

Researchers have speculated that a decrease in distance covered is related to several factors, one being dehydration. But dehydration during soccer performance has not been extensively researched, especially not over several successive days to examine cumulative dehydration. Al-Jaser et al. (2006) studied fluid changes in Kuwaiti soccer athletes during preseason match play and found that BML for the entire game was $2.7 \pm 2\%$, which is higher than the BML reported in the present study. This suggests that fluid intake was significantly less than fluid loss.⁴³ This contrasts the present study, where fluid intake was more closely approximated fluid loss, ending in mild dehydration of $< 1\%$ overall. We believe that the collegiate athletes in the present study remained so well hydrated because of fluid availability during practice. Water was consistently available during drills and breaks were frequent, approximately four 3-5 minute breaks for each session, which lasted about 100 minutes. During breaks, players were encouraged to take water and hydrate well. The staff emphasized the importance of staying hydrated and that likely played into the player's willingness to take in the amount of water necessary to produce mild dehydration.

Maughan et al. (2004) had a similar study protocol to the current study, but it was only carried out over the course of one professional controlled preseason training session. They had similar results as well, with slightly more BML and slightly lower U_{osmo} than the present study. Core temperature was not assessed, which may have given insight into

the intensity of exercise, since low exercise intensity likely causes lesser sweat losses and overall fluid loss. The authors concluded that while athletes did not adequately replace fluid loss during the session, the loss was small enough that no adverse performance effects likely occurred although performance was not measured specifically.⁴⁴ The authors were unsure that the athletes would adequately replace fluids prior to their next session, a fear which is substantiated by Carter and Gisolfi (1989). It is important to note that subjects in the present study remained well hydrated throughout the preseason period. The present study suggests that, with adequate education and encouragement, rehydration between sessions can occur and does occur in some collegiate soccer programs. U_{col} , USG , and U_{osmo} indicated that subjects were well hydrated at the start of every session, even sessions 2 and 7, which were the second sessions of the day. That would indicate that their rehydration strategy was effective in quickly and adequately rehydrating the subjects after each session.

Carter and Gisolfi (1989) describe post-exercise rehydration as being essential to restoring performance. Subjects in their study performed a 3 hr cycling session, consuming beverages *ad libitum* to determine which rehydration beverage (water or carbohydrate-electrolyte) subjects drank more of and if *ad libitum* drinking was effective in preventing dehydration/facilitating rehydration. Subjects were not aware that researchers were measuring the amount of fluid they were consuming. They found that subjects drank more water during exercise, and more carbohydrate-electrolyte beverage after exercise.⁵⁸ However, subjects did not adequately replace fluids during exercise and incurred approximately 2% BML; in recovery they only replaced up to 80% of fluid lost during exercise, which would lead to chronic dehydration if that continued over multiple

exercise sessions. Subjects in the present study were able to replace their small losses and prevent cumulative dehydration over the preseason training period. In the Carter study, subjects tended to rehydrate more with the carbohydrate-electrolyte beverage rather than water.⁵⁸ Part of the rehydration protocol that the subjects in the present study follow includes a protein-carbohydrate beverage consumed after every practice, along with a protein supplement bar. The ATC also reported that during preseason, after the athletes finished their recovery, they often went straight to a meal. The ATC encouraged the athletes to drink water, sports drinks, and juices during their meals to aid in rehydration. The subjects were also given their own water bottles to be carried with them at all times, which encourages drinking since beverages can be readily available.

As shown in Figure 8 for the present study, some days had significantly higher BML than others, however the highest percent body mass loss ($1.5 \pm 0.6\%$) occurred during the first scrimmage. This would still be considered mild dehydration during exercise, and is consistent with the previous literature which describes higher body mass losses during matches.³² Broad et al. (1996) examined BML and voluntary fluid intake in elite male soccer athletes during training sessions to determine specific fluid requirements for that team sport populations. Over one week of training sessions and matches, however it is not clear at what point in the season data collection occurred. The subjects incurred greater dehydration during matches than training sessions, but both were under 2% BML, which is concurrent with the results of the present study. The authors concluded that availability of fluids during activity and education about awareness of fluid intake are necessary for dehydration to be limited to 2%. They also stated that preloading may be the only feasible way to stay adequately hydrated during

match play, since breaks are limited.³² During scrimmages in the present study, both the ATC and SC described actively passing out water and sports drinks in the locker room during half time, encouraging the players to drink more by offering drinks multiple times. We found that all measures of dehydration during the two scrimmages were elevated in comparison to practices, but not statistically significant. This is likely due to the lack of water availability and breaks during halves. The ATC said that hydration for some players who do not come out during the game is almost impossible. They can only come to the sideline briefly to get a quick sip of water maybe once per half, which does not keep them adequately hydrated. But the finding that they still only incurred mild dehydration with limited access to fluid means that during half time and other short breaks, they made a significant dent in replacing the fluid they likely lost.

Core temperature

In the present study, subjects did have a significant rise in T_{gi} during exercise, however only to a normal exercising temperature. Based on the current literature, this could be attributed to attenuation of dehydration during exercise, moderately stressful environmental conditions, and the collegiate playing level which may be associated with lower intensities than the professional playing level. Rectal temperatures tend to be elevated more in higher division teams, which supports the concept that intensity drives rectal temperature up.¹¹

Environmental conditions during the present study were not particularly stressful and three practice sessions (6, 7, and 8) took place in an environmentally controlled indoor training facility due to poor outdoor conditions. Subjects did their normal drill activities, just as if they were outdoors. As shown by many studies, environmental

conditions have a dramatic effect on core temperature through heat storage vs. dissipation.^{15,17,23,25} More thermal stress drives core temperature up by limiting heat dissipation. However the environmental conditions in the present study were only moderately stressful and included some wind during outdoor training sessions, so heat dissipation was enhanced further. It is likely that more stressful environmental conditions would have produced higher T_{gi} , and possibly more dehydration.

The influence of hydration status on core temperature during other types of exercise, running and cycling, has been well documented in the literature. As mentioned previously, for every 1% BML, core temperature rises approximately 0.25°C .³⁵ Montain et al. (1998) studied the effect of hypohydration (3 and 5% BML) on esophageal temperature during low, moderate, and high intensity treadmill running. They found that exercise intensity was positively correlated with an increase in esophageal temperature; the hypohydrated trials had significantly higher esophageal temperatures during exercise with a faster rise in temperature at the beginning of exercise.⁵⁹ In the present study, rise in core temperature was not associated with significant dehydration, but some evidence of increased average and maximum heart rate may be associated with increased T_{gi} .

The limited dehydration that occurred in the present study likely mitigated rise in core temperature to some extent. Edwards and Clark (2006) investigated core temperature and body mass change, and heart rate during recreational and professional match play. Heart rate was significantly higher, BML was higher, and core temperature was significantly lower for professional athletes.¹⁶ Values for subjects in the present study compared more to those of the professional athletes than the recreational athletes, however they were lower by all accounts. In the present study, average T_{gi} was not

significantly high, but comparison is difficult as core temperature has not commonly been studied in soccer athletes as it can be difficult to obtain. Rectal temperatures have been reportedly higher in professional soccer athletes vs. semi-professionals during match play.¹¹ As a minor determinant of player level, researchers in the current study examined possible differences between first year vs. returning player level, however no differences in T_{gi} were found. This does not support the premise that higher level players work at a higher intensity and therefore drive up core temperature; however the difference between populations was negligible on all accounts. DeMartini et al. (2012) examined core temperature responses to exercise induced dehydration during preseason football training. They found similar average T_{gi} temperatures to the present study ($38.32 \pm 0.34^{\circ}\text{C}$). The work performed in football more closely approximates that of soccer than running or cycling. Subjects in that study did not incur significant dehydration, overall $<1\%$ BML,⁶⁰ which is also similar to the present study. The authors attribute the mild dehydration to the availability of water and encouragement to drink during training sessions. This is supported by the present study, in the athletes were encouraged to drink during breaks in training sessions, and water was available during drills as well. The availability of water during training sessions was likely a major factor that played into the subjects mild dehydration.

Perceptual measures and mood

Cognitive deficits and negative perceptual responses may become apparent with mild dehydration, however results reported in the literature are inconsistent, which suggests interactions from other factors.⁶¹⁻⁶⁴ One study by Bandelow et al. (2010)

examined the effect of dehydration on cognitive function of soccer players during match play. They also examined how a cooling intervention (cold water spray) effected cognitive function in the same scenario. Dehydration had some negative cognitive effects, however, they were not consistent across tests. BML only had negative effects on speed and visual scanning. The authors concluded that dehydration did not have clear effect on cognitive function.⁶³ Increased T_{gi} had significant negative effects on speed and some domains of visual processing. Finally, the cooling intervention had significant positive effects on several measures of cognitive function. It had no effect on T_{gi} , however the authors speculated that the cooling strategy may have made the subjects more comfortable, leading to better cognition, however perception of comfort was not measured. The effect of cooling can be related to the present study, in that subjects in the present study reacted similarly via perceptual measures to their recovery cooling post-exercise. Subjects in the present study cooled prior to returning to the lab to complete post-practice data collection. Although we did not measure cognitive function, we suspect that given the data presented by Bandelow, cognitive function would have been better after their recovery ice bath than if the measures had been taken directly after practice ended.

This study is the first to provide perceptual measures in soccer at any level. Other types of exercise however, have been examined for perceptual responses to exercise. Stearns et al. (2009) described perceptual measures during an endurance trail running study in the heat. Subjects served as their own controls and participated in two trials, hydrated and dehydrated. Thirst perception was significantly higher in the dehydrated trial compared to the hydrated trial. Thermal sensation was significantly higher in the

second half of the trial for dehydrated subjects compared to all hydrated subjects. Thermal sensation was also reportedly higher even at 20 minutes after exercise for dehydrated subjects.⁵³ This would indicate that dehydration has an effect on both thirst and thermal sensation, and the negative perception may last longer in dehydrated subjects. In the present study subject's thermal sensation was approximately even when data was collected after the recovery protocol.

Ganio et al. (2011) and Armstrong et al. (2012) performed very similar exercise (walking) and diuretic-induced dehydration studies on mood in males and females, respectively. They used both cognitive and perceptual measures to draw conclusions about overall mood due to dehydration. Subjects served as their own controls and were dehydrated approximately 1.5% for males⁶² and 1.3% for females⁶¹ for the testing sessions with diuretic-induced dehydration and exercise-induced dehydration. USG for males during dehydrated trials was approximately 1.019⁶² and females was 1.012.⁶¹ Researchers found that cognitive deficits were not present for the mildly dehydrated subjects, but the subjects POMS scores were adversely affected. Subjects also reported more headaches, difficulty concentrating, and overall more difficulty with the tasks. Researchers also reported those negative effects present in females were still present 8 hours after the trial session, which indicates a lasting effect which may become cumulative over time. The measures of dehydration are similar to those in the present study, however, mood was not significantly affected by exercise. This may be due to the difference in type of exercise or the timing of the post-practice data collection, which occurred after the subject's normal recovery protocol. No significant difference in perceptual measures after practice supports the recovery practices of the team, especially

since some mood effects in other studies were noted as long as 8 hours after trials. Theoretically, subject's mood returned to near resting values after practice due to the recovery protocol, which may have prevented lasting or cumulative effects.

A research study in review from a hydration and movement study at the University of Connecticut used the POMS as a tool to assess mood in four groups: dehydrated normothermic, hydrated normothermic, dehydrated hyperthermic, hydrated hyperthermic.⁶⁴ Soccer players from the current study had core temperatures, BML, and U_{osmo} values similar to those obtained in the hydrated hyperthermic trial. Change in POMS total mood disturbance scores for hydrated hyperthermic subjects from pre-trial to recovery period were approximately 2 ± 20 , which indicates some variation. However, the mean value was similar to the mean POMS_{TMD} from the present study (Table 9). This supports the change in POMS scores in the present study, which occurred after the recovery protocol as well.

Post-practice thirst and thermal perception ratings in the current study were slightly lower than those reported by Armstrong et al. (2012). Cyclists participating in an ultraendurance cycling event with high environmental heat stress. Even through the extreme conditions, subjects ended the race with $<1\%$ BML and USG of approximately 1.023, which indicates mild dehydration. Mean T_{gi} during exercise was 38.5°C . Approximate finishing thirst (5 ± 2) and thermal (6 ± 1) perception was significantly higher than values reported during the event.⁶⁵ Researchers reported that thirst and thermal perception was in agreement with the mild dehydration which subjects experienced during the event. Lower post-practice ratings of thirst and thermal perception could be

associated with the effects of the recovery protocol followed by the subjects in the present study.

Interview

The post-hoc interviews shed more light on the hydration practices of the team and how they relate to the findings in the present study. The ATC and the strength coach both expressed that the whole staff placed high importance on hydration, especially during preseason training. The ATC was more focused on the safety aspects of hydration, specifically injury and illness prevention. The strength coach was focused more on performance, referring to the importance of hydration during recovery. They agreed that the goal is to keep the athletes hydrated so they can perform at their best. Both the ATC and strength coach said that hydration during practice was generally orchestrated during breaks, and the practice schedule was flexible enough to accommodate extra hydration on days when they felt it was necessary. They agreed that the coaching staff encourages proper hydration, which helps the athletes see the importance. The education they give to the athletes tends to be conversational and focuses on things the athletes can do outside of practice to rehydrate appropriately.

For the first time, physiological data backs up a team's intended hydration strategy and recovery protocol. The main themes that emerged in the interview described a coaching staff that values hydration and has put measures in place to provide good hydration for the athletes. The ATC and strength coach described a hydration system that continues to evolve and change as the needs of the team change and new evidence emerges. Both the ATC and strength coach attribute the success of the program to the structure and discipline which begins with the head coach and continues throughout the

rest of the staff. The staff appears to value the effects hydration and a strict recovery program can have on performance. The recovery program they had in place was described by the mood questionnaires, which were collected after they completed their recovery protocol. Overall, the mood affects were relatively negligible after the recovery protocol, which suggests that their recovery protocol effectively returned them to pre-practice values. This is commonly the goal of recovery programs, to prevent cumulative dehydration, stress, or decreases in performance. It appears from physiological and psychological data, that this program was effective and relatively easily implemented.

Adverse outcomes

As discussed earlier, the negative consequences of dehydration range from slight cognitive deficits to increased risk of exertional heat illness and everything in between. It's important for athletes to stay properly hydrated to maximize performance and decrease risk of exertional heat illnesses. In preseason, heat acclimatization will be occurring for most athletes, but dehydration can extend the length of time to gain heat tolerance, and can limit the positive effects of heat acclimatization. Dehydration with intense exercise raises core temperature, which can lead to exertional heat illness, decreased performance, and the possibility of fatigue over the preseason period. No heat illnesses occurred during this study, but some heat illnesses may have been prevented by preventing dehydration during training sessions, since heat illnesses most commonly occurring the first 5 days of preseason training.⁶⁶ This may be due to lack of acclimatization and intensity level beyond fitness status.

Dehydration during scrimmages was greater than during training sessions in the current study. During soccer matches, athletes get fewer breaks, sometimes only the 15 minute half time period, than in training sessions where breaks can be instituted at any time. The current literature is not clear whether this is globally true, or a unique finding in the current study. Two other study examining single training sessions found significantly more dehydration than the present study;^{32,42} also the body mass loss presented in studies of professional match play report significantly more body mass loss than the scrimmages in the present study.^{8,11,43,44} The athletic trainer described hydration during scrimmages and games differently than practices. The focus shifts away from hydration during activity to hydration during any break they have. The athletes are sometimes able to go to the sideline briefly for a small drink, but most of the hydration occurs during half time. But with rate of gastric emptying and comfort may hinder total replacement of fluids in the 15 minute break. Had the subjects in the present study not been encouraged to replace fluid, they likely would have ingested less and become more dehydrated. It should also be mentioned, however, that although there was more dehydration during scrimmages, it would still fall into the realm of mild dehydration.

Dehydration is not only acutely acquired during practices and games. Cumulative dehydration also increases the risk of heat illness and has negative performance effects.¹⁹ As mentioned in another similar soccer study, the athletes lost approximately 2% body mass, but the author suspected that they would not replace that fluid, which would compound for the next session.⁴² This is especially significant when more than one session takes place in a single day. If the athletes have not adequately replaced their losses from the first session, then they begin dehydrated and accumulate even more

dehydration. Again, that puts the athletes at risk of heat illness. Also, if the athletes did not adequately replace fluids lost, they may have also not adequately replaced their energy expenditure during the first practice. This would lead to a steeper decline in performance during that session, making it less effective and possibly negating any benefits achieved during the first practice. Cumulative dehydration can also affect heat acclimatization, increasing time until acclimatized and possibly making it less effective at preventing heat illnesses or aiding performance in stressful environments.

High core temperatures are also associated with decreased performance, poor cognitive function, and increase the risk of exertional heat illness. Heat acclimatization makes the thermoregulatory system more efficient at dealing with increased metabolic and environmental heat.¹⁹ It decreases the thermoregulatory set point and increases the efficacy of heat dissipation mechanisms, the primary one being sweating. But when dehydration and rises in core temperature from exercise occur in concert, sweat rate decreases and heat storage climbs. If dehydration is present from the beginning of a training session, heat storage starts climbing earlier than if dehydration begins to occur progressively over the entire practice. In the present study, even in the first few days of training when the majority of heat acclimatization would have occurred, core temperatures were not significantly increased. But since it seems that dehydration was limited, any significant heat storage likely did not occur until the end of practice, with only a little time is left in practice. Return to a normal core temperature was probably slightly expedited by the cold water bath in the team's recovery protocol.

Limitations

This study had some limitations in both design and applicability. As it was an observational field study, no controls were set and subjects were not asked to do anything dramatically different from their usual routine beyond a short visit to the laboratory before and after each training session. Their schedule was consistent, but not ideal for collection of all types of data. Post-practice measures were always taken in the laboratory after each session, however the post-practice measures occurred after subjects participated in their normal post-practice routine which included cooling in an ice bath for 10 minutes and ingesting some recovery beverages/bars. This may have impacted %BML and perceptual measures. So this study does not simply reflect the physiological and perceptual responses to a training session, but also recovery.

In order to get T_{gi} for morning training sessions, subjects would ingest the thermistors at dinner the previous evening, which lead to some pills being excreted prior to the study the next morning. Even on double session days there was not enough time prior to the next practice to ingest another pill and ensure that it would be low enough in the GI tract for accurate temperature reading. On those days, subjects who did not start with a thermistor were lost for all training sessions that day. Drills were not interrupted to obtain any measures, so T_{gi} was not recorded at consistent time points during practice, so information on maximum T_{gi} could not be reported with any certainty of accuracy.

Fluid intake and excretion was not measured during practice, so player urination during practice, while infrequent, may have altered %BML calculations. Sessions 6, 7, and 8 were indoors in a turf training facility, which affected the use of the GPS devices. Subjects still wore the devices, however distance data was not available for those days.

The results of this study are specifically applicable to collegiate male soccer athletes. Previous studies have focused mainly on the professional population, so comparisons to previous research may have less significance. Continued research should examine collegiate athletes during mid-season match play to make a more meaningful comparison to the literature on professional soccer athletes. Also, examination of professional soccer training sessions would contribute notably to the existing literature.

Mild dehydration was observed during this field study of 21 male Division I collegiate soccer athletes during preseason training. Over the entire preseason training period, core temperatures were not extreme, hydration status did not decline, performance did not decline, and mood did not decline. Dehydration during exercise can cause performance decreases, so those soccer athletes who become less dehydrated may not incur performance decrements. The current study provides an example of a hydration strategy used by a collegiate soccer team that was successful in limiting dehydration during practices and scrimmages.

Applicability

The most effective and efficient hydration strategy has been somewhat elusive for team sports' preseason training. The negative effects of dehydration, both acute and chronic have been discussed in reference to the current study. The certified athletic trainer took an active role in preventing both acute and chronic dehydration by encouraging the athletes to consume fluids before and after practices, and having water accessible during training sessions. We propose that the hydration strategy used by the team in the present study could be applied to other team and other sports. The

importance placed on hydration was a key component to the success of the program described above. The athletic trainer claimed that the support from the coaching staff, from the top down, makes the program more effective and the athletes buy in to the theory. When the coaching staff is on board, athlete compliance is likely to increase. Using some of the questionnaires to determine whether or not mood is affected over time, or a urine color chart so athletes can judge their own hydration status may be helpful additions to the program presented in the current study. While a team's hydration strategy should be individual and specific to the needs of that team, the major themes of the current study could easily and inexpensively be introduced to any program.

Future Directions

Based on the findings of the present study, future research should focus on collegiate soccer. A comparison of the physical demands of professional soccer to collegiate soccer would shed more light on the possibility of differences between levels of soccer play. Currently, collegiate soccer base their training sessions on the match demands of professional soccer, but this likely does not truly approximate actual collegiate physical requirements. More research on training sessions, both collegiate and professional, in terms of hydration and core temperature. We can see that more dehydration occurs in match play, but very little core temperature data during match play exists. Soccer is so unique in its intense intermittent nature, but where few breaks are available during competition, physiological responses to exercise may be slightly different than endurance sports or other intermittent sports such as American football.

References

1. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. *Sports Med.* 2005;35(6):501–536.
2. Davis JA, Brewer J. Applied physiology of female soccer players. *Sports Medicine.* 1993;16(3):180–189.
3. Krstrup P, Mohr M, Ellingsgaard H, Bangsbo J. Physical demands during an elite female soccer game: importance of training status. *Med Sci Sports Exerc.* 2005;37(7):1242–1248.
4. Bangsbo J, Iaia FM, Krstrup P. Metabolic response and fatigue in soccer. *Int J Sports Physiol Perform.* 2007;2:111–127.
5. Castagna C, Impellizzeri FM, Chaouachi A, Bordon C, Manzi V. Effect of training intensity distribution on aerobic fitness variables in elite soccer players: a case study. *J Strength Cond Res.* 2011;25(1):66–71.
6. Reilly T. Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences.* 1997;15:257–263.
7. Mohr M, Krstrup P, Andersson H, Kirkendal D, Bangsbo J. Match activities of elite women soccer players at different performance levels. *J Strength Cond Res.* 2008;22(2):341–349.
8. Bangsbo J, Mohr M, Krstrup P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci.* 2006;24(7):665–674.
9. Mohr M, Krstrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci.* 2003;21:519–528.
10. Bangsbo J, Norregaard L, Thorso F. Activity profile of competition soccer. *Can J Spt Sci.* 1991;16(2):110–116.
11. Ekblom B. Applied physiology of soccer. *Sports Med.* 1986;3:50–60.
12. Bangsbo J. Energy demands in competitive soccer. *J Sports Sci.* 1994;12:S5–S12.
13. Rienzi E, Drust B, Reilly T, Carter JE, Martin A. Investigation of anthropometric and work-rate profiles of south american international soccer players. *J Sports Med Phys Fitness.* 2000;40:162–169.
14. Rampinini E, Coutts AJ, Castagna C, Sassi R, Impellizzeri FM. Variation in top level soccer match performance. *Int J Sports Med.* 2007;28:1018–1024.
15. Brotherhood JR. Heat stress and strain in exercise and sport. *J Sci Med Sport.* 2008;11:6–19.
16. Edwards AM, Clark NA. Thermoregulatory observations in soccer match play: professional and recreational level applications using an intestinal pill system to measure core temperature. *Br J Sports Med.* 2006;40:133–138.
17. Ozgunen KT, Kurdak SS, Maughan RJ, et al. Effect of hot environmental conditions on physical activity patterns and temperature response of football players. *Scan J Med Sci Sports.* 2010;20(Suppl 3):140–147.
18. Rico-Sanz J, Frontera WR, Rivera MA, Rivera-Brown A, Mole PA, Meredith CN. Effects of hyperhydration on total body water, temperature regulation and performance of elite young soccer players in a warm climate. *Int J Sports Med.* 1996;17(2):85–91.
19. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National Athletic Trainers' Association position statement: exertional heat illnesses. *J Athl Train.* 2002;37(3):329–343.
20. Kirkendall DT. Fluid and electrolyte replacement in soccer. *Clin Sports Med.*

- 1998;17(4):729–738.
21. Havenith G, Coenen JML, Kistemaker L, Kenney WL. Relevance of individual characteristics for human heat stress response is dependent on exercise intensity and climate type. *Eur J Appl Physiol.* 1998;77:231–241.
 22. Cheuvront SN, Kenefick RW, Montain SJ, Sawka MN. Mechanisms of aerobic performance impairment with heat stress and dehydration. *J Appl Physiol.* 2010;109:1989–1995.
 23. Sawka MN, Wenger CB. Physiological responses to acute exercise-heat stress. In: *Human performance physiology and environmental medicine at terrestrial extremes.*; 1988:97–151.
 24. Edwards AM, Noakes TD. Dehydration: cause of fatigue or sign of pacing in elite soccer? *Sports Med.* 2009;39(1):1–13.
 25. Wendt D, van Loon LJC, van Marken Lichtenbelt WD. Thermoregulation during exercise in the heat: strategies for maintaining health and performance. *Sports Med.* 2007;37(8):669–682.
 26. Armstrong LE. The impact of hyperthermia and hypohydration on circulation, strength, endurance, and health. *Journal of Applied Sport Science Research.* 1988;2(4):60–65.
 27. Nybo L, Nielsen B. Hyperthermia and central fatigue during prolonged exercise in humans. *J Appl Physiol.* 2001;91:1055–1060.
 28. Shephard RJ. Biology and medicine of soccer: an update. *J Sports Sci.* 1999;17:757–786.
 29. Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B. Separate and combined influences of dehydration and hyperthermia on cardiovascular responses to exercise. *Int J Sports Med.* 1998;19(Suppl 2):S111–S114.
 30. Casa DJ, Armstrong LE, Hillman SK, et al. National Athletic Trainers' Association position statement: fluid replacement for athletes. *J Athl Train.* 2000;35(2):212–224.
 31. Cheuvront SN, Carter III R, Haymes EM, Sawka MN. No effect of moderate hypohydration or hyperthermia on anaerobic exercise performance. *Med Sci Sports Exerc.* 2006;38(6):1093–1097.
 32. Broad EM, Burke LM, Cox GR, Heeley P, Riley M. Body weight changes and voluntary fluid intakes during training and competition sessions in team sports. *Int J Sport Nutr.* 1996;6:307–320.
 33. Harvey G, Meir R, Brooks L, Holloway K. The use of body mass changes as a practical measure of dehydration in team sports. *J Sci Med Sport.* 2008;11:600–603.
 34. Maughan RJ, Shirreffs SM. Nutrition and hydration concerns of the female football player. *Br J Sports Med.* 2007;41(Suppl 1):i60–i63.
 35. Sawka MN, Montain SJ, Latzka WA. Hydration effects on thermoregulation and performance in the heat. *Comp Biochem Physiol A.* 2001;128(Part A):679–690.
 36. Sawka MN, Burke LM, Eichner R, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand: exercise and fluid replacement. *Med Sci Sports Exerc.* 2007;39(2):377–390.
 37. Kilding AE, Tunstall H, Good M, Gammon C, Smith C. Sweat rate and sweat electrolyte composition in international female soccer players during game specific training. *Int J Sports Med.* 2009;30:443–447.
 38. Sawka MN, Francesconi RP, Young AJ, Pandolf KB. Influence of hydration level and body fluids on exercise performance in the heat. *JAMA.* 1984;252(9):1165–1169.
 39. Montain SJ, Latzka WA, Sawka MN. Control of thermoregulatory sweating is altered by

- hydration level and exercise intensity. *J Appl Physiol.* 1995;79(5):1434–1439.
40. Ali A, Gardiner R, Foskett A, Gant N. Fluid balance, thermoregulation and sprint and passing skill performance in female soccer players. *Scan J Med Sci Sports.* 2011;21(3):437–445.
 41. Cheuvront SN, Bearden SE, Kenefick RW, et al. A simple and valid method to determine thermoregulatory sweating threshold and sensitivity. *J Appl Physiol.* 2009;107:69–75.
 42. Mohr M, Mujika I, Santisteban J, et al. Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. *Scan J Med Sci Sports.* 2010;20(Suppl 3):125–132.
 43. Al-Jaser TA, Hasan AAA. Fluid loss and body composition of elite Kuwaiti soccer players during a soccer match. *J Sports Med Phys Fitness.* 2006;46(2):281–285.
 44. Maughan RJ, Merson SJ, Broad NP, Shirreffs SM. Fluid and electrolyte intake and loss in elite soccer players during training. *Int J Sport Nutr Exerc Metab.* 2004;14:327–40.
 45. Ganio MS, Casa DJ, Armstrong LE, Maresh CM. Evidence-based approach to lingering hydration questions. *Clin Sports Med.* 2007;26:1–16.
 46. Wingo JE, Casa DJ, Berger EM, Roberts WO, Knight JC, McClung JM. Influence of a pre-exercise glycerol hydration beverage on performance and physiologic function during mountain-bike races in the heat. *J Athl Train.* 2004;39(2):169–175.
 47. Gant N, Leiper JB, Williams C. Gastric emptying of fluids during variable-intensity running in the heat. *Int J Sport Nutr Exerc Metab.* 2007;17:270–283.
 48. Kavouras SA, Armstrong LE, Maresh CM, et al. Rehydration with glycerol: endocrine, cardiovascular, and thermoregulatory responses during exercise in the heat. *J Appl Physiol.* 2006;100:442–450.
 49. Maughan RJ, Leiper JB. Fluid replacement requirements in soccer. *J Sports Sci.* 1994;12:S29–S34.
 50. Armstrong LE, Casa DJ, Millard-Stafford M, Moran DS, Pyne SW, Roberts WO. American College of Sports Medicine position stand: exertional heat illness during training and competition. *Med Sci Sports Exerc.* 2007;39(3):556–572.
 51. Kay D, Marino FE. Fluid ingestion and exercise hyperthermia: implications for performance, thermoregulation, metabolism and the development of fatigue. *J Sports Sci.* 2000;18:71–82.
 52. Sawka MN, Young AJ, Latzka WA, Neufer PD, Quigley MD, Pandolf KB. Human tolerance to heat strain during exercise: influence of hydration. *J Appl Physiol.* 1992;73(1):368–375.
 53. Stearns RL, Casa DJ, Lopez RM, et al. Influence of hydration status on pacing during trail running in the heat. *Journal of Strength and Conditioning Research.* 2009;23(9):2533–2541.
 54. Edwards AM, Mann ME, Marfell-Jones MJ, Rankin DM, Noakes TD, Shillington DP. Influence of moderate dehydration on soccer performance: physiological responses to 45 min of outdoor match-play and the immediate subsequent performance of sport-specific and mental concentration tests. *Br J Sports Med.* 2007;41:385–391.
 55. Armstrong LE, Maresh CM, Castellani JW, et al. Urinary indices of hydration status. *Int J Sport Nutr.* 1994;4:265–279.
 56. McNair D, Lorr M, Droppleman L. *Profile of mood states manual.* San Diego, CA: Educational and Industrial Testing Service; 1971.
 57. Engell DB, Maller O, Sawka MN, Francesconi RP, Drolet L, Young AJ. Thirst and fluid

- intake following graded hypohydration levels in humans. *Physiol Behav.* 1987;40(2):229–236.
58. Carter JE, Gisolfi CV. Fluid replacement during and after exercise in the heat. *Med Sci Sports Exerc.* 1989;21(5):532–539.
 59. Montain SJ, Sawka MN, Latzka WA, Valeri CR. Thermal and cardiovascular strain from hypohydration: influence of exercise intensity. *Int J Sports Med.* 1998;19:87–91.
 60. DeMartini JK, Martschinske JL, Casa DJ, et al. Physical demands of national collegiate athletic association division I football players during preseason training in the heat. *J Strength Cond Res.* 2012;25(11):2935–43.
 61. Armstrong LE, Ganio MS, Casa DJ, et al. Mild dehydration affects mood in healthy young women. *J Nutr.* 2012;142:382–388.
 62. Ganio MS, Armstrong LE, Casa DJ, et al. Mild dehydration impairs cognitive performance and mood of men. *Br J Nutr.* 2011;106:1535–1543.
 63. Bandelow S, Maughan R, Shirreffs S, et al. The effects of exercise, heat, cooling, and rehydration strategies on cognitive function in football players. *Scan J Med Sci Sports.* 2010;20(Suppl 3):148–160.
 64. DiStefano LJ, Karslo R, VanSumeren MM, et al. The effects of hydration in mild and hot environments on landing technique. In Review.
 65. Armstrong LE, Casa DJ, Emmanuel H, et al. Nutritional, physiological, and perceptual responses during a summer ultraendurance cycling event. *J Strength Cond Res.* 2012;26(2):307–318.
 66. Casa DJ, Csillan D eds. Consensus statement: preseason heat-acclimatization guidelines for secondary school athletics. *J Athl Train.* 2009;44(3):332–333.