Medicina Sportiva, Vol. 10 (4): 98-101, 2006

INFLUENCE OF ULTRA LONG EXERCISE AND SLEEP DEPRIVATION ON PHYSICAL PERFORMANCE OF HEALTHY MEN

Tomasz Mikulski[1 (A, B, C, D, E, F, G)], Andrzej Tomczak[2 (A, B, D, E, F, G)], Patrycja Lejk[3 (B, C, E, F)], Krzysztof Klukowski[4 (A, D, E, F)]

[1]Department of Applied Physiology, Medical Research Centre, Polish Academy of Sciences, Warsaw, Poland
[2]Military Institute of Aviation Medicine, Warsaw, Poland
[3]Institute of Psychology, Polish Academy of Sciences, Warsaw, Poland
[4]The Jozef Pilsudski University of Physical Education, Warsaw, Poland

Abstract

In contrast to the well known influence of isolated effects of long lasting exercise and sleep deprivation on physical performance there are few data on effect of those factors combined.

Aim of the study was to evaluate the influence of 36 hours of exercise and sleep deprivation on selected physiological factors.

Materials and methods. The study was conducted on 11 healthy volunteers at survival camp (age 19±1 (SE) yrs, BMI 21.5±0.7 kg·m^{-2}, $\dot{V}O_2$max 55±2 ml·kg^{-1}·min^{-1}). Entry measurements were done the day before the trial: posturography, reocardiography in horizontal position and submaximal exercise test (workload increased by 50W every 3 min to 200W). First day of the trial started at 6 AM with gymnastics, followed by running and cycling; overnight there was a mountain trekking lasting 9 hrs; on the second day there was a military training and cycling. The final measurements took place after dinner after 36 hrs without sleep and 24 hrs of exercise of various intensity. Posturography was also performed at 6 AM on the second day.

Results. In posturography significant decrease in the sway area with feedback and no changes in maximal sway were recorded. In the final measurements there were significantly lower heart rates at all submaximal workloads ($p<0.001$) and lower rates of perceived exertion on Borg`s scale at 50 and 100W ($p<0.05$). In reocardiography there were no significant changes, but a tendency for an increased stroke volume in the final measurement.

Conclusion. In young men participating in the study one sleepless night combined with the long lasting exercise caused decrease in heart rate during submaximal exercise, which can be a result of adaptation to adrenergic stimulation.

Key words: exercise, sleep deprivation, heart rate, posturography, reocardiography

In a last few years there is an increasing popularity of extreme sports. They can be divided into two groups. First involves activities of short duration, associated with a decision after which the following consequences are irreversible – like a parachute or bungee jump, and it does not require endurance training. Second are the long lasting, multidiscipline events, which require a respectable amount of endurance, as well as psychomotor training, like adventure races or survival. Participants of adventure races 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. The distinctive mark of survival is that it is based on long lasting military training. During such an activities the continuous exercise without the access to proper recovery is combined with a severe sleep deprivation (1).

The influence of sleep deprivation on cardiorespiratory function has been evaluated at rest and during exercise tests of various intensities and durations. Obtained results are not fully consistent even for such a frequently and easily measured variable as the heart rate. In most studies heart rates during submaximal exercises were unaffected by sedentary sleep deprivation: 24 hours of wakefulness and exercise at 80% of $\dot{V}O_2$max (2,3), 30 hours and 25, 50 and 75% of $\dot{V}O_2$max (4,5), 36 hours and 80% of $\dot{V}O_2$max (6), 50 hours and PWC160 (7) and 60 hours and 70% of $\dot{V}O_2$max (8). The decreased resting and exercise heart rates after sedentary sleep deprivation were also observed (9-13). The study with partial 3 hours of sleep deprivation which showed increased heart rate during exercise at intensity of 75% of $\dot{V}O_2$max (14) should also be mentioned.

In contrast to those pretty well examined influences of isolated effects of long lasting exercise and sleep deprivation on physical performance there are few data on impact of those factors combined. Unaffected heart rate was reported by Myles (15) who exercised subjects for 50 min every 3 hours for 60 hours and Angus et al. (16). Also Plyley et al. (17) who kept subjects awake and exercising for one third of time for 64 hours noted no changes in maximal heart rate. Scott and McNaughton (5) confirmed those findings as they observed unchanged 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. If in the above studies rates of perceived exertion were recorded they were increased by the extended periods without sleep (4,6,15,17). On the other hand majority of athletes participating in adventure races or ultraendurance events lasting at least 24 hours who monitor their heart rates reported its decrease throughout exercise. It is also very interesting how the contractile efficiency of the heart expressed by stroke volume is affected by such an extreme conditions.

We failed to find in literature any record of posturographic test conducted in subjects submitted to sleep deprivation and long lasting physical activity, so effect of such a combination is unknown. Some experiments were performed during sleep deprivation alone and increased postural disorders were observed (18,19).

Aim of the study

The purpose of the study was to evaluate the influence of 36 hours of sleep deprivation combined with 24 hours of intermittent exercise on selected physiological factors – submaximal heart rates, stroke volume and posturography.

Materials and methods

The study was conducted on healthy volunteers at survival camp organized by the former soldiers of Polish special units "GROM" in merely civilized area in Bieszczady mountains who signed the informed consent. The characteristics of the subjects is presented in table 1. Entry measurements including exercise testing, posturography and reocardiography were done the day before the trial.

Submaximal exercise test on Monark cycloergometer was started with workload of 50 Watts and increased by 50W every 3 min to 200W. During exercise at the end of each workload the heart rate and the rate of perceived exertion on Borg`s scale were recorded (20). Maximal oxygen consumption was evaluated according to the Åstrand-Ryhming nomogram (21).

Posturography was performed on the PE48 tensometric platform, on which the subject stood straight and as still as possible for 30 sec with opened eyes. Then, after at least 3 min of rest in sitting position, the measurement was repeated with the eyes closed. After another rest the feedback was tested - the subject was conserving the dot inside the square on the display by balancing himself on the platform.

The 7 lead reocardiograph was used for 5 min in horizontal position to assess the stroke volume of the heart.

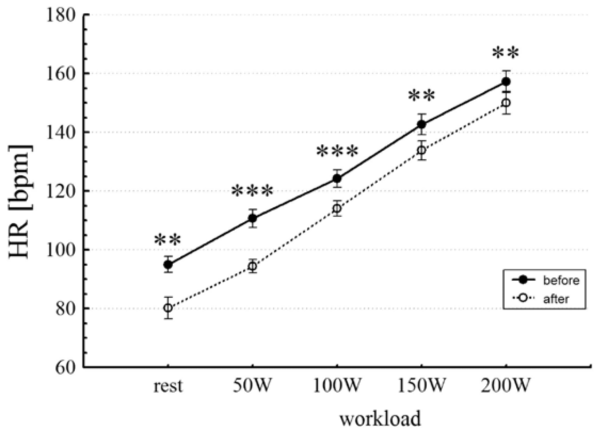
Table 1. *Characteristics of the subjects (±SE)*

n	Age [yrs]	height [cm]	body mass[kg]	BMI [kg·m^{-2}]	$\dot{V}O_2$max [ml·kg^{-1}·min^{-1}]
11	19 ± 1	184 ± 2	73.3 ± 2.3	21.5 ± 0.7	55 ± 2

All measurements were conducted at least two hours after the meal and preceding exercise. First day of the trial started at 6 AM with gymnastics, followed by overall physical fitness test including 3 km running at maximal intensity (heart rate up to 195 bpm), two hours after dinner there was a long bicycle trip; overnight the subjects were on a mountain off road trekking lasting 9 hrs; on the second day there was a military training and one hour of high intensity climbing on the mountainbikes. The final measurements (exercise testing, posturography and reocardiography) took place two hours after dinner with total of 36 hours without sleep and 24 hours of exercise of various intensity. Posturography was also performed at 6 AM on the second day. Data are presented as means ± SE and were calculated with Statistica 6.0 software.

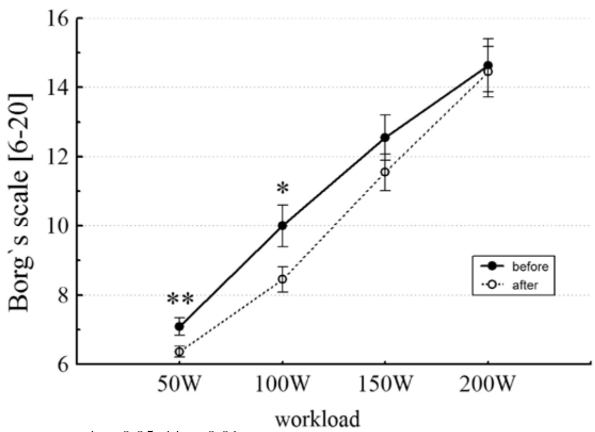
Results

During the final measurements there were significantly lower heart rates at all submaximal workloads and lower rates of perceived exertion on Borg`s scale at 50 and 100W (Fig. 1 and 2).



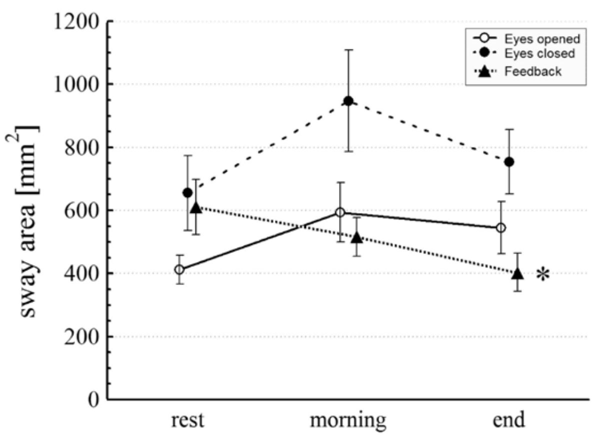
** p<0.01, *** p<0.001

Fig. 1. *Heart rates during graded submaximal exercise performed before (full circles) and after (open circles) 36 hours of exercise and sleep deprivation*



* p<0.05, ** p<0.01

Fig. 2. *Rates of perceived exertion on Borg`s scale during graded submaximal exercise performed before (full circles) and after (open circles) 36 hours of exercise and sleep deprivation*



* p<0.05

Fig. 3. *Sway area in posturography measured before, in the morning on the 2nd day and after 36 hours of exercise and sleep deprivation*

In posturography the sway area significantly decreased from entry to the final measurement in the test with feedback and tended ($p<0.09$) to increase in the morning after the overnight exercise in the test with closed eyes (Fig. 3). There were no changes in maximal sway back-forth and right-left.

In reocardiography there were only 7 reliable but widely spread results with no statistically significant changes, only a tendency ($p<0,07$) for an increased stroke volume in the final measurement was observed.

Discussion

Lower heart rates during submaximal workloads with decreasing magnitude of this phenomenon with increasing workloads were firstly described by Holland (10). Similar results were obtained later by Pickett and Morris after 30 hours of sleep deprived subjects (13). They used an incremental exercise test and recorded depressed heart rates during low and moderate intensities of exercise. Also Bond et al. reported lower heart rates during submaximal exercise (11). Regulation of heart rate is mostly governed by the autonomic nervous system and counterbalancing effects of its sympathetic and parasympathetic components. It is a very 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. Nevertheless, lower heart rates at moderate exercise intensities observed in the current study result from the decreased activity of sympathetic nervous system. We can only speculate whether it is due to exhaustion of catecholamines secretion or down regulation of its receptors. Tendency to increased stroke volume suggests that the stimulation is still on and maintaining cardiac output. The variety of receptors enables the parallel positive inotropic and negative chronotropic effects. Further studies with determination of catecholamines concentrations in blood are required. Thus, from the physiological point of view, it is a reasonable adaptive mechanism preventing overload of the heart during such a strenuous activities.

In posturographic test the tendency to increased sway area expressing the deterioration in maintaining posture corresponds to results presented by Avni et al. (18), who performed posturography 12 times for 25 hours of sedentary sleep deprivation. Maximal sway area was recorded in the early morning hours (4-6 AM). The other study conducted in Akita (Japan) lasted whole week and subjects were allowed to sleep only 3 hours a day (19). The worst postural results occurred around 4 AM and, as in our study, in the test with closed eyes. This augments how important sensory organ in human is the eye. Our results could have been affected by the wet and cold feet of subjects, as the night part of the study took place in the swamps. It was previously described, that significant cooling of feet causes problems in maintaining posture with closed eyes (22). Although there was a familiarization period the decreased sway area in the test with feedback seems to result from learning how to balance in consecutive measurements.

Conclusion

In young men participating in the study one sleepless night combined with the long lasting exercise caused decrease in heart rate and perceived exertion during submaximal exercise, which can be a result of adaptation to adrenergic stimulation. Tendency to increase in stroke volume observed in reocardiography can be an adaptive reaction to decreased heart rate in order to maintain the cardiac output. Posturography showed a decreased ability to maintain position in the morning, which disappears throughout the day.

References

1. Kalina RM, Chodała A, Tomczak A. O sportach ekstremalnych z perspektywy kryteriów współczesnego treningu militarnego i antyterrorystycznego oraz e-fektywnego funkcjonowania służb ratowniczych. In: Rakowski A, Chodała A, Kalina RM. eds. Sporty ekstremalne w przygotowaniu żołnierzy i formacji antyterrorystycznych. Polskie Towarzystwo Naukowe Kultury Fizycznej, Tom 6, Warszawa, 2003, 7-12.
2. McMurray RG, Brown CF. The effect of sleep loss on high intensity exercise and recovery. *Aviat Space Environ Med* 1984; 55: 1031-5.
3. Meney I, Waterhouse J, Atkinson G. et al. The effect of one night`s sleep deprivation on temperature, mood, and physical performance in subjects with different amounts of habitual physical activity. *Chronobiol Int* 1998; 15(4): 349-63.
4. Martin BJ, Gaddis GM. Exercise after sleep deprivation. *Med Sci Sports Exerc* 1981; 13(4):220-3.
5. Scott JP, McNaughton LR. Sleep deprivation, energy expenditure and cardiorespiratory function. *Int J Sports Med* 2004; 25(6): 421-6.
6. Martin BJ. Effect of sleep deprivation on tolerance of prolonged exercise. *Eur J Appl Occup Physiol* 1981; 47(4): 354-45.
7. Martin BJ, Chen HI. Sleep loss and the sympathoadrenal response to exercise. *Med Sci Sports Exerc* 1984; 16(1): 56-9.

8. Symons JD, VanHelder T, Myles WS. Physical performance and physiological responses following 60 hours of sleep deprivation. *Med Sci Sports Exerc* 1988; 20(4): 374-80.
9. Chen H. Effects of 30-h sleep loss on cardiorespiratory functions at rest and in exercise. *Med Sci Sports Exerc* 1991; 23(2): 193-8.
10. Holland GJ. Effects of limited sleep deprivation on performance of selected motor tasks. *Res Q* 1968; 39: 285-94.
11. Bond V, Balkisson B, Franks BD. et al. Effects of sleep deprivation on performance during submaximal and maximal exercise. *Sports Med* 1986; 26: 169-74.
12. Martin BJ, Haney R. Workload choice after sleep loss. *Eur J Appl Physiol* 1982; 49: 79-86.
13. Pickett GF, Morris AF. Effects of acute sleep and food deprivation on total body response time and cardiovascular performance. *J Sports Med* 1975; 15: 49-56.
14. Mougin F, Simon-Rigaud ML, Davenne D et al. Effects of sleep disturbances on subsequent physical performance. *Eur J Appl Physiol Occup Physiol* 1991; 63(2): 77-82.
15. Myles WS. Sleep deprivation, physical fatigue and the perception of exercise intensity. *Med Sci Sports Exerc* 1985; 17(5): 580-4.
16. Angus RG, Helsgrave RJ, Myles WS. Effects of sleep deprivation, with and without chronic physical exercise, on mood and performance. *Psychophysiology* 1985; 22: 276-82.
17. Plyley MJ, Shephard RJ, Davis GM. et al. Sleep deprivation and cardiorespiratory function. Influence of intermittent submaximal exercise. *Eur J Appl Physiol Occup Physiol* 1987; 56(3): 338-44.
18. Avni N, Avni I, Barenboim E. et al. Brief posturographic test as an indicator of fatigue. *Psychiatry Clin Neurosci* 2006, 60 (3): 340-6.
19. Liu Y, Higuchi S, Motohashi Y. Changes in postural sway during a period of sustained wakefulness in male adults. *Occup Med* 2006, 51: 490-495.
20. Borg G: Physical performance and perceived exertion. Gleerup, Lund, 1962.
21. Astrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *J Appl Physiol* 1954; 7(2): 218-21.
22. Waśkiewicz Z. Wpływ wysiłków anaerobowych na wybrane aspekty koordynacji motorycznej. AWF, Katowice.,2002.

Received: November 26, 2006
Accepted: December 27, 2006
Published: December 30, 2006

Address for correspondence:
Tomasz Mikulski
Department of Applied Physiology
Medical Research Centre, PAS
Pawinskiego 5, 02-106 Warsaw, Poland
tomik@cmdik.pan.pl

Author's contribution
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection