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Exercise In Hot Condition Is Associated With Increases In Blood Lactate, Body Temperature And Subjective Perceived Exertion, And Reduced Runner's Performance In A Submaximal Exercise Test
Influence Of Heat On Runners' Metabolic Responses

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Abstract
The objective of the present study was to evaluate heart rate (HR), subjective perceived exertion (SPE), body temperature, blood lactate and water loss of runners subjected to an aerobic exercise protocol under cold and hot conditions. 16 amateur male runners (45.12 ± 8.43 years), were evaluated. After determination of the anaerobic threshold, a submaximal test consisting of was performed in four stages of 10 minutes each, corresponding to 80%, 90%, 100% and 110% of the anaerobic threshold velocity (ATvel). Exercise was performed in both cold (17.63 ± 0.36°C) and hot (31.63 ± 0.55°C) environments. Heart rate (bpm), SPE, body temperature (°C), blood lactate (mMol) and water loss (mL) were evaluated. All physiological variables were increased in the exercise performed in the heat. From the first stage of the exercise test to the last, the values were increased about 9.82% for HR, 13.8% for SSE, 3.6% for body temperature and 47.0% for blood lactate. In addition, water loss was 41.5% greater during exercise performed in hot than in cold conditions. The results showed greater physiological stress during exercise performed in the heat, which suggests a need for an adequacy of training load and volume in these conditions.
Keywords: *Temperature, heart rate, exercise, lactacidemia.*

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I. Introduction

The human body is constantly producing heat by endogenous sources and receiving heat from the external environment. Most of the energy produced by the body is lost in the form of heat and a small portion is used to perform work (Walsh & Oliver, 2016). The amount of heat generated by tissues at rest and during physical activity varies. Intense exercise exerts the strongest effect on metabolism. At rest, muscles can produce up to 25% of total body heat, but in exercise, muscle contraction is responsible for considerable increases in heat production due to increased metabolic rate in response to high energy requirement for active muscles (Flouris & Schlader, 2015).

During physical exercise the thermoregulatory system works to maintain the internal temperature. Energy transformed by metabolic pathways increases from 3 to 12 times during exercise in relation to rest. This could increase body temperature by 1 °C every 5 minutes if thermoregulatory mechanisms were not activated (Tatterson et al., 2000).

Physical exercise promotes physiological adaptations to stress in a dependent matter of both exercise intensity and ambient temperature. Thus, even at the same intensity of effort, changes in internal temperature, heart rate (HR) subjective perceived exertion (SPE), and water loss may vary with environment temperature and affect physical performance (Galloway & Maughan, 1997).

Therefore, the aim of the present study was to evaluate HR, SPE, body temperature, blood lactate and water loss in runners subjected to two aerobic exercise protocols, in cold and hot conditions.

II. Materials And Methods

The present study was approved by the Research Ethics Committee of the Universidade Luterana do Brasil, under protocol number 83234618.5.0000.5349.

This is a cross-sectional analytical study. A total of 16 healthy male amateur runners (10, 21 and 42km) over 18 years of age were enrolled to training programs of 3 to 5 sessions per week. After signing the informed consent form, participants were instructed not to exercise for at least 24 hours prior to the evaluations. Data collection was performed in the Laboratory "X" of the University "X". The exclusion criteria were individuals with chronic diseases (diabetes or heart diseases) and individuals that, for some reason, could not perform the exercise tests. The anaerobic threshold (AT) was determined based on the exercise protocol proposed by Mognoni et al (Mognoni et al., 1990). After the AT was determined, participants took a 10-minute passive rest period. Then, a submaximal test was performed, consisting of a 40-minute running session, divided into four stages of 10 minutes each, corresponding to 80%, 90%, 100% and 110% of the individual anaerobic threshold velocity (ATvel, in km/h, respectively.

On day one, tests were performed in "cold" conditions, which was defined as a room temperature of 17.6 ± 0.4 °C and relative humidity of 54.9 ± 6.6%; after seven days, all tests were repeated in "hot" conditions, defined by room a temperature of 31.6 ± 0.6 ° C and relative humidity of 54.9 ± 6.6%.

To better understand the effects of the ambient temperature on physiological parameters, the ATvel established during" cold" conditions was used to evaluate these parameters in the heat. In this way, differences in performance would be attributed to differences in the ambient temperature only.

HR (bpm) was measured at rest, 10 minutes after AT determination at the end of each stage and at 1, 3 and 5 minutes after the end of the test. Body temperature (°C) was evaluated at rest, 10 minutes after AT determination and at the end of each stage. Blood lactate concentrations (mmol) were measured 10 minutes after AT determination and at the end of stages 3 and 4. The Borg Scale (Borg, 1982) was used to assess the SPE30 seconds before the end of each stage. Water loss was calculated as the difference between pre- and post-exercise body mass (kg), plus the volume of fluid ingested (mL). We assumed that 1kg of body mass loss represented one 1 L of water loss (Laitano et al., 2012).

The sample size was calculated using the WinPepi software (Programs for Epidemiologists for Windows) version 11.43, for a significance level of 5% and power of 80%. For descriptive statistics, the minimum, maximum, mean and standard deviation values were used. For inferential statistics the ANOVA for repeated measurements was used to verify significant changes throughout each physical test, and; paired t test to compare changes in variables between the two test conditions (cold and hot). All analyzes were performed in the statistical software SPSS for Windows 20.0, and the level of significance was 5%.

III. Results

A total of 16 participants aged 45.1± 8.4 years were included in the study. Mean body mass was 77.8 ± 8.4 Kg, and mean BMI 24.7 ± 1.5 Kg/m^2. Of the 16 runners evaluated, 14 completed the entire protocol. Two participants failed to complete the last stage (stage 4) of the test performed in the heat. Mean number of exercise sessions was 3.69 ± 0.79 per week.

Regarding the measurements of HR throughout the exercise sessions (Figure 1), no difference in HR at rest was found between the two different conditions (Cold = 79.9 ± 13.8 bpm, Hot = 84.1 ± 14.0 bpm, p = 0.062). However, HR values were significantly higher in hot than cold conditions at all other time points throughout the tests (stage 1: cold = 134.0 ± 9.9 bpm; hot = 146.4 ± 13.5 bpm, stage 2: cold = 144.4 ± 20.0 bpm, hot = 160.4 ± 14.9 bpm, stage 3: cold = 156.06 ± 11.06 bpm, hot = 172, 81 ± 14.63 bpm., stage 4: cold = 166.69 ± 11.17 bpm, hot = 180.4 ± 13.8 bpm; p < 0.0001 for all comparisons).

After the exercise session (1, 3 and 5 min post-exercise) HR values in hot conditions were significantly higher than in cold conditions (1 min after the test: cold = 111.06 ± 15.67 bpm; hot = 135.13 ± 12 bpm. After the test: cold = 98.19 ± 13.24 bpm, hot = 118.50 ± 17.42 bpm, p = 0.000, 5 min after test: cold = 89.50 ± 10.10 bpm, hot = 116.19 ± 17.94 bpm, p < 0.0001 for all comparisons).

(Figure 1)

In relation to the SPE (Figure 2), in all the four stages, significantly higher values were observed in hot conditions compared with cold conditions (stage 1: cold = 9.94 ± 1.06; = 10.81 ± 1.72, p = 0.021, stage 2: cold = 11.75 ± 0.93, hot = 12.88 ± 1.99, p = 0.011, stage 3: cold = 13.44 ± 1 , hot = 15.56 ± 2.25, p < 0.0001, stage 4: cold = 14.81 ± 2.10, hot = 17.93 ± 2.25, p < 0.0001).

(Figure 2)

Body temperature was significantly higher throughout the exercise test in hot than in cold conditions, except for rest (Figure 3) (cold = 36.53 ± 0.50 °C, hot = 36.63 ± 0.44 ° C, p = 0.441, 10 min after the Sirtori test: cold = 35.86 ± 0.41 °C; hot = 36.36 ± 0.40 °C, p = 0.003, stage 1: cold = 35.17 ± 0.65 °C, hot = 36.36 ± 0.51 °C, p < 0.0001, stage 2: temperature = 35.52 ± 0.70 °C, hot = 36.76 ± 0.57 °C, p < 0.0001, stage 3: cold = 35.98 ± 0.61 °C, hot = 37.58 ± 0 , 72 ° C, p < 0.0001, stage 4: cold = 36.35 ± 0.87 °C, hot = 38.27 ± 0.77 °C, p < 0.0001).

(Figure 3)

Also, blood lactate (mMol) levels were significantly higher in hot than cold conditions at the three time points – after the Sirtori test, and at stages 3 and 4 (Figure 4) (10 min after the Sirtori test: cold = 3.21 ± 0.97 mMol, hot = 3.62 ± 0.95 mMol, p = 0.037, stage 3: cold = 3.50 ± 0.84 mMol, hot = 6.38 ± 1.90 mMol, p < 0.0001; stage 4: cold = 5.67 ± 1.79 mMol, hot = 8.64 ± 2.57 mMol, p < 0.0001).

Total water loss (mL) was also higher during the test performed in hot than in cold conditions (1406.3 ± 376.77 mL vs. 993.8 ± 413.87 mL, p = 0.001).

(Figure 4)

IV. Discussion

In the present study, metabolic and thermoregulatory responses to exercise performed in hot and cold environments were compared. The results demonstrated that in hot conditions, exercise increased heart rate, SPE, body temperature and blood lactate levels. In fact, in hyperthermia, there is a reduction in the activation of muscle motor units by the brain, causing a sensation of fatigue and performance impairment (Lepers et al., 2013).

In hot conditions, individuals showed higher HR in response to exercise. This is in part due to the distribution of central blood towards the periphery, leading to an increase in the HR (Wilson & Crandall, 2011). As discussed by Sawka et al. (Sawka et al., 1985), a reduction in the systolic volume occurs primarily due to the increase in HR, directly mediated by the effects of body temperature on the sinoatrial node and / or by the baroreflex modulation of the sympathetic and parasympathetic systems. Thus, prolonged exercise in the heat may result in a reduction in the central volume and a shorter diastolic filling time, which directly reduces end-diastolic volume (Périard JD, Racinais S)

Other studies have reported that the increase in heat-induced heart rhythm accompanies increased internal temperature and blood flow to the skin, and decreased systolic volume (Pearson et al., 2011). This reduction in the cardiovascular reserve is the primary factor that limits the duration of aerobic exercise and reduces the capacity to perform exercises in the heat (Wingo et al., 2005).

There are two methods traditionally used to assess the impact of the cold environment on exercise. One is by reducing room temperature and the other is by reducing body temperature under water. HR in cold conditions is reduced in a compensatory manner due to reduced blood circulation in the skin and increased central circulation. Although this could improve exercise performance, in long term, it could cause a reduction in metabolic rate, affecting the individual's energy expenditure in aerobic exercises (Hornery et al., 2005; Vaile et al., 2011).

It is important to note that in the heat, a higher SPE occurred. This measure has great importance in the planning of physical activities by the coaches. A drop of motivation observed in heat stress highlights a psychophysiological phenomenon characterized by reduced activity of the central nervous system with changes in neuromuscular function, and moderate feelings of discomfort not usually noticed at the beginning of exercise, which can worsen progressively or eventually improve. As a result, the individual begins to feel fatigue, limited attention and aversion to continuing tasks (Otani et al., 2017).

The increase in body temperature in the heat is due to the above mentioned fact of the redistribution of blood flow to periphery at elevated temperatures. When compared to the results from the cold protocol, it could be noted a sudden reduction in temperature followed by an abrupt increase. This can be explained by the method chosen for the measurement of body temperature. Since the skin undergoes important adaptations to temperature changes, it is possible that during and after stage 2, sympathetic nerve-mediated vasoconstriction occurs. Perhaps the results obtained would be different if we used, for example, an intrarectal method to measure body temperature, since in this case body temperature would not be influenced by the vasogenic state of the skin.

Studies have shown that high body temperatures have an influence on muscle function and cellular metabolism in humans. In fact, exercise in the heat leads to a greater dependence on muscle glycogen and anaerobic metabolism and causes a higher post-exercise accumulation of ammonia and lactic acid, which explains in part the variations shown in Figure 4 (Febbraio et al., 1996).

The accumulation of lactate during exercise influences SPE by the sensation of burning, fatigue and increased ventilatory effort. In this study, running exercise performed in a hot environment resulted in higher accumulation of lactate when compared to cold environment. However, it was demonstrated that there is also a higher amount of lactate accumulated in cold conditions when compared to environments at normal temperature (± 25ºC). This higher lactate muscle production is associated with muscle fatigue and the decline in strength observed during exercise and at high glycolytic rates. This would also be correlated with the release of stress-dependent free hydrogen ions (H +). High temperature induces impaired function or structure of the sarcoplasmic reticulum compromising its ability to regulate calcium uptake and muscle strength (Febbraio et al., 1994; Periard et al., 2011).

In a study performed in Russia, 53 healthy male volunteers were evaluated using an infrared thermograph. The average skin temperature was characterized by higher correlation coefficients with blood lactate than other indicators of the portrait thermal. The temperature gradient and weighted average temperature were correlated with blood lactate. A decrease in the level of lactate in peripheral blood was observed when the individuals were exposed to cold environment (Akimov et al., 2010).

Also, regarding the degree of water loss during exercise performed at hot or cold temperatures, it has been established that the sympathetic system generates exacerbated responses to exercise in the heat. Higher water loss may reflect greater sweating as an attempt of the body to dissipate heat. Another hypothesis is that the lower water loss in cold conditions would be explained by the law of enthalpy, where the molecules in a lower state of energy would take more time to propagate. It is worth pointing out that water replacement is impaired during exercise in the heat and therefore, the individual must remain well hydrated before starting an activity in these climatic conditions (Montain, Latzka, & Sawka, 1995; Racinais et al., 2015).

V. Conclusions

In the studied population, ambient temperature affected different physiological parameters – HR, SPE, body temperature, water loss and lactate concentration – when aerobic exercise was performed in cold and hot conditions. All these physiological regulatory responses presented higher values when the participants were submitted to the heat test, suggesting a t need for attention by trainers and recreational athletes.

Funding Statement

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Figure Legends

Figure. 1. Heart rate (bpm) measurements throughout exercise tests performed in cold and hot conditions. Values are expressed as mean ± SD. * $p<0.05$ compared with cold condition

Figure 2. Subjective perceived exertion throughout the exercise tests performed in hot and cold conditions. Values expressed as mean ± SD; * $p<005$ compared with cold condition.

Fig. 3. Body temperature (°C) measurements throughout the exercise tests performed in hot and cold conditions. Values expressed as mean ± SD; * $p<0.05$ compared with cold condition.

Fig. 4. Blood lactate concentrations after the Sirtori test, and at stage 3 and 4 of the exercise tests performed in hot and in cold conditions; values expressed as mean ± SD; * $p<0.05$.

Figure 6

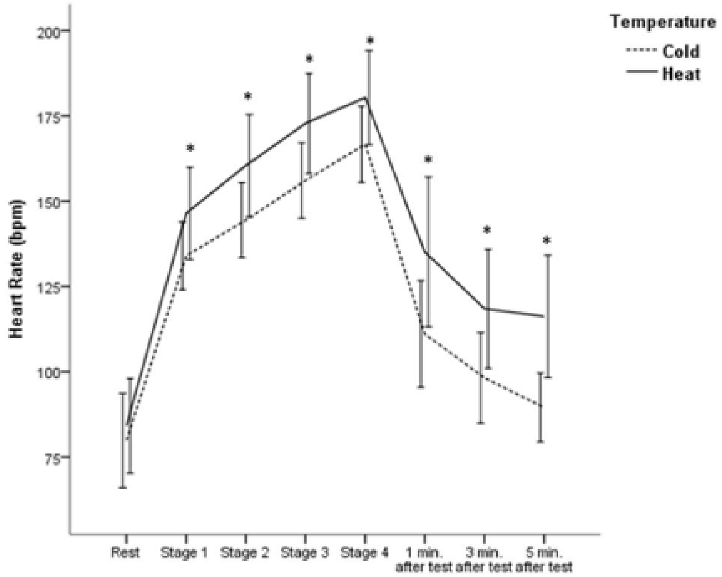


Figure 7

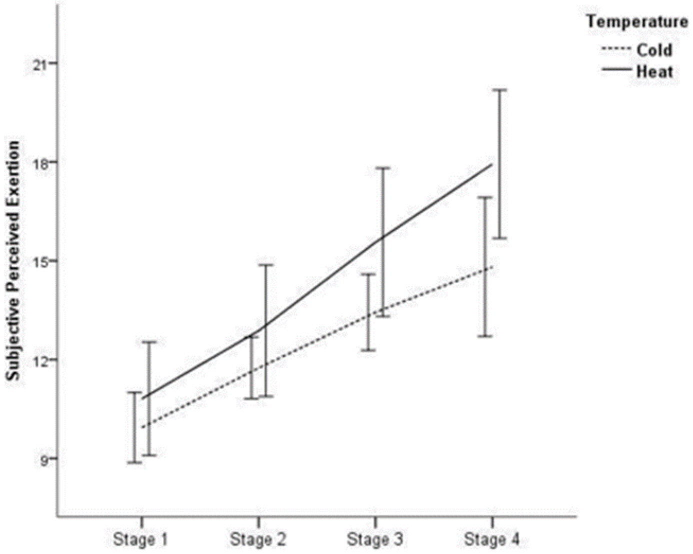
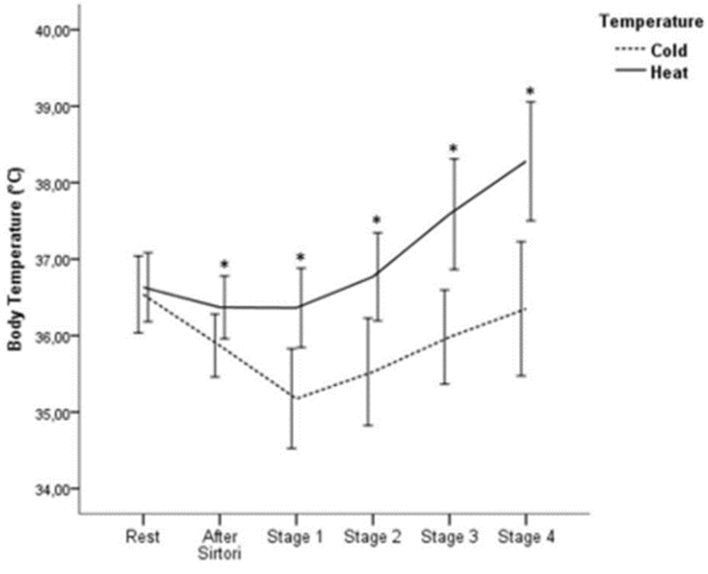
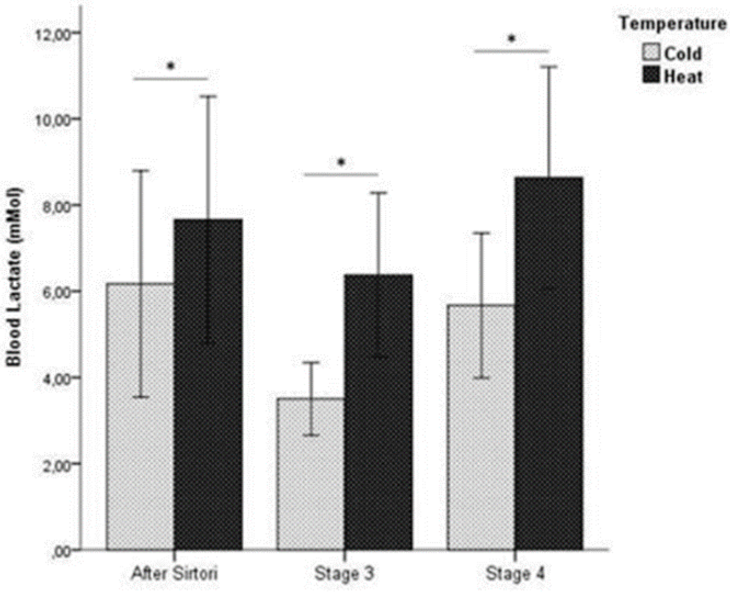


Figure 8



Figure


Temperature
Cold
Heat
Blood Lactate (mMol)
12,00
10,00
8,00
6,00
4,00
2,00
,00
*
After Sirtori
Stage 3
Stage 4