Sweating and core temperature in athletes training in continuous and intermittent sports in tropical climate

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Summary

Higher sweat rate values have been reported during intermittent compared to continuous type exercise in hot conditions in the laboratory. Studies in the training field are scarce.
Objective: Document sweat rate, rehydration and core temperature (T_c) during training in long duration-continuous (CON) and intermittent (INT) type sports, and determine the presence of a mutation in the CFTR gene in athletes with high sodium concentration ([Na^+]) in sweat.
Methods: Athletes (CON =50 and INT=123) were tested during training in tropical climate. Sweat rate, sweat [Na^+], T_c, dehydration level, and presence of Δ F508 gene mutation in the CFTR gene in athletes with high sweat [Na^+] were evaluated.
Results: Sweat rate was higher in CON (1.5 ± 0.4 L/h) compared to INT (1.2 ± 0.5 L/h) and CON athletes finished training with higher dehydration (2.1 ± 0.8 *vs* 1.2 ± 0.7%) $P < 0.05$. Sweat [Na^+] was higher in INT (62.0 ± 21.1 mmol/L) compared to CON (53.9 ± 18.1 mmol/L), $P < 0.05$. A tennis player with high [Na^+] was heterozygous for the ΔF508 mutation. Average and highest Tc was similar for CON (38.4 ± 0.3 and 38.8 ± 0.4 ºC) and INT (38.3 ± 0.3 and 38.7 ± 0.4 ºC), $P > 0.05$.
Conclusion: During training in a tropical climate, sweat loss and dehydration level are lower, and fluid intake is higher in intermittent compared to continuous type sports. Core temperature may rise to a similar level in intermittent type sports due to the repeated high intensity bouts and/or the effects of clothing worn while training in hot venues. Healthy athletes with high [Na^+] in sweat who are heterozygous carriers of CFTR mutations may be at increased risk for hyponatremic dehydration and whole-body muscle cramps.

Key words:
Sweating. Tropical climate. Dehydration. Athletes. Body temperature. Sodium.

Sudoración y temperatura interna en atletas durante entrenamiento para deportes continuos e intermitentes en clima tropical

Resumen

Se reportan tasas de sudoración más altas durante ejercicio intermitente comparado con continuo en condiciones de calor en el laboratorio. Estudios en el campo de entrenamiento son escasos.
Objetivo: Documentar la tasa de sudoración, rehidratación y temperatura central (T_c) durante entrenamiento para deportes de tipo continuo (CON) e intermitente (INT), y determinar presencia de mutación genética en el gen CFTR en atletas con alta concentración de sodio ([Na^+]) en sudor.
Metodología: Se evaluó la tasa de sudoración, la [Na^+] en sudor, la T_c, y el nivel de deshidratación en atletas (CON =50; INT =123) durante entrenamiento en clima tropical, y la presencia de la mutación genética ΔF508 en el gen CFTR en aquellos con alta [Na^+] en sudor.
Resultados: La tasa de sudoración fue mayor en CON (1,5 ± 0,4 L/h) comparado con INT (1,2 ± 0,5 L/h) y los atletas en CON terminaron el entrenamiento con mayor deshidratación (2,1 ± 0,8 *vs* 1,2 ± 0,7%) P < 0,05. La [Na^+] en sudor fue más alta en INT (62,0 ± 21,1 mmol/L) comparado con CON (53,9 ± 18,1 mmol/L), P < 0,05. Un tenista con alta [Na^+] era heterocigoto para la mutación ΔF508. La T_c promedio y más alta fueron similares para CON (38,4 ± 0,3 y 38,8 ± 0,4 ºC) e INT (38,3 ± 0,3 y 38,7 ± 0,4 ºC), P > 0,05.
Conclusión: Durante el entrenamiento en clima tropical, la pérdida de sudor y el nivel de deshidratación son más bajos, y la ingesta de líquido es más alta en deportes intermitentes que en deportes continuos. La temperatura interna puede aumentar a nivel similar en deportes intermitentes debido a periodos repetidos de alta intensidad y/o la vestimenta usada durante el entrenamiento. Atletas saludables con alta [Na^+] en sudor que son heterocigóticos para mutaciones de CFTR pueden estar en mayor riesgo de deshidratación hiponatrémica y calambres musculares.

Palabras clave:
Sudoración. Clima tropical. Deshidratación. Atletas. Temperatura corporal. Sodio.

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Introduction

Exercise in tropical environments may cause considerable elevations in core temperature that contribute to high sweat production and sodium loss, impairment in athletic performance[1] and heat related illnesses[2]. The risk is higher if athletes begin training in a state of body fluid deficit and do not drink enough during exercise to replenish losses[2]. Sweat losses of 1 to 2 L/h are common during training and competition in hot and humid tropical environments and may reach or exceed 2.5 L/h in heavy sweaters. Heat acclimatized elite athletes with high sweat production that train for long duration-continuous type (CON) sports, are most prone to dehydration. Athletes in intermittent type (INT) sports, such as team, ball and combat sports, are also at risk since multiple high intensity time periods elevate metabolic heat production and core temperature and induce heavy sweating[3]. This may be particularly true in athletes who wear heat-retaining clothing and/or protective equipment that decreases the effectiveness of heat loss through the evaporation of sweat.

Athletes with high sweat rates are more susceptible to large electrolyte losses in sweat, which have been implicated in the development of skeletal muscle cramps[4]. Athletes born and raised in the tropics may be protected from large sodium losses because regular exposure to high environmental temperatures induces physiological adaptations in the sweat glands such as an increased sodium reabsorption which result in a decreased sweat sodium concentration ($[Na^+]$) for a given sweat rate[5,6]. However, a proportion of athletes exhibit "salty sweat". Those whose sweat $[Na^+]$ is typically higher than 55 mmol/L[4,7] may have a reduced Cl^- and Na^+ reabsorption across the sweat duct membrane.

Studies have identified persons without cystic fibrosis (CF) have sweat Na^+ levels like those of CF patients[8]. It is possible that some healthy "salty sweaters," are heterozygous for a CF mutation and have a malfunction of plasma membrane CF transmembrane conductance regulator (CFTR) in the sweat glands that results in sweat with high sodium chloride concentration like CF patients[9]. Approximately 1 in 46 Hispanics carry one mutation of the CFTR gene that causes hypo-absorption of Na^+ in sweat gland ducts and high sweat $[Na^+]$[10]. In the United States, the most common mutation in the CFTR gene associated to the development of CF is the deletion of phenylalanine 508 (ΔF508)[11] and its prevalence in athletes with salty sweat is currently unknown.

Studies in the laboratory have shown that prolonged variable intensity exercise with periods of high intensity exercise (≥15 minutes) may elicit similar or higher heat storage, core temperature (T_c), and sweat production, as prolonged constant intensity exercise with no rest periods[3,12-14]. Studies in the playing field show a predisposition to heat strain due to hyperthermia and dehydration in American Football players[15] but very little is known about other intermittent type or endurance sports in tropical environments. Particularly lacking are data in female athletes.

The aims of the present observational field study were to: 1) document the sweating response and rehydration during training sessions in tropical climate in CON and INT sports in both genders; 2) investigate the presence of the ΔF508 mutation in the CFTR gene in athletes with high sweat $[Na^+]$; and 3) compare the T_c response in a subset of male and female athletes in CON and INT sports. We hypothesized that athletes in INT sports would show a lower sweat rate, a lower average T_c and a higher sweat $[Na^+]$.

Material and method

Subjects

One hundred and seventy three competitive athletes participating in long duration-continuous (endurance=50; 30 males [M] and 20 females [F]) or intermittent (ball/team= 94, 45 M and 49 F; combat =29, 15 M and 14 F) sports (Table 1) were tested during a typical training session for their sport. The subjects were recruited from teams in a Central American and Caribbean competition in the summer in Puerto Rico and from National teams, top ranked university teams, and recreational athletes ranked in the top of their age categories in Puerto Rico. All were natives of tropical countries with a predominantly warm and humid climate all year long.

All subjects were informed of the purpose and procedures of the study and written informed consent was obtained. There were 52 athletes between the ages of 17 and 21 who gave their written assent, and written consent was also obtained from their parents. The study was approved by the Institutional Review Board of the University of Puerto Rico, Medical Sciences Campus.

Study design and procedures

Athletes were studied under environmental conditions typical of training sessions for their sport, and wearing uniforms and equipment used in competition. This field study design allowed us to collect information in conditions that are difficult to simulate in the laboratory. Athletes completed a questionnaire about heat exposure during exercise and past history of muscle cramps. General health status was also documented to assure they did not have a medical condition that would affect thermoregulatory or body fluid balance variables.

All subjects were tested during the summer months in Puerto Rico. The average WBGT (10 am to 4 pm) was 29.9 ± 1.6 °C[16]. The runners, cyclists, triathletes, soccer, tennis, and beach volleyball players trained outdoors exposed to direct sunlight, while the judo, basketball, team

Table 1. Athletes in long duration-continuous (CON) and intermittent (INT) sports.

CON (N=50) Endurance Sports	F	M	INT (N=123) Team/Ball Sports	F	M
Running	8	13	Soccer	10	18
Cycling	7	9	Tennis	3	10
Triathlon	5	8	Basketball	7	0
			Team Handball	13	0
			Beach Volleyball	16	17
			Combat Sports	**F**	**M**
			Judo	7	3
			Fencing	7	12
Total	20	30		63	60

handball, and fencing athletes trained indoors in non-air conditioned gyms. The triathletes were tested while running. All athletes wore official competition uniforms required for their sport. The judokas and fencers wore t -shirts and shorts underneath the uniforms.

- *Pre-training session*. Subjects urinated into a pre-weighed container. Nude body weight was determined using an electronic scale accurate to 50 g (precision health scale uc321). After cleaning the area with distilled water, absorbent patches (Tegaderm +pad, 3m Health Care, Borken, Germany) were applied to the subject's right posterior forearm and right anterior thigh for regional sweat collection in all but the beach volleyball players, in which it was applied to the right anterior thigh only. Athletes were then fitted with an accelerometer (Actigraph GTX3; Actigraph, Pensacola, FL, USA) that was programmed to record activity counts in one-minute epochs. The cyclists wore the accelerometer on the right thigh.
- *Training session*. The duration of training was similar to a typical session for the sport. Training sessions were organized and directed by the athletes' coaches. Environmental conditions were measured before, every 30 min, and at the end of training, using a heat stress monitor (Questemp 32, Quest Technologies, Wisconsin), which was placed in the training area. Athletes drank voluntarily from labeled bottles with water and/or sports drinks. Any subject who needed to urinate during the training session did so into a pre-weighed container and the volume was measured. The absorbent patches were removed when saturated and placed in sealed plastic tubes.
- *Post-training session*. Athletes removed the accelerometer and clothes, towel dried and pre-training measures were repeated (urine sample, nude body weight).
- *Measures and calculations*
- *Hydration status*. Urine specific gravity (USG) was used as an index of pre-exercise hydration status[17] and determined using a hand-held refractometer (URC-NE, Atago Clinical, Japan).
- *Environmental conditions*. Dry bulb (DB), wet bulb (WB), globe temperature (GT), and relative humidity (RH) were measured on site. The wet bulb globe temperature (WBGT) heat stress index was calculated using the following equations: CON sports: (WB x 0.7) + (GT x 0.2) + (DB x 0.1); INT sports: (WB x 0.7) + (GT x 0.3)[18].
- *Regional sweat [Na^+]*. Sweat was extracted from each patch using a 5-ml syringe and two 100 µl samples were analyzed using an ion selective electrolyte analyzer (Easylyte Plus, Medica, Bedford, MA) to determine the [Na+].
- *Body fluid balance*. The bottles with the fluid that was used for hydration during the session were weighed before and after the session with a scale accurate to 1 g (CS2000 Compact Scale). Sweat loss was calculated as: change in body mass, corrected for fluid intake and urine loss. Sweat rate was calculated as sweat loss divided by exercise duration. The level of dehydration was determined using the following formula: (body mass pre-training – body mass post-training) / body mass pre-training.
- *Core temperature*. Core temperature was measured in 62 athletes that lived and trained in Puerto Rico (females, CON= 10 and INT=34; males, CON=13 and INT=5) using ingestible sensors (Cortemp™, HQ Inc.) before, every 10 minutes, and at the end of training. We measured T_c only in athletes who could satisfy requirements for valid measurements (sensor calibration, timing of ingestion and electromagnetic interference). Eight hours prior to the beginning of the exercise session, each subject swallowed a disposable pill that contained a temperature sensor for T_c determination. Pre-exercise T_c was the value taken after sitting quietly for five minutes in the exercise area before the start of training. The T_c of the exercise session was the average of measures taken every 10 minutes. The change in T_c was calculated as the highest minus the pre-exercise T_c. A final measure was taken immediately after the coach indicated the session had finished.

Genetic analysis

Athletes with a sweat [Na^+] ≥ 70 mmol/l were identified for subsequent genetic analysis[19]. Athletes were asked to provide two ml of saliva which were collected into a DNA genotek's oragene® DNA self-collection vial. The container had approximately 2 ml of cell lysis solution or DNA-preserving fluid, that was mixed with the saliva. Genomic DNA was assayed for the Δ F508 mutation in the CFTR gene, using restriction fragment length polymorphism (Ambry Genetics, Aliso Viejo, CA). As per standard procudedures, DNA was extracted from saliva and purified. The purified DNA was digested using restriction endonucleases. The restriction fragments produced during DNA fragmentation were analyzed using gel electrophoresis.

Statistical Analysis

Means and standard deviations were calculated for each variable. Student's *t*-tests were used to compare CON and INT in pre-exercise urine specific gravity, sweat rate, percent dehydration, percent rehydration, minutes of exposure to exercise in the heat in the past month, activity counts/min, sweat [Na^+], pre, average, change and highest T_c, and the WBGT index. An alpha level of $P < 0.05$ was considered significant.

Results

Subjects, environmental conditions and training sessions

Descriptive characteristics of the subjects and training session characteristics are presented in Table 2. The WBGT index for CON and INT was > 28 ºC, which is typical of tropical countries during the summer and indicates that all subjects were exposed to a high level of heat stress without exhibiting symptoms of heat illness. Activity counts per minute[20] revealed that in INT sports the training sessions were of predominantly light- to- moderate intensity whereas in CON sports they were shorter and of vigorous intensity. The average time spent training exposed to solar radiation in the month preceding the study was 17% higher in CON.

Hydration status and fluid balance

Athletes in INT arrived to the training session in a state of hypohydration as evidenced by a mean pre-exercise USG of 1.021 ± 0.006. Athletes in CON had a higher sweat rate (P< 0.05) and finished training with higher ($P < 0.05$) level of dehydration (2.1 ± 0.8 *vs* 1.2 ±0.7%) due

Table 2. Descriptive characteristics of the subjects, environmental conditions and training sessions in long duration-continuous (CON) and intermittent (INT) type sports.

	CON (N=50)			INT (N=123)		
	Females N=20	Males N=30	Total N=50	Females N=63	Males N=60	Total N=123
Age (y)	26.0 ± 6.5	26.2 ± 5.4	26.1 ± 5.8	23.4 ± 5.2	23.9 ± 4.4*	23.6 ± 4.8
Height (cm)	159.7 ± 5.5	173.9 ± 7.1	168.2 ± 9.6	167.2 ± 9.4*	179.0 ± 8.9*	173.1 ± 10.9*
Weight (kg)	53.8 ± 5.9	68.5 ± 10.7	62.6 ± 11.6	65.8 ± 10.2*	76.5 ±11.2*	71.0 ± 11.9*
Training exposed to sun (min/day in past month)	122.0 ± 63.2	164.3 ± 83.1	147.4 ± 78.0	96.7 ± 84.4	147.5 ± 90.0	121.9 ± 90.5
Duration of Training Session (min)	69.6 ± 20.6	78.7 ± 24.0	75.0 ± 22.9	91.6 ± 19.1*	86.8 ± 20.1	89.2 ± 19.7*
Activity counts (counts/min)	7,695.0 ± 1,666.7	7,189.7 ± 2,367.7	7,414.3 ± 2,078.9	2,421.9 ± 539.6*	2,909.0 ± 882.4*	2,654.7 ± 760.9*
Minutes at light intensity (< 1,952 counts/min)	1.7 ± 1.9	8.6 ± 18.9	5.6 ± 14.4	46.4 ± 18.2*	32.6 ± 17.2*	39.8 ± 19.0*
Minutes at moderate intensity (1,952 – 5,724 counts/min)	10.4 ± 21.7	16.6 ± 30.1	13.8 ± 26.6	37.8 ± 11.6*	45.5 ± 17.1*	41.5 ± 14.9*
Minutes at vigorous intensity (> 5,724 counts/min)	57.1 ± 28.2	54.9 ± 28.3	55.9 ± 27.9	6.8 ± 5.0*	8.7 ± 8.4*	6.9 ± 0.6*
WBGT heat stress index (ºC)	30.9 ± 1.1	30.8 ± 1.7	30.8 ± 1.1	28.9 ± 1.4*	30.2 ± 1.7	29.5 ± 1.7*

*Significant difference between CON and INT, P < 0.05.

Table 3. Hydration status and fluid balance in long duration-continuous (CON) and intermittent (INT) type sports.

	CON			INT		
	Females N=20	Males N=30	Total N=50	Females N=63	Males N=60	Total N=123
USG Pre (mg/dL)	1.017 ± 0.001	1.018 ± 0.001	1.017 ± 0.000	1.020 ± 0.001	1.022 ± 0.000*	1.021 ± 0.006*
Sweat rate (L/h)	1.3 ± 0.3	1.6 ± 0.4	1.5 ± 0.4	0.9 ± 0.3*	1.5 ± 0.4	1.2 ± 0.5*
Dehydration (%IBW)	1.9 ± 0.7	2.2 ± 0.8	2.1 ± 0.8	0.9 ± 0.6*	1.4 ± 0.8*	1.2 ± 0.7*
Fluid replaced (% of fluid loss)	30.9 ± 20.9	29.3 ± 20.0	29.9 ± 20.1	57.8 ± 27.5*	52.8 ± 19.3*	55.4 ± 23.9 *
Sweat [Na^+] (mmol/L)	57.2 ± 20.6	57.2 ± 18.2	53.9 ± 18.1	63.2 ± 22.6	67.7 ± 18.7*	62.0 ± 21.1*

*Significant difference between CON and INT, P < 0.05.

to lower fluid replacement. Sweat [Na^+] was higher (P < 0.05) in INT compared to CON and there was no difference between genders and history of muscle cramps.

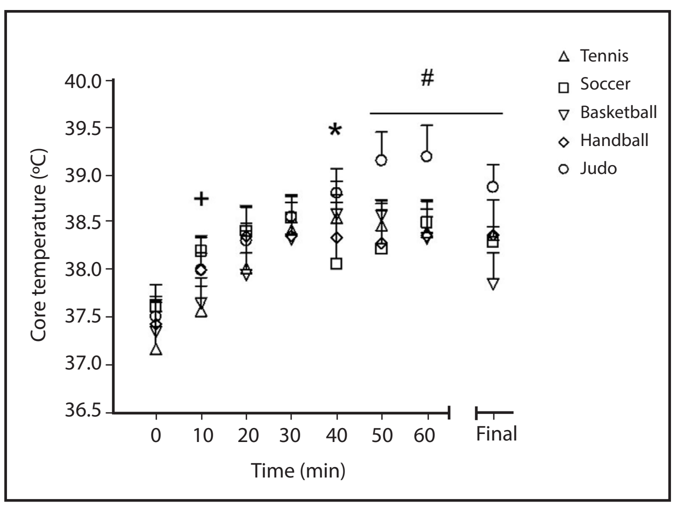
Sixty athletes (28% of the group) had a sweat [Na^+] >70 mmol/L and sweat [Cl^-] > 60 mmol/l. Forty-nine of those (82%) provided saliva samples for genetic analysis. One male tennis player was identified as having heterozygous presence of the ΔF508 mutation in the CFTR gene. He had a history of whole body muscle cramps and his sweat [Na^+] was 74.9 mmol/L (average of thigh and forearm regional sweat samples).

Core temperature

We measured core temperature in 23 athletes in CON (females=10; males=5) and in 39 athletes in INT (females=34; males=5). For this subgroup, the CON sports were running, cycling, and triathlon and the INT sports were soccer, basketball, handball, and judo. For the whole group, the average and highest T_c for the session was similar for CON (38.4 ± 0.3 and 38.8 ± 0.4 ºC) and INT (38.3 ± 0.3 and 38.7 ± 0.4 ºC), P < 0.05.

In Figure 1 we present the T_c before, during and at the end of the INT training sessions. The judo athletes, who were exposed to a high

Figure 1. Core temperature before, during, and at the end of the intermittent intensity training sessions.



+Soccer higher than tennis ans basketball; *Judo higher than soccer and handball; #judo higher than all; P<0.05.

level of heat stress while wearing two layers of clothing, showed the highest values for T_c during the final part and at the end of the INT exercise sessions.

Discussion

The present study examined the body hydration status and thermoregulatory responses to exercise under tropical conditions in athletes in continuous and intermittent type sports. The main findings were: 1) sweat rate and the change in core temperature were higher in CON compared to INT; 2) low fluid intake resulted in a higher level of dehydration in CON; 3) a proportion of athletes exhibit "salty sweat" and one was a healthy carrier of a CFTR gene mutation; and 4) athletes in INT exhibited maximal T_c similar to athletes in CON who trained at high intensity for longer periods.

Hydration status and fluid balance

Athletes in our study are indigenous to the tropics and have physiological adaptations induced by repeated exposure to a hot and humid environment that lead to increased capacity and sensitivity of the sweat glands[21]. The sweat rate values in males (1.6 ± 0.4 L/h) and females (1.3 ± 0.3 L/h) in CON and in males in INT (1.5 ± 0.4 L/h) in the present study are higher than normative data reported for adult male (1.42 ± 0.72 L/h) and female (1.10 ± 0.57 L/h) athletes[22].

Whole body sweat rate comparisons between continuous and intermittent type exercise in the heat in controlled, artificial, thermoneutral[13,23], and hot-dry[3] conditions have revealed mixed results. Drust *et al*[13] found a similar sweat rate during a laboratory-based soccer protocol in male athletes that ran on a treadmill for 45 minutes either intermittently (7.5 min exercise/1.2 min rest) or continuously in a thermoneutral environment. In contrast, Mora-Rodriguez *et al.*[3] found higher sweat rate during 90 min of variable intensity intermittent exercise (1.5 min high intensity/4.5 min low intensity) compared to same amount of work performed at a constant load in endurance-trained, heat-acclimated males exercising in hot-dry environment. In the present field study, in which we did not control for exercise intensity or environmental conditions, we found higher sweat rates in athletes in CON which may be expected for two reasons: 1) a greater proportion of the CON sessions were at high exercise intensity; and 2) athletes in CON were exposed to a higher heat stress.

Our data are consistent with the observation that athletes replace less than 50% of their sweat losses during exercise and thus, they are hypohydrated at the end of training[24]. In CON sports opportunities to drink may be frequent but athletes may be reluctant to drink, to avoid slowing down and the abdominal discomfort associated with large fluid consumption. On the other hand, in intermittent type sports, regular opportunities for hydration are available during substitutions, pauses in play, time-outs, intermissions, and change of sides of court, which leads to frequent and better fluid replacement.

Sweat sodium and genetic mutation in CFTR gene

When the sweat rate is high, sodium reabsorption capacity in the sweat gland can be exceeded resulting in a higher [Na^+] appearing in sweat. However, the linear increase seen in sweat [Na^+] as sweat rate increases can be modulated by heat acclimation[5]. For example, Buono *et al.*[5] showed that heat acclimation may increase the absorptive capacity of the sweat gland duct, reducing the sweat [Na^+] for a given sweat rate up to 1 mg. cm^{-2}. min^{-1}. In the present study athletes in CON showed a lower sweat [Na^+] despite their higher sweat rate in comparison to athletes INT, which may be attributed to their higher level of heat exposure and acclimatization. An advantage of a higher sweat rate coupled with a lower sweat [Na^+] for athletes in CON is a lower risk for developing hyponatremia during exercise in the heat[25].

A factor proposed for high Na^+ excretion in healthy athletes is the presence of genetic mutations in the CFTR that affects the Cl- channel in the sweat glands[7,8]. The majority of CF patients have the ΔF508 mutation and exhibit [Na^+] in their sweat that may be up to five times higher than healthy individuals[26]. It is estimated that 2% (1 in 46) of Hispanic Americans are heterozygous carriers of a mutated CFTR gene[10] and may be genetically predisposed to high sweat Na^+ loss. The prevalence of CF mutations in athletes with salty sweat is currently unknown.

A reduced ductal luminal membrane expression of the Cl^- channel was found in six healthy recreationally active subjects with a mean sweat [Na^+] of 94.9 ± 15.2 mmol/l[7]. However, in that study, none of the subjects was a carrier of any of the 39 most common CFTR mutations in the United States. The authors concluded that a full CFTR gene sequencing of the subjects would be required before excluding a possible genetic link between excessive Na^+ loss in sweat and CFTR mutations.

A novel finding of our study was that one of 45 Hispanic athletes (2%), classified as "salty sweaters" was heterozygous for the ΔF508 mutation in the CFTR gene. That athlete was a tennis player with a history of whole body muscle cramps that lead to collapse on court requiring medical attention.

Core temperature response

During prolonged high intensity exercise, the heat stored is higher and Tc rises faster when the same amount of exercise is performed in a variable intensity mode that includes short (1.5 to 7.5 min) high intensity bouts followed by rest periods compared to constant intensity mode[3,13,23,27]. However, if longer bouts (15-30 min) of high intensity exercise are used, a similar T_c rise is observed[28,29]. We found that although athletes in INT spent the majority of the exercise session at lower exercise intensity with multiple resting periods, they exhibited a maximal T_c (38.7 ± 0.4 °C) similar to athletes in CON (38.8 ± 0.4 °C) who trained at high exercise intensity for most of the session. This response suggests that the heat stored during the few periods of high exertion was not dissipated significantly and T_c remained elevated instead of decreasing as expected during low intensity exercise periods.

The highest core temperature response in INT was observed in judokas who trained in a non-air-conditioned gym (WBGT= 30.0 °C). Similar to our previous report[30], judokas in the present study arrived to training with a fluid deficit, as evidenced by USG. The combination of a pre-exercise fluid deficit that worsened during training because of inadequate fluid Intake, hot and humid environmental conditions, and insulation properties of the uniform that decreased heat dissipation, predisposed the athletes to hyperthermia during training. In fact, 8 of the 9 judokas felt overheated and 7 of them had maximal $T_c \geq 39.0$ °C.

Two athletes reached a T_c of 39.6 ºC and felt dizzy, had a headache, and stopped training with symptoms of exhaustion. High T_c and increased physiologic strain have been reported in American football athletes wearing a full uniform while training in similar climatic conditions[15]. We believe this to be the first study documenting the rate of T_c rise in judo athletes during training in the heat. Our data indicate that training in full uniform in a non-air conditioned gym in the tropics predisposes judo athletes to heat illness and should be discouraged.

Conclusions

This observational field study demonstrates that during training in a tropical climate, sweat loss and dehydration level are lower, and fluid intake is higher in intermittent compared to continuous type sports. Nonetheless, core temperature may rise to a similar level in intermittent type sports due to the repeated high intensity bouts and/or the effects of clothing worn while training in hot venues. For athletes in continuous sports, high sweat rates may not provide a thermoregulatory advantage in a tropical climate because humidity hinders the evaporation of sweat. Coaches should pay special attention to factors that may increase fluid intake, such as availability of cool, palatable fluids, encouragement to drink, and frequent, short pauses. Healthy athletes with high [Na^+] in sweat who are heterozygous carriers CFTR mutations may be at increased risk for hyponatremic dehydration and whole-body muscle cramps during exercise.

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Conflict of interest

The authors do not declare a conflict of interest.

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