

Effects of human head hair on performance and thermoregulatory responses during 10-km outdoor running in healthy men

Efeitos do cabelo da cabeça humana no desempenho e na resposta termorregulatória durante a corrida de 10 km ao ar livre em homens saudáveis

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Abstract – The aim of the present study was to evaluate the effects of human head hair on performance and thermoregulatory responses during 10-km outdoor running in healthy men. Twelve healthy males (29.5 ± 3.7 years, 174.9 ± 4.3 cm, 72.7 ± 3.2 kg and VO_{2max} 44.6 ± 3.4 ml.kg⁻¹.min⁻¹) participated in two self-paced outdoor 10-km running trials separated by 7 days: 1) HAIR, subjects ran with their natural head hair; 2) NOHAIR, subjects ran after their hair had been totally shaved. Average running velocity was calculated from each 2-km running time. Rectal temperature, heart rate and physiological strain index were measured before and after the 10-km runs and at the end of each 2 km. The rate of heat storage was measured every 2 km. The environmental stress (WBGT) was measured every 10 min. The running velocity (10.9 ± 1 and 10.9 ± 1.1 km.h⁻¹), heart rate (183 ± 10 and 180 ± 12 bpm), rectal temperature (38.82 ± 0.29 and $38.81 \pm 0.49^\circ\text{C}$), physiological strain index (9 ± 1 and 9 ± 1), or heat storage rate (71.9 ± 64.1 and 80.7 ± 56.7 W.m⁻¹) did not differ between the HAIR and NOHAIR conditions, respectively ($p > 0.05$). There was no difference in WBGT between the HAIR and NOHAIR conditions (24.0 ± 1.4 and $23.2 \pm 1.5^\circ\text{C}$, respectively; $p = 0.10$). The results suggest that shaved head hair does not alter running velocity or thermoregulatory responses during 10-km running under the sun.

Key words: Body temperature regulation; Hair; Running; Solar radiation; Velocity..

Resumo – O objetivo do presente estudo foi avaliar os efeitos do cabelo da cabeça humana no desempenho e na resposta termorregulatória durante 10 km de corrida ao ar livre em homens saudáveis. Doze saudáveis do sexo masculino ($29,5 \pm 3,7$ anos, $174,9 \pm 4,3$ cm, $72,7 \pm 3,2$ kg e VO_{2max} $44,6 \pm 3,4$ ml.kg⁻¹.min⁻¹) participaram de 2 corridas de 10km separadas por 7 dias de intervalo em ritmo auto regulado: 1) HAIR- voluntários correram com seus cabelos intactos, 2) NOHAIR- voluntários correram após terem seus cabelos totalmente raspado. A velocidade média da corrida foi calculada a cada série de 2 km. Temperatura retal, frequência cardíaca e índice de estresse fisiológico foram medidos antes e depois dos 10 km da corrida e no fim de cada 2 km. Taxa de armazenamento de calor foi medida a cada 2 km. Além disso, o estresse ambiental (WBGT) foi medido a cada 10 min. A velocidade de corrida ($10,9 \pm 1$ e $10,9 \pm 1,1$ km.h⁻¹), frequência cardíaca (183 ± 10 e 180 ± 12 bpm), temperatura retal ($38,82 \pm 0,29$ e $38,81 \pm 0,49^\circ\text{C}$), índice estresse fisiológico (9 ± 1 e 9 ± 1) e taxa de armazenamento de calor ($71,9 \pm 64,1$ e $80,7 \pm 56,7$ Wm⁻¹), não foi diferente entre as situações HAIR e NOHAIR, respectivamente ($p > 0,05$). Não houve diferença no WBGT entre HAIR e NOHAIR ($24,0 \pm 1,4^\circ\text{C}$ e $23,2 \pm 1,5^\circ\text{C}$, respectivamente; $p = 0,10$). Os resultados sugerem que raspar o cabelo da cabeça não altera a velocidade da corrida e as respostas termorregulatórias durante 10 km de corrida sob o sol.

Palavras-chave: Cabelo; Corrida; Radiação solar; Regulação da temperatura corporal; Velocidade.

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INTRODUCTION

Citizens of tropical countries usually perform physical activities outdoors, mainly in hot environments. The endurance performance of humans is known to be affected by many factors, including dehydration¹, substrate depletion², accumulation of metabolites³⁻⁴, and heat storage⁵. Outdoor physical activity, especially in hot environments, may increase the physiological strain imposed on the human body due to the solar radiation. During outdoor exercise, the amount of heat gained through solar radiation is added to the heat produced by natural metabolism, causing an increase in body temperature. Nielsen et al.⁶ reported a higher heart rate, oxygen consumption and sweat rate during exercise under solar radiation when compared to exercise performed under a sunshade.

Human body temperature can reach hyperthermic levels during exercise, which represents a critical situation for brain function and results in early fatigue⁷. Studies have shown the importance of head temperature for exercise performance⁸. Cooling the head by sprinkling water at 4°C during submaximal exercise in a hot and dry environment was found to reduce the rate of perceived exertion and heart rate⁹. The use of headwear to protect the head against radiation decreased physiological stress levels during submaximal exercises¹⁰.

A previous study¹¹ showed that the head hair may play an important role by protecting the head from solar radiation, with consequent lower autonomic thermoregulatory responses. In that study, Coelho et al.¹¹ observed that shaved head hair resulted in a higher sweat rate during a one-hour submaximal treadmill exercise (50% $\text{VO}_{2\text{max}}$) under solar radiation compared to the intact hair condition, suggesting greater physiological strain in the absence of head hair. Increased physiological stress has been shown to compromise exercise performance^{7,12,13}. However, it is unknown whether the higher physiological stress seen in the shaved hair condition impairs outdoor running performance, a situation in which the amount of heat gained through solar radiation is added to the heat produced by an increased metabolism during exercise. Investigation of this issue using an outdoor methodological approach such as the protocols described by Ferreira-Junior et al.¹⁴ and Borba et al.¹⁵ is important because most athletes and subjects compete or train in outdoor environments. Thus, the effects of head hair on outdoor running performance need further investigation.

Therefore, the aim of the present study was to evaluate the effects of human head hair on performance and thermoregulatory responses during 10-km outdoor running in healthy men. We hypothesized that running performance would be impaired when subjects run with shaved hair. According to Coelho et al.¹¹, the presence of hair is a natural barrier that protects the head from solar radiation and promotes lower environmental heat gain, thus reducing autonomic thermoregulatory responses and physiological strain during exercise. This lower physiological strain may increase running performance.

METHODOLOGICAL PROCEDURES

Subjects

The present study was approved by the Research Ethics Committee of the Federal University of Minas Gerais (ETIC 297/08). The subjects were informed about the objectives and risks of the study and provided written informed consent prior to commencement of the study. The sample size was determined with the GPower program (version 3.1.2; Franz Faul, Universität Kiel, Germany) taking into account running velocity and the following design specifications: $\alpha = 0.05$; $(1-\beta) = 0.8$; effect size $f = 0.35$; test family = F test, and statistical test = repeated measures ANOVA, within-between interaction¹⁶. According to these specifications, the estimated sample size was 12 subjects. The subjects were recruited through folders and advertising banners distributed around the university campus. Thirteen subjects, naturally acclimated to tropical weather (latitude 19.5° S, longitude 43° W), were initially recruited 5 months prior to data collection and then included considering the inclusion criteria. The criteria for inclusion were subjects considered healthy and fit by the PAR-Q questionnaire¹⁷, participation in running exercise at least 2 days per week for 6 months prior to the study, and a hair length of at least 6 cm in the upper central head region, measured from 10 randomly chosen threads. Hair type was standardized using a maximum ratio of 0.6 between the extended and relaxed status of a single strand. One subject was excluded because he did not complete the study protocol due to knee injury. The data of 12 young males (mean \pm SD: age 29.5 \pm 3.7 years; height 174.9 \pm 4.3 cm; body mass 72.7 \pm 3.2 kg; body surface area 1.9 \pm 0.1 m²; $\Sigma_{\text{skinfolds}}$ 96 \pm 33 mm; $\text{VO}_{2\text{max}}$ 44.6 \pm 3.4 mL O₂·kg⁻¹·min⁻¹, and running performance 11.5 \pm 1.1 km·h⁻¹) were included in the study.

Experimental design

Two days after obtaining the physical assessments, the subjects were asked to visit the laboratory on three occasions at intervals of 7 days. The first visit consisted of familiarization to the outdoor 10-km running time trial. After this period, the volunteers participated in two experimental conditions always in the same order: 1) HAIR subjects ran with their natural head hair; 2) NOHAIR subjects ran after their hair had been totally shaved. The subjects were asked to let their head hair grow for 5 months to reach the required length, which did not allow us to perform a fully randomized experiment. Before the second experimental condition, the hair was carefully shaved and all subjects reported to feel comfortable and to have no itching or head skin problems. In both experimental trials, the volunteers performed a 10-km running time trial that was divided into 5 sets of 2 km each, with 2 min of rest between sets in order to assess rectal and skin temperatures, heart rate and physiological strain index. Additionally, the rate of heat storage was measured every 2 km. The exercises were performed outdoors under solar radiation on a grass running track at an interval of

7 days. After each lap (200 m), the participants received verbal feedback regarding the number of laps remaining to finish the trial.

The experiment was always carried out at the same time of the day, between 10:00 and 15:00 h, to avoid circadian influences. The subjects wore shorts, socks and running shoes and were instructed to avoid extenuating physical activity, caffeine, alcoholic beverages, tobacco and medications 24 h prior to the experiment and on the day of the experiment. The hydration status of the subjects was verified approximately 30 min before the run with a refractometer previously calibrated with distilled water (JSCP, Uridens®, São Paulo, Brazil). The upper limit for urine specific gravity, which could lead to a subject's exclusion from the experiment, was 1.030. In order to ensure adequate hydration, the subjects were instructed to drink water according to their thirst 30 min prior to the exercise trials. The subjects received water *ad libitum* throughout the experiments and the ingested volume was recorded. In the HAIR and NOHAIR conditions, the volunteers were prepared for the run while sitting on a chair under an umbrella. The heart rate monitor was placed and spots for skin temperature measurement were marked. The data were collected between September and November, a period that is characterized by hot and humid weather. Previous studies have used similar experimental designs^{14,15}.

Measurements

Height (cm) and body mass (kg) were measured with a stadiometer (Filizola®, São Paulo, Brazil, ± 0.5 cm) and a digital weight scale (Filizola® MF-100, ± 0.02 kg), respectively. For $S_{\text{skinfolds}}$, seven sites were measured (triceps, subscapular, pectoral, subaxillary, abdominal, suprailiac, and mid-thigh) with a caliper (Lange®, Cambridge, MD, USA, precision: 1 mm). The body surface area was calculated from weight and height as described by DuBois and DuBois¹⁸. A 1600-m race was used to indirectly determine maximal oxygen uptake ($VO_{2\text{max}}$)¹⁹.

Running velocity (V_{race}) was calculated from each 2-km running time (Cronobio, SW2018, São Paulo, Brazil). The baseline test/retest reliability coefficient (ICC) for V_{race} was 0.90. Heart rate (HR) was measured with a telemetry heart rate monitor (Polar Vantage NV, Kajaani, Finland). Core temperature (T_{rectal}) was measured with a rectal probe (Yellow Spring Instruments, Series 400, Yellow Springs, OH, USA), inserted 12 cm above the anal sphincter after the subjects were weighed naked. Skin temperature was measured at three sites with an infrared thermometer (Fluke 566, Everett, WA, USA). The previously marked sites were the chest (T_{chest} , mid-point between the nipple and sternum), arm (T_{arm} , lateral area, superior), and thigh (T_{thigh} , anterior area, central). Mean skin temperature was calculated according to Roberts et al.²⁰: $T_{\text{skin}} = (0.43 T_{\text{chest}}) \times (0.25 T_{\text{arm}}) \times (0.32 T_{\text{thigh}})$. Mean body temperature was calculated according to Marino et al.¹: $T_{\text{body}} = 0.8 T_{\text{rectal}} + 0.2 T_{\text{skin}}$.

The physiological strain index (PSI) was calculated according to Moran et al.²¹: $PSI = 5 (T_{\text{rectal } t} - T_{\text{rectal } 0}) (39.5 - T_{\text{rectal } 0})^{-1} + 5 (HR_t - HR_0) (180 -$

$HR_0)^{-1}$, where $T_{rectal t}$ and HR_t are the rectal temperature and heart rate measured at the end of each 2-km running, and $T_{rectal 0}$ and HR_0 are the baseline values.

Heat storage (ΔS) was measured according to Marino et al.¹: $\Delta S (W.m^2) = 3480 (W_{body} \cdot \Delta T_{body} / S) BSA^{-1}$, where $3480 J \cdot ^\circ C^{-1} \cdot kg^{-1}$ is the specific heat of the body tissue, W_{body} is the body weight in kg, ΔT_{body} is the change in body temperature in degree Celsius, S is the time in seconds, and BSA is the body surface area in m^2 .

Sweat rate was calculated as the difference in body mass corrected for body surface area and divided by the time elapsed between the body mass measurements.

Thermal environmental stress was evaluated every 10 min throughout the run. Dry, wet and globe temperatures were measured with an appropriate device (RSS-214, Wibget, Concord, USA). The wet bulb globe temperature index (WBGT) was estimated as follows: $WBGT = 0.7 \text{ wet temperature} + 0.2 \text{ dry temperature} + 0.1 \text{ globe temperature}$ (RSS-14 Wibget[®], $0.1^\circ C$ precision). Wind velocity was measured with an anemometer (Turbo MeterTM, Davis Instruments, Hayward, CA, USA).

Statistical analysis

The data are reported as the mean \pm standard deviation. Normal distribution, homogeneity and sphericity of the data were confirmed using the Shapiro-Wilk test, Levene's test and Mauchly's test, respectively. Two-factor (hair and distance) repeated measures ANOVA was used to evaluate differences in V_{race} , mean HR, T_{rectal} , PSI, ΔS , dry, wet and globe temperatures, WBGT, wind velocity and luminosity between the HAIR and NOHAIR conditions. In case of significant differences, a Tukey post-hoc was used. The paired Student t-test was applied to analyze sweat rate and ingested water. Two-step cluster analysis was used to create homogenous groups according to mean V_{race} alterations. The level of statistical significance was set at $p < 0.05$. Cohen's f and d values were calculated according to Beck¹⁶ and Cohen²². Cohen's ranges of 0.1, 0.25, and 0.4 were used to define small, medium and large f values, respectively, for V_{race} , mean HR, T_{rectal} , PSI and ΔS . Cohen's ranges of 0.2, 0.5 and 0.8 were used to define small, medium and large d values, respectively, for sweat rate and ingested water^{16,22}.

RESULTS

V_{race} did not differ between the HAIR and NOHAIR conditions ($F=0.007$, $p=0.94$, Figure 1) and the condition effect size for V_{race} was small ($f=0.07$). However, V_{race} decreased throughout the run ($F=17.6$, $p < 0.001$). There was no significant interaction between condition and distance covered for V_{race} ($F=1.69$, $p=0.17$). Figure 2 shows the individual mean running velocities in the HAIR and NOHAIR conditions. Two clusters were formed for mean V_{race} alterations: 1) HAIR responders ($n=6$): $3.58 \pm 3.02\%$, and 2)

NOHAIR responders (n=6): $-3.42 \pm 1.56\%$. Six subjects had higher mean V_{race} in the HAIR condition, whereas six other volunteers had higher mean V_{race} in the NOHAIR condition.

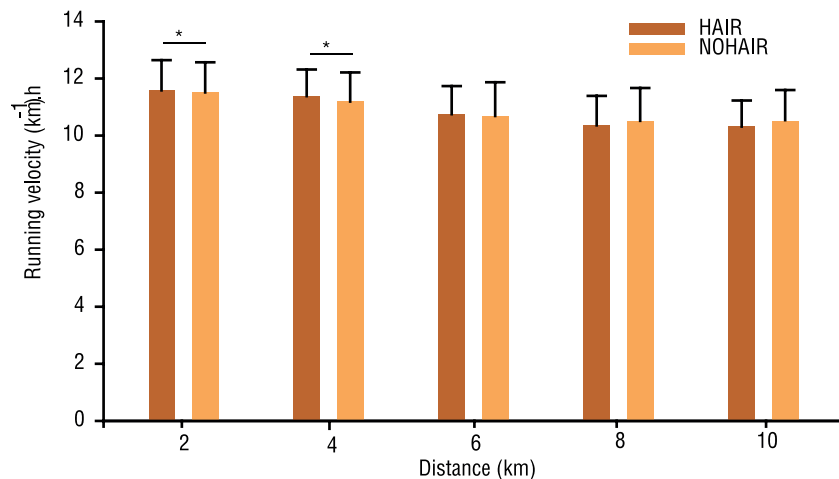


Figure 1. Mean \pm SD of running velocity in the HAIR and NOHAIR conditions. (*) $p < 0.05$ compared to 6, 8 and 10 km.

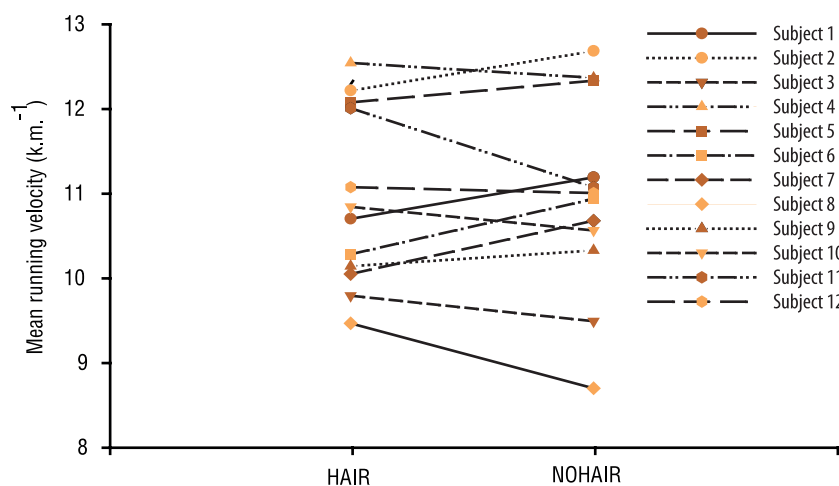


Figure 2. Individual mean running velocity in the HAIR and NOHAIR conditions.

HR did not differ between the HAIR and NOHAIR conditions ($F=2.1$, $p=0.17$, Figure 3) and the condition effect size for HR was small ($\eta^2=0.04$). However, HR increased until the 4th km, remaining constant thereafter ($F=580.7$, $p<0.001$). Moreover, there was no significant interaction between condition and distance covered for HR ($F=0.57$, $p=0.81$). No significant interaction was observed between condition and distance covered ($F=1.91$, $p=0.10$), and there was no main effect of condition ($F=0.15$, $p=0.15$) on T_{rectal} (Figure 4). Additionally, the condition effect size for T_{rectal} was small ($\eta^2=0.07$). On the other hand, there was a significant main effect of distance covered on T_{rectal} ($F=162.2$, $p<0.001$). The T_{rectal} increased at the beginning of running and remained constant after the 6th km ($p<0.01$).

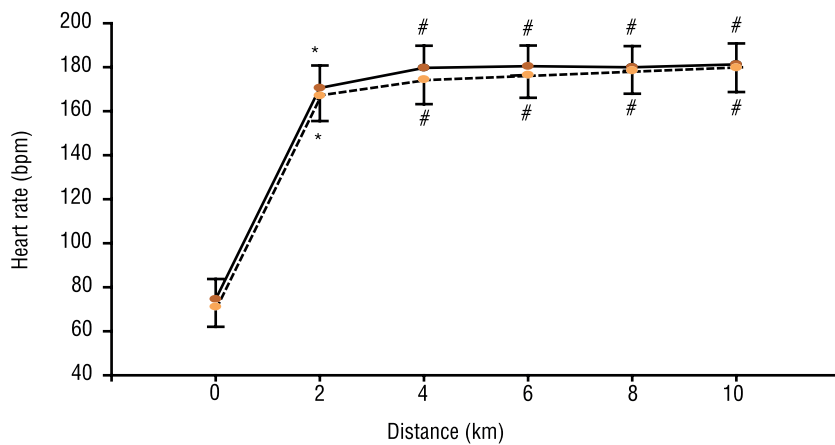


Figure 3. Mean \pm SD of heart rate in the HAIR and NOHAIR conditions. (*) $p < 0.05$ compared to 0 km. (#) $p < 0.05$ compared to 0 and 2 km.

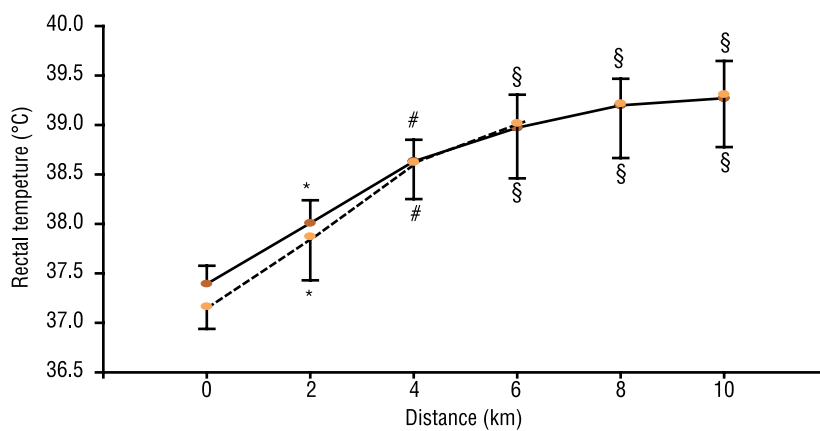


Figure 4. Mean \pm SD of rectal temperature in the HAIR and NOHAIR conditions. (*) $p < 0.05$ compared to 0 km. (#) $p < 0.05$ compared to 0 and 2 km. (§) $p < 0.05$ compared to 0, 2 and 6 km.

No significant interaction was observed between condition and distance covered ($F=0.22$, $p=0.92$), and there was no main effect of condition ($F=1.28$, $p=0.23$) on the heat storage rate (Table 1). Additionally, the condition effect size for the heat storage rate was small ($\eta^2=0.09$). However, there was a significant main effect of distance covered on heat storage ($F=9.78$, $p < 0.001$). The heat storage rate decreased after the 4th km ($p < 0.001$). PSI did not differ between experimental conditions ($F=0.02$, $p=0.9$), but increased throughout the run ($F=60.9$, $p < 0.001$) (Table 1). Furthermore, the condition effect size for PSI was small ($\eta^2=0.03$), and there was no significant interaction between condition and distance covered ($F=0.25$, $p=0.91$).

Table 1. Mean \pm SD of physiological strain index and heat storage rate in the HAIR and NOHAIR conditions.

		Distance (km)				
		2	4	6	8	10
Heat storage rate ($W \cdot m^{-2}$)	NOHAIR	140.9 \pm 60.1*	131.1 \pm 61.0*	85.9 \pm 52.3 [†]	28.0 \pm 51.4	17.1 \pm 58.4
	HAIR	97.4 \pm 49.4*	109.8 \pm 52.6*	63.1 \pm 83.0 [#]	62.4 \pm 66.8	15.3 \pm 63.5
PSI	NOHAIR	6.3 \pm 1.3	8.1 \pm 1.1 [†]	9.0 \pm 1.4 [§]	9.6 \pm 1.4 [‡]	9.9 \pm 1.6 [‡]
	HAIR	6.4 \pm 0.9	8.1 \pm 0.9 [†]	8.9 \pm 0.9 [§]	9.4 \pm 0.9 [‡]	9.8 \pm 1.1 [‡]

PSI, physiological strain index. (*) $p < 0.05$ compared to 6, 8 and 10 km. (#) $p < 0.05$ compared to 8 and 10 km. (†) $p < 0.05$ compared to 2 km. (§) $p < 0.05$ compared to 2 and 4 km. (‡) $p < 0.05$ compared to 2, 4 and 6 km.

The sweat rate (HAIR: 8.33 ± 1.15 and NOHAIR: 8.56 ± 1.59 g.min⁻¹) and ingested water (HAIR: 0.90 ± 0.49 and NOHAIR: 0.91 ± 0.45 ml) did not differ between the experimental conditions ($t=-0.68$, $p=0.51$; $t=-0.19$, $p=0.82$, respectively). In addition, a small condition effect size was found for sweat rate and ingested water ($d=0.16$ and $d=0.02$, respectively).

There was no significant interaction between condition and distance covered for the environmental variables (WBGT: $F=0.66$, $p=0.68$; wind velocity: $F=0.59$, $p=0.74$). There was also no significant main effect of condition on WBGT (HAIR: $24.0 \pm 1.4^{\circ}\text{C}$ and NOHAIR: $23.2 \pm 1.5^{\circ}\text{C}$, $F=2.93$, $p=0.11$). However, wind velocity was higher in the HAIR condition (1.7 ± 0.9 m.s⁻¹) when compared to the NOHAIR condition (0.9 ± 0.3 m.s⁻¹) ($F=15.67$, $p=0.002$).

DISCUSSION

This study evaluated the effects of human head hair on performance and thermoregulatory responses during 10-km outdoor running in healthy men. The main finding of this study was the similar V_{race} in the HAIR and NOHAIR conditions ($p=0.94$), with six subjects presenting a higher mean V_{race} in the HAIR condition, whereas six other volunteers had a higher mean V_{race} in the NOHAIR condition. Furthermore, the treatment effect size for V_{race} , mean HR, T_{rectal} , PSI, ΔS , sweat rate, and hydration status was small^{16,22}. The present results can be explained by the physiological similarities of the trials (T_{rectal} , HR, PSI, ΔS , sweat rate, hydration status), suggesting that the self-paced protocol may allow minor adjustments in running velocity that would balance the supposed, if any, protective effect of intact head hair observed in a previous study¹¹.

It was hypothesized that the presence of hair would serve as a natural barrier that could protect the head from solar radiation and promote lower environmental heat gain, reducing the physiological strain during exercise. However, despite a higher wind velocity in the HAIR condition compared to NOHAIR, V_{race} did not differ between conditions. The presence of wind is known to affect heat loss by contributing to sweat evaporation²³, suggesting that hair may have acted as an insulator layer to trap heat. This hypothesis is supported by Rasch and Cabanac⁸ who found impaired heat loss in subjects using a wool hat during indoor submaximal exercise.

To the best of our knowledge, only one study evaluated the effect of head hair on thermoregulatory variables during exercise. Coelho et al.¹¹ observed that shaved head hair resulted in a higher sweat rate during a one-hour treadmill exercise at a fixed intensity (50% $\text{VO}_{2\text{max}}$) under solar radiation compared to the intact hair condition, suggesting greater physiological strain in the absence of head hair. The difference between the present results and the previous study may be due to: 1) the volunteer's hair type, 2) the subject's aerobic capacity, 3) the type of exercise performed by the subjects, and 4) thermal stress. In the previous study, the subjects' hair was curlier (loose/stretched thread ratio < 0.4 versus 0.60 in the present

study). We hypothesize that curlier hair provides more protection against solar radiation than straight hair because it increases the layer of protection between the head's skin and the environment, permitting air flow through the hair. This, in turn, would slow down warming of the head and increase the dissipation of heat by convection. Regarding aerobic capacity, the VO_{2max} of the volunteers of the present study was lower than that reported in the study of Coelho et al.¹¹ (44.6 ± 3.4 vs. 56.2 ± 5.3 mL O_2 . kg⁻¹.min⁻¹). It is known that aerobic capacity affects sweat production and exercise performance²⁶. Additionally, the previous study did not report the physical status of the subjects.

Considering the type of exercise, self-paced exercise in the heat permits to evaluate the responses to exercise through the interaction of performance regulation mechanisms with the environment without the dissociation of one or more fatigue variables, as established for fixed-intensity exercise^{4,15,25}. Therefore, minor physiological changes may not be sufficient to elicit a higher exercise intensity during self-paced exercise^{14,15}. In this respect, a recent study¹⁴ showed that a decrease of 1.7°C in head temperature during self-paced outdoor running was not sufficient to alter running velocity. Additionally, an altered PSI did not affect 10-km outdoor running performance¹⁵.

With respect to thermal stress, it is important to note that Coelho et al.¹¹ reported greater thermal stress than that observed in the present study (28.6 ± 1.6 vs. 23.6 ± 1.4 °C, respectively). This suggests that the environmental characteristics of the present study were not stressful enough to elicit the same thermoregulatory responses. However, although the WBGT in the present study was not extreme, the environmental stress caused by it should not be disregarded. According to ACSM²⁷, a WBGT ranging from 23 to 24°C can increase the risk of hyperthermia in subjects non-acclimatized to the heat. Moreover, two other studies reported WBGT of 23 to 26°C^{14,15} during self-paced outdoor running, in agreement with the WBGT found in the present study. Thus, a WBGT between 23 and 24°C renders heat an important factor in prolonged exercises.

The reduction in V_{race} observed throughout running in both the HAIR and NOHAIR condition supports some recent findings suggesting that an anticipatory control mechanism during exercise would ensure the maintenance of homeostasis and avoid flaws in the physiological systems throughout the constant adjustment of intensity during exercise with gradual heating^{25,28,29}. The present study has some limitations. The main limitation was the difference in wind velocities between conditions. Furthermore, our data only apply to the specific HAIR and NOHAIR conditions, exercise, and environmental stress employed.

CONCLUSION

This study showed that the presence of head hair does not alter performance or thermoregulatory responses during 10-km outdoor running in healthy

men. Further studies on this topic are necessary to determine the effects of longer distances or exercise durations, higher wind velocities, extreme temperatures, and different hair types and sizes on an individual's performance and physiological responses during exercise.

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