Original Article

Thermoregulation during exercise in the heat of American football players

GABRIELA TOMEDI LEITES[1] , GIOVANI DOS SANTOS CUNHA[2], MAURÍCIO PECHINA[2], JULIANA LOPES TEODORO[2], RAISA VIEIRA BRANCO OZORIO[2], RONEI SILVEIRA PINTO[2], FLAVIA MEYER[2]

[1]*Federal University of Health Science of Porto Alegre (UFCSPA). Porto Alegre, Brazil.*
[2]*Federal University of Rio Grande do Sul (UFRGS). Porto Alegre, Brazil.*

ABSTRACT

American football players might face challenges during a prolonged exercise in the heat which can lead to impairments in performance and induce heat-related illness. The purpose of this study was to verify the body temperature and sweating responses in American football players while exercising at a moderate-high intensity effort as prescribed by metabolic heat production. Seven heat-acclimatized players participated in the study. Players exercised 4×20-min bouts at moderate-high intensity as 8.0W.kg^{-1} of metabolic heat production, with 10min rest between them, totalizing 110min of heat exposure (39oC and 50% relative humidity). Rectal (Tre) and skin (Tsk) temperatures, heart rate (HR), metabolic heat production were measured continuously. Dehydration was calculated from ∆body mass pre-and post-exercise. Initial Tre and HR were 37.0 ± 0.3 °C and 80 ± 9 beats.min^{-1}, respectively. Players began the trial euhydrated according to the initial urine specific gravity (1.014 ± 0.008) and colour (2.4 ± 1.4). During experimental trial, core temperature increased overtime ($p < .001$) resulting in a ΔTre of 2.2 ± 0.6 °C. Average HR during exercise was 166 ± 11 beats.min^{-1} and weighted Tsk was 36.7 ± 0.5 °C. Sweat volume was 2.6 ± 0.3 L, resulting a % hypohydration of -3.1 ± 0.4 % reflecting a moderate level of hypohydration. Final urine specific gravity and colour were 1.024 ± 0.009 and 5.0 ± 1.0, respectively. Experimental trials were interrupted at the end of the third and the fourth exercise bouts in two players due to the respective adverse conditions: leg muscle cramps, and excessive Tre increase (reached 39.9 °C). Thermoregulation and hydration must be a major concern, mainly related to greater exercise intensities and long-time practice, inducing high hypohydration levels and risk of hyperthermia.
Keywords: Sport medicine, Health, Heat, Body temperature, Sweating, Metabolic heat production, Exercise.

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Corresponding author. *Federal University of Health Science of Porto Alegre (UFCSPA), Sarmento Leite Street, 245 – Centro Histórico, Porto Alegre, RS – Zip-Code 90050-170, Brazil.* https://orcid.org/0000-0002-2563-7193
E-mail: gabriela.tomedi@ufcspa.edu.br
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INTRODUCTION

American football is characterized by an intermittent high intensity team sport that is often practiced and competed under heat stress. Athletes may face hot and humid air conditions during preparation for competitions, especially in the preseason period, which often happens during the summer (CBFA, 2019). During the preseason, it is usual that athletes practice twice a day, which increases their risk to exertional heat illness (EHI) (Davies et al., 2016; Kucera et al., 2014). From 1960 to 2009, 123 cases of heat-related deaths occurred among American football athletes in the United States (Mueller & Colgate, 2010). The occurrence of EHI is higher in football players compared to other populations and they are 12 times more likely to develop EHI compared to other athletes (Keer, Marshall & Comstock, 2013). Some sport-specific aggravating factors for EHI are 1) the higher metabolic heat production due to large body size and mass of the players, 2) the uniform and protective gears, 3) the intermittent high intensity efforts under heat stress (Kulka & Kulka, 2002). Therefore, is it important to acknowledge perceptual and physiological strain that American football players might face during a prolonged exercise in the heat which can lead to impairments in their exercise performance and induce heat-related illness.

Exercise intensity *is* an important factor in understanding increases body core temperature and heat illness. During exercise if metabolic heat production (Hp) and heat gain (inputs) are greater than heat losses (outputs), the body temperature will rise (Nishi, 1981). During exercise, Hp is the most important input to the heat gain and it is related to the large total body mass often observed in American football athletes. In addition, when environment temperature is higher than skin temperature the only possible mechanism to lose heat is evaporation, however protective gear and uniforms can lead to a microenvironment that make sweat difficult to evaporate. Another important point to be considered about exercise intensity is that the most usual exercise prescription method that is based in percentual of peak oxygen uptake (%$\dot{V}O_{2peak}$), did not independently contribute to the variation in end-exercise evaporative heat loss, and only described a very small (<2%) amount of variability in whole-body sweat rate (Gagnon, Jay & Kenny, 2013). For these reasons, it is important to understand the body core temperature and adaptation responses such as sweating and perceived responses during a hot exposure, regularly observed in practices and completions, in American football athletes exercise intensity must be prescribed to elicit a fixed $\dot{H}$p per their unit body mass which was not considered in previous studies for this population.

Heat acclimatization develops through repeated natural heat exposures and refers to the gradual advancement of physiological adaptations to exercise in conditions of high environmental heat stress. American football players often practice outdoors in hot environment conditions and consequently players are naturally acclimatized to the heat. Heat acclimatization improves thermal comfort and exercise performance in warm-hot conditions (Machado-Moreira, 2005); therefore it is considered essential for athletes preparing for competitions in warm/hot environments. To understand the impact heat acclimatization and body adaptation it is important to analyse body heat balances in these athletes during exercise in the heat.

As practice and competitions at a professional level of American football increase worldwide, advices to prevent risk of heat illness and negative responses in their performance must be promoted both for players, coaches and health professionals. The majority of field and lab-based studies or case reports verified outcomes mostly in not heat-acclimatized athletes from the northeastern of the United States (Davies et al., 2016). Less information is derived from players who practice and compete American Football in other countries. Thus, knowing the thermoregulatory responses of American football players is important since it represents an important factor regarding overall performance and health status of those athletes. The purpose of this study was to verify the body temperatures, sweating and perceived responses in naturally acclimatized Brazilian American football players while exercising at a moderate-high intensity effort as prescribed by their metabolic heat production ($\dot{H}_p$) per unit body mass (BM).

METHODOLOGY

Participants
Seven 21- to 29-year-old heat-acclimatized American football male players participated in the study. All players were healthy and reported no medical conditions, no musculoskeletal injury, and no cardiovascular conditions that could affect thermoregulatory responses. They were not taking any medications at the time of participation. Participants were informed of the experimental protocol and the potential risks and provided written informed consent prior to participation. The study was approved by the University Research Ethics Board (Protocol: 63683717.2.0000.5347) and was conducted in compliance with the standards set by the Declaration of Helsinki.

Preliminary session
Each participant attended a preliminary session and responded a health status questionnaire. Standing height and body mass (BM) were assessed. Body surface area (BSA) was calculated from the measurements of body height and BM (DuBois & DuBois, 1989). Body composition was measured using Dual-energy X-ray absorptiometry (DXA).

Aerobic fitness
To determine $\dot{V}O_{2peak}$, an incremental cardiopulmonary exercise testing (CPET) was performed using the McMaster All-Out Progressive Continuous Cycling Test (Bar-Or & Rowland, 2004). Measurements of O_2 and CO_2 were made continuously using a calibrated metabolic cart (Quark CPET, COSMED - Italy). To verify an exhaustive effort, each participant had to satisfy at least two of the following criteria upon termination of the cycling test due to volitional exhaustion: 1) inability to maintain a cycling cadence above 60 rpm in spite of strong verbal encouragement; 2) heart rate (HR) > 195 beats·min^{-1}; 3) rate of perceived exertion (RPE) > 19; and 4) respiratory exchange rate (RER) > 1.1 (Cunha et al., 2019; Leites et al., 2016). The participants were verbally encouraged during the test to achieve their maximal performance. According to these criteria, all participants showed a valid VO_{2peak}.

At the end of the session, participants were provided with verbal and written instructions to refrain from practicing any strenuous physical activity, and from ingesting caffeine and alcohol 24 hrs prior to the experimental trial. They were also told to avoid changing eating habits over the course of the entire experimental protocol. To guarantee that participants arrived euhydrated, they were instructed to ingest an individually calculated amount of water corresponding to 12 mL·kg^{-1} per day, on top of their usual intake on the day prior to each experimental trial. This extra volume was divided between morning and night. On the morning of the experimental trials, participants ingested an additional 6 mL·kg^{-1} of water (Leites et al., 2016).

Experimental session
Hydration status was verified from an initial urine specific gravity (USG) (Atago refractometer, 2722-E04; Tokyo, Japan) and colour. A USG cutoff of 1.020 was applied as the need for additional hydration prior to exercise. This was followed by a measurement of nude weight. Participants exercised wearing only shorts and athletic shoes. Rectal temperature (T_{re}) was measured using a flexible thermometer (YSI 400 series thermistor, USA). Skin temperature (T_{sk}) was measured using skin thermistors (YSI 400 series temperature sensors, USA), placed on the upper back, arm, and thigh. T_{re} and T_{sk} were measured through all the exercise

protocol. Participants received standardized instructions on how to answer the following four perceptual evaluations: RPE (Borg scale); thermal (9-point scale from "*very cold*" to "*very hot*") and comfort (6-point scale from "*very comfortable*" to "*very uncomfortable*") sensations; and intensity of thirst (9-point scale from "*not thirsty*" to "*very thirsty*").

Exercise in the heat protocol

Upon entering the climate chamber participants rested in a seated position for 5 min. The chamber was set at 39˚C and 50% relative humidity and these conditions were verified continuously. The exercise protocol consisted of 80 min of cycling divided into 4 × 20-min bouts, with a 10-min rest between bouts. Cycling was performed at a fixed $\dot{H}_p$ per unit BM (~8.0 W·kg^{-1}). $\dot{V}O_2$ and RER was measured for 3 min in the middle (7-10 min) and at the end (17-20 min) of each bout to guarantee exercise intensity according to their $\dot{H}_p$. T_{re}, T_{skin}, HR, and RPE were recorded every 5 min. Thermal sensation, thermal comfort, and thirst perception were recorded at the beginning, middle, and in the last minute of each bout.

After each bout, participants were asked to void their bladder and their BM was measured wearing their shorts, shoes, and probes. Participants did not drink during the session and change in BM was used as the indicator of body water balance. Upon completion of the entire exercise protocol and recovery period, participants were instructed to void their bladder and dry their skin with a towel before a nude BM was obtained. In addition, a hand grip test was conducted before and after exercise in the heat condition to understand the impact of hypohydration associate to hyperthermia in strength performance.

Calculations

The rate of metabolic energy expenditure (M; in W·m^{-2}) was estimated using the average VO_2 (L·min^{-1}) and RER measured during the experimental trials, and calculated as Nishi (1981):

$$M = \dot{V}O_2 \cdot \frac{\left[\left(\frac{RER - 0.7}{0.3}\right) \cdot e_c\right] + \left[\left(\frac{1.0 - RER}{0.3}\right) \cdot e_f\right]}{60 \cdot BSA} \cdot 1000$$

where e_c is the caloric equivalent per litre of oxygen for the oxidation of carbohydrates (21.13 kJ), and e_f is that of fat (19.62 kJ). $\dot{H}_p$ (in W·m^{-2}) was calculated as the difference between *M* and the external work rate (W): $\dot{H}_p = M - W$.

Statistical analyses

To verify data normality and homogeneity of variance, the Shapiro-Wilk test and the Levene test were used, respectively. One-way ANOVAs were used to verify changes over time. All data are expressed as mean and standard deviation (SD). Statistical significance was set at ≤ .05, and all analyses were performed using the statistical SPSS software version 22.0 (SPSS Inc, Chicago, Illinois).

RESULTS

Participants physical and physiological characteristics are presented in Table 1. As expected, large body size was found in the American football players, such as their total body mass, body height, total muscle mass, and body surface area.

Table 1. Physical and physiological characteristics of American football players.

Characteristics	**n = 7**
Age (years)	24.1 ± 2.6
Body mass (kg)	87.8 ± 9.9
Body height (cm)	182 ± 4.8
Body fat (%)	16.7 ± 3.8
Total muscle mass (kg)	70.7 ± 9.6
Body surface area ($m^2.kg^{-1}$)	0.68 ± 0.036
$\dot{V}O_{2peak}$ ($L.min^{-1}$)	4.49 ± 0.65
$\dot{V}O_{2peak}$ ($mL.kg^{-1}.min^{-1}$)	51.3 ± 5.0
HR_{rest} (bpm)	77 ± 9
HR_{max} (bpm)	188 ± 9
$Workload_{max}$ (W)	355 ± 25

Table 2 depicts the exercise intensity performed during exercise in the heat condition. Exercise intensity was guarantee during all experimental trial as prescribed to elicit a fixed $\dot{H}_p$ per unit BM that allowed to understand the physiological and perceived responses during exercise in the heat.

Table 2. Exercise intensity during exercise in the heat.

Exercise intensity	**n = 7**
$\dot{H}p$ (W)	684.76 ± 66.4
$\dot{H}p$ ($W\cdot kg^{-1}$)	8.0 ± 0.86
Workload (W)	154 ± 10

Figure 1 shows the responses of T_{re}, T_{skin} and HR responses during exercise in the heat Initial T_{re} and HR were 37.0 ± 0.3 °C and 80 ± 9 beats.min^{-1}. T_{re} and T_{skin} increased overtime (p = .0124 and p < .001, respectively). As expected, HR responses did not differ during the four exercise bouts (p = .07). By the end of exercise, T_{re} increased by 2.06 ± 0.47 °C. However, earlier interruption of exercise occurred in two participants: at the end of the 3rd bout due leg muscle cramps, and at the 4th due to excessive T_{re} increase - final T_{re} reached 39.9 °C. Average weighted T_{skin} was 36.7 ± 0.5 °C.

Players began exercising euhydrated, as indicated by urine specific gravity (1.015 ± 0.008) and urine colour (3.0 ± 1.2). Both final urine specific gravity and colour increased for 1.024 ± 0.009 (p = .02) and 5 ± 1.0 (p = .001), respectively. By the end of exercise, participants lost 2.6 ± 0.3 kg (p < .001) representing a % dehydration of 3.1 ± 0.4 reflecting a moderate level of hypohydration.

Figure 2 depicts the perceived responses of thermal sensation and comfort, rate of perceived exertion, and thirst during exercise of American football players during exercise in the heat condition. Participants responded overtime they felt warmer thermal sensation, greater rate of perceived exertion, and felt thirster, while exercise in the heat affect thermal comfort negatively (p < .001). Finally, prior and post-exercise handgrip decreased from 52.9 ± 7.4 to 50.60 ± 6.3 Kg for the dominant hand (p = .04).

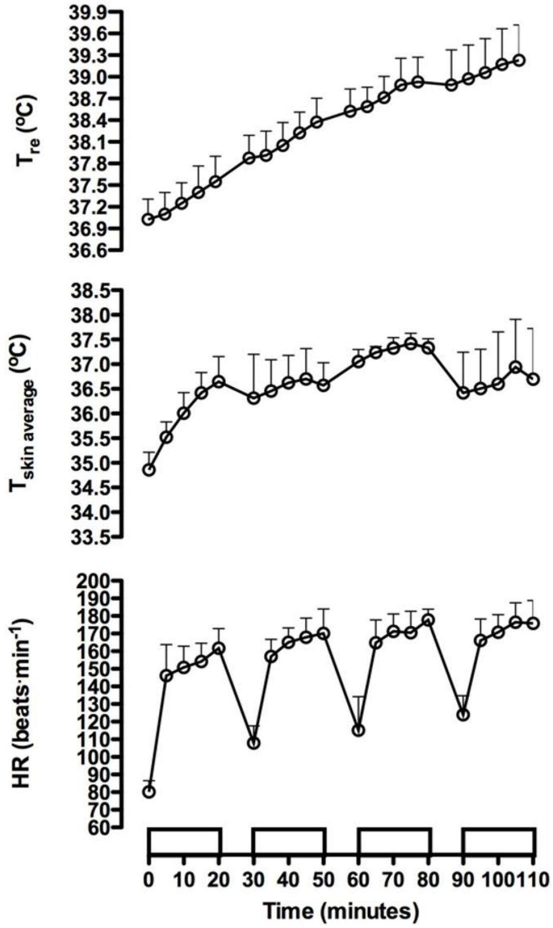

Figure 1. Rectal and skin temperature and heart rate responses during exercise in the heat.

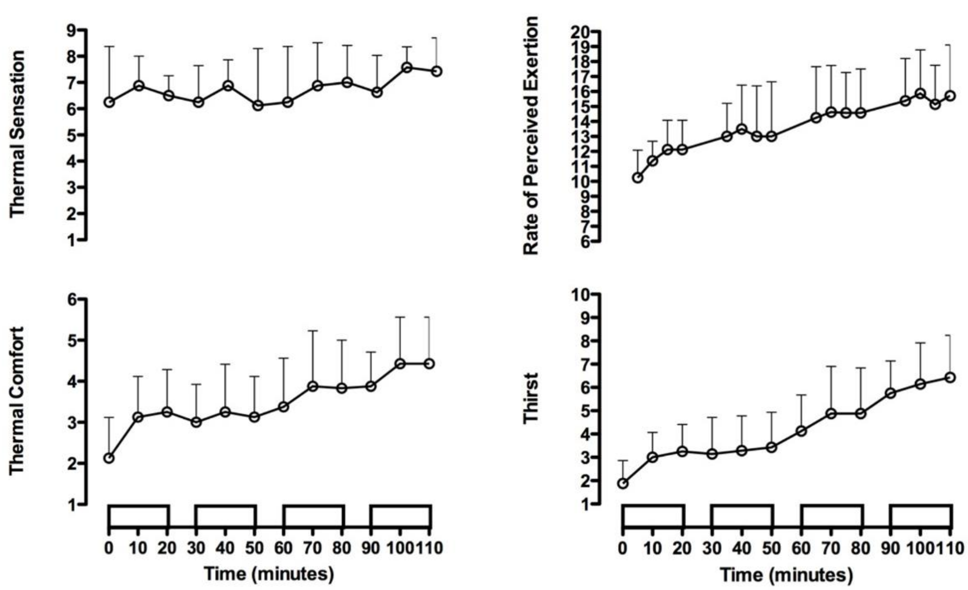

Figure 2. Thermal sensation and comfort, rate of perceived exertion, and thirst in American football players during exercise in the heat.

DISCUSSION

The present data showed that American football players that practice the modality in a tropical country, such as Brazil, had a considerable increase in body core temperature at a moderate-high intensity exercise in the heat. Although they were naturally acclimatized to the heat two participants showed symptoms and signs of heat illness. Other two relevant points must be considered in the present study: (1) players were not allowed to drink any fluids during exercise trials, as often happen in the field; and (2) players were not wearing uniforms and helmets, factor that may have attenuated these results.

The frequency of EHI in high school football players is 4.42 / 100,000 athlete exposures (Davies et al., 2016). Interestingly, research showed an increased relative risk of EHI during the first 14 days of practice, especially during the first 7 days, and when WBGT was greater than 27.8 °C the rate of EHI increased. Therefore, the pre player faces extra thermoregulatory challenges to optimize performance and prevent health problems. The National Athletic Trainers Association (Casa et al., 2000) list several non-environmental risk factors for EHI, including body size, such as body mass index. American football players morphological profiles include large body mass, height, total muscle mass and BSA. Active muscle mass is the main input to $\dot{H}_p$, that during exercise can result in greater increases in body core temperature. In addition, the lower surface area to mass ratio of larger players is a main contributing factor to higher core temperature (Epstein, Shapiro & Brill, 1983, Wailgum, 1984) and might be a concern when environment temperature is similar or higher than skin temperature, not allowing dry heat losses. The result is a greater sweat loss, with sweating, heat is transferred from the body to water (sweat) on the surface of the skin. When this water gains sufficient heat, it is converted to water vapor, thereby removing heat from the body (Wenger, 1972). This mechanism is the most important during exercise in heat conditions to control increases in body core temperature leading to hyperthermia, but also can induce a greater hypohydration during exercise in the heat.

Hypohydration greater than 3% was observed for football players in the present study. Exercise in the heat leas leads to an increase in the sweat volume e rate that usually varies between 1. 0 $L.h^{-1}$ up to 2.9 $L. h^{-1}$ and in larger players such as linemen, it can reach a sweat rate of 3.0 $L.h^{-1}$ or higher (Godek & Godek, 2005; Godek et al., 2010). An important point to emphasize is that es well reported that sweat loss over 2% of total body mass impairs the athlete's performance, mainly aerobic. In the present study, we showed that handgrip was lower after exercise in the heat with a moderate hypohydration level. As a result, fluid intake is individually recommended to avoid the adverse effects of hypohydration and early fatigue during prolonged exercise (Machado-Moreira, 2005). Few studies have assessed the impact of hypohydration on strength performance in adult population. The available studies show either detrimental (Ftaiti, Grelot & Coudreuse, 2001, Hayes & Morse, 2010) or no effect (Bigard et al., 2001, Saltin, 1964). A general accepted explanation to the muscle strength performance decrease is that hypohydration affect some neuromuscular components that impairs the ability of the central nervous system to stimulate the musculature or muscle membrane excitability (Judelson et al., 2007) that might be important to performance and algo for tactical decision during games and competitions.

The excessive football gear (helmets, shoulder pads, gloves, and padded pants) worn during practices and matches covers up to 70% of the athletes' body surface area (BSA) (Armstrong et al., 2010) threaten heat dissipation of the accumulated heat production. Because of a non-evaporative environment and higher core temperature increase, body respond with higher sweat rates than usual as which poses an extra risk of dehydration (Godek & Godek, 2005; Godek et al., 2010 & Armstrong et al., 2010). In the present study, football players display an accentuated increase of core temperature during exercise even not wearing uniform and protective gears. A report showed that under an exercise protocol with three different clothing (i.e. full uniform, partial uniform, and control [regular sports clothing]) and environmental humidity, the athletes that exercised in full and partial uniforms showed a higher increase of rectal temperature (Full = 2.37 ± 0.45 ºC; Partial = 2.36 ± 0.24 ºC) when compared to regular clothing (i.e. socks, sneakers, and shorts) (Control = 1.81 ± 0.40 ºC) (Armstrong et al., 2010). Hence, it is important to emphasize that exertional heat illness it might a great concern for football players in a real-life situation as they are more likely to develop EHI when wearing full uniform.

CONCLUSION

Considering the disproportionate EHI and deaths observed in American football compared with other sports, it is important to emphasize that only few studies were conducted to describe thermoregulatory, sweating, and perceived responses in American football players. This is a gap in the literature that must be acknowledged, and it is suggested that future studies include in the experimental trial the use of uniform and protective gears and investigate their responses conducting field-based studies. The present study showed that even for heat-acclimatized Brazilian football players thermoregulation and hydration must be a major concern, mainly related to greater exercise intensities and long-time practice, inducing high hypohydration levels and risk of hyperthermia. As practice and competitions at a professional level of American football increase worldwide, advice to prevent risk of heat illness and to maintaining performance during exercise in the heat must be promoted for players, coaches and health professionals involved in the sport.

AUTHOR CONTRIBUTIONS

Each author made significant individual contributions to this manuscript. GTL, GSC and FM conceived and designed the research, GTL, GSC, JT, MP, ROB contributed to acquisition of data, all authors contributions to analysis and interpretation of data, drafting the article or revising it critically for important intellectual content and final approval of the version to be published. All authors read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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