Hydration Status in College Football Players During Consecutive Days of Twice-a-Day Preseason Practices

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Background: Football players lose 3.5 to 5 kg of body weight during preseason practices because of heavy sweating. This fluid may be difficult to replace when practices occur 2 times per day on consecutive days.

Hypothesis: Football players are hypohydrated during twice-a-day preseason training in a hot, humid environment.

Study Design: Descriptive laboratory study.

Methods: In 10 college football players, body weight was measured, and blood and urine samples were obtained before and after practices on days 2 through 8 of preseason training. Baseline samples were obtained when subjects were euhydrated. Blood samples were used to calculate plasma volume changes. Urine samples were analyzed for specific gravity, sodium, and potassium. Sweat rate was calculated. Core temperature was monitored during half- and full-padded practices.

Results: Mean wet bulb temperatures were 23.3°C during morning practices and 23.7°C during afternoon practices. Plasma volume was below baseline on day 2 and expanded by day 6. Urine specific gravity was higher than baseline for 12 of 20 measurements over the 8 days. It was 1.0175 ± 0.006 at baseline but subsequently ranged from 1.0214 ± 0.007 to 1.0321 ± 0.004. Mean daily urine sodium dropped from baseline to day 2 (194 ± 43 vs 43 ± 38 mmol × L^{-1}), remaining lower on days 3, 4, and 6 (40 ± 39, 39 ± 39, and 68 ± 40 mmol × L^{-1}, respectively). Urine potassium was lower on days 6 and 8 compared with baseline and day 3. Body weight was below baseline before and after both daily practices. Core temperature was higher in full pads; sweat rate and body weight loss were not different between half and full pads.

Conclusion: Body weight, plasma volume, urine specific gravity, and urine sodium indicate that football players become dehydrated by day 2 of preseason training. Urine sodium increased to near baseline by day 8; urine specific gravity was elevated.

Clinical Relevance: Football players struggle to maintain euhydration during preseason twice-a-day sessions.

Keywords: sweat; urine sodium; plasma volume

Heat-related deaths occur each year in high school and college football players during preseason training camps. Of the 20 players who died of heatstroke since 1995 as a result of practicing football in extreme environmental conditions, 19 were high school and college athletes.[32] Heatstroke fatalities are particularly alarming, as the literature would suggest that most heat illnesses are preventable.[9,14] Maintaining a normal state of hydration is thought to be critical for the prevention of heat-related illness because dehydration is believed to play a role in hyperthermia.[2,9,13,14,16,31,33] However, 2 football practices per day in warm and humid conditions can cause sweat losses to exceed 14 L × d^{-1} in some players.[19,20] This volume of fluid loss may make it nearly impossible for these large athletes to avoid dehydration during preseason training.

Few authors have addressed thermoregulation in football players.[28,30,38] Physiological responses to exercise in football uniforms were studied by Mathews et al[30] in 1969, Wailgum and Paolone[38] in 1984, and more recently by Kulka and Kenney[28] in 2002. These were laboratory studies, and only Wailgum and Paolone used football players as subjects.[38] There are very few studies to date that have reported physiological changes in football players during preseason training.[18,29] Ehlers et al[18] reported elevated serum creatine kinase levels in football players on the fourth and seventh days of twice-a-day practices. They suggested that the rhabdomyolysis seen in their football

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players may have been related in part to dehydration, although they did not directly measure hydration status.[18]

An extensive literature search indicated a lack of information about how American football players adapt physiologically to the rigors of preseason training in a hot and humid environment. Specifically, measures of daily hydration status and acclimatization have not been reported. We have noted that football players routinely lose 3.5 to 5 kg during practice, and many do not gain this weight back before the next practice (unpublished data from preseason weight charts). Therefore, the purpose of the study was to assess physiological indices of hydration status in football players during preseason training to determine if chronic dehydration exists when practices occur 2 times per day on consecutive days.

METHODS

Subjects

Ten football players who were members of a National Collegiate Athletic Association Division II football team volunteered to participate in the study. All of the players were upperclassmen who participated in spring football and the summer conditioning program that consisted of weight lifting, plyometrics, agility drills, and sprint training. Only 1 of the subjects routinely performed additional work (related to his summer job) for extended periods of time in the heat before preseason training camp. Mean age, height, mass, body surface area, surface area/mass, and percentage body fat were 21.2 ± 1.14 years, 187.95 ± 4.76 cm, 116.6 ± 16.3 kg, 2.414 ± 0.16 m^2, 0.0209 ± 0.0017 $m^2 \times kg^{-1}$, and 17.9% ± 5.5%, respectively. The subjects represented the following positions: wide receiver (1), defensive back (1), linebacker (1), tight end (1), defensive lineman (3), and offensive lineman (3). The study was approved by the university Institutional Review Board's Human Subjects Subcommittee. All of the players were apprised of the risks involved with the study and signed consent forms.

Procedures

The players reported to the Human Performance Laboratory for baseline measurements the day they reported for preseason camp. They had been contacted and instructed to consume at least 500 mL of water the night before reporting to ensure a urine specific gravity (USG) of 1.020, which is considered the standard cutoff in experimental research. The subjects were instructed not to take creatine or ephedra, and we are confident that they were not taking these supplements. After baseline measurements were taken, they reported to the laboratory 4 times per day on days 2, 3, 4, 6, and 8 of preseason training camp. Data were not collected on day 1 because that day was devoted to testing by the coaches, and the football players were not wearing equipment. From day 2 to 8, the team practiced 2 times per day, every day except day 7 when they participated in a scrimmage in the morning and did not practice in the afternoon. Generally, they were dressed in half pads (shorts, shoulder pads, practice jersey, and helmets) for the morning practice and full pads for the afternoon practice. Full pads consisted of helmets, shoulder pads, practice jersey, pants, and hip and thigh pads. The daily schedule is in Table 1.

TABLE 1
Daily Schedule: Half Pads in Morning and Full Pads in Afternoon

Time	Task
6:10 AM	Wake up
6:30 AM	Breakfast
7:00 AM	Athletic training room opens
8:30–8:45 AM	On practice field, team stretch
8:45–10:45 AM	Practice
11:30 AM	Lunch
1:30 PM	Athletic training room opens
2:30 PM	Unit meetings
3:15–3:30 PM	On practice field, team stretch
3:30–5:30 PM	Practice
6:30 PM	Dinner
8:00 PM	Special teams meeting
8:30 PM	Team meeting/position meeting
11:30 PM	Lights out

Baseline Testing

During preparticipation screening on the first day the players were on campus, blood and urine samples were taken, and physical characteristics (height, mass, and body composition) were recorded. Body composition was calculated (skinfold technique) using a 7-site formula.[27] On the basis of work by Wilmore and Haskell,[39] 6- to 8-site formulas are considered accurate methods of assessing body composition in football players, as cited by others.[7,12,23] Blood samples were collected for baseline measurements of hematocrit (Hct) and hemoglobin (Hb). Using a lancet technique, we collected blood in microcapillary tubes. The samples were spun in triplicate and read for Hct. A blood sample was also immediately analyzed for Hb with an Hb meter (Hemosite Inc, Mission Viejo, Calif). Changes in plasma volume (PV) were calculated from Hct and Hb.[17]

Urine samples were collected and measured for specific gravity, sodium, and potassium. The USG was assessed by urine reagent strips (Multistix 10 SG, Bayer Corp, Pittsburgh, Pa) and verified by a refractometer. If the 2 measures differed, the value obtained by refractometry was used because it is considered the more reliable measurement.[15] Urine sodium (UNa) and urine potassium (UK) were measured by an ion-selective electrode (AVL 988, Roche Diagnostics, Indianapolis, Ind) and recorded in $mmol \times L^{-1}$.

Blood and Urine Measurements During Preseason

Blood and urine samples were collected on days 2, 3, 4, 6, and 8 of preseason training camp at the following time periods: before morning practice (pre-AM), after morning practice (post-AM), before afternoon practice (pre-PM), and after afternoon practice (post-PM). An indication of daily urinary excretion of sodium and potassium was obtained by averaging the 4 samples from each subject each day. Nude body weight (BW) was recorded to the nearest one-fourth pound on a certified scale (Detecto, Webb City, Mo) before and after every practice.

Sweat Rates While Wearing Half Pads Compared to Full Pads

Sweat rates were determined on 3 separate days, including 3 practices in which the players were in half pads and 3 practices in which they were in full pads. Sweat rate in $L \times h^{-1}$ was calculated using the following formula: sweat rate = preexercise body mass − postexercise body mass + fluid intake − urine volume/exercise time in hours.[14] During practice, the players drank from premeasured, individually labeled 2-L bottles. The bottles were filled with plain tap water and kept on ice in coolers placed next to the on-field water fountains. The bottles were continuously monitored by the researchers and carefully refilled when empty. The players were instructed to drink only from their water containers and not to let water drop to the ground. They were also encouraged to use the water fountains to cool themselves but not to drink from them. Immediately after practices, the players briefly showered, towel dried, were weighed, and voided their bladders completely. Urine volume was then measured and used in the sweat rate calculation. Practices began at 8:30 AM and 3:15 PM and lasted 2.25 hours. The first 15 minutes of each practice session consisted of stretching. This time period was included in the sweat rate calculations because the players were sweating while they were stretching.

On the days when sweat rate data were not collected, the players drank water ad libitum from the on-field water fountains during frequent rest periods. The water that supplies the fountains comes from an underground source and ranges in temperature from cool to tepid, depending on environmental conditions.

Core Body Temperature Measurements

Core body temperature (T_c) was measured in the players during 4 separate practices (2 practices in half pads and 2 practices in full pads). The players ingested sensors (CorTemp, HQ Inc, Palmetto, Fla) at a minimum of 6 hours (range, 6-10 hours) before the morning practices. This period ensured that the sensors were in the intestines, which is optimal for accurate readings. Each sensor has a serial number that is programmed into the handheld recorder, which allows accurate T_c readings (±0.1°C) of individual subjects.[35] Each subject's T_c was recorded a minimum of 3 times (range, 3–8 times) during each of the 4 practices. Care was taken to measure T_c when the players were most active (just after completing a series of plays, drills, scrimmaging, and conditioning). The 2 highest T_c readings recorded for each subject during each practice were used for statistical analysis. All T_c data were recorded on the days when the players consumed cold water.

STATISTICAL ANALYSIS

One-way analyses of variance (SPSS 11.1, SPSS Science Inc, Chicago, Ill) with repeated measures were used to determine differences over time on the following dependent measures: change in BW, percentage change in PV, USG, UNa, and UK. For the dependent variables of BW, PV, UNa, and UK, Tukey honestly significant difference post hoc tests were employed when a significant F value was obtained to determine where the differences existed. Dunnett post hoc test for differences from baseline measurements was used for USG. Paired t tests were used to determine differences in sweat rates and T_c while wearing half pads compared with full pads and to determine changes in BW during practices in which the subjects drank cold versus fountain water. The level for significance was set a priori at $P < .05$.

RESULTS

Daily mean on-field temperatures and relative humidity (RH) over the 8-day period during morning and afternoon practices were 28.4°C and 64.9% RH and 34.5°C and 43% RH, respectively (see Table 2 for details). Mean wet bulb temperatures during the practices when sweat rate data were collected were 23.7°C, 22.8°C, and 23.9°C for the morning practices (half pads) and 24.3°C, 22.5°C, and 23.3°C for the afternoon practices (full pads). The results are presented as means ± SDs.

Measures of Hydration Status

Mean change in BW for days 2 through 8 was significantly different from baseline at pre-AM, post-AM, pre-PM, and post-PM time periods ($P < .01$) (Figure 1). One of the subjects actually gained 3.64 kg by the morning of day 4, whereas the other 9 players consistently lost weight. The differences in BW were significant ($P < .01$) with N = 10, but there was less variability without the subject (n = 9) who gained weight (Figure 1). Mean BW was consistently below baseline values at all weigh-ins as shown in Table 3. The Hct, Hb, USG, UNa, and UK for the 21 measures over the 8-day period are also presented in Table 3.

Compared with baseline values, USG was significantly higher after every practice and in pre-PM on days 3 and 8. Of note is that the mean USG was >1.030 in post-PM on days 2, 3, and 4.

Significant differences also existed in UNa and UK over time. The UNa was lower than baseline values at all 4 times measured on days 2, 3, 4, and 6 and in both morning samples on day 8. On the other hand, UK was significantly higher in post-PM on days 3 and 4 compared to many other times measured. See Table 3 for details.

Because UNa and UK excretion normally varies throughout the day depending on hydration status and

TABLE 2
Mean Daily Temperatures, Humidity, and Wet Bulb Temperatures During Sweat Rate Data Collection

	All Days (2–8)				Sweat Rate: Wet Bulb, °C		
Time of Day	Temperature, °C	Humidity, %	Wet Bulb, °C	Heat Index, °C	Day 1	Day 2	Day 3
8:35 AM	26.6 ± 2.1	70.6 ± 6.1	23.4 ± 0.8	28	23.9	21.7	22.8
9:45 AM	28.3 ± 1.0	64.9 ± 4.6	22.7 ± 1.98	31	22.8	23.3	23.9
10:30 AM	30.2 ± 0.9	59.1 ± 6.1	23.8 ± 0.54	33	24.4	23.3	25
3:35 PM	34.9 ± 1.9	43.4 ± 10.9	23.9 ± 1.14	38	23.9	23.9	23.3
4:30 PM	34.0 ± 2.5	43.0 ± 10.8	23.3 ± 1.37	36	25	21.1	23.3
5:25 PM	34.7 ± 1.8	43.0 ± 10.1	23.9 ± 0.64	38	23.9	[a]	23.3

[a]Practice ended early because of the weather.

TABLE 3
Changes in Body Weight, Blood, and Urine Measures in Football Players[a]

	Change in BW from BL, kg	Hct	Hb	USG	UNa, mmol × L^{-1}	UK, mmol × L^{-1}
BL		44.76 ± 0.98	15.2 ± 0.54	1.0175 ± .006	196.4 ± 61.41	69.35 ± 42.14
Day 2						
Pre-AM	−0.80 ± 0.83	45.75 ± 2.05	15.83 ± 0.98	1.0230 ± 0.007	34.87 ± 16.23	36.16 ± 27.3[b]
Post-AM	−2.23 ± 1.2	47.79 ± 1.5	16.21 ± 0.51	1.0281 ± 0.006[c]	22.93 ± 16.85[c,d]	90.1 ± 54.9
Pre-PM	−1.13 ± 1.08	45.69 ± 2.1	15.83 ± 0.04	1.0231 ± 0.011	60.19 ± 52.8[c]	55.3 ± 32.3[b]
Post-PM	−2.73 ± 0.56	47.56 ± 1.9	15.94 ± 1.04	1.0310 ± 0.002[c]	35.08 ± 30.16[c,d]	108.59 ± 38.98
Day 3						
Pre-AM	−1.48 ± 1.6	45.8 ± 1.57	15.45 ± 1.0	1.0250 ± 0.007	42.01 ± 49.13[c,d]	48.07 ± 27.45[b]
Post-AM	−2.64 ± 0.96	45.69 ± 1.9	15.13 ± 0.95	1.0265 ± 0.006[c]	24.54 ± 36.5[c,d,e]	76.89 ± 22.42
Pre-PM	−1.01 ± 0.98	44.7 ± 1.4	15.4 ± 0.81	1.0286 ± 0.003[c]	53.26 ± 40.36[c]	62.80 ± 14.8
Post-PM	−2.93 ± 1.5	44.8 ± 2.27	14.9 ± 0.54	1.0321 ± 0.004[c]	39.28 ± 37.36[c,d]	108.69 ± 32.86
Day 4						
Pre-AM	−0.91 ± 1.8	43.47 ± 2.9	14.7 ± 0.7	1.0240 ± 0.008	31.19 ± 27.4[c,d,e]	47.74 ± 20.43[b]
Post-AM	−2.25 ± 0.96	45.02 ± 1.98	15.26 ± 1.17	1.0274 ± 0.006[c]	22.28 ± 46.05[c,d,e]	82.12 ± 32.74
Pre-PM	−1.09 ± 1.6	43.58 ± 2.8	14.14 ± 1.2	1.0220 ± 0.009	52.2 ± 73.45[c]	58.42 ± 22.53[b]
Post-PM	−2.93 ± 1.5	44.29 ± 2.1	14.89 ± 1.4	1.0303 ± 0.005[c]	49.23 ± 57.69[c]	83.71 ± 23.17
Day 6						
Pre-AM	−1.09 ± 0.96	43.13 ± 3.3	14.33 ± 1.5	1.0214 ± 0.007	45.71 ± 46.4[c,d]	43.95 ± 20.67[b]
Post-AM	−2.29 ± 1.56	43.0 ± 2.9	14.45 ± 1.5	1.0269 ± 0.009[c]	40.86 ± 41.6[c,d]	56.78 ± 16.94[b]
Pre-PM	−0.76 ± 1.29	41.63 ± 3.1	14.29 ± 0.73	1.0241 ± 0.007	83.16 ± 74.41[c]	54.81 ± 26.42[b]
Post-PM	−2.23 ± 1.25	42.47 ± 2.7	14.03 ± 1.6	1.0287 ± 0.005[c]	71.89 ± 63.37[c]	85.12 ± 24.14
Day 8						
Pre-AM	−0.51 ± 1.17	43.4 ± 2.8	14.34 ± 1.33	1.0245 ± 0.004	106.58 ± 34.88[c]	30.16 ± 30.42[b]
Post-AM	−2.13 ± 1.2	43.4 ± 2.8	14.33 ± 1.3	1.0282 ± 0.005[c]	78.08 ± 47.03[c]	62.88 ± 32.22
Pre-PM	−0.6 ± 1.0	42.6 ± 2.7	13.98 ± 1.26	1.0260 ± 0.007[c]	133.26 ± 68.06	46.09 ± 25.11[b]
Post-PM	−2.27 ± 1.0	43.44 ± 3.1	14.35 ± 1.6	1.0292 ± 0.004[c]	119.31 ± 75.83	76.05 ± 21.29

[a]All significance levels set at $P < .05$. BW, body weight; BL, baseline; Hct, hematocrit; Hb, hemoglobin; USG, urine specific gravity; UNa, urine sodium; UK, urine potassium; pre-AM, before morning practice; post-AM, after morning practice; pre-PM, before afternoon practice; post-PM, after afternoon practice.
[b]Significantly different from post-PM day 2 and post-PM day 3.
[c]Significantly different from baseline.
[d]Significantly different from pre-PM day 8.
[e]Significantly different from post-PM day 8.

diet, we assessed daily excretion by using the mean of the 4 samples for each day. The mean daily excretion of UNa changed significantly from baseline to day 8 ($F_{5,40}$ = 23.102, P = .000). Post hoc testing revealed a drop in UNa excretion on days 2, 3, 4, and 6 compared with baseline levels (Figure 2). The UNa dropped from 194 ± 43 mmol × L^{-1} at baseline to 43 ± 38 mmol × L^{-1}, 40 ± 39 mmol × L^{-1}, 39 ± 39 mmol × L^{-1}, and 68 ± 48 mmol × L^{-1} on days 2, 3, 4 and 6, respectively. By day 8, however, daily UNa excretior (123 ± 51 mmol × L^{-1}) was higher than on days 2, 3, and 4 The subject who gained weight during the first 4 days o preseason continued to excrete UNa at near-baseline lev

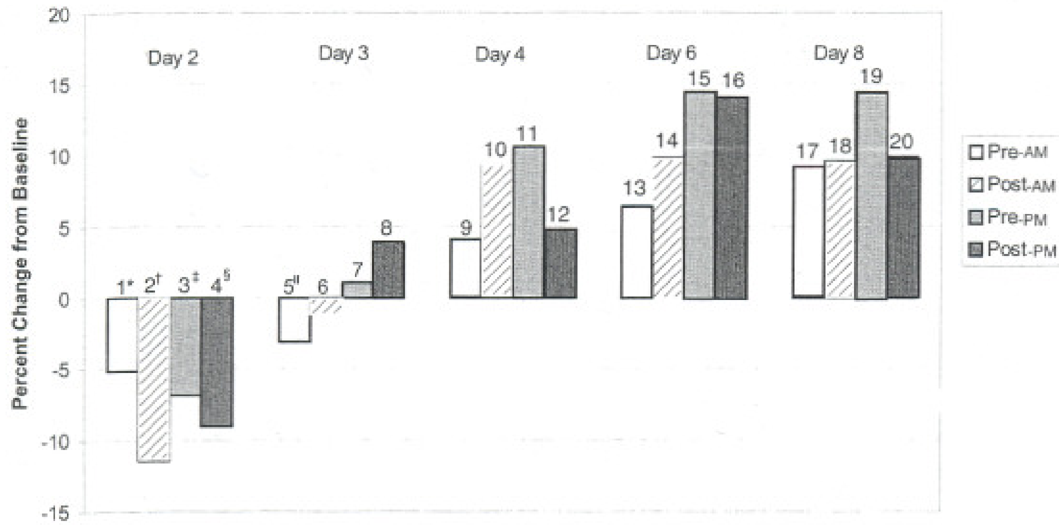

Figure 4. Football players' percentage change in plasma volume from baseline (the day they reported to camp) through day 8. *Significantly different from 15, 16, and 19. †Significantly different from 10, 11, 13, 14, 15, 16, 17, 18, 19, and 20. ‡Significantly different from 11, 15, 16, and 19. §Significantly different from 10, 11, 14, 15, 16, 17, 18, 19, and 20. ‖Significantly different from 15, 16, and 19. All $P < .05$.

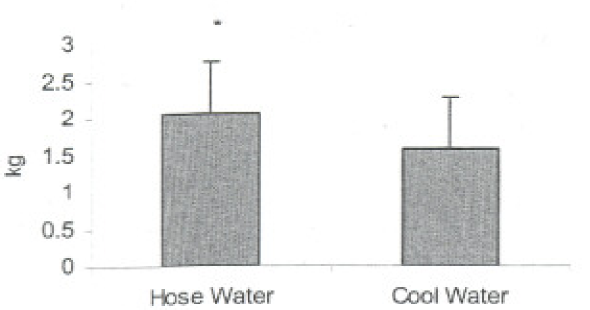

Figure 5. Weight loss during practices when players drank from on-field watering fountains compared with individual containers of cool water. *Significantly different from cool water, $P < .001$.

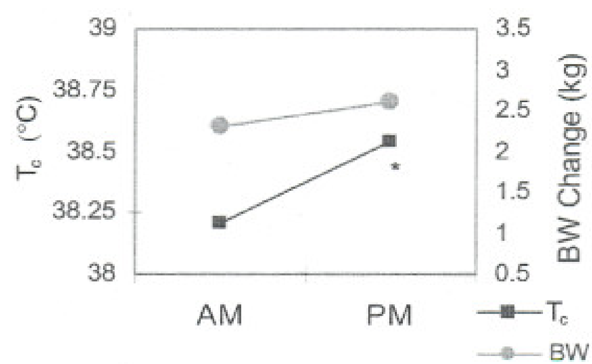

Figure 6. Body core temperatures and change in body weight during morning (half pads) and afternoon (full pads) practices. *Significantly different from morning core temperature ($P < .01$). T_c, core temperature; BW, body weight.

became further dehydrated during practice. In fact, they were actually more dehydrated after practices on days 3, 5, and 7 (data not shown for days 5 and 7). These were the days when the players drank water from the on-field water fountains that are supplied from underground pipes and hoses. This water is not as palatable or as cold as the water supplied to them during the 3 days when sweat rate data were collected. In addition, they may have been more attentive to drinking on the days when sweat rate data were collected because we were measuring their fluid consumption. The players lost a mean of 24.3% (0.5 kg) more weight when they drank the fountain water compared with when they drank the cold water. Our finding that the players consumed more fluid and subsequently lost less weight when cold water was made available to them has been well documented.[1,10,25,26]

Although the use of fluid-replacement drinks during practices may have improved hydration status, it is cost prohibited at our university, as is likely the case in many college/university and high school settings. Our football players frequently consumed such beverages between practices and were instructed to salt their food liberally during preseason.

Elevated USG was another indication of chronic dehydration in our football players during preseason training. After evaluating each player's individual USG data, we observed that out of 99 prepractice exposures (9 players before 10 practices each and 1 player before 9 practices), USG was >1.020 on 66 occasions and ≥1.030 on 29 occasions. If we followed heat illness and fluid-replacement guidelines[9,14] conservatively, our 10 players would not have been allowed to practice two thirds of the time. If we were more liberal (allowing players to practice with USG = 1.030), they would have still been held out of practice almost one third of the time. In reality, none of the players missed a practice because of heat-related issues. It is possible that USG is not an appropriate measure to use for determining hydration status in these large athletes. Subsequent research by the lead author revealed that professional football players also routinely had prepractice USG readings that exceeded 1.020 to 1.030.[22]

The indication that chronic dehydration exists in football players during preseason training when 2 practices are held per day on consecutive days is not surprising given the rate at which these athletes sweat. Sweat rates were slightly higher when the players were in full pads but not statistically different from half pads. Overall, the environmental conditions that existed while the 3 morning and afternoon sweat rate data were collected were fairly consistent (Table 2). Individual sweat rates were also consistent, and it seems likely that our football players reached their maximum sweating rates quickly and maintained these rates under both half- and full-pad conditions.

Plasma Volume Changes, UNa, and UK

With sweat rates of approximately $2\ L \times h^{-1}$ and 4.5 hours of practice per day, it is estimated that our football players were losing approximately 9 L of sweat per day. Large daily volumes of sweat loss replaced with hypotonic fluids could promote sodium dilution in athletes such as these. Our PV and UNa data appear to support this hypothesis, especially during the initial 3 or 4 days of twice-a-day sessions. We recently found this to be the case in professional football players on the third morning of twice-a-day training.[21]

Plasma volume increased steadily in the football players from day 2 when it was 5% below baseline through day 8. This expansion of PV during the acclimatization process is well documented.[3,24,37,40] Overall, there were significant increases from day 2 to 4, with a further expansion by days 6 and 8. A definite shift in PV occurred on day 3 when it increased throughout the day, beginning below baseline and expanding to 4% above baseline in post-PM. This increase coincided with the lowest daily values of UNa excretion (on days 3 and 4), possibly indicating an isoosmotic PV expansion due to sodium retention as described by others.[34] Overall, PV increased by as much as 14% on days 6 and 8, which is very similar to the rate seen by Nielsen et al,[34] who reported a 13% expansion in PV after acclimatization.

During the first 3 days of twice-a-day practices, it appeared that PV in our football players was not well defended, which may be explained by chronic dehydration and low body sodium levels.[21] Sanders et al[36] found that during 4 hours of intermittent exercise, serum sodium concentrations were maintained at the expense of a contracted extracellular fluid volume. Our findings of a contracted PV before both practices on day 2 and the morning practice on day 3 suggest that serum sodium was being maintained by this mechanism even during extended periods of rest (between practices and overnight). We observed this phenomenon in professional players, possibly indicating inadequate sodium replacement.[21] Some authors have suggested that sodium depletion could occur if prolonged exercise took place on consecutive days or when daily sweat losses exceeded 8 L.[5,8] Both scenarios applied to our football players.

We did not control for dietary intake of sodium, but the football players were eating 3 meals per day (including when baseline measures were obtained) in a dining hall that offers a limited choice of foods during preseason. As a consequence, it is likely that they were consuming similar foods and therefore similar amounts of sodium over the 9-day period. Although they drank only water during practices, they were instructed to consume salty foods and generously add salt to their food at meals. Therefore, we assume that they ingested at least a moderate amount of sodium (approximately 8-10 g $NaCl \times d^{-1}$) on a daily basis.

The UNa declined in our players on days 2, 3, 4, and 6 compared with baseline levels, indicating renal conservation of sodium. Daily UNa on days 2 to 6 ranged from 39 to 68 $mmol \times L^{-1}$ (N = 10) to 27 to 60 $mmol \times L^{-1}$ (n = 9). These values are similar to those reported by Armstrong et al[4,6] in subjects on a low-sodium diet (5.7 g $NaCl \times d^{-1}$) during acclimatization studies. The UNa in their subjects ranged from 27.6 to 88.8 on days 2 to 8, and PV was lower than in subjects on a high-sodium diet (23.2 g $NaCl \times d^{-1}$). The subjects on the low-sodium diet were clearly in negative sodium balance while still excreting some sodium. Remarkably, UNa was undetectable ($<1.0\ mmol \times L^{-1}$) in 6 of our 10 football players in a total of 21 urine samples. In 2 players (on either day 2 or 3), UNa was actually <1.0 $mmol \times L^{-1}$ in all 4 samples per day, and in 1 player, UNa was <1.0 $mmol \times L^{-1}$ in 3 of the 4 samples. Although renal sodium excretion varies widely depending on dietary consumption, undetectable levels in 4 urine samples over a 10-hour time period may indicate that these athletes were in negative sodium balance. In professional football players, we recently found a similar decline in UNa excretion and a significant reduction in blood sodium after 2 consecutive days of multiple practices.[21,22]

Armstrong et al[4] reported depressed UK on days 5 and 8 in subjects on a high-sodium diet and on days 3, 4, and 6 in subjects on a low-sodium diet. The UK excretion remained unchanged from baseline values in our football players until it declined on days 6 and 8. When UK excretion was evaluated at each individual time period, it was significantly higher in post-PM on days 2 and 3 and was consistently at its highest in post-PM. A possible explanation may be renal excretion of excess potassium due to rhabdomyolysis. Elevated serum creatine kinase levels reported in football players on the fourth and seventh days of twice-a-day practices clearly indicate that rhabdomyolysis occurs in these athletes during preseason.[18] Muscle damage causes potassium to leak from the injured cells, which subsequently must be excreted. The combination of intermittent high-intensity exercise for 4.5 hours in the heat and the physical contact inherent to the game of football does cause rhabdomyolysis and therefore would necessitate an increased excretion of potassium, particularly at the end of the day. It is also probable that potassium was lost as a consequence of aldosterone-mediated conservation of sodium at the expense of potassium secretion. It is clear that the football players were conserving sodium during the first 6 days of preseason, and aldosterone has been shown to be elevated during periods of heat acclimatization.[34] It is possible that both mechanisms apply.

Core Temperature in Half Pads Versus Full Pads

Statistically, T_c was more elevated in the afternoon (full pads) compared with the morning (half pads); however, this difference (0.2°C) means little from a biological or clinical standpoint. Greater skin surface area for heat dissipation when the players were wearing half pads and shorts likely contributed to the lower T_c in the morning practices, particularly because wet bulb temperatures were similar. It is also possible that radiant or convective heat loss or gain differed or that exercise intensity during practice was higher in the afternoon. It is reasonable to suggest that more than one of these factors contributed to the lower T_c in the morning. In any case, the level of dehydration at the end of both the morning and afternoon practices did not differ and therefore did not likely play a large role in the different T_c. The players were approximately 2.0% and 2.2% dehydrated in post-AM and post-PM, respectively (see Figure 6), which was expected because sweat rates were similar.

Although field studies can be invaluable, they also have inherent limitations, such as the number of subjects who can be monitored with this type of rigorous data collection. In addition, our decision to use only returning players, who served as subjects in a previous experimental study, most likely skewed the results conservatively. We would expect that the upperclassmen would be more fit coming into preseason and more attentive to hydration practices compared with first-year players who were likely even more hypohydrated.

In summary, BW, urine, and blood measures indicated that our football players were chronically dehydrated and likely sodium depleted during the first week of twice-a-day practices. These athletes were unable to maintain BW over the entire 8-day period and were not successful in defending PV during the first few days. In addition, we observed a drastic drop in sodium excretion. The consistent sweat losses of approximately $2\ L \times h^{-1}$, regardless of environmental conditions or equipment worn, resulted in mean daily sweat losses of more than 9 L. Adequate replenishment of both fluids and electrolytes is challenging under these circumstances. Daily fluid losses of this magnitude would explain the chronic dehydration and could induce sodium depletion, as seen in professional football players exposed to an aggressive hydration protocol that included an unlimited supply of a common fluid-replacement drink with added electrolytes.[21,22]

Importantly, cold water should always be available during football practices, as the players were less dehydrated when they consumed cold water compared with when they drank water from on-field water fountains. To assist with the challenge of meeting the fluid and electrolyte needs of football players on days with multiple practice sessions, one might consider the following: (1) require that all meals are mandatory and provide an evening snack of salty foods and fluid, (2) ensure that salty foods and carbohydrate/electrolyte drinks are available at all meals and that players regularly add additional salt to foods, and (3) provide adequate time between practice sessions for rest, rehydration, and food consumption. On the basis of the observation of gradual acclimatization over the 8-day study period, it also seems reasonable to suggest a gradual increase in the intensity of exercise during preseason training camp. As PV expands and sodium excretion normalizes, as is characteristic of the acclimatization process, players can more safely be expected to perform at higher levels of physical exertion.

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