Head Hair Reduces Sweat Rate During Exercise Under the Sun

Authors

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Key words
- heat
- temperature
- solar radiation
- thermoregulation
- sweating

Abstract

The purpose of this study was to evaluate the effects of human head hair on thermoregulation during exercise carried out under solar radiation. 10 healthy male subjects (mean ± SD: 25.1 ± 2.5 yr; height: 176.2 ± 4.0 cm; weight: 73.7 ± 6.7 kg; $\dot{V}O_{2max}$ 56.2 ± 5.3 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$) took part in 2 1 h-long trials of continuous exercise on a treadmill at 50% $\dot{V}O_{2max}$ under solar radiation that were separated by at least 2 days. Whereas for the first trial they retained their natural head hair (HAIR), in the second trial their hair was totally shaved (NOHAIR). Several properties were measured, including environmental heat stress (Wet Bulb Globe Temperature index – WBGT, °C), heart rate, rectal temperature, skin temperature, head temperature, and global sweat rate. The main findings were that whereas there was a lower sweat rate in the HAIR condition (HAIR: 7.08 ± 0.79 vs. NOHAIR: 7.67 ± 0.79 $g \cdot m^{-2} \cdot min^{-1}$; $p = 0.03$), there were no significant differences in any of the other variables between the HAIR and NOHAIR trials. In conclusion, the presence of head hair resulted in a lower sweat rate.

Introduction

The fur of an animal protects it against a variety of environmental conditions, such as solar radiation, humidity, cold, wounds, and insect bites [32]. The reduced body hair in Homo sapiens has been attributed to many different factors, including sexual selection [9], a supposed aquatic stage [16], hunting habits [3], clothing [22], bipedalism [40,41], adaptation against ectoparasites [32] and parental selection [18]. Wheeler [40,41] proposed that hypotrophy of the human body hair could promote more efficient sweating and superior body cooling under heat stress and exercise conditions. However, a clear explanation for the unique maintenance of human head hair (HH) during evolution has not yet been provided, and the thermoregulatory effects of HH during exercise have never been investigated.

Human body temperature increases during exercise, and it may reach hyperthermic levels in hot environments; this represents a critical situation for cerebral function, and results in anticipated fatigue and exhaustion [13,15,25]. The human brain temperature results from a balance between heat production, gain and dissipation, and brain heat loss depends mainly on cerebral blood flow. Both at rest and during exercise, either with or without hyperthermia, the brain has a higher temperature (at least 0.2 °C higher) than the body core [30]. During outdoor exercise, the temperatures of the head hair, skin and bones could be influenced by solar radiation and environmental temperatures, which could in turn influence brain temperature [6]. However, due to the absence of direct experimental studies, the effect of these interactions remains unknown [19].

We hypothesized that the presence of HH as a natural external barrier could protect the head from solar radiation and promote a lower absorption of environmental heat; this could reduce the thermoregulatory autonomic responses and physiological strain during exercise. The aim of the present study was to measure the effects of HH on physiological responses that were measured during a running trial that was conducted under solar radiation.

Methods

Participants

This study has been performed in accordance with the ethical standards of the IJSM [17] and

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approved by the Human Ethics Research Committee of the Federal University of Minas Gerais. 10 healthy men (mean ± SD: age 25.1 ± 2.5 yr; height 176.2 ± 4.0 cm; weight 73.7 ± 6.7 kg; body surface area $1.89 \pm 0.09\,m^2$; $\Sigma_{skinfolds}$ 104.0 ± 34.8 mm; body fat 13.6 ± 2.8 %), physically fit ($\dot{V}O_{2max}$ $56.2 \pm 5.3\,mLO_2 \cdot kg^{-1} \cdot min^{-1}$), and inhabitants of a tropical region (latitude 19.5° S and longitude 43° W), volunteered for the study. The subjects were informed of the purpose, procedures, possible discomforts, risks, and benefits of the study prior to signing an informed written consent. One of the main inclusion criteria was that they were required to have a layer of curly hair of at least 3 cm length in the upper central head region. Hair type was standardized using a maximum value of 0.4 for the ratio between the extended and relaxed status of a single strand. The volunteers were instructed to refrain from the use of tobacco, caffeine, alcoholic beverages, and drugs, and required to abstain from physical activities for 24 h before the experiments. They were also requested to sleep for at least 8 h on the night prior to the study. To ensure adequate hydration, all subjects were instructed to drink 500 mL of water 2 h before the exercise sessions commenced.

Descriptive measurements and experimental trials

Height (cm) and body mass (kg) were measured with a stadiometer (Filizola®; Sao Paulo, SP, Brazil, precision of 0.5 cm). and a digital weight scale balance (MF-100 Filizola®; Sao Paulo, SP, Brazil, precision of 0.02 kg), respectively. For body fat and $\boldsymbol{\Sigma}_{skinfolds}$, 9 sites were measured (biceps, triceps, subscapular, pectoral, subaxilla, abdominal, suprailiac, mid-thigh, and medial calf) with a plicometer (Lange®; Cambridge, USA, precision of 1 mm) and body surface area was calculated from mass and height as described by DuBois and DuBois [11]. During exercise until fatigue on an electronically paced treadmill (ST65 Quinton Med-Track; USA), maximal oxygen uptake ($\dot{V}O_{2max}$) was determined using an open-circuit gas analyzer (BIOPAC Systems; Inc, USA) calibrated previously, in a thermoneutral environment (22.1 ± 0.3 °C 60.9 ± 3.2 % RH) using the Bruce protocol [2].

After the physical test, the subjects took part in 2 experimental sessions of continuous outdoor exercise on the same treadmill at 50 % of $\dot{V}O_{2max}$ under the sun for 1 h. These sessions were separated by at least 2 days. In the first session, the volunteers retained their natural hair (HAIR), and in the second experimental situation their hair was totally shaved (NOHAIR) and they were submitted to the same procedures as in the first experimental situation. The hair was carefully shaved and weighed (mean hair weight was 55.05 ± 16.7 g); thereafter, all volunteers reported feeling comfortable and reported no itching or skin problems.

To reduce circadian cycle effects and to maximize external temperature values and environmental radiation, each trial was performed outdoors and at the same time of the day (11:00–13:00 h). The subjects wore shorts, socks, and athletic shoes. During exercise, they had access to water *ad libitum*, and the ingested volumes were noted.

Environmental conditions and physiological measures

The environmental heat stress was measured using the WBGT equipment (RSS-214 WIBGET®; USA, precision of 0.1 °C). This indicated the Wet Bulb Globe Temperature index (WBGT) [42] in °C, which was estimated from the globe temperature (T_g), wet bulb temperature (T_w), and dry bulb temperature (T_d) as follows: $WBGT = 0.7T_w + 0.2T_g + 0.1T_d$. An electric fan (SL40 Arno®; São Paulo, SP, Brazil), which was directed towards the head and torso, provided artificial ventilation (wind speed: $1.45 \pm 0.01\,m \cdot s^{-1}$).

Urine specific gravity was measured (JSCP Uridens; São Paulo, SP, Brazil) to ensure that the subjects were properly hydrated for the protocols; this value should be lower than 1 030 in both experimental situations. Hydration status was similar prior to exercise trials (HAIR: 1 024.4 ± 1.8 vs. NOHAIR: 1 024.8 ± 1.8). Subjects were asked to insert a rectal thermometer (YSI, series 4400–4491-E, Yellow Springs Instruments, OH, USA) 12 cm beyond the anal sphincter to register rectal temperature (T_{re}). A heart rate monitor (Polar Vantage; NV, Kempele, Finland) was attached to their chest, and monitored continuously. Skin temperature was measured at the top of the head, forehead, chin, chest, arm and thigh, using thermo probes (Probe model 409-B Yellow Springs Instruments; OH, USA). Mean skin temperature (T_{sk}) was calculated using the following equation [34]: $T_{sk} = 0.43$ (chest) + 0.25 (arm) + 0.32 (thigh). The head temperature (T_{Head}) was calculated using the average of head top, forehead and chin temperatures. For the HAIR condition, the temperature probe at the top of the head was attached directly onto the scalp. All continuous variables were recorded at 4-min intervals.

To estimate sweat rate (SR), subjects were weighed naked using a digital weight scale balance (MF-100 Filizola®; São Paulo, SP, Brazil, precision of 0.02 kg) before and after the exercises. SR was taken to be the body weight variation (uncorrected for respiratory and metabolic losses) divided by the time between measurements and corrected for body surface area and water intake during the trials. Subjects were then transferred to a treadmill located outdoors to begin exercise.

Statistical analysis

Results are presented as mean (M) ± standard deviations (SD) values. 2-way ANOVA with repeated measures was performed to compare all continuous variables (environmental variables, HR, T_{re}, T_{head} and T_{sk}). The value of F was used to test differences between the curves. The paired Student's t-test was used to compare SR and water intake. Significance was accepted at the level of $p < 0.05$. All analyses were performed using SPSS (version 15.0).

Results

▼

The thermal environmental values (T_w and WBTG) were higher in the HAIR condition. There were no differences in the T_d, T_g and relative humidity (RH) values between the trials (▶ **Table 1**).

Although there was no difference in resting T_{re}, the resting HR was greater in the HAIR condition (HAIR: 78.1 ± 11.0 vs. NOHAIR: $65.1 \pm 11.0\,b \cdot min^{-1}$; $p < 0.05$). During exercise, there were no differences in HR, T_{re}, T_{head} or T_{sk} values between the trials (▶ **Table 1**). Moreover, no differences were observed in forehead temperature (HAIR: 34.0 ± 1.8 vs. NOHAIR: 33.7 ± 2.2 °C; $F = 0.18$, $p = 0.68$) and chin temperature (HAIR: 32.8 ± 1.4 vs. NOHAIR: 32.7 ± 1.2 °C; $F = 0.02$, $p = 0.87$). However, the top head temperature was greater in the HAIR condition (HAIR: 40.2 ± 2.4 vs. NOHAIR: 38.0 ± 2.3 °C; $F = 5.32$, $p = 0.03$). Water intake did not differ between trials, but the p-value (0.07) showed a tendency towards a higher water intake in the NOHAIR condition (▶ **Table 1**).

Despite a greater environmental and local (top of the head) thermal load in the HAIR condition, the SR was lower (HAIR:

	HAIR	NOHAIR	Significance			
environmental variables						
WBGT (°C)	29.3 ± 1.8*	27.9 ± 1.6	**p = 0.04**	**F = 4.91**	DF = 135	n^2 = 0.22
dry bulb temperature (°C)	35.5 ± 4.2	34.2 ± 2.6	p = 0.32	F = 1.04	DF = 135	n^2 = 0.05
wet bulb temperature (°C)	24.0 ± 1.5*	22.4 ± 1.8	**p = 0.03**	**F = 5.35**	DF = 135	n^2 = 0.23
globe temperature (°C)	44.9 ± 5.6	43.6 ± 3.6	p = 0.44	F = 0.61	DF = 135	n^2 = 0.04
relative humidity (%)	41.0 ± 15.0	36.3 ± 11.0	p = 0.40	F = 0.83	DF = 135	n^2 = 0.05
physiological measures						
heart rate ($b \cdot min^{-1}$)	142.3 ± 9.0	146.8 ± 9.0	p = 0.7	F = 0.14	DF = 135	n^2 = 0.01
rectal temperature (°C)	37.9 ± 0.2	37.8 ± 0.2	p = 0.4	F = 0.69	DF = 135	n^2 = 0.04
head temperature (°C)	35.5 ± 0.1	35.1 ± 0.2	p = 0.6	F = 0.30	DF = 135	n^2 = 0.02
mean skin temperature (°C)	34.5 ± 0.9	34.2 ± 0.5	p = 0.45	F = 0.59	DF = 135	n^2 = 0.03
water intake (mL)	255 ± 300	373 ± 270	p = 0.07	–	DF = 19	n^2 = 0.2

WBGT: Wet Bulb Globe Temperature index. DF: Degrees of Freedom; n^2: Effect Sizes. * $p < 0.05$ indicates significant differences between 2 trials

Table 1 The average values of several environmental variables and physiological measures during continuous exercise, with and without head hair, under solar radiation.

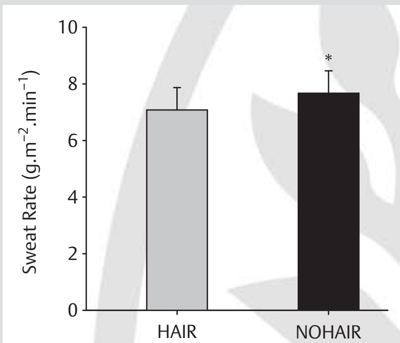

Fig. 1 Sweat rate during continuous exercise with and without head hair under solar radiation. * Significant difference between trials, $p < 0.05$, Paired Student's t-test ($p = 0.03$). Degrees of Freedom (DF) = 19; Effect Size (n^2) = 0.34.

7.08 ± 0.79 vs. NOHAIR: $7.67 \pm 0.79\,g \cdot m^{-2} \cdot min^{-1}$; $p = 0.03$) during the HAIR condition (Fig. 1).

Tests of analysis of covariance (ANCOVA) using WBGT as co-variable were performed for all physiological variables. The results obtained by ANOVA were similar, except for top head temperature, which did not affect the main results or the discussion. Therefore, only data from the ANOVA are shown in order to make the text simpler.

Discussion

The main finding of the present study was the lower SR during exercise under solar radiation with intact HH. Considering that the other physiological variables did not change between trials, the lower SR in the HAIR situation provides support to the hypothesis that HH has some protective effect against thermal stress. The protective effect may be a result of a possible shadow protective mechanism that absorbs part of the environmental heat and reduces the direct incidence of solar radiation on the scalp.

Although physical activities are commonly carried out in natural external environments, most of the thermoregulation studies in humans have been performed in artificial environmental chambers. Though it was possible to simulate a solar heat gain situation in our laboratory settings, we performed the study in an external environment to better represent the real situation of exercising under solar radiation. The experiments were performed only during sunny weather and when the minimum temperature requirements were met (at least 26.0 °C of WBGT). Nevertheless, as expected, the environmental factors measured during the present study showed some variation between trials (Table 1) [28].

The finding of greater SR in the NOHAIR condition ($p < 0.05$) (Fig. 1) suggests that during physical activity there is a higher autonomic response to enable the dissipation of heat, and that this may prevent hyperthermia and sustain performance [35, 38]. The thermal stimuli to the sweating response are both internal and skin temperature, and both of these can modulate variations in the sweat rate [8, 10, 26, 37]. However, the sweat rate can be influenced by exercise intensity [20, 21, 24, 44], environmental conditions [1, 4, 7, 13, 43, 45], hydration level [12, 14, 24, 36] and heat acclimation [23, 27, 29, 31]. Nevertheless, in the present study (with the exception of the greater WBGT in the HAIR situation) all of these influencing factors were the same between trials; this suggests that the absence of HH would be the only factor remaining to stimulate the higher SR in the NOHAIR situation.

In our study, the rest HR was greater in HAIR situation. This difference can be attributed to 1 or 2 factors: 1) higher environmental heat stress in HAIR [5] and/or 2) anxiety due to the beginning of experimental protocols, leading to vagal tone reduction [39]. However, after the first measurement, no differences were observed between exercise situations.

During the exercise trials, no differences were found in HR, T_{re}, T_{sk} and T_{head}, although due to the higher environmental temperature, the head top temperature was greater in the HAIR situation. Therefore, it is possible that this increased local temperature alone was not a sufficiently strong stimulus to account for differences between the physiological responses during exercise under solar radiation.

A previous study [33] found that the use of a headband and a woollen cap during exercise (23.4 ± 1.9 °C, 35 ± 10 % RH) resulted in reduced heat dissipation by increasing the humidity and limiting the vaporization. The present study was performed in an outdoor environment with greater temperature and humidity stress (Table 1) than the Rasch and Cabanac [33] study. Nevertheless, similar to the use of a cap, the maintenance of HH in the present study resulted in a lower physiological strain (as represented by the lower SR). It is possible that the structure of natural curly hair does not jeopardize aeration and sweat vaporization, while at the same time it reduces the solar radiation; this could result in a lower stress situation in the HAIR exercise condition. Even if the evaporation rate suffered some degree of impairment in the HAIR condition, it would be preferable to protect the head from direct solar radiation instead of exposing the scalp directly to the sun.

Nielsen et al. [28] studied the whole body protection from solar radiation during exercise where subjects cycled at a fixed power of 92 W and 60 revolutions per minute for 2 h. The first 60 min were performed under direct sunlight followed by 30 min protection with an umbrella that shadowed the entire body, and the remaining 30 min were conducted without the umbrella. It was observed that under shadow conditions HR, skin temperature, oxygen consumption and SR decreased, and increased on removal of the umbrella. There were no differences in T_{re} throughout the entire experiment. These results are similar to our observations of T_{re} and SR in the present study, and suggest that the hair may have played a protective role similar to the umbrella.

However, according to Wheeler, the maintenance of hair on the head does not only concern the area of the head that is shadowed [40,41] but the bipedalism hypothesis suggests that the shoulders should also be covered by hypertrophied hair. An interesting future study could involve analysing the possible thermoregulatory protective effect of hair colour and long curly hair that covers the shoulders in humans.

Ideally, the 2 experimental situations in the present study should be randomized between HAIR and NOHAIR conditions. Unfortunately, a randomized protocol would be very difficult as it would be necessary to perform the NOHAIR condition in the first trial in half of the subjects and then wait for the hair to grow again to fulfil the minimum requirements of the study's protocol. This process would require at least 6 months, and it could create additional problems with regards to controlling other variables, such as aerobic capacity, acclimation, healthy status and adherence to the project. Although it could constitute a study limitation, we expected that the training effect would reduce the stress of the second trial; however, we observed the opposite: the second (NOHAIR) condition showed a greater SR. Thus, we believe that the order of the trials did not affect the present results.

The present study suggests that HH maintenance could be associated with a protective mechanism that has persisted through natural selection. It can be hypothesized that if HH could exert some influence on scalp temperature, it would result in lower skull heat gain, and this in turn could produce a lower brain temperature during exercise under solar radiation.

In conclusion, the presence of head hair resulted in a lower sweat rate during exercise under solar radiation. Further studies on the role of HH in exercise tolerance should be carried out, especially in outdoor environments. Even considering the fact that sweat rate was the single variable to show a significantly different behaviour in the absence of head hair, the results reinforce the importance of further investigation on head protection during physical activity under solar radiation. Also, further studies should test if the use of special apparatus (caps, hats or helmets) can result in lower fatigue and increased sports performance under solar radiation.

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