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Core Temperature and Percentage of Dehydration in Professional Football Linemen and Backs During Preseason Practices

Sandra Fowkes Godek*; Arthur R. Bartolozzi†; Richard Burkholder‡; Eric Sugarman‡; Gary Dorshimer§

*The H.E.A.T. Institute of West Chester University, West Chester, PA; †Pennsylvania Hospital, Philadelphia, PA; ‡Philadelphia Eagles, Philadelphia, PA; §Delancy Medical Associates, Philadelphia, PA

Sandra Fowkes Godek, PhD, ATC, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Arthur R. Bartolozzi, MD, contributed to conception and design, analysis and interpretation of the data, and critical revision and final approval of the article. Richard Burkholder, MS, ATC, and Eric Sugarman, MS, ATC, contributed to acquisition of the data and critical revision and final approval of the article. Gary Dorshimer, MD, contributed to conception and design and critical revision and final approval of the article.

Address correspondence to Sandra Fowkes Godek, PhD, ATC, 214 SHSC, West Chester University, West Chester, PA 19383. Address e-mail to sfowkesgod@wcupa.edu.

Context: Thermal responses of average-sized male subjects (mass of approximately 70 kg) may not accurately reflect the rate of heat storage in larger athletes with greater muscle mass.

Objective: To determine if core temperature (T_c) is different in National Football League linemen and backs and if T_c is related to percentage of dehydration or sweat rate.

Design: We measured T_c and sweat rate in professional football players during preseason twice-daily practices.

Setting: Preseason training camp.

Patients or Other Participants: Eight linemen (age = 26.6 ± 2.1 years, height = 191.8 ± 4.5 cm, mass = 134.8 ± 10.7 kg, body surface area = 2.61 ± 0.12 m²) and 6 backs (age = 27.0 ± 4.2 years, height = 185.0 ± 6.3 cm, mass = 95.6 ± 11.1 kg, body surface area = 2.19 ± 0.16 m²).

Main Outcome Measure(s): We measured T_c using ingestible sensors. Resting T_c was recorded in the mornings of data collection with players dressed in shorts and then every 15 minutes during 2-hour practices in full pads or shells. Mass was recorded before and after practices for determining the percentage of dehydration. In 8 of the 14 subjects (4 linemen, 4 backs), sweat rate was calculated using the change in mass adjusted for fluid intake and urine production.

Results: Height, mass, and body surface area were greater in linemen than in backs. We noted a linear trend over time for T_c in both groups. Maximal T_c was higher in linemen (38.65 ± 0.48°C) than in backs (38.44 ± 0.32°C), but linemen were less dehydrated than backs (−0.94 ± 0.6% versus – 1.3 ± 0.7%). Sweat rate was 2.11 ± 0.77 L/h and correlated significantly with body surface area (r = 0.77, P < .05). Maximal T_c was not correlated with either percentage of dehydration or sweat rate.

Conclusions: Maximal T_c was not associated with percentage of dehydration or sweat rate. Linemen were less dehydrated but demonstrated higher T_c than backs during practice. Maximal T_c was generally achieved during live scrimmaging.

Key Words: sweat rate, thermoregulation, heat storage, fluid regulation

Heat illnesses and deaths due to heat stroke have been documented in football players at the high school, college, and professional levels of competition.[1] Physical characteristics such as total body mass, lean muscle mass, percentage of body fat, body surface area, and surface area-to-mass ratio affect thermoregulation. Aerobic fitness, acclimatization, clothing and equipment worn, and environmental considerations can contribute to the incidence of heat illness.[2] Additionally, dehydration (determined by how quickly fluids are lost via sweating combined with inadequate fluid intake) is considered one of the primary precursors to heat-related disorders.[2,3] Although sweat rates vary widely from one athlete to another, the average-sized male athlete generally sweats at a rate of between 0.75 and 1.75 L/h.[4,5] Football players, however, sweat at higher rates than smaller distance runners.[6] Most sports medicine professionals believe the incidence of heat illness can be reduced with proper hydration, an idea strongly supported by the National Athletic Trainers' Association position statements on fluid replacement[2] and exertional heat illness.[3]

Several investigators[7–10] have studied thermoregulation experimentally in subjects exercising in football equipment, but competitive football players were subjects in only one of the studies.[10] Thermal responses of average-sized male subjects (mass of approximately 70 kg) may not accurately reflect the rate of heat storage in larger athletes with greater muscle mass. Using ingestible temperature sensors that allow accurate measurements of body temperature during activity, we documented core temperatures in collegiate football players and cross-country athletes while they participated in their respective pre-

Subjects' Physical Characteristics

Characteristics	Linemen	Backs
Age (y)	26.6 ± 2.1	27.0 ± 4.2
Height (cm)	191.8 ± 4.5*	185.0 ± 6.3
Mass (kg)	134.8 ± 10.7‡	95.6 ± 11.1
Body surface area (m^2)	2.61 ± 0.12†	2.19 ± 0.16
Body surface area/mass (m^2/kg)	0.0194 ± 0.0007‡	0.0230 ± 0.0011

*Significantly different from backs ($P < .05$).
†Significantly different from backs ($P < .001$).
‡Significantly different from backs ($P < .0001$).

season practices.[11] We noticed that the highest core temperatures recorded in football players tended to occur in the interior linemen. Additionally, we were unable to find a correlation between the highest core temperature reached and the athlete's level of hydration.[11]

Professional teams in the National Football League (NFL) begin preseason training camp earlier than college teams. Their 2-a-day sessions generally start at the end of July and continue for 4 or more weeks, when it is typically hot and humid in many parts of the United States. To date, we are unaware of published field research related to core temperature, sweat rates, and hydration status in football players other than our own, and these studies involved collegiate players.[6,11–14] Therefore, the purpose of this field study was 2-fold: (1) to measure the rise in core temperature during practice in professional football players and compare the core temperatures of larger interior lineman to those of backs and receivers, and (2) to determine if the highest core temperatures reached (T_{cmax}) were related either to the players' level of dehydration or their sweat rate.

METHODS

Subjects

Participants in the study were 8 interior linemen, consisting of 2 offensive tackles, 1 center, 1 guard, 2 defensive ends, and 2 defensive tackles, and 6 backs, consisting of 1 wide receiver, 1 running back, 2 corner backs, 1 tight end, and 1 linebacker (Table). All subjects were NFL first-team or second-team veteran players on 1 NFL team who were apprised of the minimal risks involved with the study and signed consent forms. The university's institutional review board approved the study.

Procedures

Core Temperature Measurements. Subjects ingested a temperature sensor (HQ Inc, Palmetto, FL) at 11:00 PM on the first evening of preseason training camp, before data collection on days 2 and 3. These sensors are capable of transmitting accurate core temperature (T_c) readings (± 0.1°C) to a handheld recorder.[15] Resting T_c was recorded in an air-conditioned area 1 hour before morning practice. T_c was then recorded in each player approximately every 15 minutes during 2 hours of football practice in full equipment. T_c was also measured during the afternoon practice (with the team dressed in shells) and during the next morning practice in those players who retained their sensors. Body mass was recorded before and after all practices to the nearest 0.23 kg (Detecto Scale, Webb City, MO) for determining percentage of dehydration (%DHY). Weight measures paralleled both T_c and sweat rate measures. Practices began at 8:45 AM and 2:45 PM and consisted of 3 distinct periods, including individual drills and 7-on-7 team and live scrimmages. On data collection days, the highest wet bulb and dry bulb temperatures were 22.8°C and 25°C, 20.6°C and 29.2°C, and 18.5°C and 19.4°C during the morning, afternoon, and next morning practices, respectively.

Sweat-Rate Measurements

In addition to the T_c data collection, a subset of 8 first-team veteran players participated in data collection that allowed us to determine each individual's sweat rate. Physical characteristics of this group were age = 27.1 ± 3.4 years, height = 189.2 ± 7.9 cm, mass = 114.9 ± 26 kg, body surface area (BSA) = 2.4 ± 0.3 m^2, and BSA-to-mass ratio = 0.0214 ± 0.0023 m^2/kg. This group included 3 offensive linemen, 1 defensive lineman, 1 tight end, 1 wide receiver, and 2 corner backs. The sweat rate data were collected on the sixth and 10th days of training camp, when environmental conditions were similar. On day 6, mean wet bulb and dry bulb temperatures (3 readings recorded at the beginning of practice, mid practice, and immediately postpractice) were 21.5°C and 23.7°C and 24.7°C and 28.2°C for the morning and afternoon practices, respectively. On day 10, mean wet bulb and dry bulb readings during practices were 20.1°C and 20.1°C in the morning and 23.2°C and 30.1°C in the afternoon, respectively. Sweat rate was calculated using the change in mass adjusted for fluid intake and urine production. Specifically, the following protocol was followed: before practice, the players voided the contents of their bladders and recorded body weight (dressed in dry shorts or a towel) to the nearest 0.23 kg under the supervision of a research assistant. From the time body weight was recorded before practice to the postpractice body weight measurement (with players dressed as for the prepractice measurement), they drank only from their own premeasured, prelabeled containers of water and carbohydrate-and-electrolyte drink. Each football player had a personal fluid replacement attendant who was responsible for providing fluids of choice during practice. The players were instructed to drink only from their containers and not to let any fluid drop to the ground. During practice, the players could use the on-field water pumpers to cool themselves but did not drink from them. Individual urine containers were available on the field; however, none of the players urinated during practice. After practice, the players returned to the locker room to shower and towel dry. They emptied their bladders completely and recorded postexercise body weights, again under the supervision of a research assistant. Each player's postpractice urine volume was accurately measured and recorded. The amount of fluid remaining in each bottle was measured and subtracted from the starting volume to calculate fluid consumed during each practice. The following formula was used to calculate sweat rate:

(Prepractice body mass − postpractice body mass − urine produced + fluids consumed) ÷ time of practice[2]

This formula does not account for insensible fluid losses, which were considered minimal. Sweat rate was calculated for each of the 8 players in both morning and afternoon practices. The mean sweat rate for each player was used in the statistical analysis.

Hydration Protocol

The intrusive hydration program used by this NFL sports medicine staff consists of the following regimen: (1) cold water is offered to each player between repetitions during practice, and carbohydrate-and-electrolyte drinks are provided on request, (2) cold bottled fluids (water, carbohydrate-and-electrolyte drinks, high-carbohydrate drinks) are kept in ice chests and offered to players as they exit the field after practice, and (3) bottled water and carbohydrate-and-electrolyte drinks are stocked in coolers in the locker rooms for consumption before and after practice.

Statistical Analysis

We analyzed changes in T_c over time using a repeated-measures general linear model (version 11.0; SPSS Inc, Chicago, IL). Group differences (linemen versus backs) in T_c and %DHY were analyzed using independent *t* tests. We calculated Pearson product moment correlations to assess the relationships between T_c and %DHY and between T_c and mass and, in the subset of 8 players, between T_c and sweat rate and BSA and sweat rate. The α level was set a priori at $P < .05$.

RESULTS

Height, mass, and BSA were all higher in linemen than in backs, and the BSA-to-mass ratio was lower in linemen. No differences were noted in wet bulb temperatures between the 2 morning or 2 afternoon practices when the sweat rate data were collected. The wet bulb readings were higher during the afternoon of T_c data collection than during the second morning. Results are reported as mean ± SD.

Core Temperature in Linemen Versus Backs

A significant linear trend over time was found for T_c in both groups, $P < .0001$ (Figure 1). During the morning practice, T_c rose from 37.07 ± 0.13°C to 38.81 ± 0.48°C in linemen and from 36.99 ± 0.09°C to 38.36 ± 0.44°C in backs. When the 2 highest instances of T_c recorded in each subject were compared, T_{cmax} was higher in linemen (38.65 ± 0.48°C, range = 37.47 to 39.29°C) than in backs (38.44 ± 0.32°C, range = 37.81 to 39.08°C) ($P < .05$, Figure 2). However, as measured by change in mass during practice, the linemen were less dehydrated than the backs (−0.94 ± 0.6% versus −1.3 ± 0.7%) ($P < .05$, Figure 3).

Correlations Between Core Temperature and Percentage of Dehydration and Core Temperature and Mass

To increase statistical power, we calculated the T_{cmax} and %DHY correlations using n = 30 (all 14 players in the morning practice, 12 players who retained their sensors for the afternoon practice, and 4 players who retained their sensors for the next morning practice). As depicted in Figure 4, no correlations were found for T_{cmax} and %DHY (r = 0.24, P = .204). The %DHY for this group was −1.11 ± 0.7, ranging from a weight gain of 0.63% in one player to −2.4 %DHY in 2 players. A small (r = 0.44) but significant correlation was found for T_{cmax} and mass (P = 0.02).

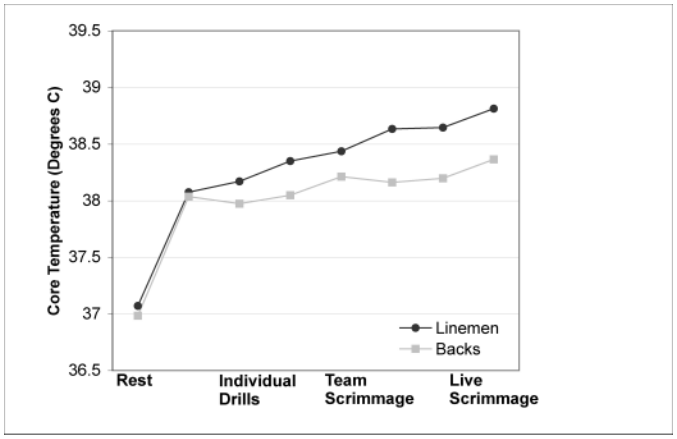

Figure 1. Core temperature over time for backs and linemen. *P* < .001.

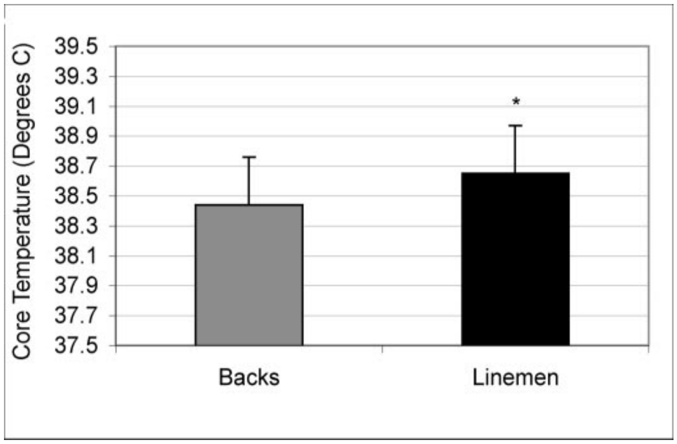

Figure 2. Maximal core temperatures in backs and linemen. *P* < .05. * Indicates significant difference.

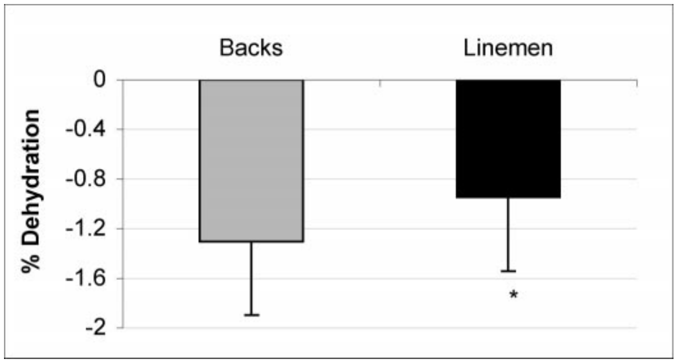

Figure 3. Percentage of dehydration in backs and linemen. *P* < .05. * Indicates significant difference.

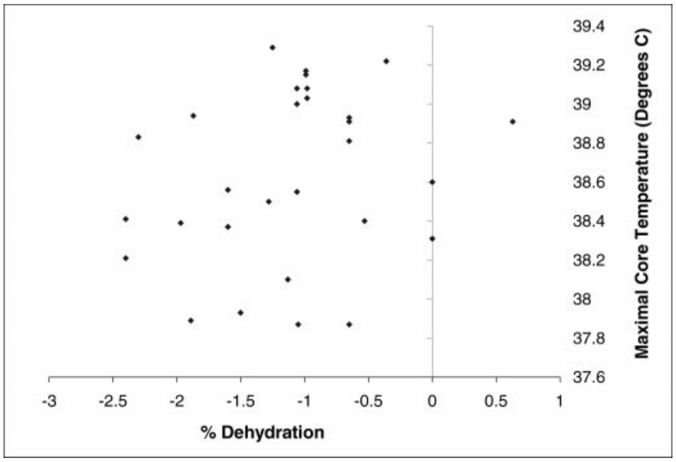

Figure 4. Percentage of dehydration plotted against maximal core temperature. r = .24, *P* = .204.

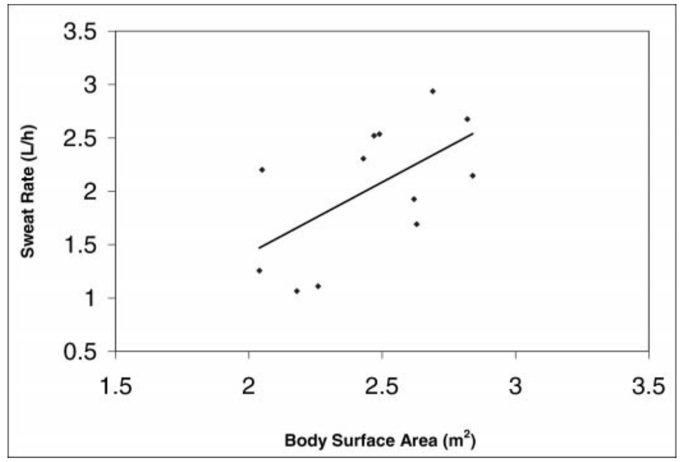

Figure 6. Body surface area plotted against sweat rate. r = .77, *P* < .05.

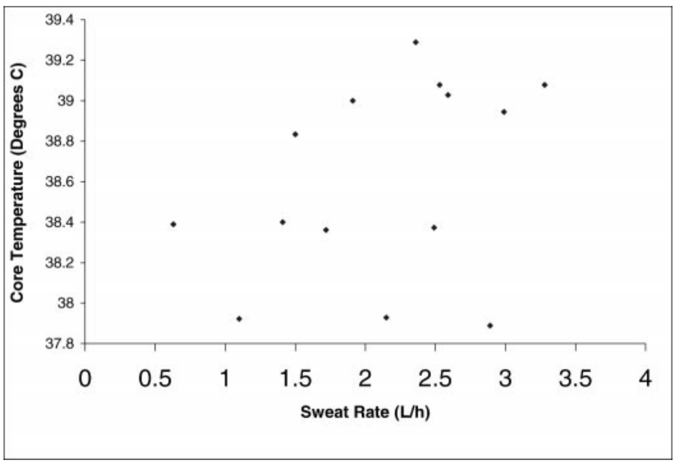

Figure 5. Sweat rate plotted against maximal core temperature. r = .36, *P* = .19.

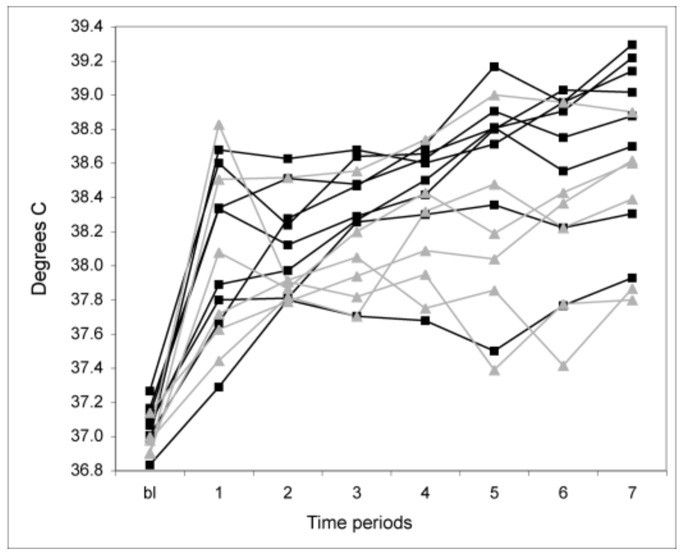

Figure 7. Core temperature over time. Gray lines indicate linemen. Black lines indicate backs. bl indicates baseline.

Correlations Between Core Temperature and Sweat Rate and Sweat Rate and Body Surface Area

Correlations between T_{cmax} and the players' average sweat rate were calculated using n = 14, combining the morning (n = 8) and afternoon (n = 6) T_c data. We were unable to detect a correlation between T_{cmax} and sweat rate ($r = 0.36$, $P = .19$) (Figure 5). Sweat rate was 2.11 ± 0.77 L/h and %DHY was −1.4 ± 0.49%, ranging from −0.98 to −2.3%. As depicted in Figure 6, sweat rate and BSA were significantly correlated ($r = 0.77$, $P < .05$).

DISCUSSION

We were successful in documenting the T_c responses in professional football players about every 15 minutes and found a linear trend over time in T_c indicating gradual heat storage (see Figure 1). As depicted in Figure 7, this trend was more apparent in the linemen. The change in T_c in the backs was greater in response to bouts of exercise and rest. This finding was similar to that of a previous study[11] in collegiate football players in whom T_c increased after periods of activity and decreased after periods of rest. This more gradual heat storage in the linemen may partially explain our finding that T_{cmax} was higher than in the backs.

Plausible explanations for greater heat storage and higher T_{cmax} in linemen include a larger body mass and lower BSA-to-mass ratio. Additionally, linemen have a lower aerobic fitness level than backs as measured by both $\dot{V}O_{2max}$[10] and a timed 1.5-mile (2.41-km) run.[16] It is also possible that exercise intensity or the duration of exercise during individual drills was different between the groups or that distances run (feet in the linemen versus yards in the backs) affected evaporative heat losses differently. A larger mass, higher percentage of body fat, greater BSA, and lower BSA-to-mass ratio in linemen than backs have been documented by others.[10,17] Higher body mass increases metabolic rate and, therefore, heat production, resulting in greater heat storage.[10,18,19] The lower BSA-to-mass ratio in larger football players diminishes heat dissipation via dry avenues such as conduction, convection, and radiation compared with smaller players.[10,19] Wailgum and Paolone[10] studied collegiate football players in an experimental investigation of heat tolerance during anaerobic exercise in environmental conditions of 35°C and 80% relative humidity. They reported higher rectal temperature and skin temperature and greater heat storage in the linemen compared with the backs. Epstein et al[19] reported greater metabolic heat production, lower work efficiency, and higher rectal temperatures in larger subjects, and the mass differences between their groups were minimal compared with the differences between our linemen and backs. They studied 3 groups: heat intolerant (mass = 77.8 ± 6.2 kg, BSA-to-mass ratio = 0.0247 ± 0.0007 m^2/kg), normal thermoregulatory response (mass = 65.2 ± 2.6 kg, BSA-to-mass ratio = 0.0271 ± 0.0005 m^2/kg), and control (mass = 67.5 ± 1.7 kg, BSA-to-mass ratio = 0.0272 ± 0.0004 m^2/kg). They concluded that the lower BSA-to-mass ratio was the greatest contributor to the higher rectal temperatures found in their larger, heat-intolerant subjects. In addition, other researchers[18] have concluded that lighter runners have a distinct thermoregulatory advantage over runners with greater mass who produce and store more heat at the same running speed.[18] Our finding of greater heat storage and higher T_{cmax} in the larger linemen (mass = 134.8 ± 10.7 kg, BSA-to-mass ratio = 0.0194 ± 0.0007 m^2/kg) than in the backs (mass = 95.6 ±11.1 kg, BSA-to-mass ratio = 0.0230 ± 0.0011 m^2/kg) supports the results of these studies.[10,18,19]

We were unable to accurately measure exercise intensity in the players, making it difficult to comment on the possibility that work rate, work duration, or work-to-rest ratios may have been different between the groups. During certain time periods, for example, the backs and receivers were involved with the rest of the team running 7-on-7 plays, while the linemen were participating in 1-on-1 drills. The differences in work rate and the running distances covered by the linemen compared with the backs could at least partially explain the higher T_{cmax} in the linemen. Generally, backs run greater distances per play, frequently more than 10 yd (9.14 m) and often longer, whereas the linemen rarely run more than that distance per play. Because running speeds were higher in the backs, wind velocity and, therefore, evaporative cooling would also be greater. Adams et al[20] reported that during exercise in environmental conditions of 35°C, an airflow velocity greater than 3 m/s resulted in lower skin and rectal temperatures in subjects than wind speeds of less than 2 m/s. This airflow concept as it relates to positional differences that affect running duration and, therefore, running velocity per play is interesting and requires further investigation in football players.

Importantly, certified athletic trainers need to recognize that core temperatures above 38.9°C are not unusual. Three years of recording body temperatures in collegiate and professional football players during practices and games (approximately 60 players in 156 player-exposures) led us to believe that core body temperatures in football players of between 38.9 and 40°C (102°F to 104°F) are normal when environmental conditions are warm or hot and humid.[11–14,21,22] This has recently been documented by others.[23,24]

We were not surprised to find a lack of correlation between level of hydration and T_{cmax} in our players. The backs, who had lower T_{cmax}, were actually more dehydrated after practices than the linemen, although the differences in hydration level were small. On 5 occasions, players reached a T_{cmax} greater than or equal to 39.0°C (102.2°F), (range, 39.08°C to 39.29°C); however, their %DHY was −1.04 ± 0.01%, ranging from −0.98 to −1.25%. Additionally, the 3 players who were most dehydrated had relatively low T_{cmax} (−2.3%DHY and 38.8°C, −2.4%DHY and 38.4°C, and −2.4%DHY and 38.2°C). Previous field studies[11,13] involving collegiate players also failed to reveal a significant relationship between T_c and level of hydration as measured by body weight loss or urine specific gravity. In these studies, T_c was recorded using the identical core temperature telemetry system (CorTemp; HQ Inc), and the mean body weight losses were greater in the collegiate players, ranging from 2.25 ± 0.9% to 2.9 ± 1.5%.

Despite reports of a direct relationship between hydration status and T_c,[25–27] the inability to detect a correlation in field studies should not be viewed as unusual, particularly at mild to moderate levels of dehydration. Even in carefully controlled experimental studies, researchers have found no differences in the maximal T_c reached at exhaustion in subjects wearing protective clothing and dehydrated −2.3% compared with when they were euhydrated.[28] Additionally, subjects hypohydrated by 3.5% to 4% before exercise in the heat did not have different T_c responses compared with trials when they were euhydrated, as long as fluids were available ad libitum during the exercise bouts.[29]

We offer 2 explanations for our finding that T_{cmax} was not related to the players' level of hydration. First, at the modest levels of dehydration experienced by our subjects (<2.5%), it seems reasonable to suggest that the changes in core body temperature were more related to another factor, presumably exercise intensity. This is supported by previous findings[11] that T_c in football players increases and decreases in response to periods of activity and rest. Second, experimental protocols, methods, and subsequent data used for statistical analysis are likely different between field studies[6,11–14,21–24] and the experimental investigations that report a direct relationship between T_c and hydration status.[25–27] These former authors sought to document the effect of graded levels of hydration on core temperature during exercise,[25–27] and the data support the conclusion that during continuous exercise in warm and humid or hot conditions, the change in core temperature is greater when subjects are hypohydrated or progressively dehydrated than when they are euhydrated.[25,26] In a classic study[25] in which subjects were dehydrated on separate occasions to between 1% and 4% (and maintained at that level of hypohydration during the exercise bout), Montain and Coyle[25] reported a significant linear relationship between the change in esophageal temperature during 2 hours of continuous exercise and state of hydration. Data from this and other studies indicate that the rise in T_c is small at low levels of dehydration and increases as body weight loss increases.[25–27] The subjects in these studies weighed approximately 70 to 80 kg, and the work bouts involved moderate-intensity continuous exercise, which often does not elicit excessively high core temperatures. Importantly, experimental investigators must adhere to safety protocols, which generally preclude subjects from continuing to exercise with core temperatures higher than or equal to 39.5°C. Because these exercise protocols are quite different from the type of work football players perform during practice, we cannot ascertain from these studies how high core temperature could rise at a given level of hydration, particularly in athletes with large muscle mass performing high-intensity, intermittent exercise in the heat. Importantly, however, in these experimental studies, the change in T_c varies considerably from one subject to another at any level of hydration. In one study,[25] the variability in T_c among subjects ranged from approximately 0.1°C to 0.8°C at 1% body weight loss and from 0.6°C to 1.4°C at 3% body weight loss. In another study,[27] the T_c differences between subjects were nearly 1.0°C at a given level of hydration.

As with field studies, it should be recognized that experimental investigations have different but inherent limitations, especially with regard to generalizing results to real-life situations. Consequently, they do not necessarily support the premise that minimizing dehydration will actually prevent hyperthermia in football players during practices.[2,3] Data from our study, other recent field studies in football players,[11,12,14,22] and a previous field report in marathon runners[30] suggest that level of hydration may not give an accurate indication of which athletes will reach the highest core temperatures. In fact, several of our players with the highest core temperatures were the least dehydrated and vice versa. We believe this finding is extremely important to the clinician providing on-field care to football players. Although we believe that fluid replacement and recording weight loss during practices are critical in football players, our field data do not support the common dogma that the heaviest sweaters or most dehydrated players are at the greatest risk for developing high core temperatures.[2,3]

The sweat rate of 2.11 $\pm$ 0.77 L/h in our NFL players was nearly identical to the sweat rate reported in collegiate players (2.14 $\pm$ 0.53 L/h) practicing in similar environmental conditions.[6] This was not unexpected because BSA is an important factor in determining the rate at which humans sweat.[31] This finding was further supported by the positive correlation ($r = 0.77$) between BSA and sweat rate in the professional football players we studied. The physical characteristics of the subgroup of professional players (height = 189.2 $\pm$ 7.9 cm, mass = 114.9 $\pm$ 26 kg, BSA = 2.4 $\pm$ 0.3 m^2) who participated in the sweat rate data collection were indistinguishable from the collegiate players (height = 188 $\pm$ 4.8 cm, mass = 116.63 $\pm$ 16.3, BSA = 2.4 $\pm$ 0.16 m^2) who participated in the previous study.[6] In that study, sweat rates were higher (greater than 2 L/h) in football athletes than in smaller runners who sweated at a rate of 1.77 L/h in identical environmental conditions.[6] This was expected given the body size differences. Body surface area in the football players was significantly greater (2.4 $\pm$ 0.16 m^2) than in the runners (1.87 $\pm$ 0.16 m^2).[6] Sweat rates as high as 3.9 L/h have been documented in a 139-kg lineman during a full, padded practice in hot conditions. This football player consistently lost more than 10 L per day (range, 10.9 to 14.8 L), which likely contributed to his chronic state of dehydration during preseason twice-a-day training.[12] Data from our current study support conclusions that football players sweat at high rates and, therefore, must be vigilant with regard to both fluid and sodium replacement,[6,12,13] as we recently documented a significant decline in blood sodium on the third and fifth days of preseason training in professional football players.[32]

The hydration protocol employed by this team appeared to be successful in ensuring that the players were appropriately hydrated during practices. The 2 subjects with the greatest weight loss were only −2.4% dehydrated. A body weight loss of less than 3% is considered minimal dehydration.[2]

CONCLUSIONS

Interior linemen playing in the NFL reached higher maximal core temperatures during football practice than smaller backs and receivers. The highest core temperatures in all subjects were generally obtained at the end of practice during live scrimmaging. At the modest levels of dehydration our football players experienced, body weight loss was not associated with core temperature. Linemen had higher core temperatures but were less dehydrated than backs, although neither of these significant differences were likely clinically relevant. However, although an intrusive hydration protocol can be successful in minimizing dehydration in football players during practice, athletic trainers should be aware that core temperature is not necessarily associated with either percentage of dehydration or sweat rate in these athletes.

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COMMENTARY

Lawrence E. Armstrong

Editor's Note: Lawrence E. Armstrong, PhD, is a Professor in the Human Performance Laboratory, University of Connecticut, Storrs, CT, and a *JAT* Editorial Board member.

I appreciate the opportunity to provide my perspectives regarding this article, because it contains information that may directly affect decisions regarding the health of athletes and the paradigms of athletic trainers.

Commencing in 1926 with the work of D. B. Dill and colleagues, at the Harvard Fatigue Laboratory and Nevada desert sites, investigators have measured the sweat rates, dehydration levels, and core body temperatures of young athletes, soldiers, and laborers, with and without uniforms.[1,2] Authors of numerous scientific publications, review articles, and book chapters have focused on the nature of these responses and the resultant physiologic principles.[3,4] The primary contribution of the present study lies in describing subtle differences among athletes who play different positions in American football.

Unfortunately, one primary conclusion of this study runs counter to a widely accepted physiologic principle. This conclusion is stated as follows: ‘‘our field data do not support the common dogma that the heaviest sweaters or most dehydrated players are at the greatest risk for developing high core temperatures’’ and later as ‘‘core temperature is not necessarily associated with either percentage of dehydration or sweat rate in these athletes.’’ The principle stems from numerous controlled laboratory studies reporting that core body temperature increases with increasing dehydration when all other factors are controlled.[4] To understand why the present data disagree with a recognized tenet of thermal physiology, it is important to note that both exercise intensity and duration and dehydration are critical to heat storage. The authors acknowledge that exercise intensity was not controlled in the present study (ie, all subjects performed different runs, moves, tackles, and blocks for different durations) and that dehydration was not controlled (ie, the loss of body weight as water was different in all athletes); thus, 2 independent variables coexisted as uncontrolled factors in this experimental design. Although uncontrolled factors are common to field studies, a scientist may not then draw conclusions about the influence of one variable on another. Also, the dehydration levels experienced by the present football players were mild (−0.98% to −2.3% of body mass) and should not be used to draw conclusions about players who experience −6% or −8% dehydration. Changes in physical performance, cardiovascular responses, and thermoregulation are dramatic beyond −3% dehydration. In my opinion, the above conclusion should be revised as follows: ‘‘Our field data do not support the common dogma that the heaviest sweaters or most dehydrated players are at the greatest risk for developing high core temperatures because exercise intensity and dehydration were not controlled. This does not negate the well-known relationship between increasing dehydration and increasing core body temperature. It also does not mean that our findings apply to environmental temperatures greater than 29.2°C.’’

In the following paragraphs, I express 2 reservations about statistical methods and 5 concerns about the interpretation of data in the present study.

Statistical Methods

1. The Results section presents statistical correlations between core body temperature and sweat rate. However, the Methods section states that measurements of core body temperature were made on days 2 and 3 of preseason training camp (ie, when athletes were not fully acclimatized to the heat) and that measurements of sweat rate were recorded on days 6 and 10 (ie, when most heat acclimatization adaptations had occurred). Presentation of correlation data, representing practices that were separated by 3 to 8 days, is perplexing and invalid. Increased sweat rate and reduced core body temperature are among the well-known adaptations that occur during heat acclimatization.
2. Thirty data points (which appear as 29 symbols) were used to plot Figure 4, but these represented only 14 different players. The rationale presented for this approach was to ‘‘increase statistical power.’’ Although it is true that 29 data points will provide greater statistical power (ie, to find significant differences) than 14 data points, that does not mean this approach is valid. Certain assumptions underlie every statistical analysis, as stated by the mathematician who invented the technique. Statistical correlations assume that all

data points are independent of each other. Figure 4 violates this assumption, in that 12 players are represented by 2 data points and 4 players are represented by 3 data points. This means that a few players may influence a correlation coefficient or graph more than others, because their data appear more than once. If those players are ''outliers'' (ie, at one extreme), the correlational analysis is affected to a greater extent.

Interpretation of Data

1. The following advice is offered about football players: ''athletic trainers should be aware that core temperature is not necessarily associated with either percentage of dehydration or sweat rate.'' After reading this statement, athletic trainers may be led to believe that they need not worry about athletes becoming dehydrated and that on-field water discipline is unnecessary. The following sentence in particular has great potential to confuse caregivers: ''Although we believe that fluid replacement and recording weight loss during practices are *critical* [my emphasis] in football players, our field data do not support the common dogma that the heaviest sweaters or most dehydrated players are at the greatest risk for developing high core temperatures.'' It is reasonable to ask: If dehydration is not related to core body temperature, why is fluid replacement critical? I believe this statement misuses a simple field study observation (ie, without control of key variables; see above) in a way that may cause more harm than good to the athletic training profession.
2. The Discussion section states that the present study supports sodium replacement for football players. Sweat sodium levels were not measured in the present study.
3. The text refers to the experiments of McLellan et al[5] as support for the present study. However, McLellan et al's study involved encapsulated, uniformed soldiers who experienced severe heat stress that was uncompensable (ie, core temperature continued to rise without a plateau). Clearly, the football players in the present study did not experience uncompensable heat stress (average maximal daily air temperature ranged from 19.4°C to 29.2°C). Thermoregulatory responses during uncompensable heat stress are considerably different from those that occur in a mild environment. Thus, it is invalid to compare the data of McLellan et al with those of the present study.
4. Although the average daily maximal air temperatures in the present study were mild (range, 19.4°C to 29.2°C [67.0°F to 84.6°F]; see reference[6]) when compared with summer training environments in the southern United States, the Discussion section did not acknowledge this fact as a limitation of data interpretation.
5. The text misinterprets an investigation that was conducted in our laboratory[7] as supporting the present study, by emphasizing only 1 of 4 experiments that each subject performed while in different hydration states (−1.0%, −1.4%, −3.0%, −5.1% of body mass). Indeed, the most relevant experimental trial was not mentioned in the Discussion section: the one involving the greatest level of dehydration. When body water loss at the end of 90 minutes of treadmill walking equaled −5.1%, the average rectal temperature of test subjects was 0.9°C (100.9°F versus 102.2°F) greater than all other trials. Further, our findings demonstrated that sweat sensitivity (ie, the amount of sweat produced per degree rise in rectal temperature) decreased in proportion to body water loss, indicating impaired thermoregulation due to dehydration. Thus, our investigation disputes the statement that dehydration is not related to rectal temperature.

In conclusion, the authors interpret the lack of correlation (ie, between core body temperature and dehydration level or sweat rate) as a meaningful finding that athletic trainers ought to understand. From my perspective, this is due to an experimental design that did not control these variables and an unwarranted interpretation of data. Although I realize that field studies ordinarily do not control all physiologic variables and I value field studies, I cannot ignore conclusions that mislead readers.

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AUTHORS' RESPONSE

We thank Dr Armstrong for his thoughtful commentary and appreciate the opportunity to respond.

We respect Dr Armstrong's insight into the past and, in particular, the many laboratory and field investigations involving military personnel and the relatively small-sized athletes (compared with football players) who have been studied. Additionally, we recognize the importance of laboratory research that focuses on carefully controlling all variables.

With regard to our conclusion that ''our field data do not support the common dogma that the heaviest sweaters or most dehydrated players are at the greatest risk for developing high core temperatures,'' we are stating what we have found repeatedly in our field studies of football players, with the clinical implication that ''level of hydration may not give an accurate indication of which athletes will reach the highest core temperatures.''[1–9] We believe that such field studies provide data to bridge the gap between laboratory findings and what the certified athletic trainer actually experiences when dealing with athletes on the playing field.

We feel strongly that certified athletic trainers and other clinicians associated with football should not be misled into believing that a good hydration program (ie, one that minimizes dehydration) will prevent high core temperatures in football players. This is evidenced by a recent case study of a player who was less than 0.5% dehydrated with a core body temperature of nearly 106°F.[5] Although core temperature and hydration status have been correlated in some studies, other factors are equally significant modulators of this response.[10] In addition, elevated core temperatures are common in high-performance athletes.[5,10]

If physiologic responses vary among players of different positions in one sport (eg, football linemen and backs), then it seems reasonable to suggest that there are also differences between the frequently studied runners, cyclists, or military personnel, and football players. We caution that data from ''nonathletes'' or ''other athletes'' should not be extrapolated to our subjects. The physical differences that exist among football players, smaller male athletes, and female athletes translate into physiologic differences that affect thermoregulation. For example, weight-trained athletes have significantly greater fat-free mass and greater water weight, nearly 75% of their body mass than nonathletes.[11] A comparison of body composition between male and female National Collegiate Athletic Association Division I athletes participating in football, gymnastics, volleyball, basketball, swimming, and track and field revealed that football players had the highest skeletal muscle-to-fat-free mass ratio of all groups and, subsequently, a high water content to fat–free-mass ratio.[12] Conversely, females are known to have less total body water, about 50% of body weight, and a higher percentage of body fat than the average male, who is generally assumed to contain 60% total body water.[13,14] Because water is the largest component of skeletal muscle and football players have large ratios of skeletal muscle to fat-free mass, it is reasonable to suggest that total body water in a football player is greater than 60% and could easily be 70% or more.[11]

The following calculations show that alterations in body fluid balance may be different between these groups. Let's consider the following:

Total body water = 50% in the average female, 60% in the average male, and 70% in the average football player. A 6% loss of body weight equals the following body water deficits:

12% in the average female (6% divided by 50%)
10% in the average male (6% divided by 60%)
8.5% in the average football player (6% divided by 70%)

A 6% reduction in body weight associated with sweat loss during exercise translates into a lower percentage of body water loss in the football player.

We offer a second example of how body size results in physiologic differences with regard to fluid balance and thermoregulation strategies. The average lineman in our present study had a body surface area of 2.60 m^2, compared with 2.19 m^2 in the average back and 1.87 m^2 in the average runner in a previous study.[15] A large body surface area (more skin and, therefore, larger or a greater number of sweat glands) should translate into greater total volumes of sweat in larger athletes. In fact, football players (linemen and backs combined) sweat faster and in greater volumes than runners,[15] and linemen produce more sweat than backs.[16] Once again, physiologic differences are manifested in the football athlete.

Dr. Armstrong suggests that we not draw conclusions from the mild level of dehydration experienced by our players but rather concern ourselves with ''players who experience 6% or 8% dehydration.'' In our conclusions, we state, ''At the modest levels of dehydration that our football players experienced, body weight loss was not associated with core temperature.'' If we used these levels of dehydration (6% to 8%) for our calculations, body weight loss would be the following: our average 210-lb (95.25-kg) back would lose 12.6 to 16.8 lb (5.72 to 7.62 kg), our average 297-lb (134.72-kg) lineman would lose 18 to 24 lb (8.16 to 10.89 kg), and our largest lineman weighing 330 lb (149.69 kg) would have to lose more than *26 lb (11.79 kg)* [our emphasis] during practice to incur an 8% reduction in body weight. A competent athletic trainer would readily recognize a player with 6% to 8% dehydration from his or her symptoms. We do not dispute that high levels of dehydration would likely affect core temperature, but we also do not suggest that keeping athletes hydrated will prevent increases in core temperature. Maintaining proper hydration will clearly prevent dehydration from approaching dangerous levels. Moreover, minor elevations in core temperature are expected and well tolerated.

STATISTICAL METHODS

1. We acknowledge the potential discrepancy in our study involving the core temperature and sweat rate data collection. Unfortunately, the logistics of collecting data from professional athletes precluded us from measuring core temperature and sweat rate on the same day. In defense of our conclusions, we have previously demonstrated that sweat rates do not change significantly in football players from the first to the second week of preseason camp, which may reflect the fact that football players (because of their equipment) begin sweating very early (and probably maximally) during practice and continue to do so throughout practice.[2,17]
2. The core temperature and percentage of dehydration data in Figure 4 were intended to increase statistical power, with the understanding that none of the subjects was an outlier. Our subjects' maximal core temperatures ranged from 37.9 to 39.3°C (100.2°F to 102.7°F), well within the normal range previously reported in practicing football players.[1,6–9] Two players had the same data points.

INTERPRETATION OF DATA

1. Dr Armstrong's comment allows us to clarify another issue. Considering the volumes of sweat football players lose during 2-a-day practices, sodium replacement is just as critical as fluid replacement.[15,16,18,19] During warm, humid environmental conditions, we have consistently found daily fluid losses in both collegiate and professional football players of 9 to 12 L/d, with some almost reaching 15 L/d.[15,16,17,18] We documented a significant decline in blood sodium, with a corresponding decrease in plasma volume on the third and fifth mornings of preseason training camp in professional football players who had 24-hour availability to carbohydrate-and-electrolyte drinks and were educated and encouraged to consume them.[19] An average football player who replaced half of the lost sodium with food consumption would still need to ingest 10 L of a sports drink every day; the heavy, salty sweater would need to ingest 14 L or more. Both fluid and salt are, therefore, vital for maintain-

ing or restoring sodium and body water balance, not simply for modulating core temperature.
2. Based on scientific literature of average sodium concentrations and over 2L of sweat loss per hour in our football players, we believe the need for sodium supplementation is an understatement.
3. We interpret the McLellan et al[20] article as supporting the premise that even under uncompensable heat stress conditions, hydration level is not related to core temperature. Data from Armstrong et al[21] also suggest this is the case in compensable situations as long as subjects are not dehydrated to 5%. At the modest levels of dehydration experienced by our football players, body weight loss was not associated with core temperature.
4. Dr. Armstrong is correct that average daily maximal air temperatures in our study were mild to moderate.
5. Data from this study indicated that the only trial resulting in an elevated core temperature (compared with the other 3 trials) was when subjects began 90 minutes of continuous exercise hypohydrated to 3.6% and were fluid restricted. This is the −5.1% dehydration trial Dr Armstrong references. We suggest that neither hypohydration beyond 3.5% nor fluid restriction (either alone or in combination) should be tolerated in any athlete.[22–24] We also believe that the Armstrong et al findings imply that fluid availability during exercise is what is important, not necessarily the level of dehydration or hypohydration.

Athletic trainers are the health care professionals most responsible for preventing and treating heat injury in football players. Therefore, athletic trainers must understand that simply keeping players hydrated will not prevent hyperthermia,[5] yet at the same time, fluids should always be available for ad libitum consumption.

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