Effects of Acclimation on Cognitive Performance in Soldiers during Exertional Heat Stress

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This study investigates the effects of exertional heat stress and acclimation status on physiological and cognitive performance. Forty male soldiers performed an exertional heat stress test (EHST) either in a cool (20°C, 16°C wet bulb globe temperature), or in a hot environment (40°C, 29°C wet bulb globe temperature), unacclimatized, or after 10 days of passive or active acclimation. Mean skin and tympanic (Tty) temperatures and heart rates (HR) measured physiological strain. A cognitive test (the computerized Cambridge Neuropsychological Test Automated Batteries attention battery) is administered before and immediately after EHST. EHST in hot conditions induced physiological heat stress (increase in Tty and HR), which caused mild deficits in attention in U group (decreased number of correct responses, and prolonged movement time). Acclimated (passive and active) soldiers suffered no detrimental effects of exertional heat stress, despite almost the same degree of heat strain, measured by Tty and HR.

Introduction

Heat stress can be a significant problem in the military services. Common preventive measures (restriction of physical activity, taking off clothes, and moving into shade) are often impossible to obtain. Heat stress can impair both physical and mental performance.[1–3] Studies of cognitive performance under hot conditions are difficult to evaluate due to various methodological designs, exposure duration, skill, and acclimation level, as well as to the absence of concise theory on which experimental work can be based.[4]

Computerized Cambridge Neuropsychological Test Automated Batteries are a set of neuropsychological test batteries specifically designed for comparative assessment of cognition. The tests are graded in nature, avoiding ceiling effects in young, normal subjects.[5] Computer testing is given in a standardized form with standardized feedback and a detailed recording of accuracy and speed. Standardized scores are produced from a large pool of normative data.

It is well established that acclimation to heat produces physiological adaptations which result in decreased physiological strain and increased tolerance during exercise in the heat.[6] However, the effects of acclimation on cognitive performance during exertional heat stress have been of little interest so far. The aim of this study was to investigate the effect of exertional heat stress and the influence of acclimation on physiological and cognitive responses in young soldiers.

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This manuscript was received for review in November 2005. The revised manuscript was accepted for publication in July 2006.

Subjects and Methods

Forty male soldiers (20.1 ± 0.9 years) participated in the trial after being informed of the purpose and details of the trial, any known risks and discomforts, and their right to terminate participation at will. After briefing, the soldiers gave their written informed consents to participate. Standard anthropometric measurements were conducted; baseline levels of maximal aerobic power (VO_{2max}) were determined on treadmill.[7]

The investigation was conducted during winter (late November and December) in the Military Medical Academy in Belgrade. The soldiers were randomly divided into four equal groups. The first group was unacclimatized controls, who performed the exertional heat-stress test (EHST) in a cool environment (C). Another unacclimatized group performed the EHST in a hot environment (U), and the other two groups performed the same test, but after 10 days of acclimation in a climatic chamber (3 hours each day, in 35°C, relative humidity 40%, wind speed <0.1 m/s); acclimation was, in one group, conducted passively (P), and in the other actively, with 1 hour walking on a treadmill, 5.5 km/h (A). EHST consisted of walking on a motorized treadmill (5.5 km/h) either in a cool (20°C, wet bulb globe temperature (WBGT) 16°C–C group) or hot (40°C, WBGT 29°C–U, P, and A group) environment, while wearing a normal combat uniform, with a backpack filled with 20 kg of sand to simulate regular weight burden. Duration of EHST was maximally 90 minutes; the criteria for termination were: Tty 39.5°C,[8] heart rate (HR) 190 beats/minute, or intolerable subjective discomfort. The subjects were allowed to drink tap water at will, up to 1.5 L. Cognitive tests were administered to each soldier before and immediately after the EHST.

The soldiers were closely monitored for up to 5 hours after finishing the trial and medically examined after 2 days (ECG, blood pressure and routine blood analysis). Environmental conditions (dry bulb-temperature, WBGT, relative humidity and wind speed) were measured by MiniLab Light Laboratories (Brighton, United Kingdom). Skin temperatures were measured continuously using contact probes with transducers (precision ± 0.1°C, range 0–50°C; Ellab Instruments, Elektrolaboratoriet, Kopenhagen). The thermistors were set at four locations (neck, right scapula, left hand, right shin). Mean skin temperatures (Tsk) were calculated every 5 minutes from values obtained and weighted.[9] Core (tympanic) temperatures (Tty) were measured discontinuously, by introduction of a thermistor into the auditive canal every 5 minutes and placing it toward the tympanic membrane. HR was continuously telemetrically monitored (Biotel Instruments, Eagan, Minnesota) and recorded every 5 minutes.

Cognitive performance was assessed using the Computerized Cambridge Neuropsychological Test Automated Batteries, version 2.0. We used the attention battery, which includes tests of selective, divided, and sustained attention[5]: motor screening (MOT), reaction time (RTI), and rapid visual information processing (RVP). The tests are administered using a computer with a touch-sensitive screen and a response key was used for reaction timing. During all tests, an investigator was present to explain and supervise the tests.

Data are presented as means ± SD. The difference was assessed by two-way analysis of variance for repeated measures and Student's *t* test for paired samples. The normal distribution was tested by Shapiro Wilk's test. SPSS 10.0 was used to process statistical material and the 0.05 level of significance was used.

Results

The physical characteristics of the subjects are shown in Table I. All groups were similar in all characteristics investigated. Not 1 of the 40 soldiers showed any symptoms of heat stroke during or after the EHST. Results of all medical examinations showed no sign of serious dysfunction. All soldiers in C group completed the EHST. However, only 1 soldier in U group successfully completed EHST; in the rest of the cases, tests have been terminated between 45 and 70 minutes, mostly due to reaching the ethical barrier for core temperature (Tc) (39.5°C), or intolerable subjective discomfort. In acclimatized groups, most of the soldiers managed to finish the test; 3 soldiers in P group and 1 in A group terminated the test between 60 and 80 minutes, reaching the Tc barrier. Even so, their subjective sensation of discomfort was tolerable and they were willing to continue the test.

Mean Tsk, Tty, and HR values are presented in Figures 1, 2 , and 3, respectively. In the C group, in the first 20 minutes (until sweating occurred) there was an increase in Tsk and Tty and after that period there was a mild decrease in Tsk, while Tty remained constant. In all groups that performed EHST in a hot environment, Tsk was significantly higher all throughout the EHST, and the values recorded in the U group between 50 and 70 minutes were significantly higher compared to acclimatized groups ($p < 0.05$). Tty raised steadily in all groups that performed EHST in hot environment, with slightly lower values recorded in acclimatized groups. HR in hot conditions were increasing in all groups similarly, but the limit of 190 beats/minute was never reached. Maximal recorded HR was 163 beats/minute.

The means of the performance tasks are summarized in Table II. In the MOT test, there was no difference between responses for latency or number of errors before and after EHST, regardless of heat condition and acclimation. In the more complex RVP test, latency in all groups did not differ after EHST compared to baseline levels, but in the U group, there was a significant decrease in the percentage of correct responses (79.4 ± 7.1% before vs. 69.7 ± 10.3% after EHST; $p < 0.05$) and significant delay of movement in the RTI test, i.e., an increase in movement time (368.4 ± 72.1 ms before vs. 410.1 ± 80.7 ms after EHST; $p < 0.05$). The rest of the variables registered in the RTI test (percentage of correct responses and reaction time) in all groups were similar before and after EHST.

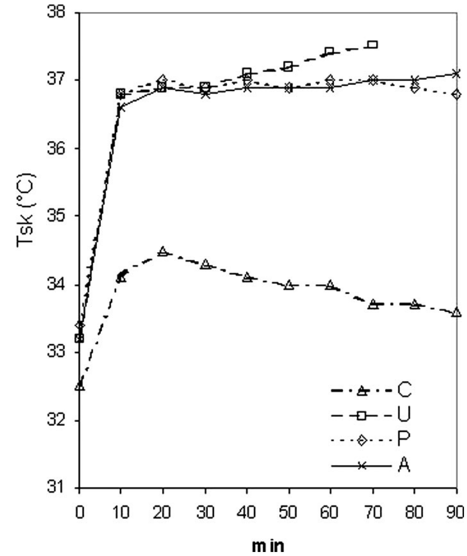

Fig. 1. Tsk during EHST.

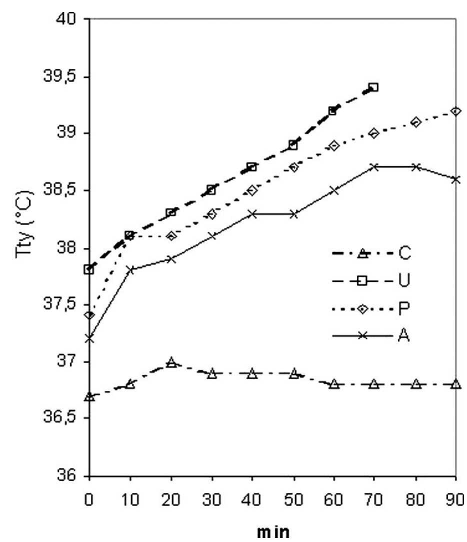

Fig. 2. Tty during EHST.

TABLE I

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

Group	Height (m)	Body Mass (kg)	Body Fat Content (%)	VO_{2max}, (ml/kg/min)
C	1.79 ± 0.05	78.1 ± 5.3	17.1 ± 4.5	56.6 ± 5.9
U	1.82 ± 0.03	75.9 ± 6.6	16.8 ± 2.4	62.9 ± 10.1
P	1.84 ± 0.04	73.9 ± 3.4	15.7 ± 1.9	55.4 ± 5.1
A	1.79 ± 0.05	73.7 ± 9.4	16.9 ± 3.8	56.2 ± 7.7

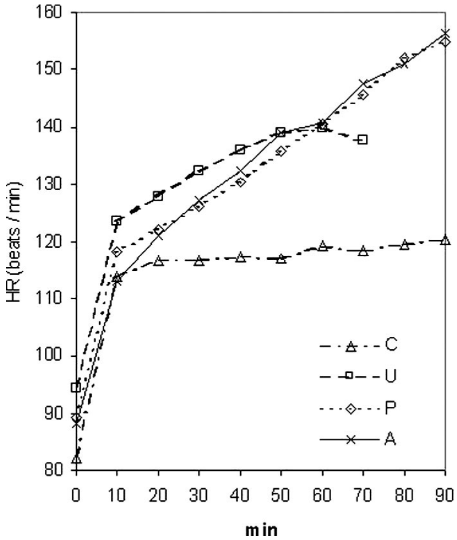

Fig. 3. HR during EHST.

Discussion

Impaired working efficiency is a well-known consequence of heat strain.[10] This is particularly important for military services. Core temperature is considered as a relevant indicator of thermal strain. Military training guidelines for continuous physical work times are based on achieving Tc of 40°C in acclimated individuals with appropriate fluid replacement.[3] In this trial, the tympanic thermometry was used as a measure of Tc, as a reliable method for monitoring changes in body temperature during exercise.[11] During military operational settings, even less conservative guidelines (higher Tc) can be employed[3]; these high Tc are possible and not so rare in real situations related to military service and deserve to be investigated. In our study, at high degree or heat strain, three unacclimatized soldiers experienced subjective discomfort (generalized weakness, fatigue, and pain/heaviness in shoulders—the latest was attributed to the weight they carried) and urge to terminate the test, but acclimatized soldiers did not approach levels at which their activity should be reduce.

HR values were well within the predicted maximum for their age, indicating that the workload had not exceeded their physical capabilities, considering their baseline levels of VO_{2max}, which were relatively high. In terms of heat stress, the major advantage attributed to a higher aerobic fitness is the ability to tolerate a higher Tc at exhaustion.[8]

The combination of dynamic physical activity and heat stress leads to fatigue, which originates from cerebral changes (reduced neural drive and cerebral blood flow, gradual slowing of the electroencephalogram,[12] along with disturbances in cerebral neurotransmitter levels).[13] There were a number of reports of impaired neurological and neurobehavioral functions during exertional heat stress,[14,15] long-term memory,[16] and vigility.[1] It is well known that exercise-induced heat stroke is best defined by severe mental dysfunction, regardless of body temperature,[17] and may lead to long-term cognitive impairment.[18]

The aim of this study was to investigate the effect of exertional heat stress on attention responses and the influence of acclimation. EHST in unacclimatized soldiers lowered performance in

TABLE II

COGNITIVE PERFORMANCE BEFORE AND AFTER EHST

	MOT				RTI						RVP			
	Latency (ms)		No. of Errors		Correct Responses (%)		Reaction Time (ms)		Movement Time (ms)		Correct Responses (%)		Latency (ms)	
Group	Before	After EHST	Before	After EHST	Before	After EHST	Before	After EHST	Before	After EHST	Before	After EHST	Before	After EHST
C	582.5 ± 95.1	552.2 ± 9.3	26.0 ± 5.4	20.5 ± 3.5	96.8 ± 2.6	98.3 ± 1.7	322.0 ± 44.6	317.8 ± 25.0	439.6 ± 90.0	393.2 ± 101.6	80.0 ± 14.7	82.5 ± 13.9	420.0 ± 60.9	410.7 ± 30.7
U	509.1 ± 47.7	599.6 ± 77.9	28.6 ± 7.3	28.7 ± 6.5	95.3 ± 3.1	93.0 ± 2.7	296.1 ± 24.9	322.1 ± 20.9	368.4 ± 72.1	410.1 ± 0.7[a]	79.4 ± 7.1	69.7 ± 10.3[a]	436.4 ± 32.1	439.4 ± 53.7
P	537.5 ± 55.8	558.1 ± 59.7	33.5 ± 14.0	30.2 ± 10.5	96.7 ± 2.7	95.3 ± 2.6	295.4 ± 19.8	300.0 ± 25.6	360.8 ± 71.4	395.3 ± 104.2	78.2 ± 14.8	79.9 ± 15.8	423.6 ± 38.4	418.3 ± 56.6
A	542.7 ± 45.0	540.8 ± 90.6	25.2 ± 4.6	23.9 ± 4.6	96.2 ± 2.7	94.9 ± 2.8	305.6 ± 21.1	307.1 ± 29.9	366.3 ± 76.9	332.2 ± 97.7	72.8 ± 8.1	79.3 ± 10.6	398.0 ± 33.6	398.9 ± 21.9

[a] Value of $p < 0.05$, before vs. after EHST.

some tasks. However, despite the relatively high degree of heat strain, even the unacclimatized soldiers did not show any substantial deficit of attention performance. Some investigators[19] reported that the performance in the state of heat strain depends not only on the absolute value or the Tc, but also on the direction of its movement, i.e., performance was significantly worse as the Tc was rising compared to falling—the latter was the case in our trial. It must be also highlighted that subjects may have been stressed at the start of the trial by the uncommon computerized testing (their mean baseline scores were relatively poor), while at the end they felt more relaxed, so they might have compensated for the effect of heat stress. A similar observation was reported by Amos et al.[20] Subjects in C group showed a trend of improving cognitive performance after the EHST (although without statistical significance), which can also be attributed to facilitation of specific aspects of information processing by the aerobic exercise of submaximal intensity without heat stress.[21]

In addition, performance deficits were significant only in complex tests (RTI), so simple motor performance (assessed in the MOT test) was relatively unaffected by heat stress. This is in agreement with the opinion that heat affects cognitive performance differentially, based on the type of cognitive task. According to Hancock,[22] simple mental tasks show little, if any, decrement in the heat, and are frequently enhanced during brief exposures. However, substantial heat stress (30–33°C WBGT) may lead to impairment of performance in more complex tasks (perceptual motor and dual tasks).[4,23]

Heat acclimation is an extremely important modifiable risk factor for tolerance to exercise-induced heat stress.[24] In this study, 10-day acclimation led to complete prevention of the detrimental effects of exertional heat stress on attention performance. There was no significant difference between passive and active acclimation. This could be attributed to relatively high baseline levels of VO_{2max}, but, since we did not measure VO_{2max} after acclimation, we can only assume that short-time aerobic exercise of moderate intensity was not sufficient for further improvement of thermotolerance.

It would be interesting to investigate the improvement of cognitive functions day-by-day during acclimatization, but some authors[25] have indicated that frequent repeated testing can lead to a "training" phenomenon: the more experienced the subject is, the less likely he is to be disturbed by thermal stress.

Conclusions

This study demonstrated effects of physical activity in a hot environment on physiological parameters, as shown by an increase in Tty and HR. This physiological heat stress caused mild deficits in attention in unacclimatized soldiers, as shown by a fall in the percentage of correct responses, and a delay in movement responses to the test stimuli. In addition, performance deficits were significant only in complex tests, so the simple motor performance was relatively unaffected by physical activity in the heat. Ten-day acclimation in a duration of 3 hours daily, either passive or active, has influenced both physiological and cognitive response, and acclimatized soldiers suffered no detrimental effects of exertional heat stress, despite almost the same degree of heat strain, measured by Tty and HRs.

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