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Hydration status, sweating rate, heart rate and perceived exertion after running sessions in different relative humidity conditions: a randomized controlled trial

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Keywords:
Dehydration;
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ABSTRACT

The purpose of this study was to analyze the impact of running in normal relative humidity (RH = 53%) and very high RH (94%) on hydration status (HS), sweating rate (SR), heart rate (HR), and rating of perceived exertion (RPE). Fourteen men (25.2 ± 6.6 yrs) performed two sessions of treadmill running. Body mass (normal RH: -1.35%, very high RH: -1.65%) HS (normal RH: -14.8%; very high RH: -20.8%) were reduced while RPE (normal RH: +26%; very high RH: +28%) and HR were increased (very high RH: +5.8%: 20–40 min, +3.1%: 40–60 min, +3%: 20–40 min; +2.3%: 40–60 min for normal RH). As expected, SR was significantly greater during very high RH (-20/8%) compared to normal RH (-14.8%). Running in very high RH at moderate temperature has a greater negative impact on SR, HS, body mass, HR, RPE in men than running in normal RH at the same temperature, which places the runner in greater danger of heat illnesses such as heat exhaustion or heat stroke.

Palavras Chave:
Desidratação;
Exercícios aeróbicos;
Esforço fisiológico;
Esforço percebido.

RESUMO

Analisar o impacto da corrida em diferentes humidade relativa (HR) (normal (53%), muito alto (94%)), estado de hidratação (EH), taxa de transpiração (TT), freqüência cardíaca (FC), esforço percebido (RPE). Quatorze homens (25,2 anos) realizaram duas sessões de corrida em esteira. Massa corporal (HR normal: -1,35%, HR muito alta: -1,65%) e EH reduziram (HR normal: -14,8%, HR muito alta: -20,8%), RPE (HR normal: + 26%, HR muito alta: + 28%), aumento da FC (HR muito alta: + 5.8%: 20–40 min, + 3.1%: 40–60 min, HR normal: + 3%: 20–40 min; + 2.3%: 40–60 min). TT foi significantemente diferente entre HR (HR normal: -14.8%, HR muito alta: -20.8%). Há um impacto negativo na corrida em EH, massa corporal, FC e RPE em homens com HR normal e muito alta, e TT é mais afetada com HR muito alta.

Palabras Clave:
Deshidratación;
Ejercicio aeróbico;
Esfuerzo fisiológico;
Esfuerzo percibido.

RESUMEN

El objetivo de este estudio fue analizar las repercusiones de correr con diferentes niveles de humedad relativa (HR) (normal [53%], muy alta [94%]) sobre el estado de hidratación (EH), la tasa de sudoración (TS), la frecuencia cardíaca (FC) y el esfuerzo percibido (EP). Catorce hombres (25,2 ± 6,6 años) realizaron dos sesiones en cinta de correr. La masa corporal (HR normal: -1,35%; HR muy alta: -1,65%) y el EH (HR normal: -14,8%; HR muy alta: -20,8%) se redujeron, mientras que el EP (HR normal: +26%; HR muy alta: +28%) y la FC (HR muy alta: +5,8%: 20–40 min; +3,1%: 40-60 min; HR normal: + 3%: 20-40 min; + 2,3%: 40-60) aumentaron. La TS fue considerablemente diferente entre las HR (HR normal: -14,8%; muy alta HR: -20,8%). Hay repercusiones negativas por correr con una HR muy alta y una temperatura moderada en TS, EH, masa corporal, FC y EP en corredores que corren a una HR normal a la misma temperatura, lo que sitúa a estos en gran peligro de sufrir un enfermedad provocada por el calor, como agotamiento por calor o golpe de calor.

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INTRODUCTION

Running training, as well as other physical exercise modalities, causes numerous acute physiological alterations, such as the impaired hydration status (HS). Inadequate hydration conditions before and during an exercise session can have serious negative effects on performance and physiological function (Shirreffs *et al.*, 2005; Maughan *et al.*, 2007). During exercise, negative alterations in HS are mainly caused by increased sweating rate (SR) which can be influenced by individual factors (e.g., age, sex, hydration and feeding condition), type of physical exercise performed, type of clothing used during exercise, and environmental conditions (Sawka *et al.*, 2007).

Among the significant environmental factors that can cause thermal discomfort and alteration in HS and SR, environmental temperature and relative humidity (RH) are considered the most important. These variables can drastically influence the body's thermoregulation since the more the environment temperature rises, the greater will be the SR. The higher the RH, the less will be the sweat evaporation, which will drive up the exerciser's heat production and SR consequently increase the rating of perceived exertion (RPE) (Millard-Stafford *et al.*, 2007; Maughan *et al.*, 2012). Heat production during exercise is approximately 15–20 times higher than during resting conditions. Central body temperature may increase 1 °C every five minutes of exertion if there is no thermoregulatory adjustment (e.g., sweat evaporation) (Nadel *et al.*, 1977; Gleeson, 1998). Therefore, adequate maintenance of HS is important for thermoregulation to maintain adequate cardiovascular function and physical performance during exercise (Gleeson, 1998; Coris *et al.*, 2004).

Studies that seek to verify the physiological and perceptive responses to running under different conditions of RH may convince athletes and recreational practitioners to adopt better hydration strategies prior to running on a day with high RH (Goulet *et al.*, 2008; Morris *et al.*, 2015). Although previous studies have evaluated physiological responses to both elevated RH and heat (Shirreffs *et al.*, 2005; Maughan *et al.*, 2007; Murray *et al.*, 2007), more studies are needed to assess physiological responses in conditions of high RH without elevated temperature since the mechanisms that decrease HS in high heat and high RH are different. To our knowledge, there is no study that has attempted to verify the physiological effects of running in controlled environments with same temperature but different RH.

Therefore, the aim of this study was to analyze the impact of a running session in two conditions of controlled temperature with different RH on HS, SR, HR, and RPE. Our hypothesis was that the running session in a very high RH condition could increase SR, HR, and RPE, and decrease HS more than in normal RH session independent of environmental temperature.

METHODS

This investigation was approved by the local University Ethics Committee, according to Helsinki Declaration, the norms of Resolution 196/96 of the Brazilian National Health Council on research involving human beings, and the ethical standards of the International Journal of Sports Medicine (Harriss and Atkinson, 2015).

PARTICIPANTS

Recruitment of the participants was through publicity in posters and pamphlets in the university community and central region of the city. Participants who were interested in participating of the study were instructed to contact in-person, by phone or e-mail the responsible researcher of this study.

The following inclusion criteria adopted for the present investigation were: (1) to practice running in an advanced way for at least six months prior to the beginning of the study with a minimum frequency of two times a week; (2) present no musculoskeletal dysfunctions that could prevent performance of the tests to be applied; (3) not be taking any medicament or drugs that affect hydration.

Thirty-five individuals were interested in participating in the study, but according to inclusion criteria only 14 men (25.2 ± 6.5 years) were considered for participation. After receiving information about the purpose of the study and the procedures to which they would be submitted, all participants signed a written informed consent. Participants received instructions outlining guidelines advising them to refrain from any physical exercise (except for the proposed running sessions) and to avoid alcohol, caffeinated beverages, and related diuretics during the study period (from the first to the last visit to the laboratory). Moreover, participants were instructed to maintain their eating habits.

STUDY DESIGN

The participants made three visits to the laboratory, with a minimum of 72 h and a maximum of 120 h between sessions. Visit 1 was directed to study explanation and distribution of a heart rate (HR) monitor to participants for assessing resting HR. Using a crossover scheme, participants were randomly separated for two 60-min running sessions on a treadmill in two different conditions, one with a normal RH (53±1%) and other with a very high RH

(94 ± 2%) (Figure 1). Randomization was done via a computer program (random.org). Anthropometry measurements, HR, ratings of perceived exertion (RPE), and urine collection were performed throughout the run (Figure 2). Running in both visits was performed on treadmill (Movement, LX-160, São Paulo, Brazil), without inclination.

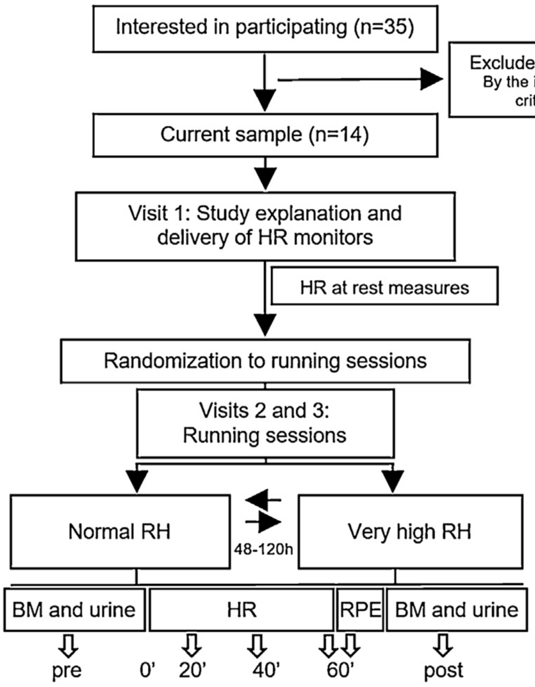

Figure 1. Schematic representation of sample selection and study design.

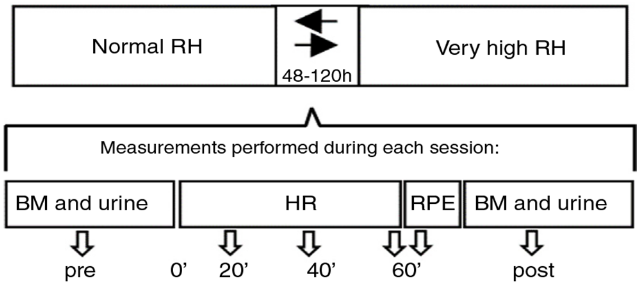

Figure 2. Schematic representation of the experimental sessions (visits 2 and 3).

Anthropometry and body composition

At visit 2, anthropometric measures and body composition were performed. Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Welmy®, model W300, São Paulo, Brazil), and height was measured to the nearest 0.1 cm with a stadiometer attached on the scale. Participants wore light clothes and no shoes. Body mass index was calculated as body mass in kilograms divided by the square of height in meters (WHO 1998). A single-frequency bioelectrical impedance device (Biodynamic Body Composition Analyzer, model 310e, Biodynamics Corporation, Seattle, USA) was used to determine relative body fat (%), fat mass (kg), and fat-free mass (kg), according to the manufacturer's proprietary equation. In addition to the initial advice on abstention, participants were also instructed to empty their bladder immediately before the bioimpedance measurement.

Sweating rate

The SR was estimated by considering the loss of body mass over the course of the running session (Harvey *et al*., 2008). Body mass was measured 10 min before (body mass pre) and immediately after (body mass post) the participants performed the sessions. SR was estimated by the following equation: SR = (([body mass pre − body mass post]*1000)/ total time session) (Sawka *et al*., 2007) and expressed in mL/min.

Hydration status (urine color)

As a parameter for measuring HS at each of the visits (2 and 3), participants provided a urine sample in transparent plastic bottles (~40 mL) before and immediately after the tests. The urine color was analyzed using a previously proposed scale (Armstrong *et al*., 1994; Sawka *et al*., 2007). This scale evaluates eight different urine colors, ranging from very light yellow (color 1) and brownish green (color 8) to define a urine color index to assess HS.

Approximately 60–90 min before the sessions (prior to measurement of body weight), all participants consumed 500 mL of water in an attempt to standardize/equalize their initial HS. Participants were not allowed to ingest any type of liquid during treadmill running. The higher the HS value on the scale, the greater the dehydration.

Exercise intensity

In order to determine the intensity to be used in the two running sessions, each participant received a HR monitor (Reebok®, model RS1, Finland) at visit 1. They were instructed how to measure the HR using the monitor. To determine resting HR, each participant was to wear the monitor immediately after waking up without standing and record the HR values after one minute of complete rest in supine position. The mean of obtained values of the three days (between visits 1 and 2) was used to characterize the resting HRrest.

Maximum was estimated using the equation proposed in the literature (220 − age$_{\text{[in years]}}$). The target HR for both running sessions was estimated to be 70–80% using the HR reserve (HRres) method

(HRexercise = HRres × 0.7 and 0.8 + HRrest) (ACSM, 2011). HR was continuously measured throughout the running sessions and recorded at 20, 40, and 60 min. Exercise intensity was maintained at a HR within the HRres range by manipulating treadmill velocity.

RPE was utilized as indicator of stress/physical effort through the application of the modified 11-points scale presented by Borg (1982). The scale, containing verbal and illustrative indications of effort, was presented to participants to assign a numerical value (0–10) corresponding to their overall perception of effort after each session, with 0 being referred as “extremely easy”and 10 as “extremely difficult’’. RPE was assessed in the last minute of each session.

Environmental conditions for sessions

A digital hygrometer (Instrutherm, model HD-260, São Paulo, Brazil) and an air conditioner (Split Consul, 12000 BTUs, Whirlpool Latin America, Amazonas, Brazil) were used to determine and control the ambient temperature in each test session. The ambient temperature was 22.0±0.7 °C. The RH control was performed using three humidifiers, one from WaterClear-Max (model Turbo Ultrasonic, São Paulo, Brazil) and two from Ventisol (model U-01, Santa Catarina, Brazil). Normal RH was maintained at 55.9±5.3% and very high RH with maintained at 93.1±2.3%.

Statistical analysis

Normality of data was analyzed by the Shapiro–Wilk test. Paired *t*-tests were used to compare SR, distance, RPE, and average speed between RH conditions. Two-way repeated-measures analysis of variance (ANOVA) was used to compare body mass and HS at pre and post sessions between RH conditions. Fisher’s post hoc test was employed to identify the mean differences when *F*-ratio was significant. For all statistical analyses, significance was accepted at $P < 0.05$. The data were analyzed using STATISTICA software version 10.0 (Statsoft Inc., Tulsa, OK, USA). Data are presented as mean and standard deviation.

RESULTS

Table 1 depicts physical characteristic of the participants of the study. The results of Table 2 show the exercise conditions and their respective responses pre–post testing. Running speed, RPE and distance were not different between humidity conditions (*P*>0.05). Body mass presented a main effect of time (Table 2), with reductions of 1.35%, and 1.65% for normal and very high RH, respectively. HS was also reduced significantly with no differences between humidity conditions (normal RH: reduction of 14.8%; very high RH: reduction of 20.8%). For the SR, there was a significant difference between RH conditions, with greater SR for very high RH (+15%) compared to normal RH condition.

Table 1. Participants' physical characteristics (n = 14).

Variables	Mean ± standard deviation
Age (years)	25.2 ± 6.6
Body mass (kg)	67.5 ± 10.6
Height (cm)	168.0 ± 9.5
Body mass index (kg/m^2)	23.8 ± 3.0
Relative body fat (%)	18.6 ± 6.5
Fat mass (kg)	12.5 ± 5.4
Fat-free mass (kg)	55.0 ± 8.3

The HR measured at the three points during the tests presented a main effect of time (*F*=28.49, *P*<0.05) but not an interaction effect (*F*=0.17, *P*=0.83), showing similar progressive increases in both conditions. The HR obtained in very high RH was significantly elevated by 5.8% from 20 to 40 min, 3.1% from 40 to 60 min. In normal RH, it increased by 3% from 20 to 40 min and 2.3% from 40 to 60 min (Figure 3). Similarly, %HR presented a main effect of time (*F*=3.77, *P*<0.05) but not for an interaction effect (*F*=0.25, *P*=0.62).

DISCUSSION

The main findings of the present study were that running under very high RH or normal RH at the same environmental temperature causes similar effects on body mass, RPE, HS, and HR. However, a very high RH condition causes greater dehydration (represented by SR) in adult men. Thus, our results partly confirm our previous hypothesis that greater RH condition produce greater negative physiological alterations in runners.

The body has several ways to transfer heat externally in an attempt to avoid hyperthermia. Among these cooling mechanisms, about 98% of the effect is through evaporation of sweat (Armstrong and Maresh, 1993; Coris *et al.*, 2004). Attempts at heat dissipated by increased sweating causes reductions in blood circulatory volume and cardiac output and increases in vascular resistance and plasma osmolality (Logan-Sprenger *et al.*, 2012) which result in significant increases in core temperature (Nadel *et al.*, 1977; Murray, 1996; Coris *et al.*, 2004). Additionally, HR will increase approximately 3–5 bpm for every 1% of body mass loss due to dehydration (Mack *et al.*, 1988). Moreover, a very high RH will make it difficult to evaporate the sweat, which would prevent heat dissipation by perspiration, further increasing body temperature and

Table 2. Exercise conditions and respective responses pre and post testing (n = 14).

	Condition		*p*-value		
	Normal RH	**Very high RH**	**Condition**	**Time**	**Interaction**
Running speed (km/h)	8.7 ± 0.9	8.8 ± 0.9	0.109	–	–
Distance (km)	8.3 ± 0.9	8.3 ± 0.8	0.552	–	–
Physical effort (RPE)	6.4 ± 1.3	5.4 ± 1.7	0.07	–	–
Sweating rate (mL/min)	15.7 ± 4.9	18.0 ± 4.4^{b}	0.028	–	–
Body mass (kg)					
Pre	67.4 ± 10.6	67.6 ± 11.1	0.955	<0.0001	0.619
Post	66.5 ± 10.4^{a}	66.5 ± 10.9^{a}			
Hydration status					
Pre	3.3 ± 1.1	3.3 ± 0.9	0.436	<0.0001	0.853
Post	3.9 ± 1.0^{a}	4.1 ± 0.9^{a}			

Note: RH, relative humidity; RPE, rating of perceived exertion. ^{a} P < 0.05 vs. Pre. ^{b} P < 0.05 vs. Normal RH.

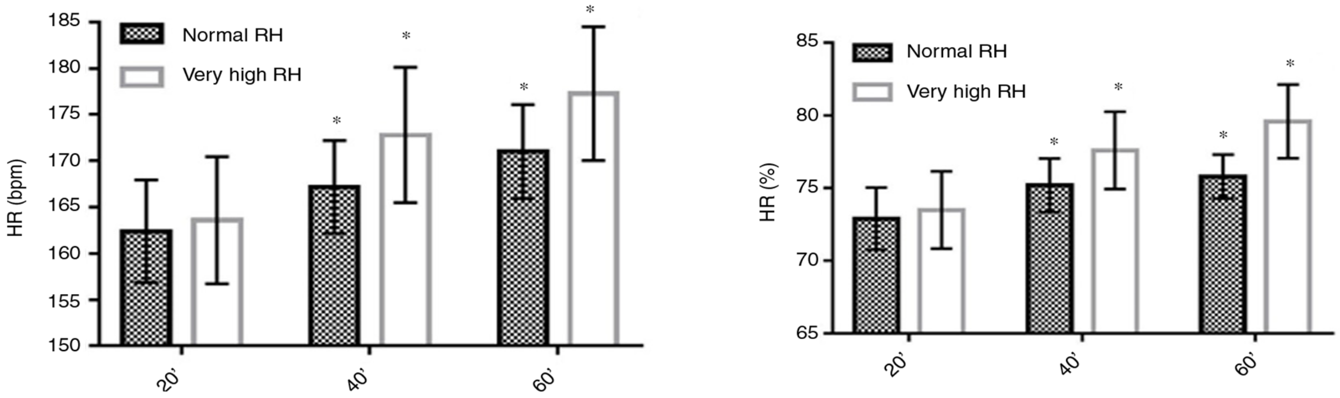

Figure 3. Participants' values of heart rate in both running sessions (n = 14). Note. Data are presented as mean and standard deviation for HR. RH, relative humidity; HR, heart rate; *P < 0.05 vs. 20'.

overloading metabolism and impairing performance (Wendt *et al*., 2007). Thus, the increase of SR observed in this study may have occurred due to the body's altered thermoregulation mechanism (i.e., decreased sweat evaporation) and an increase in core temperature (Nadel *et al*., 1977; Armstrong *et al*., 1994; Gleeson, 1998).

However, studies involving the analysis of the specific influence of variations in RH on performance and physiological responses to exercise are scarce. Maughan *et al*. (2012) analyzed the influence of RH on endurance performance in heat (30.2 ± 0.2 °C). Eight men participated in four trials to voluntary fatigue at an intensity equivalent to 70% of maximal oxygen uptake in four different RH conditions: 24, 40, 60 and 80%. SR was significantly higher in the two conditions of higher RH (60 and 80%), corroborating the results of the present study. Recently, the changes in game profiles of soccer players under the simultaneous influence of different combinations of ambient temperature and RH that characterized the games of the FIFA World Cup 2014 were evaluated. The indicators evaluated included total distance covered and number of sprints performed under the consideration of three air temperature ranges (i.e., below 22 °C, 22–28 °C and above 28 °C) and two levels of RH (i.e., below 60% and above 60%). The results showed that the longest total distances occurred at air temperature below 22 °C and RH below 60%, while the worst results were in the same temperature range but with RH conditions above 60%. As for the number of sprint, in games where the temperature was below 22 °C, players performed approximately 30% more sprints compared to games with temperatures above 28 °C, but this was only observed when the RH was less than 60% (Chmura *et al*., 2017). These results indicate that RH influences performance negatively even when environmental temperatures are similar.

Although our results did not show differences of HR between very high RH and normal RH sessions, Hayes *et al*. (2014) observed significant increases in HR and RPE, as well as reductions in power, in athletes that performed 40 min of intermittent sprint on cycle ergometer in a high RH condition (34°C, 78%), compared with normal RH condition (21°C, 49%). Thus, it may be an interaction effect between temperature and humidity that causes HR to increase when both conditions are high.

For the determination of heat stress and general effort, RPE can be used as a general assessment of effort since it attempts to integrate physiological (type, intensity, and duration of the exercise) and psychological evaluations (feeling of difficulty) (Borg, 1970, 1982). Several investigations have shown that subjects with lower HS usually exhibit higher RPE (Logan-Sprenger *et al*., 2012; Périard *et al*., 2012; Hayes *et al*., 2014; Davis *et al*., 2015). However, in our investigation, there was no difference in RPE between RH conditions, which may have been because our results on HS were not different between humidity conditions. The initial urine color values in the present study were similar between the two conditions of RH; after both conditions, HS decreased with the magnitude of this dehydration being slightly greater but not significant ($P > 0.05$) for the very high RH.

Regardless of the results, some limitations need to be addressed. First, the lack of measurement of core body temperature did not allow us to gauge the change in the internal environment during exercise. Another important limitation was the lack of verification of blood and urine biochemical markers, a fact that would allow greater inferences on fluid loss induced by high RH associated with exercise, and its effects on metabolism. The small sample size may limit inferences to larger groups in different sports.

According to ours results, we conclude that running sessions in differing RH conditions may alter HS, body mass, SR, HR, and RPE in young men. The longer the effort, the greater may be the changes in these parameters suggesting a greater physiological impact of high RH despite similar environmental temperatures.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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