Hydration and Core Temperature in a Football Player During Preseason: A Case Study

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Dehydration and its potential link to hyperthermia are a concern for sports-medicine professionals and athletes who practice and compete in the heat. Sweat rates, fluid losses, and fluid consumption have been reported in tennis, soccer, and basketball players and in runners.[1-3] These athletes are physically different from football players, especially linemen, who generally have a high lean body mass, body surface area, and percent body fat but low surface-area to body-weight ratio. These physical characteristics and the fact that these athletes exercise in equipment that hinders evaporative cooling can increase the potential for elevated fluid losses during practices. Chronic dehydration can occur when two or more bouts of exercise are performed on successive days in a hot, humid environment. This can predispose athletes to heat-related disorders, as well as performance decrements.[4]

Key Points

- Sweat rates in large football linemen can reach 3.9 L/hr, and sweat losses can exceed 14 L/day.
- Football players can be chronically dehydrated during preseason when practices occur two times per day on consecutive days.
- Sodium replacement is necessary during preseason in football players who sweat heavily.
- Key Words: sweat rate, sodium, linemen

A recent study[5] evaluated creatine kinase levels in football players during preseason. By the fourth morning of two-a-day practices, serum creatine kinase increased 5- to over 10-fold from baseline levels measured before camp. Hydration status was not assessed in this study, but the authors suggest that dehydration/hypohydration might have played a role in the exertional rhabdomyolysis seen in their athletes. Many authors have suggested monitoring hydration status by using changes in body weight and urine indices such as specific gravity and color.[6,7] For completeness, in addition to the usual recommended assessments we measured urinary excretion of sodium and potassium, sweat rates, sweat loss, fluid consumption, and body core temperature in 1 football player during preseason training. These data allowed a more in-depth physiological evaluation of his hydration status.

Case Report

The athlete (JC) who volunteered for these assessments was a 5th-year senior starting guard on a Division II football team. His physical characteristics, noted in the sidebar, are significant for a body mass of 138.6 kg, body surface area of 2.66 m^2, and surface-area to body-mass ratio of 0.1920 m^2/kg. Percent body fat and fat-free mass were determined by skinfold technique using seven sites. The day-to-day environmental conditions were very similar over the 8-day period. Morning temperature and relative humidity (RH) ranged from 26.6 °C and 70.6% RH to 30.2 °C and 59% RH. Afternoon environmental conditions ranged from 34.7 °C and 43% RH to 34.9 °C and 43% RH (Table 1). Morning practices began at 8:30 a.m. and ended at 10:45 a.m., and afternoon practices were

Subject Characteristics

Subject: JC

Age: 23 years

Height: 193.5 cm

Weight: 138.6 kg

Body fat: 20.8%

Lean body mass: 110.5 kg

SA: 2.66 m^2

Ratio of surface area to body weight: 0.0192 m^2/kg

TABLE 1. AVERAGE DAILY TEMPERATURES AND HUMIDITY DURING PRACTICES

Time of Day	Temperature, °C	Humidity, %
8:35 a.m.	26.6 ± 2.1	70.6 ± 6.1
9:45 a.m.	28.3 ± 1.0	64.9 ± 4.6
10:30 a.m.	30.2 ± 0.9	59.1 ± 6.1
3:35 p.m.	34.9 ± 1.9	43.4 ± 10.9
4:30 p.m.	34 ± 2.5	43.0 ± 10.8
5:25 p.m.	34.7 ± 1.8	43.0 ± 10.1

from 3:15 p.m. to 5:30 p.m. Each practice session lasted 2.25 hr, except on the afternoon of Day 6, when practice was ended after 1.75 hr because of lightning. Practices were held twice a day, every day, except Day 7, when the team scrimmaged in the morning and was off in the afternoon.

JC recorded a nude body weight and provided a urine sample before and after each practice on the following days of preseason training camp: baseline (on arrival on campus on August 11) and Days 2, 3, 4, 6, and 8. Body weight was recorded to the nearest quarter pound. Urine samples were tested for specific gravity (USG) by both refractometer and urine reagent strips (Multistix® 10 SG, Bayer Corp.). Urine sodium (Na) and potassium (K) were measured by ion-selective electrode (AVL 988, Roche Diagnostics) and recorded in millimoles per liter. On Days 4, 6, and 8, sweat rate was determined during each practice. Sweat rate in liters per hour was calculated using the following formula: BW pre – BW post – Uvol + fluid consumed/hr, where BW pre is body weight before practice in kilograms, BW post is body weight after practice in kilograms, Uvol is urine volume produced during practice in liters, fluid consumed is the amount of water consumed during practice in liters, and hours is the length of practice. The first 15 min of all practice sessions consisted of stretching. Although exercise intensity was low, this time period was included in the sweat-rate calculations because it was hot and humid and JC was already sweating before the actual start of practice. Core body temperature was monitored on Days 4 and 8. Body temperature was assessed using an ingestible thermistor and handheld recorder (CorTemp™2000, HTI Technologies, Inc.). JC was instructed to ingest the thermistor at 11:00 p.m. the night before data collection, which ensured that it had passed through the stomach and was beyond the level of the liver.

Current literature recommends fluid replacement of 25–50% more than that lost via sweating.[6,8] Based on this information we calculated the amount of fluid that JC would need to consume before the next practice as 130% of the total amount of sweat lost during practice corrected for fluid consumed during practice. From those data, total daily fluid requirements were estimated.

Fluid Turnover

Fluid consumption during practice, urine volume, sweat loss, sweat rate, and estimated fluid consumption for proper rehydration for Days 4, 6, and 8 are listed in Table 2. On the morning of Day 6, JC completed half his normal number of repetitions in drills (coach's choice), resulting in the lowest volumes for these parameters. For example, total sweat losses during practices ranged from 4.06 L during the morning practice when JC was on half-repetitions to 8.08 L on the afternoon of Day 8, and fluid consumption ranged from 2.67 L to over 5.7 L for those same two practices. His highest sweat rate was 3.91 L/hr, which occurred during the afternoon practice on Day 6. That practice involved scrimmaging (first-team offense vs. first-team defense) and was shortened by half an hour because of inclement weather. Average weight loss, sweat loss, sweat rate, fluid consumption during

TABLE 2. BODY WEIGHT, FLUID CONSUMPTION, URINE VOLUME, SWEAT LOSS, SWEAT RATE, AND ESTIMATED FLUID CONSUMPTION FOR EUHYDRATION								
	Pre BW (kg)	Post BW (kg)	Fluid Consumed During Practice (L)	Fluids (L/hr)	Uvol (L)	Sweat Loss (L)	Sweat Rate (L/hr)	Estimated Fluid Consumption for Euhydration (L)
Day 4								
a.m. practice	138.64	135.45	4	1.778	0.136	7.054	3.14	5.17
p.m. practice	136.82	134.09	4	1.778	0.086	6.64	2.94	4.64
daily total	138.64	134.09	8	1.778	NA	13.67	NA	9.81 + 8 during practice = 17.81
Day 6								
a.m. practice, 1/2 normal reps	137.05	135.55	2.665	1.184	0.106	4.06	1.8	2.6
p.m. practice	137.5	134.09	3.565	2.037	0.126	6.85	3.91	5.34
daily total	137.05	134.09	6.23	1.611	NA	10.91	NA	7.94 + 6.23 during practice = 14.17
Day 8								
a.m. practice	138.18	135.0	3.73	1.658	0.180	6.73	2.99	5.02
p.m. practice	137.05	134.55	5.712	2.539	0.130	8.08	3.59	4.79
daily total	138.18	134.55	9.44	2.099	NA	14.81	NA	9.81 + 9.44 during practice = 19.3

Note. BW = body weight; Uvol = urine volume.

Average Fluid Turnover During the Five Full-Repetition Practices

- Weight loss: 3.0 ± 0.37 kg
- Fluid consumed during practice: 4.2 ± 0.86 L
- Fluids consumed per hour: 1.958 ± .35 L
- Sweat loss: 7.07 ± 0.59 L
- Sweat rate: 3.3 ± 0.38 L/hr
- Estimated fluid consumption for normal hydration, based on (sweat loss × 130%) – fluid consumed during practice: 4.99 ± 0.25 L

practice, and estimated fluid requirements for the five practices in which JC completed his full number of repetitions are listed in the sidebar. JC routinely consumed a copious amount of water during practice (4.2 ± 0.86 L, range 3.6–5.7) but was still approximately 3% dehydrated on average at the end of each practice (Table 3). Calculated from baseline values, his change in body weight after practices was −4.09 ± 0.57 kg.

Urinary Indices of Hydration and Electrolyte Balance

JC's urinary excretion of Na and K, as well as his USG, are included in Table 3. There was no data collection on the afternoon of Day 2 because JC missed practice to take a test for a summer-school course. Of note is that sodium excretion fell from an average of 121 mmol/L during baseline measurements to 11.7 mmol/L after the morning practice of Day 2 and remained well below baseline at every assessment until Day 8. Potassium excretion, on the other hand, rose from 20.3 mmol/L at baseline measurement to as high as

TABLE 3. CHANGE IN BODY WEIGHT, URINE SODIUM, POTASSIUM, AND SPECIFIC GRAVITY

Day	Change in Weight From Baseline (kg)	Dehydration (%)	Na+ (mmol/L)	K+[a] (mmol/L)	Specific Gravity
Baseline			121	20.3	1.020
Day 2, pre a.m.	−2.5	1.8	24.1	46.3	1.025
post a.m.	−4.77	3.44	11.7	62.9	1.030
pre p.m.	no data	no data	no data	no data	no data
post p.m.	no data	no data	no data	no data	no data
Day 3, pre a.m.	−0.91	0.007	21.7	44.5	1.025
post a.m.	−3.41	2.46	10.4	65.5	1.025
pre p.m.	−1.59	1.15	42.9	69.2	1.025
post p.m.	−4.55	3.28	16.1	97.6	1.030
Day 4, pre a.m.	0	0	51.7	58.7	1.030
post a.m.	−3.18	2.3	19.5	79.6	1.025
pre p.m.	−1.82	1.3	37.9	83.9	1.030
post p.m.	−4.55	3.28	13.5	120.5	1.0325
Day 6, pre a.m.	−1.59	1.15	57	37.5	1.025
post a.m.	−4.1	2.96	14.2	59.5	1.025
pre p.m.	−1.14	0.82	36	79.7	1.025
post p.m.	−4.55	3.28	54	85.3	1.025
Day 8, pre a.m.	−0.45	0.32	115.4	74.3	1.020
post a.m.	−3.64	2.63	95.8	43.9	1.030
pre p.m.	−1.59	1.15	135.6	38.8	1.025
post p.m.	−4.1	2.96	129.2	72.2	1.030

[a]Significant correlation between Na and K excretion ($r = -.54$, $p = .036$).

120.5 mmol/L after the afternoon practice on Day 4 and remained elevated through Day 8. A significant negative correlation was found between urinary Na and K excretion, $r = -.54$, $p = .036$, from baseline measurements through Day 6. Urine specific gravity was 1.020 when JC reported to camp but did not return to that level at any time measured until the morning of Day 8, which followed the afternoon off on Day 7. It was consistently the highest on Day 4, ranging from 1.025 to 1.0325.

Core Body Temperature

On Day 4, both morning and afternoon sessions were full-padded practices. Before the morning practice, while JC was dressed in shorts and a T-shirt, his resting core body temperature was 37.11 °C. Core temperature rose to 38.88 °C by midpractice and was 39.06 °C immediately after conditioning in full pads. That afternoon, JC's resting temperature before practice was 37.6 °C. Midway through and immediately after practice his temperature was 38.76 and 38.86 °C, respectively (Figure 1). Core temperatures were not as high at rest or during practice on Day 8 as on Day 4.

Discussion

Sweat rate varies depending on environmental conditions (ambient temperature, humidity, wind speed, cloud cover), clothing and equipment (shorts, half-pads or full pads), and exercise intensity, and there are considerable individual differences.[4] Published sweat

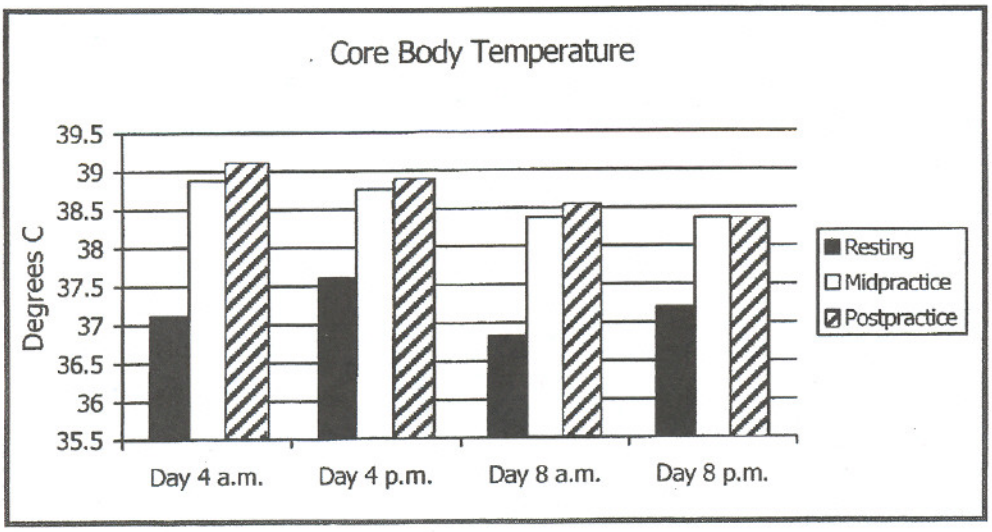

Figure 1 Core body temperature.

rates for soccer players during training sessions and competitions have been measured at 0.985 and 1.209 L/hr, respectively.[2] A nationally ranked tennis player reportedly had a sweat rate of 2.5 L/hr during match play, and male runners were found to have mean sweat rates of 1.71 L/hr during a 40-km run.[1,3] To our knowledge, the highest sweat rate reported in the literature was 3.71 L/hr, in Alberto Salazar during preparation for the 1984 Olympic marathon.[8] Average sweat rates for college and professional football players during full-padded practices under hot and humid conditions were 2.14 and 2.42 L/hr, respectively (unpublished data). JC's mean sweat rate for the five full-padded, full-repetition practices was 3.3 L/hr, reaching a high of 3.91 L/hr during one afternoon scrimmage. In previous unpublished data, his sweat rate was 2.93 and 2.43 L/hr during dehydration protocols in an environmental chamber. During these trials, JC was dressed in shorts and a T-shirt and performed 25-min bouts of continuous exercise in environmental conditions of 35°C and 60% RH. This implies that playing or practicing football, even with the intermittent activity associated with the game, results in higher sweat rates than those in controlled testing conditions involving exertional testing methods that are not sport specific. The insulating effect of the protective equipment and the increased physiological demands associated with football are implicated as causative factors for these high sweat rates. Furthermore, this player has a body surface area of 2.66 m², and the average 23-year-old man has a body surface area of 1.94 m². Therefore, JC has more total sweat glands than the average person. This fact coupled with the insulating effect of equipment and the extreme demands of the sport might account for the tremendous amount of sweat loss that was seen in this athlete.

JC's sweat loss during each practice was consistently very high (6.6 to over 8 L). His fluid intake during practice averaged 1,958 ml/hr and was as high as 2,539 ml/hr. This is considerably higher than the estimated amount required for adequate rehydration of between 600 and 1,800 ml/hr according to the fluid-replacement guidelines of the NATA.[6] This implies that the gastric emptying rate of this athlete exceeds the 1.0–1.5 L/hr believed to be the upper limit during exercise for the average male[4] or that ingested fluid remained in his stomach. If the gastric emptying rate is not higher, this player might have as much as 2 L remaining in his stomach at the end of practice. It is likely that both scenarios apply.

Total daily fluid losses via sweating for the 3 days measured ranged from nearly 11 L to over 14 L. Following fluid replacement guidelines, this requires an astonishing daily fluid consumption of between 14.2 and 19.3 L to replace these sweat losses.[6] JC routinely consumed 8 L of water during practices but still required an additional replacement of up to 11 L per day. One is left to consider whether this volume of fluid can be consumed in 24 hr and whether there is a risk of hyponatremia related to such high fluid intake.[9]

Considering the fluid replacement requirements for this athlete, it is easy to see why JC was in a chronic state of hypohydration throughout training camp. His baseline USG was borderline for normal hydration (1.020), but on 5 separate days (Days 2, 3, 4, 6, and 8) and 18 urine samples, a USG of 1.020 was recorded only one other time. Understandably, this was on the morning of Day 8 after 22 consecutive hr without football practice. Although heat-illness guidelines suggest that USG should be no more than 1.020, it appears that this goal might be unrealistic for a football athlete like JC during two-a-day practices in a hot, humid environment.[10] Despite his state of hypohydration, he did not miss a single practice for medical reasons and reported feeling fine throughout camp, nor did his coaches report any discernable decline in his performance. His level of dehydration (USG frequently > 1.030 during practice and body-weight losses > 3%) did not appear to be related to an abnormally elevated core temperature—his core temperature never exceeded 39.06°C. His average core temperatures on Days 4 and 8, recorded six separate times during each practice, were 38.72°C and 38.26°C, respectively.

Electrolyte replacement should also be addressed, considering the high volume of sweat loss per day. Average sodium concentration of sweat in exercising individuals is 40–50 mmol/L (range 35–80 mmol/L).[11] In professional football players, average sweat sodium concentration has been measured at 63.8 mmol/L, ranging from 47.09 to 82.5 mmol/L (unpublished data). Although we did not measure sweat electrolytes in JC, at a sodium concentration of 50 mmol/L, 1.15 g of sodium would be lost per liter of sweat. On Day 8, JC lost a total of 14.8 L of sweat during practices, which would mean a loss of 17.02 g of sodium. The average dietary intake of sodium for a 23-year-old man is between 2.5 and 5.0 g, which is equivalent to 1.25 to 2.5 tsp of salt per day. Even if JC consumed a high-sodium diet (8 g/day) he would still require substantial sodium supplementation. In order to maintain sodium balance on days when sweat losses exceed 14 L, this athlete would require a salt intake of over 8.5 tsp to replenish the sodium losses. The drop in urinary sodium concentration from baseline through Day 4 is an indication of renal conservation.

As expected, JC's core body temperature rose as exercise intensity increased during practice, reaching a high of over 39 °C immediately after morning conditioning in full pads. His temperature was monitored periodically throughout each of the four practices and fluctuated depending on his activity level, but most of the temperature recordings were lower on Day 8 than on Day 4. This might have been the result of the well-known benefits of acclimatization—a better sweat response and increased blood volume improving heat dissipation and subsequently lowering core temperature. Another possibility is that it resulted from a lower exercise intensity on Day 8 or the fact that the team conditioned that morning without pads.

Summary

This case report demonstrates that a football player in training camp can lose a substantial amount of fluid and electrolytes and that it is extremely difficult to adequately replenish these losses. This is especially problematic because two-a-day practices can frequently go for several weeks during the preseason camp. Many players might therefore be chronically dehydrated, and many are likely chronically sodium depleted. Most of the evaluations of fluid loss and rehydration have been done on ectomorphic endurance athletes such as runners or cyclists. The physiological adaptation to heat and exercise of the endomorphic football player (clad in nylon garments, plastic gear, and a helmet) most likely is very different and has not been well defined to date. The pathophysiological response to heavy exertional exercise in the presence of chronic dehydration with respect to heat dissipation, fluid redistribution, and electrolyte replenishment is of great concern. This is especially true in this case, where the player was carefully supervised and encouraged to maximize his rehydration and electrolyte replenishment and still was unsuccessful in adequately replenishing. Because of the extremely large volume of sweat loss, it is practically inconceivable that the player in this case could have consumed enough sodium in his diet to restore homeostasis on an ongoing basis.

The practical implications of this evaluation are that coaches and medical personnel need to be aware of the consequences of repetitive, heavy exertional football-training activities on the physiology of the athletes. The large and frequently overweight athletes, some of whom are not entirely acclimatized at the start of training camp, are clearly at risk for serious fluid and electrolyte imbalances. Although it is known that some players will respond differently to physiological challenges in the same environment, the fact that more serious consequences are not observed lends credence to the premise that there is substantial leeway in tolerable variations. Nonetheless, the consequences of even minor dehydration on athletic performance have been documented, and very serious and even lethal consequences of exercise in the heat have been reported. The fact that JC did not demonstrate a decline in performance is indicative of the wide variability in adaptive capabilities.

The results of this study support the idea that athletic trainers should carefully monitor hydration status, electrolyte balance, and temperature regulation for football players exercising in extreme conditions. The enormous amounts of fluid and electrolyte losses are certainly difficult to adequately replace in a timely fashion. Further study is needed to assess the most efficient methods for replenishment, especially because of the unique conditions in the sport of football. ▮

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