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PHYSICAL PERFORMANCE OF HEALTHY MEN EXPOSED TO LONG EXERCISE AND SLEEP DEPRIVATION

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Abstract

Introduction: There are only few data on influence of combined effects of long lasting exercise and sleep deprivation on physical performance.

Objective: To evaluate the influence of 36 hours of sleep deprivation combined with 20 hours of intermittent exercise on selected physiological and psychomotor indices.

Methods: Eleven participants of survival camp exercised without sleep and were examined three times (C – before effort, M – after 24 hours, E – after 36 hours) for submaximal heart rate, multiple choice reaction time (MCRT), motion coordination, handgrip force differentiation and shooting accuracy.

Results: There were no significant differences in MCRT throughout the whole experiment. Heart rate showed significant decrease between C and M ($P < 0.004$) and C and E ($P < 0.037$) trials. Shooting was performed only twice and was significantly less accurate in E than in C (6.71±0.42 vs. 7.71±0.31 respectively, $P < 0.001$). Handgrip force differentiation was not different between the measurements (C – 6.2±1.8%, M – 5.3±0.9%, E – 4.1±0.9%). Number of mistakes in rotational test increased significantly from session C to M (4.95±0.59 vs. 6.76±0.70; $P < 0.001$) and C to E (4.95±0.59 vs. 6.90±0.90; $P < 0.01$).

Conclusions: One sleepless night combined with the long lasting exercise caused decrease in heart rate, shooting performance and motion coordination, however it did not affect psychomotor performance and handgrip sensitivity. Such data can be a result of adaptation to adrenergic stimulation unevenly alters phenomena linked with central and peripheral fatigue.

Key words: *exercise, psychomotor performance, heart rate*

The lifestyle in recent years is getting busier and people participate in many activities, not only associated with their occupational duties and not only sedentary. As a result the sleeping time is shorter, which is definitely bad, and amount of physical activity is increased, what is superb but must be done reasonably. People who exercise regularly completing their daily training sessions before dusk, then go to work till evening and family life afterwards are luckily not such a rare species and need different approach and understanding from physicians and physiologists. The popularity of ultra endurance events is increasing rapidly, the number of competitors is growing each year in marathons, ultramarathons (Sparta marathon 246 km), mountain runs, ironman triathlons, adventure races and survival camps. Some of those activities last over 24 hours and thus combine sleep deprivation with exercise, which are both well examined separately, but very poorly understood if happening simultaneously. Adventure races are multidiscipline events, which require a respectable amount of endurance, as well as psychomotor training, participants have to run, ride a bike, swim, row, climb, solve special tasks and effectively navigate in wild terrain, all of this also overnight and for many days, a unique combination in the sporting world [1]. The similar conditions occur in survival, which distinctive mark is that it is based on long lasting military training requiring continuous exercise and wakefulness [2]. Both those disciplines are distinguished by ultra prolonged physical activity without the access to proper recovery in combination with a severe sleep deprivation and a constant need to maintain sufficient mental performance.

The results of the studies examining influence of sleep deprivation on cardiorespiratory function and even just heart rate are not fully consistent [3]. Heart rates during submaximal exercise were unaltered by sedentary sleep deprivation: 24 hours of wakefulness and exercise at 80% of $\dot{V}O_2max$ [4,5], 30 hours and 25, 50 and 75% of VO_2max [6,7], 36 hours and 80% of $\dot{V}O_2max$ [8], 50 hours and PWC160 [9] and 60 hours and 70% of $\dot{V}O_2max$ [10]. The decreased resting and exercise heart rates after sedentary sleep deprivation were also observed [11-14] but increased heart rate during exercise at intensity of 75% of $\dot{V}O_2max$ in a study with partial 3 hours of sleep deprivation was reported as well [15]. There are few data on combined sleep deprivation and prolonged exercise. Myles [16] reported unaffected heart rate in subjects who exercised for 50 min every 3 hours for 60 hours. Similar finding was described by Angus et al. [17]. Plyley et al. [18] noted no changes in maximal heart rate in subjects kept awake and exercising for one third of time for 64 hours. Those results were confirmed by Scott and McNaughton [7] as they observed unaltered heart rate during submaximal test of 50% of $\dot{V}O_2$peak after 30 hours of sleep deprivation combined with exercising for 20 minutes every 2 hours. Majority of interviewed athletes who participate in adventure races or ultra endurance events lasting at least 24 hours report that their heart rates decrease throughout exercise [1].

Our previous experience [19] showed the decreased heart rates during submaximal workloads after 36 hours of physical activity and sleep deprivation.

Participants of most sport activities during physical effort simultaneously have to respond to perceptual stimuli with rapid decisions and their execution. Therefore, multiple choice reaction time (MCRT) appears to be a good method to evaluate psychomotor performance. Influence of exercise on reaction time is well established, both during long lasting and short, graded efforts. The fastest MCRTs are observed at approx. 70-80% $\dot{V}O_2$max intensity in graded tests to exhaustion [20-23] reflecting the optimal level of vigilance resulting from stimulation induced by exercise. During intermittent and long lasting exercises results are not so consistent, even 100 hours showed no significant decrease in psychomotor performance [24], but improved psychomotor performance is described after 100 min [25] and 120 min [26,27]. In ultra long lasting events psychomotor performance is decreased [28]. Development of central and peripheral fatigue due to carbohydrate depletion, acidosis, dehydration, etc. occurring in the later stages of exercise (exceeding one hour) are hypothesized to deteriorate benefits of increased alertness of nervous system. Sleep deprivation is a generally accepted factor resulting in detriments in psychomotor performance of similar magnitude to alcohol consumption (1 night = 0.05% alcohol in blood) [29].

The effect of combined sleep deprivation and long lasting physical activity on maintenance of posture are also unexplored, some experiments were performed during sleep deprivation alone and increased postural disorders were observed [30,31]. Posturographic test conducted in subjects submitted to 36 hours of physical activity and sleep deprivation showed decreased ability to maintain balance [19]. In the present experiment some new tests were introduced to establish the workstation to examine the different aspects of complex fatigue phenomenon occurring during extended exercise without sleep.

Rotational test was applied [32], as it respectfully reflects the ability of subjects to maintain balance in dynamic conditions. Experiments conducted in sportsmen and soldiers showed increased ability to maintain dynamic balance in people submitted to regular physical activity with drills focused on balance and proprioception. Specific athletic training also positively affects postural functions in motion [33].

Efficient shooting requires mental and physical focusing combined with proper relaxation, thus, besides enjoyment by subjects, it is a handy test to assess those factors. The results of shooting are adversely affected by most forms of physical exercise, especially performed at high intensities followed by shooting in standing position [34]. Even partial sleep deprivation (4 hrs less than normal) results in decreased accuracy at targeting [35]. Influence of moderate, ultra long exercise combined with sleep deprivation is not sufficiently described in literature.

Consecutive factor important in efficient body functioning in sports and other activities is the ability to apply proper strength by involved muscles. For this purpose handgrip test with dynamometer pressed blindly to 50% of max force is applied. As with factors mentioned above, training improves results of this test [36] and the knowledge of combined influence of long exercise and sleep deprivation is very limited.

Such experiments are methodologically difficult and hard to reproduce in the laboratory due to their length and specific arousal present only in the field, thus, the testing must be very fast and efficient as the whole group is moving according to the schedule and any delay results in subjects falling asleep.

Aim of the study was to evaluate the influence of 36 hours of sleep deprivation combined with 20 hours of intermittent exercise on selected physiological and psychomotor factors – submaximal heart rates, multiple choice reaction time, motion coordination, handgrip sensitivity and shooting accuracy.

Materials and methods

Eleven participants were recruited for this study. The study was conducted at summer survival camp, participants were selected among the healthy male students of University of Physical Education who volunteered and signed the informed consent. Ethics Committee of Medical University in Warsaw approved the study protocol (permission no KB/213/2010). The characteristics of the subjects is presented in table 1. First experimental measurements (control – C) were performed in the early afternoon when subjects arrived at the camp, afterwards they were preparing themselves for the all-night, 30 km walk in the

Table 1. *Characteristics of the subjects (±SE)*

n	age [yrs]	height [cm]	body mass [kg]	BMI [kg/m^2]
11 (♂)	21.5 ± 0.2	180.1 ± 1.6	80.6 ± 1.6	24.9 ± 0.7

difficult, swampy terrain, during which additional special survival tasks were completed. Second testing was executed at dawn when the group returned to the camp after 24 hours without sleep (morning – M). Throughout the second day subjects were all time busy with moderate physical and camp activity; the final third session of measurements (end – E) was done in the evening at the end of the study, with total 36 hours of sleep deprivation. Multiple choice reaction time (MCRT) was recorded to asses psychomotor ability of the subjects with accuracy of 0.001 sec, testing program consisted of 15 positive (red light and sound) and 15 negative (green and yellow light) stimuli emitted in varying order during 107 sec. Subjects were supposed to react to positive stimuli as quickly as possible by pressing buttons placed in their hands and to ignore the negative ones. Heart rate was recorded at rest and every minute during 5 min submaximal step test (step height 50 cm, frequency of an up and down cycle 30 per min) and 3 min of recovery period. Shooting was performed in a standing position with an air rifle from a distance of 7 meters to 12 cm target, after several familiarizing shots the final seven were recorded and result averaged. Maximal handgrip force of dominating hand was measured with dynamometer (Si, Poland), afterwards subjects were supposed to press 50% of achieved maximum without the visual control and repeat it 5 times, with information from the assistant of scored result after each attempt. The result of the test was expressed by the difference between expected 50%max and achieved average value of five handgrips calculated as percentage of maximal force. Motion coordination was assessed with rotation test; starting standing on the line subjects were supposed to spin 360° in the air (alternately three times clockwise and three times counterclockwise) and land with both feet on the line in approx. 12 sec in constant rhythm. Several training jumps were allowed. Accuracy of landing and maintenance of balance is scored (0 – clean jump, 1 – one foot off the line, 2 – both feet off the line, 3 – lost balance with hand support) and summarized from 6 jumps (score range from 0 – excellent to 18 – unsatisfactory) [32].

Statistical analysis

All data are presented as means ± SE and were calculated with Statistica 6.0 software. Values' normal distribution was examined with Kolmogorow-Smirnow test. Two values were compared with Student's t test for dependent measures. For more complex analyses two-way ANOVA for repeated measures was used. Accepted level of significance was $P < 0.05$.

Results

There were no significant differences in MCRT throughout the whole experiment (C – 324±10 msec; M – 327±10 msec; E – 324±8 msec). Multiple ANOVA analysis of the course of heart rate showed significant increase induced by exercise and decrease between C and M ($P < 0.004$) and C and E ($P < 0.037$) (Fig. 1). Average heart rates from 5 min of exercise showed no significant differences between measurements. Magnitude of heart rate decrease during 3 min of recovery period was similar in all measurements (C – 53±3 bpm; M – 57±4 bpm; E – 54±5 bpm). Calculation of significance in heart rate measurements was disturbed by decreased down to 8 number of subjects completing the exercise in session E. Shooting was performed only twice and was significantly less accurate in E than in C (6.71±0.42 vs. 7.71±0.31 respectively, $P < 0.001$). Maximal force of handgrip increased throughout the study (C – 68.9±2.7 kG vs. M – 76.4±2.6 kG, $P < 0.01$; C vs. E – 75.0±3.1, $P < 0.05$). Sensitivity of handgrip was not different between the measurements (C – 6.2±1.8%, M – 5.3±0.9%, E – 4.1±0.9%).

Score (number of mistakes) in rotational test was

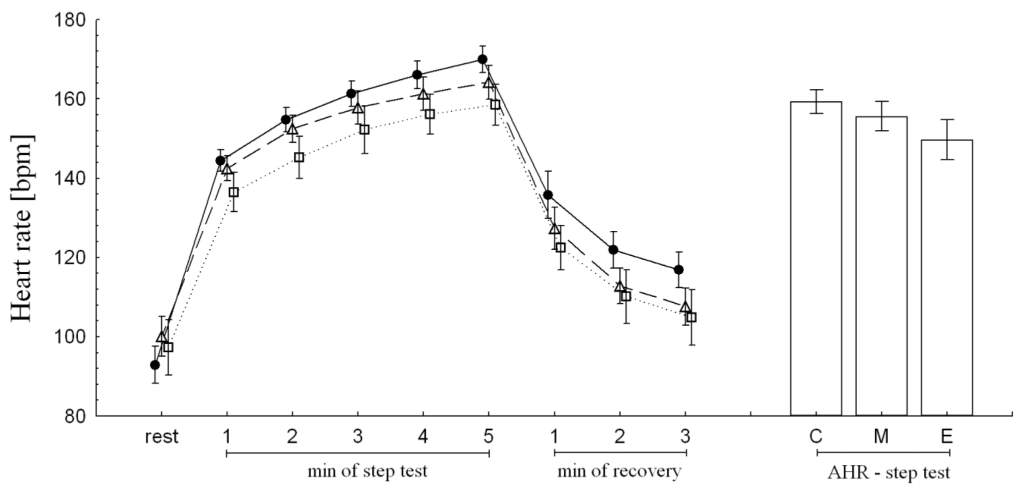

Fig. 1. *Heart rates at rest, during 5 min submaximal exercise and 3 min recovery performed before (full circles - C), in the morning after 24 hours (triangles - M) and at the termination (36 hours) of exercise and sleep deprivation (squares - E). Bars show average heart rates from each exercise. Multiple ANOVA analysis of the course of heart rate showed significant increase induced by exercise and decrease between C and M and between C and E.*

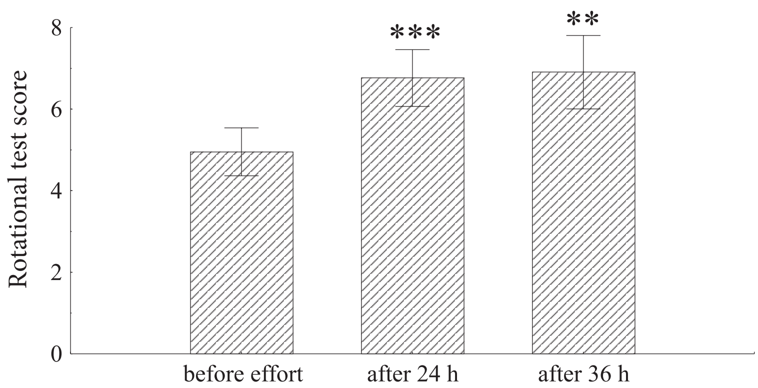

Fig. 2. *Score of rotational test before, in the morning (after 24 hours) and at the termination (36 hours) of exercise and sleep deprivation, **P < 0.01, ***P < 0.001 compared to control*

increased significantly from session C to M (4.95±0.59 vs. 6.76±0.70; $P < 0.001$) and C to E (4.95±0.59 vs. 6.90±0.90; $P < 0.01$, Fig. 2). There was no difference between M and E measurements.

Discussion

Performance in MCRT depends on many factors like age, vigilance and mood, it is independent of conduction speed in nerve fibers. The shortest (best) reaction times are obtained in the range of optimal activation of human body and its nervous system, both exaggerated excitation and sleepiness impair psychomotor abilities. Results obtained in the previous studies indicate that combined application of long lasting moderate exercise and sleep deprivation did not affect psychomotor performance [19]. Detrimental effect of sleep deprivation was annihilated by maintenance of activation of nervous system in its optimal functional range achieved by continuous stimulation by exercise. Duration of the test (107 seconds) is so short that subjects can remain focused long enough to overcome detrimental effects of sleep deprivation described in studies involving longer psychomotor testing procedures [28].

Lower heart rates after sleep deprivation during submaximal workloads had been already described [13]. Similar results were obtained later by Pickett and Morris [14] after 30 hours of sleep deprived subjects. They used an incremental exercise test and recorded depressed heart rates during low and moderate intensities of exercise. Also Bond et al. [11] reported lower heart rates during submaximal exercise. Moreover, such pattern of heart rate changes is in opposition to the one usually observed during the circadian rhythm [37], emphasizing the influence of the applied procedure on examined factor. Regulation of heart rate is mostly governed by the autonomic nervous system and counterbalancing effects of its sympathetic and parasympathetic components. It is a complex system that could be affected by many factors occurring during such a long experiments as examined in this paper (exercise, energy balance, hydration, thermoregulation, psychological stress, etc.). Additional complications arise if the study is conducted in the field. Lower heart rates at moderate exercise intensities observed in the current study most likely result from the attenuated action of sympathetic nervous system. We can only speculate whether it is due to exhaustion of catecholamines secretion or down regulation of its receptors. Thus, from the physiological point of view, it is an adaptive mechanism preventing overload of the heart during such a strenuous activities.

Impaired shooting performance after moderate, long lasting exercise probably results mostly from one night of sleep deprivation. Significantly increased percentage of targets missed, distance from center of the mass of the target, shot group tightness and sighting time after 72 hours of sleep deprivation, operational and environmental stress were previously described [38]. Shooting performance is also adversely affected by shorter periods of sleep deprivation – even 22 hours produced similar effects demonstrated by decreased target engagement time, accuracy and precision [39]. Intense exertion decreases shooting performance executed directly after or during exercise, as in biathlon, whereas moderate workloads, additionally with some rest periods and shooting not directly at the end of exercise, are not supposed to detriment it [40,41]. Physical strain was not so significant in this study, as the unaltered results of psychomotor performance and handgrip sensitivity indicate, nevertheless period of sleep deprivation was long enough to impair shooting performance.

The increased maximal handgrip strength resulted from the overall stimulation of subjects by moderate, long lasting exercise, which also enhanced the strength of forearm muscles. Thus, the overall strain was not so exhausting (neither physically nor thermoregulatory) to deteriorate/impair the ability to apply handgrip force with precision.

Moderate long lasting exercise combined with sleep deprivation adversely affects motion coordination. Higher scores in rotational test indicate deterioration in maintenance of dynamic balance, component of motion coordination, which is completed by impaired static balance, recorded previously in similar conditions by means of posturographic test [19] and in sedentary sleep deprivation conditions [30,42]. It is not possible to quantify contribution of those components because of the different nature of those tests, though the dynamic balance seems to be disturbed more markedly and is itself more important for efficient functioning in outdoor conditions.

Conclusion

One sleepless night combined with the long lasting moderate exercise caused decreases in heart rate, shooting performance and motion coordination. It did not affect psychomotor performance and handgrip sensitivity. Such data can be a result of adaptation to adrenergic stimulation which unevenly alters phenomena linked with central and peripheral fatigue, constituting self preventing mechanism against overload of the heart. Performance indices affected similarly by prolonged exercise and sleep deprivation deteriorated as expected, whereas ones affected counterbalancely annihilated their effects showing no change in recorded indices.

Declaration of interest

The author reports no conflicts of interest.

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D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection