Journal of Thermal Biology 77 (2018) 145–156

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Uncoupling psychological from physiological markers of heat acclimatization in a military context

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ARTICLE INFO

Keywords:
Heat acclimatization
Training
Military
Rectal temperature
Thermal discomfort
Rates of perceived exertion

ABSTRACT

Heat acclimatization may help personnel who travel to areas with a hot climate (WBGT > 27 °C), making them operationally more efficient and performant through improvements in physiological and psychological parameters. Their work-related physical activities may aid active heat acclimatization. However, it is unknown whether adding physical training to improve adaptation is effective, particularly if there is sufficient time for full acclimatization, classically reached after 15 days. Thirty French soldiers (Training group, T) performed a progressive and moderate (from three to five 8-min running sets at 50–60% of their speed at VO_{2max} with 4-min periods of active recovery in between) aerobic training program upon arriving at their base in United Arab Emirates (~40 °C and 20% RH). A control group (30 soldiers; No Training, NT) continued to perform only their usual outdoor military activities (~5 h d^{-1}). A field heat stress test (HST: three 8-min running sets at 50% of the speed at VO_{2max}) was performed before (D0), during (D10), and after (D15) the heat acclimatization period to assess physiological and psychological changes. An 8-km trial in battledress was then performed at D17. Although physiological modifications were mostly similar ($p < 0.001$ for all) for both groups (rectal temperature at the end of the HST: −0.58 ± 0.51 *vs* −0.53 ± 0.40 °C, HR at the end of the HST: −21 ± 12 *vs* −19 ± 9 bpm, and sweat osmolality: −47 ± 30 vs −26 ± 32 mOsmol.l^{-1} between D15 and D0 for T and NT groups, respectively), thermal discomfort (−31 ± 4 *vs* −11 ± 5 mm between D15 and D0, $p = 0.001$) and rates of perceived exertion (−3.0 ± 0.4 vs –1.4 ± 0.3 D15 and D0, $p = 0.001$) were much lower in the T than NT group during the HST. HST-induced modifications in facial temperature only decreased in the T group (−1.08 ± 0.28 between D15 and D0, $p < 0.001$). Moreover, there was a difference in perceived thermal discomfort during the 8-km trial (40 ± 20 *vs* 55 ± 22 mm for the T and NT groups, respectively, $p = 0.010$). Thus, a 15-day, low-volume training regimen during a mission in a hot and dry environment has a modest impact on physiological adaptation but strongly decreases the perceived strain of exertion and climate potentially via greater reductions in facial temperature, even during a classical operational physical task in a military context.

1. Introduction

The performance of physical activities in a hot environment is made easier and safer after a period of heat acclimation (repetitive artificial heat exposures; i.e. in a thermal room) or acclimatization (continuous environmental heat exposure) (Houmard et al., 1990; Cheung and McLellan, 1998; Garrett et al., 2009; Lorenzo et al., 2010, Lee, 2012). Sawka et al. (2011) considered a decrease in rectal temperature, heart rate (HR), and sweat osmolality and an increase in sweat loss to be the principal markers of complete physiological acclimation. These improvements may respect various patterns of adaptation. Thus, Périard et al. (2015) estimated that maximal decreases of core temperature (-4%) and HR (-20%) may be reached as soon as four and seven days, respectively, and the maximal increase of sweat loss (-15–20%) after 10 days. Another complementary, but less documented, aspect of a heat acclimation-induced improvement is the lowering of the perception of

Abbreviations: HR, heart rate; HST, heat stress test; NT, no training group; PSI, physiological strain index; RH, relative humidity; RPE, rate of perceived exertion; T, training group; VO_{2max}, maximal oxygen uptake; WBGT, wet bulb globe temperature

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https://doi.org/10.1016/j.jtherbio.2018.08.017
Received 14 June 2018; Received in revised form 23 August 2018; Accepted 23 August 2018
Available online 24 August 2018
0306-4565/

heat (Gibson et al., 2015; Charlot et al., 2017) and effort (Lui et al., 2014; Charlot et al., 2017) that may participate in the improvement of exercise performance (McCormick et al., 2015; Tyler et al., 2016). However their quantification is more complex, given the low amount of available data (Tyler et al., 2016).

Athletes are the most targeted population in the literature, given that many competitions take place in areas with a hot climate (Périard et al., 2015; Racinais et al., 2015a, 2015b). Other groups of individuals concerned by heat acclimation/acclimatization include professionals (soldiers, workers, engineers, rescue workers, and humanitarians, among others) performing mid to long-term missions (from one week to several months) abroad in areas with a hot climate. The need to be rapidly operational is incompatible with the adverse acute effects of heat stress, which reduce physical (Périard et al., 2015; Székely et al., 2015), cognitive, and psychomotor performance (Cian et al., 2000; Hocking et al., 2001; Hancock et al., 2007). Heat also increases the occurrence of exertional heat illnesses, such as exertional heat stroke (Pryor et al., 2012), which are common in worker populations (Marchetti et al., 2016) and, especially, soldiers (Armed Forces Health Surveillance Bureau, 2017). Indeed, approximately 10 cases of exertional heat stroke per 100,000 American soldiers were reported between 1991 and 2002 (Carter et al., 2005) and between 19 and 36 cases per 100,000 French soldiers between 2005 and 2011 (Duron-Martinaud et al., 2012).

We recently tested whether a program of moderate exercise could aid heat acclimatization with a sample of soldiers. They performed daily and moderate-intensity (32–54 min at 50% of speed at VO_{2max}) training during the first five days of a mission in a hot desert-like environment, characterized by a high volume of work-related physical activity (approximately 6 h d^{-1} of physically stressful professional activity performed between 35 and 50 °C) (Charlot et al., 2017). We found such training to be effective in amplifying the decrease in HR by 50% during exercise and reducing thermal discomfort at rest and during exercise (by 90% and 57%, respectively), as well as the level of perceived exertion (by 77%) relative to the group that did not train. However, the conclusions of this study were only partial, because the heat acclimatization period was short (seven days) versus the traditional 2-wk period required to observe complete adaptation (Périard et al., 2015; Tyler et al., 2016) and the operational performance and occurrences of undesirable heat-related effects were not assessed.

The aim of the present study was therefore to assess the effects of additional moderate and progressive training during a complete period of heat acclimatization (15 days) in soldiers deployed in the Middle-East during a very hot and dry spring period (more than 40 °C and less than 20% relative humidity) on classical physiological markers of heat acclimation (Sawka et al., 2011) and thermal discomfort at rest and during moderate exercise performed in dry heat. A typical military test (8-km trial) was used to assess operational performance at the end of this period. As in our first study (Charlot et al., 2017), all participants of each group (those enrolled in the training [T] group and those in the No Training [NT] group) performed a large amount of professional physical activity, mostly outdoors, during the acclimatization period (approximately 6 h d^{-1} in the study of Charlot et al., 2017). We hypothesized that the supplemental training-induced physiological and perceptive improvements observed after six days would also be observed after fifteen days, even during operational tasks, and would reduce the risk of heat illness.

2. Methods

2.1. Design

We used a repeated-measures and within-participants design to determine whether 2 weeks of low-volume training is sufficient to enhance heat acclimatization in French Army soldiers deployed in desert-like conditions near Abu Dhabi in United Arab Emirates. Physiological factors (HR, rectal and face temperatures, sweat loss, and osmolality) were measured and subjective factors (thermal discomfort using visual analogic scales and rates of perceived exertion [RPE]) were assessed during a heat-stress test (HST) performed before (D0), during (D5 and D10), and after the 2-wk period of heat acclimatization (D15). At D17, participants had to perform a group 8-km trial in the desert without leaving a member behind. This trial was performed early in the morning with subjects wearing battledress and a light pack (5 kg). Thermal discomfort before and after and the RPE after were measured. Twenty-five participants were included in a training program, whereas 30 were not. However, all participants performed similar indoor and outdoor physical military activities during this period. Thus, the effect of additional training was assessed in this protocol.

2.2. Participants

Sixty French Army soldiers were selected to participate in this study during their regulatory acclimatization period. Participants were briefed before leaving France and were informed of the benefits and risks of the investigation prior to giving their written consent, in accordance with the Declaration of Helsinki. This study was performed at the request of the French Forces in United Arab Emirates and approved by the scientific leadership of the French Armed Forces Biomedical Research Institute, under the direction of the French Inter-Armies Medical Center of the military city of Zayed near Abu Dhabi. All participants were found to be healthy by military physicians. The study took place in May-June 2017 and the participants did not participate in a mission (in France or elsewhere) where the climate could be considered to be hot (dry or humid) in the previous six months. They were therefore considered to be unacclimated, as a 6-wk period is generally considered to allow complete decay of the effect (Ashley et al., 2015). Twelve participants in the NT group (40%) and 10 (33%) in the T group participated in such a mission between 6 and 48 months before the experiment. Participant characteristics are shown in Table 1. Each regiment was familiar with the Cooper 12-min run test (Cooper, 1968) (a test routinely used by the French Army to annually assess the level of aerobic fitness). The last test was performed in the month before departure to United Arab Emirates in a temperate environment (15–20 °C). Indeed, this is one of the most accurate field tests to determine aerobic fitness (Grant et al., 1995). Maximal oxygen uptake (VO_{2max}) and speed at VO_{2max} can be estimated from the test results. In this study, running intensities were calculated from the estimated speed at VO_{2max}.

2.3. Procedures

Participants stayed in air-conditioned spaces for the entire day after their arrival on site by military airplane. Two days after their arrival (D0), they performed a HST consisting of three 8-min runs outdoors at 50% of their estimated speed at VO_{2max}. Rectal temperature, nude and dry body mass, and HR were measured and thermal discomfort assessed

Table 1
Participant characteristics.

	No Training (n = 30)	Training (n = 25)
Age (y)	24.1 ± 4.2	23.8 ± 3.0
Height (cm)	177 ± 7	178 ± 6
Weight (kg)	72.8 ± 9.1	75.5 ± 10.0
Body mass index (kg m^{-2})	23.2 ± 2.4	23.8 ± 2.7
12-min Cooper performance (m)	2877 ± 162	2862 ± 158
Speed at VO_{2max} (km h^{-1})[a]	15.1 ± 1.0	15.1 ± 1.0
VO_{2max} (ml min^{-1} kg^{-1})[a]	53.0 ± 3.6	52.7 ± 3.5

Mean ± SD. VO_{2max} = maximal oxygen uptake.
[a] Values deduced from the results of the Cooper 12-min run test (Cooper, 1968).