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Thermal Responses in Football and Cross-Country Athletes During Their Respective Practices in a Hot Environment

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Objective: To determine if football (FB) players and cross-country (CC) runners had different thermal responses to their respective training sessions.

Design and Setting: On days 4 and 8 of preseason training, we assessed core (T_c) and skin (T_{sk}) temperatures.

Subjects: Fifteen collegiate athletes volunteered: 10 FB players (age = 21.2 ± 1.14 years, height = 193.5 ± 4.8 cm, mass = 116.6 ± 16.3 kg, and $\dot{V}O_{2max}$ = 44.7 ± 9.4 mL·kg^{-1}·min^{-1}) and 5 CC runners (age = 22.8 ± 2.77 years, height = 176.3 ± 8.9 cm, mass = 71.16 ± 8.9 kg, and $\dot{V}O_{2max}$ = 71.3 ± 6.18 mL·kg^{-1}·min^{-1}).

Measurements: We measured T_c using ingestible sensors before, during, and immediately after exercise. The T_{sk} was measured at the calf, forearm, back, chest, and forehead sites. Level of dehydration was assessed by urine specific gravity.

Results: Mean wet-bulb temperature was 74°F (23.33°C). Resting T_c in shorts and T-shirts was higher in the FB group. The T_c midway through practices and runs was higher in the CC and FB subjects when active, compared with the FB subjects when inactive. Postexercise T_c was higher in the CC group than the FB group with pads, and postconditioning T_c was higher in the FB subjects with pads versus no pads. Forehead, chest, back, and mean weighted T_{sk} were higher in the FB group. The T_c and urine specific gravity were not correlated.

Conclusions: The T_c fluctuated in the FB subjects during practice depending on exercise intensity, whereas T_c increased steadily in the CC subjects during continuous running. Thus, CC athletes may have to decrease intensity to maintain thermoregulation. Our FB players seemed to dissipate heat adequately during rest periods.

Key Words: core temperature, intermittent exercise, hydration

Deaths caused by heat stroke are well documented in American football (FB).[1] However, studies involving heat stress in FB players are lacking. Most information on heat stress during exercise is based on endurance-trained athletes who are smaller and leaner than FB players and who participate in continuous exercise,[2–9] compared with the intermittent activity associated with American FB.[10–12]

Thermal balance during exercise is affected by ambient temperature, humidity, radiant energy, air flow, equipment, and exercise intensity and duration.[13–17] Additionally, physical characteristics such as body mass, surface area-to-mass ratio, aerobic fitness level, and acclimatization and hydration status also affect thermoregulation.[2,5,8,18–27] Studies that have addressed issues specifically related to FB, such as the clothing and equipment worn, have been experimental in nature and have used non-FB players as subjects performing bouts of continuous exercise.[28–30] For example, Kulka and Kenney[30] found uncompensable heat stress (the body is unable to maintain thermal balance) in male subjects who exercised continuously in FB equipment in certain environmental conditions.

Ingestible temperature sensors allow for accurate measurement of core body temperature in athletes while they are participating in their sport activity.[31,32] Our purpose was to use this new technology and standard skin temperature probes to assess core and skin temperatures in FB athletes during practice and to make comparisons with those of a control group of cross-country (CC) runners. We hypothesized that FB players exercising intermittently in equipment would experience an increase in core body temperature similar to distance runners exercising continuously in the same hot and humid conditions. Additionally, we wanted to document the effects of both dehydration and acclimatization on core temperatures in both groups of athletes.

METHODS

Subjects

Ten National Collegiate Athletic Association Division II FB athletes and 5 male CC runners volunteered to participate in the study. The FB group represented the following positions: defensive linemen (3), offensive linemen (3), tight end (1), linebacker (1), wide receiver (1), and defensive back (1). They participated in a summer conditioning program consisting of weight lifting, plyometrics, agility drills, and speed training at distances ranging from 10 to 60 yd (9.14 to 54.86 m). The CC

Table 1. Physical Characteristics of Football Players and Cross-Country Runners

Subject Characteristics	Football Players	Cross-Country Runners
Age (y)	21.2 ± 1.14	22.8 ± 2.77
Height (cm)	187.95 ± 4.76*	176.3 ± 8.9
Mass (kg)	116.63 ± 16.3†	71.16 ± 8.9
Body fat (%)	17.9 ± 5.5†	6.98 ± 1.5
Lean body mass (kg)	95.5 ± 9.64‡	66.13 ± 7.76
$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	44.7 ± 9.4‡	71.3 ± 6.18

*$P < .01$.
†$P < .001$.
‡$P < .0001$.

athletes were males running an average of 52 miles (83.69 km) per week outside during the summer months in hot and humid conditions. All subjects were participating in their respective summer training programs during the 2 months before data collection. Subject characteristics are presented in Table 1. All subjects were fully informed of risks involved with the study and signed consent forms. The study was approved by the university's Institutional Review Board of Human Subjects Subcommittee.

Procedures

The FB players practiced twice per day (two-a-days) every day, except day 7, for 8 consecutive days. The first day involved 2 sessions of physical testing without pads, and on day 7, the team participated in an intrasquad scrimmage. The FB players were dressed in half pads (shorts, shoulder pads, and helmets) for the morning practices and full pads for the afternoon practices. The CC runners continued with their normal training, which consisted of running 1 or 2 times per day, either 5 or 6 days per week.

During preparticipation screening the day before the first preseason practice, physical characteristics (height, mass, and body composition) were recorded. Body composition was calculated (skinfold technique) using a 7-site formula.[33]

In separate sessions using a graded treadmill test protocol (Q4500, Quinton, Bothell, WA), maximal oxygen uptake was measured using breath-by-breath, online open-circuit spirometry (O_2 analyzer model S-3A/1 and CO_2 analyzer CD-3A Applied Electrochemistry; Ametek, Paoli, PA).

On days 4 and 8 of preseason training, we measured core temperature (T_c) and skin temperature (T_{sk}). Additionally, urine samples were provided before and after each practice or run for determination of specific gravity by a refractometer. This allowed for analysis of the relationship between T_c and level of hydration as determined by urine specific gravity (USG). Subjects were questioned about their individual intestinal motility, and based on that information, each subject ingested a temperature sensor (CorTemp, HQ Inc, Palmetto, FL) between 11:00 PM and 3:00 AM the night or morning before data collection. This ensured that the sensor was in the intestines, which is optimal for accurate T_c readings, but was not passed before data collection.

Each sensor had a serial number that was preprogrammed into the handheld recorder, allowing accurate temperature readings (±0.1°C)[31] of individual subjects. Baseline temperatures were recorded between 7:30 and 8:30 AM in an air-conditioned laboratory with all subjects dressed in shorts and T-shirts. The T_c was then recorded every 10 to 15 minutes in the FB group during practice and in the CC group prerun, midrun, and postrun. The T_c readings were recorded in the FB players when they were most active (just after completing a series of plays or drills), when they were inactive (resting or standing and watching), and after their postpractice conditioning. Postpractice conditioning was performed after 2 of the 4 FB practices during which data were collected. One of the postpractice conditioning sessions was performed in full pads, and one was performed without pads.

The T_{sk} was assessed at 5 sites (calf, forearm, back, chest, and forehead) during and immediately after the practice or run. The T_{sk} probes were placed on the skin at each of the 5 sites, and after the digital thermometer (Precision 4000, YSI Corp, Yellow Springs, OH) stabilized, the temperature was recorded. In the FB players, T_{sk} measurements were taken under the shoulder pads (for the chest and back sites) and on the forehead with the helmet both on and off. Care was taken when the probes were placed on the skin so as not to touch the back of the probe to the equipment. Mean weighted T_{sk} was calculated according to an approximation of the regional area distribution using the following formula[14]:

$$T_{sk} = 0.058\ T_{forehead} + 0.335\ T_{chest} + 0.335\ T_{back} + 0.136\ T_{arm} + 0.136\ T_{calf}$$

The FB players practiced from 8:30 AM to 10:45 AM and 3:15 to 5:30 PM. The CC athletes, dressed in shorts, shoes, and socks, performed 2 runs each day, beginning at 9:00 AM and 4:00 PM. Each training bout for the runners lasted approximately 60 minutes and specifically involved 25 to 28 minutes of continuous running, a brief period of time (approximately 2 minutes per runner) for T_c and T_{sk} temperature readings, and a second 25- to 28-minute run, followed by postrun temperature recordings. To control environmental conditions, the runners ran around the fields where the FB team practiced. All subjects had cold water available to them at all times during their respective exercise bouts. The runners tended to drink at midrun and postrun, whereas the FB players generally consumed water during breaks in practice (about every 15 minutes).

Statistical Analyses

We calculated a 2-way (group-by-time) analysis of variance to assess T_c during exercise. Independent *t* tests were used to determine group differences in physical characteristics T_{sk} and T_c. Dependent *t* tests were computed to assess T_c differences with pads on and pads off and between-site T_{sk} differences in the FB players as well as T_c comparisons between days 4 and 8. A Bonferroni correction was used when required. For correlation analyses, each subject's USG before exercise was paired with his highest T_c midpractice or midrun, and the postexercise USG was paired with the T_c immediately after exercise. The significance level was set at $P < .05$.

RESULTS

Significant group differences were found for height, mass, percentage of body fat, lean body mass, and $\dot{V}O_{2max}$ (Table 1). Ambient temperature and humidity readings were taken on the FB field 3 times during each of the 4 practices (Table 2). These environmental data are plotted on a graph of critical environmental conditions for exercising at 35% $\dot{V}O_{2max}$ in different

Table 2. Environmental Conditions

Time of Day	Day 4 Temperature °C	Day 4 Temperature °F	Day 4 Humidity %	Day 8 Temperature °C	Day 8 Temperature °F	Day 8 Humidity %
8:40 AM	26.1	79	71	27.2	81	68
9:45 AM	27.8	82	68	29.4	85	62
10:45 AM	30	86	63	31.1	88	58
Mean ± SD	28 ± 2.2	82 ± 3.5	67 ± 4	29.2 ± 2	85 ± 3.5	63 ± 5
3:25 PM	33.8	93	47	33.9	93	38
4:30 PM	34.4	94	44	35	95	36
5:30 PM	33.3	92	44	33.9	93	38
Mean ± SD	34 ± 0.6	93 ± 1.0	45 ± 2	34 ± 0.6	94 ± 1.2	37 ± 1.2

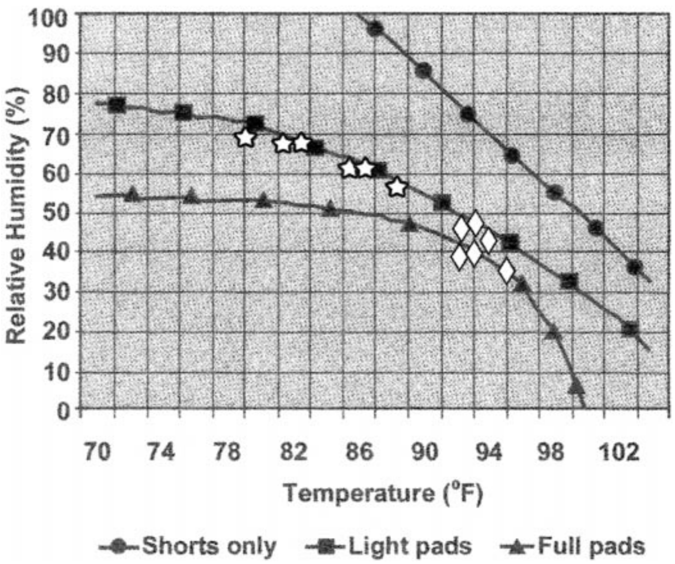

Figure 1. Heat stress risk temperature and humidity graph. Environmental conditions above ■ = no pads, between ■ and ▲ = half pads and below ▲ = full pads. Stars indicate morning temperature and humidity when football players were wearing helmets, shoulder pads, and shorts. Diamonds indicate afternoon temperature and humidity when football players were wearing full pads. Figure adapted with permission, from Kulka TJ, Kenney WL. Heat balance limits in football uniforms. *Physician Sportsmed.* 2002;30(7):29–39.

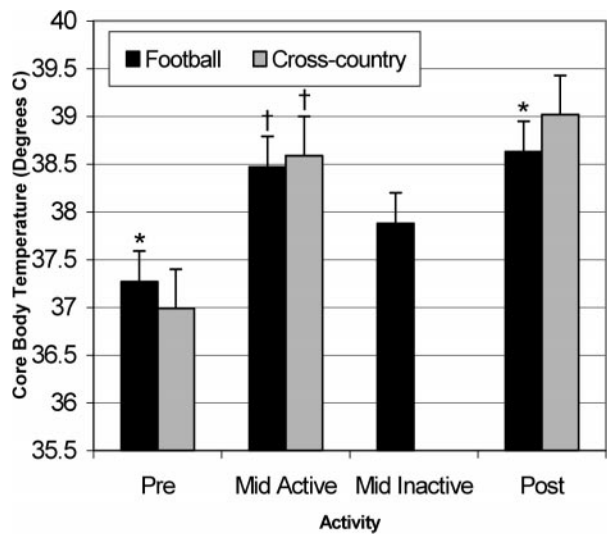

Figure 2. Core body temperature in football players and cross-country runners at rest and during practice. *Significantly different from cross-country. †Significantly different from football mid inactivity. All $P < .05$.

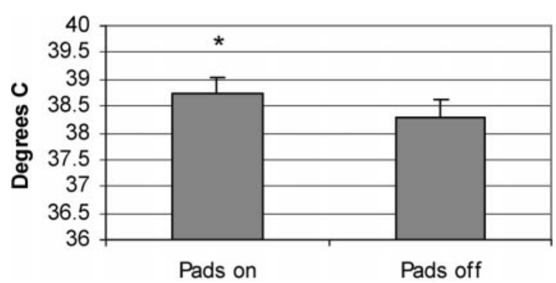

Figure 3. Core body temperature in football players immediately after conditioning with pads on versus pads off. *Significantly different from pads off; $P < .05$.

FB clothing and equipment (Figure 1). (This graph was originally published by Kulka and Kenney[30] and later reprinted in the National Athletic Trainers' Association position statement on heat illness[16] as well as in a recent book on exertional heat illnesses.[9]) It should be noted that during the afternoon practices, the FB players were in full equipment, even though guidelines,[9,16] based on the findings of Kulka and Kenney,[30] recommend that only half pads should be worn.

The mean pace for the runners was 6:50 per mile and ranged from 6:34 to 7:27 per mile. The group-by-time analysis of variance revealed a significant interaction for T_c (Figure 2). The T_c was higher in the FB group prepractice but lower postpractice compared with the runners. Additionally, T_c was higher in the CC subjects midrun and in the FB subjects when active during practice compared with the FB subjects when inactive (see Figure 2). As shown in Figure 3, T_c in the FB group was higher when they wore pads during postpractice conditioning compared with when no pads were worn. The T_c was lower in both the FB and CC subjects on day 8 compared with day 4 (Figure 4). Mean weighted T_{sk} was higher in the FB group (35.29°C ± 0.78°C versus 33.11°C ± 0.78°C; $P < .0001$). Forehead T_{sk} was as follows: FB with helmets on (36.62°C ± 0.90°C) was greater than FB with helmets off (34.4°C ± 0.99°C), which was greater than CC (32.59°C ± 1.25°C); all were $P < .05$. Forehead, chest, and back T_{sk} were higher in the FB subjects compared with the CC subjects (Figure 5). No group differences were seen in T_{sk} of the forearm or calf. The correlation coefficient between T_c and USG was not significant ($r = -.17$; $P = .13$) (Figure 6).

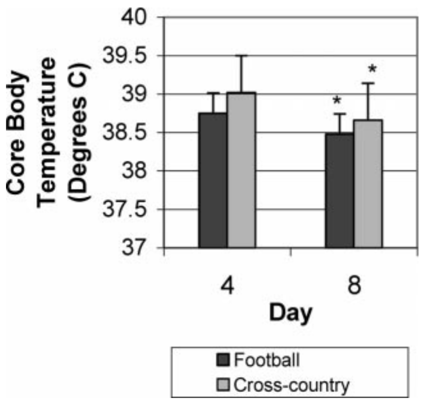

Figure 4. Core temperature in football players and cross-country runners on day 4 versus day 8. *Significantly different from day 4; *P* < .05.

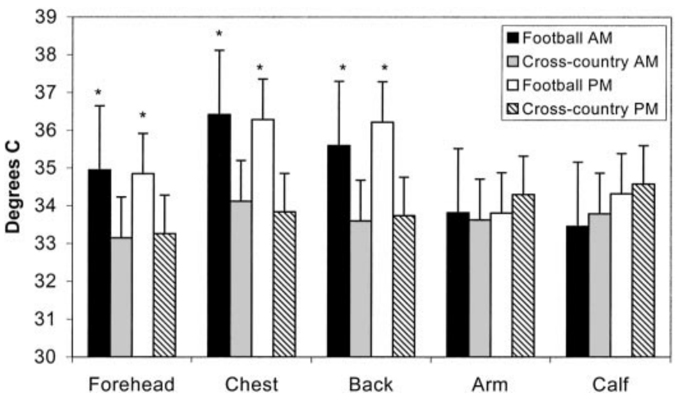

Figure 5. Skin temperature in football players and cross-country runners during both morning (AM) and afternoon (PM) practices. *Significantly different from cross-country runners; *P* < .05.

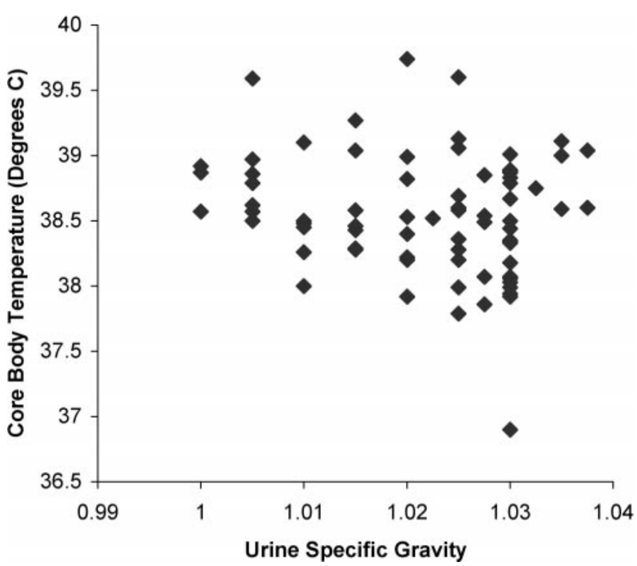

Figure 6. Core body temperature and urine specific gravity in football players and cross-country runners; *r* = −.17; *P* = .13.

DISCUSSION

We sought to document the thermal responses in athletes participating in FB practice and distance running in a hot environment. Our CC athletes exercised continuously at moderate to high exercise intensity, whereas the FB players exercised intermittently. The T_c responses in our FB and CC athletes seemed to reflect these differences in the types and intensities of the exercise bouts. The T_c in the runners increased over time throughout the exercise bout, whereas in the FB players, it increased and decreased in response to their activity level during practice. Kranning and Gonzalez[14] noted that during compensable heat stress, both rectal and esophageal temperatures increased and decreased in response to intermittent exercise (120 minutes of 4 minutes of walking, 2 minutes of jogging, and 4 minutes of rest), but during uncompensable heat loads, rectal temperature increased more linearly. However, rectal temperature increased slightly and then remained stable during continuous exercise in a compensable heat stress environment but increased linearly during uncompensable heat loads.[14] The T_c response in our FB players was similar to what Kranning and Gonzalez[14] found in subjects exercising intermittently during compensable heat stress, whereas the T_c response in our CC runners resembled that of their subjects exercising continuously in conditions of uncompensable heat load. Drust et al[15] used bouts of exercise organized to replicate the noncyclic nature of running while playing soccer. Their exercise protocol involved two 22.5-minute intermittent exercise sessions with a brief period of complete rest (71 seconds) between the sessions. Unlike what we found in our FB players, their subjects' T_c did not decrease during the complete rest period. They reported higher T_c at the end of the intermittent exercise protocol compared with 45 minutes of continuous running.[15] Our results likely reflect the fact that rest periods between exercise bouts during FB practices were often longer than 71 seconds. Further comparisons of our results with those found in these experimental studies are difficult because their intermittent exercise protocols were different from what we observed during FB practices.

In addition to wearing equipment and clothing that covered most of the body, the FB players had greater muscle mass (which means the potential for greater metabolic heat production), higher percentages of body fat, lower body surface area to body mass ratios, and lower aerobic fitness levels and were not as well hydrated compared with the runners. All of these factors increased the potential for greater heat storage by FB players compared with the runners.[2,17,19–25,28–30] Because these physical differences should have favored higher T_c in the FB players, the likely explanation for the higher T_c in the CC runners postrun compared with the FB players postconditioning is the periods of inactivity inherent to playing FB. Consequently, appropriate rest periods during FB practice seem to be critical for ensuring that these large athletes maintain a thermal steady state.

An important finding of our field study was that the T_c response in our FB players during practice was quite different from what Kulka and Kenney[30] found experimentally when subjects walked on a treadmill at 35% $\dot{V}O_{2max}$ while dressed in different FB clothing and equipment. Uncompensable heat stress occurred in subjects dressed in full or partial FB equipment in certain environmental conditions. They reported a linear increase in T_c, which is similar to what we observed in our CC runners who were exercising continuously. We did not find this linear rise in T_c in our football players. More importantly, as depicted in Figure 1, of the 12 environmental conditions plotted (3 readings during each of 4 practices) our FB players were dressed in clothing and equipment that were not recommended half of the time. However, none of them showed signs or symptoms of heat-related illness. Even in environmental conditions that Kulka and Kenney reported as being responsible for uncompensable heat stress, the periods of inactivity associated with our FB practices were apparently adequate for ensuring thermal balance. The highest T_c in the FB players, including after conditioning in full FB equipment, was 39.11°C (102.4°F). The highest T_c recorded overall was 39.84°C (103.7°F) in a CC runner after his 60-minute run the afternoon of day 8. It is important for certified athletic trainers to recognize that core body temperatures such as these are not uncommon in athletes exercising in hot and humid conditions.[4,7,8] However, these core temperatures had no ill effects on any of our subjects.

Another important result was that we were unable to find a correlation between T_c and USG. The runners consistently had lower USG (indicating better hydration) but higher T_c compared with the FB players. Our results suggest that exercise type (continuous versus intermittent) and intensity may be more important determinants of T_c than hydration status. Although fluid balance plays a role, our findings support those of others who propose that exercise intensity and, therefore, metabolic rate and not the level of dehydration may be more responsible for elevated T_c.[8]

The finding that T_c was higher after conditioning in pads versus when pads were not worn was expected and should be a consideration for FB coaches and medical personnel. The T_{sk} was clearly higher at the chest and back sites under the pads compared with the leg and forearm sites. Furthermore, allowing players to remove their helmets whenever possible should also be encouraged, because forehead T_{sk} was higher under the helmet than when the helmets were not being worn. On the other hand, it should also be noted that T_c was not dangerously high when the FB players were in full equipment. The finding that the highest T_c in both groups of athletes was less on day 8 than on day 4 was anticipated, especially in the FB players who did little outdoor conditioning before preseason. This most likely reflects well-documented adaptations because of acclimatization.[5,16,18,27]

A limitation of this study was that we did not document exercise intensity in the FB players. However, we believe that the FB practices at our university were similar to those in studies that have documented the intermittent activity inherent to practicing or playing FB.[10,11] Using telemetry, Gleim et al[10] documented that playing FB required short periods of high-intensity exercise interspersed with periods of rest. Heart rates in professional FB players during practice ranged from 85 to 160 beats/min in a defensive back and 90 to nearly 200 beats/min in a lineman. Heart rates reflected changes in exercise intensity during individual drills, 7-on-7 line scrimmaging, and full scrimmaging. We believe that our FB players participated in this type of intermittent activity during practices.

In summary, FB players and CC runners have very different physical characteristics, and they participate in very different forms of physical activity. The T_c seemed to increase steadily throughout the exercise bout in our runners who participated in 60 minutes of continuous running. However, in our FB players, T_c increased and decreased in response to their varying activity levels during practice. Rest periods associated with FB practice at our university seemed to allow adequate time for heat dissipation even under extreme environmental conditions. Recommendations for equipment to be worn during FB practice are based on non-FB players participating in continuous exercise. Although it may be prudent to be conservative during the first few days of preseason, the guidelines could be loosely interpreted after that time because the increase in T_c during continuous exercise may not reflect the actual T_c changes occurring during the intermittent activity associated with FB practice. Additionally, T_c was not related to the level of dehydration, as measured by USG, in either of our groups of athletes and may depend more on exercise type and intensity. Frequent rest breaks for FB players and decreased exercise intensity for CC runners are important considerations for these athletes when they exercise in the heat.

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