Central European Journal of Sport Sciences and Medicine | Vol. 5, No. 1/2014: 27–34

VISUOMOTOR PROCESSING AFTER PROGRESSIVELY INCREASED PHYSICAL EXERCISE

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Abstract. We assessed the effect of physical effort with increasing intensity on the visuomotor processing in physically active young men (n = 22). Subjects performed three 10-minute effort-tests with increasing intensity on a cycloergometer. Each participant was assigned individual workload values below the lactate threshold (40% VO_2max), at the lactate threshold (60% VO_2max) and above the lactate threshold (80% VO_2max). Special Ability Signal Test included in the Vienna Test System (Schuhfried, Austria) was used to examine visuomotor processing. The numbers of correct reactions and the median reaction time as a measure of the speed of the detection process were analyzed. Four Signal test recordings were taken: pre-exercise and immediately after the three subsequent effort tests. The numbers of correct reactions increased after the first effort (40% VO_2max) in comparison to the pre-exercise state and then significantly decreased after the third effort test (80% VO_2max). In contrast, no significant changes in time of signal detection were observed. Physical effort with high intensity might disturb the visuomotor processing in accordance to the accuracy of the visuospatial differentiation of the relevant signal within irrelevant signals.

Key words: exercise, differentiation of visual signal, reaction time

Introduction

Visuomotor processing is defined as the neural activity associated with processing of the visual (sensory) input leading to the motor response (Fadiga et al. 2000). Physical exercise has been observed to exert various effects on visuomotor processing (for reviews, see Brisswalter et al. 2002). On the one hand, researchers have indicated that exercise has a beneficial effect on the excitation and activity of the peripheral and central nervous system (McMorris and Graydon 2000; Davranche et al. 2005; Royal et al. 2006, MacMorris and Hale 2012). In contrast, other researchers have reported that intense physical effort may interfere with neural signal transmission on different stages of visuomotor processing (Ando et al. 2005; Kamijo et al. 2004; Yagi et al. 1999). In addition, some researchers have noted a lack of influence of exercise on visuomotor processing even though the exercise intensity was very high (Cian et al. 2001; McMorris et al. 2000). The mechanism of exercise-induced effects on visuomotor processing remains unclear. The lack of consensus in the literature might be due to different factors, such as the type of physical effort that the subjects performed during the experiment (intensity and duration of exercise protocols), subjects' individual level of physical fitness, complexity of task, selection of a research subjects and experimental procedures (see Tomporowski 2003).

Lambourne and Tomporowski (2010) postulated that cognitive performance are affected differentially by exercise mode. For example, cycling was associated with enhanced performance during and after exercise, whereas treadmill running led to impaired performance during exercise and a small improvement in performance following exercise. These results are indicative that cognitive performance may be enhanced or impaired depending on when it is measured, the type of visuomotor task selected, and the type of exercise performed. However, in our mind, the more sensitive factor indicated a visuomotor processing change induced by exercise is the individual reactivity to physical effort intensity. The purpose of our study was to systematically investigate the effect of exercise on visuomotor processing. Thus, we examined the effect of exercise with progressively increased physical load on consecutive stages of visual and motor processing in physically active men. Effort intensity was determined by the individual lactate threshold of each participant. Using this procedure, we were able to determine the speed and accuracy of visuomotor processing after physical effort with different energy-yielding processes: aerobic (below the lactate threshold), aerobic–anaerobic (in the lactate threshold range) and anaerobic (above the lactate threshold).

Methods

Participants

To investigate the effect of exercise on visuomotor processing, twenty-two physical education students from the University of Szczecin (men aged 21.19 ±1.3 years) were recruited. All subjects participating in the experiment had intact basic functions of the eye, confirmed by routine eye examinations. The Bioethical Committee at the Medical Academy in Szczecin approved the research project.

Preliminary protocol

Participants completed an effort test with incremental intensity using a cycloergometer (Monark E834, Varberg, Sweden). The experiment began with a 10-min rest in a reclining position. After 10 minutes, blood sample was collected from a finger for biochemical determinations. Participants completed a 5-min warm-up at 25 watt (W). The effort test was commenced at 70 W, with 70 revolutions per min (rpm). The exercise continued with an increasing workload (20 W increments every 3 min) until refusal. During the last 15 sec of each 3-min effort at a given workload, capillary blood samples were drawn from a fingertip for enzymatic determination of blood lactate concentration (Dr Lange Cuvette Test LKM 140, Germany). Lactate concentration was determined using miniphotometer LP 20 Plus (Dr Lange, Germany). Resting heart rate and its change during exercise were measured using a Polar S610 heart-rate monitor (Polar, Finland). Oxygen consumption during exercise was estimated using an Oxycon gas analyzer (Jaeger, Germany). Individual lactate threshold was calculated using a linear regression graph log lactate and the log of effort intensity. Based on the results of the exercise test, each subject was assigned an individual workload value (W) at (1) 40% VO_2max – load value below the lactate threshold, (2) lactate threshold range, which in the case of all participants was average 60% VO_2max, and (3) 80% VO_2max (above lactate threshold).

Special Ability Signal Test included in the Vienna Test System (Schuhfried, Austria) was used to examine visuomotor processing. The test measured the visuospatial differentiation of a relevant signal within irrelevant signals. In our experiment, we used standard version S1with white signals (dots) on a black background. Dots were displayed over the entire screen area; pseudo-randomly some of the dots disappeared and others came into view. The participants were requested to perform a key-press response to programmed stimulus constellation whenever it occurred. This critical stimulus constellation consisted of four dots forming a square. Each of the participants was prepared for the main task by participating in pre-tests that allowed them to familiarise themselves with the apparatus and the nature of the task. The total testing time was estimated to be between 11 and 12 minutes. The main variables calculated were the numbers of correct reactions and the median reaction time as a measure of the speed of the detection process.

Procedure

The experiment was carried out 5 days after the effort test that determined the maximal oxygen uptake (VO_2max). The first Signal test was performed at rest . Next, all participants completed a 5-min warm-up on the cycloergometer (25 W). Participants then completed a 10-min effort at an intensity below the lactate threshold (40% VO_2max). The second Signal test was performed immediately after the effort test. Participants then performed a 10-min effort at the lactate threshold (60% VO_2max). Next, participants performed a 10-min effort at an intensity above the lactate threshold (80% VO_2max) which was followed immediately by the third Signal test. During cycling, participants maintained a constant frequency of revolutions (68–72 rate per min). Heart rate was monitored throughout the experiment.

Data analyses

All data is expressed as mean and standard error of the mean (±SEM). The normality of distribution of results was estimated using the Shapiro-Wilk tests. Data analysis was performed using one way ANOVA variance analysis. Post-hoc tests were performed using a Fisher correction with a p-value < 0.05 considered significant.

Results

Effects on the number of correct reactions

The results of a one way ANOVA indicated that there was a significant main effect of progressively increased physical exercise on Signal test results, according to the number of correct reactions ($F_{(3,84)} = 2.85$, $p < 0.05$). The number of correct responses analysis showed a significant increase after effort at an intensity with 40% VO_2max and then reduction after subsequent two efforts. Post-hoc tests indicated a significant difference ($p < 0.05$) between Signal test results at rest and after effort at an intensity with 40% VO_2max, between Signal test results after effort at an intensity with 40% VO_2max, and results after effort at an intensity of 80% VO_2max ($p < 0.05$). Effort-induced changes in Signal test variables are presented in Figure 1.

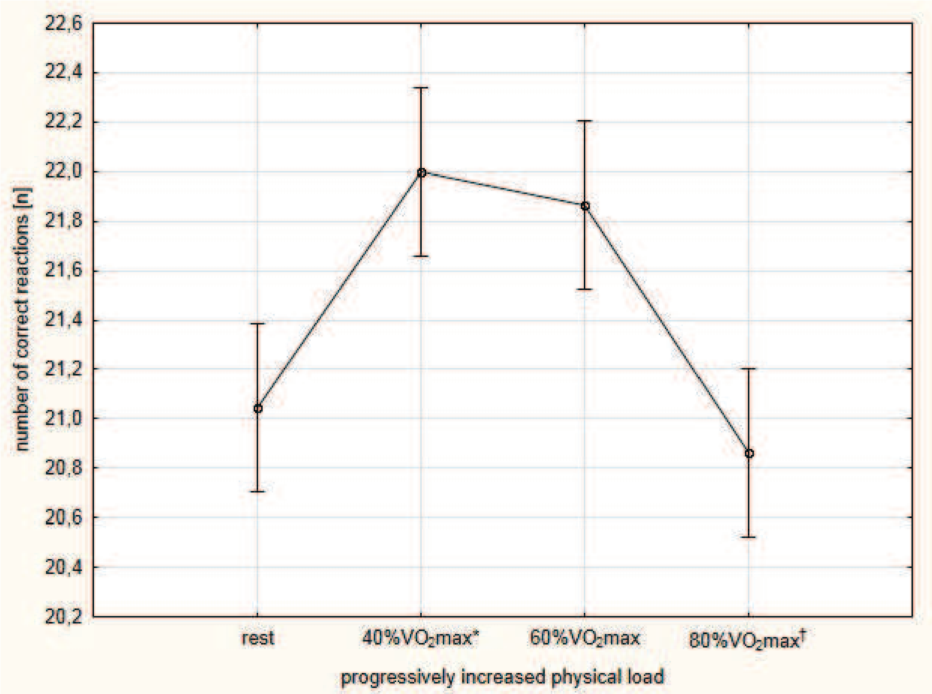

Figure 1. Pre- and post-exercise values of number of correct reactions of Signal test are presented as means and ±SEM. A significant difference ($p < 0.05$) between Signal test results at rest and after effort at an intensity of 40% VO$_2$max is denoted with (*). A significant difference ($p < 0.05$) between Signal test results after effort at an intensity of 40% VO$_2$max and results after effort at intensity of 80% VO$_2$max is denoted with (†)

Effects on the time of signal detection

The time of signal detection was not significantly different after subsequent three effort tests in comparison to the baseline ($F_{(3,84)} = 0.40$, $p > 0.05$). It was observed that the reaction time decreased after the first effort (40% Vo$_2$max) and slightly increased after the third effort with high intensity (80% VO$_2$max), but the changes were not significant ($p > 0.05$). The results are presented in Figure 2.

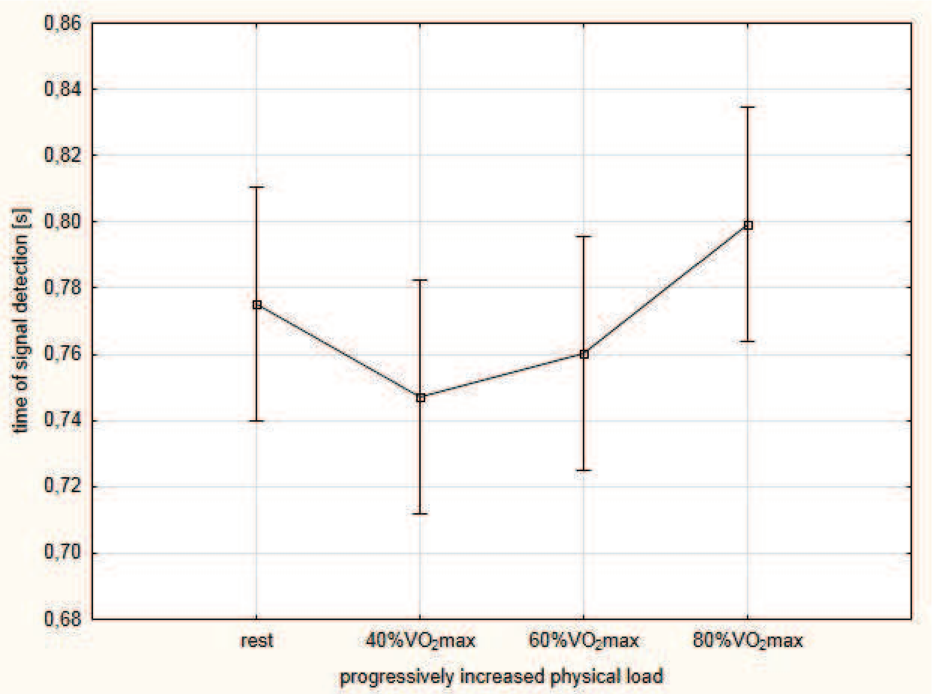

Figure 2. Pre- and post-exercise values of time of signal detection are presented as means and ± SEM

Discussion

We investigated the effect of exercise of varied intensity: 40% VO_2max (below lactate threshold), 60% VO_2max (at lactate threshold) and 80% VO_2max (above lactate threshold) on the visuomotor processing in physically active men. The main findings in our study are that physical effort caused varied changes (in the direction and range) in the accuracy of visuomotor processing. The direction and size of these changes depended on the intensity of the physical effort. Specifically, as the intensity of physical effort increased, the accuracy in visuomotor processing was improved until a critical value of exercise intensity was reached, which was followed by the significant worsening of the correct motor responses. In particular, our results showed (1) an increase in the number of correct responses after exercise of low (40% VO_2max) intensity, and (2) a decrease in the number of correct responses after exercise of moderate (60% VO_2max) and especially high (80% VO_2max) intensity. Our results confirm previous experimental data which showed that acute exercise has been claimed to have an inverted U-effect on the performance of a visuomotor and cognitive tasks (e.g. Chmura et al. 1994; Brisswalter et al. 1995; Kamijo et al. 2004). In our study, no significant changes in time of signal detection were observed although the course of the results was similar to U-effect.

Looking for an explanation of the observed results in the present study, we suppose that an impact of exercise on visuomotor processing might be related to physiological mechanisms. It is generally known that physical exercise affects the body's state of arousal. Oxygen uptake and cardiac output increase during the first few minutes of exercise to a steady state. During exercise of low intensity, the energy output is delivered aerobically and lactic acid does not accumulate in the body. We surmise that the improvement of visuomotor processing in the first stage of our study could have been due to the increased blood flow with a simultaneous increase in delivery of oxygen and glucose to the tissues. It is also possible that exercise-induced body arousal leads to the release of certain neurotransmitters. Experimental evidence showed that the effect of exercise on the visuomotor processes may be mediated via the noradrenergic system. Chmura et al. (1994, 1998) have reported a negative correlation between plasma catecholamine concentration and choice reaction time during incremental exercise until exhaustion and after the plasmatic threshold of adrenalin is reached. Additionally, Hasbroucq et al. (2003) reported that a single dose of 50 mg levodopa (a precursor of dopamine and noradrenaline) can shorten the motor time response in healthy subjects. It has been suggested that high levels of blood adrenaline are associated with changes in the CNS that might improve cognitive performance (Clark et al. 1989). Previously, researchers reported shorter reaction time to visual stimulus during or after sub-maximal exercise in healthy subjects (Arcelin et al. 1998; Davranche and Audiffren, 2004) suggesting that exercise can improve visuomotor processing. For example, Davranche et al. (2005) used the onset of voluntary electromyographic activity to analyze the reaction time in terms of pre-motor (the time interval between the onset of the response signal and the onset of electromyographic activity) and motor time (time interval between the onset of electromyographic activity and the onset of the required motor response), observed that exercise (50% of maximal aerobic power – MAP) interacted with visual stimulus intensity on pre-motor time, and consequently shortened the motor time in athletes. Taking into account the fact that visual stimulus intensity affects the discharge of the ganglion cells in the retina, authors suggested that the interaction between exercise and visual stimulus intensity modified the early stage of visual processing. Additionally, the electrophysiological study result showed that after the exercise with low intensity (40% VO_2max) the neuroretinal excitation increased in healthy subjects (Zwierko et al. 2010). Authors observed an increase of amplitude ($p < 0.001$) and a decrease in the b-wave implicit time ($p < 0.01$) of the electroretinogram in cone-mediated responses.

Our analysis showed a significant decrease in the accuracy of visuomotor processing after exercise with high intensity (80% VO2max). During intensive physical effort, the work done to contract the muscle for the most part comes from anaerobic energy-yielding metabolic processes (Wilmore and Costill 2004). Reduction of oxygen concentration, in response to cellular demand, blood acidosis or accumulation of metabolic waste lead to bioenergetic hypoxia states (Luk'janowa 1997) which impact neural processing. However, some researchers have noted a beneficial effect of exercise on visuomotor processing even though the exercise intensity was very high. For example, McMorris and Graydon (1997) evaluated the effects of exercise on soccer players visual search time, choice-response speed, and choice-response accuracy. The cognitive task required participants to search each of 15 slides that showed familiar soccer scenarios and to press a button when they detected a ball (target stimulus) and then to choose one of four play options. The slides were presented at rest, at 70% and 100% MAP. Study showed that exercise facilitated both speed and accuracy of athletes' decision making. It seems that the main explanation of the difference in experimental results between the present study and study of McMorris and Graydon (1997) is the level of participants' physical fitness. Tomporowski and Ellis (1986) suggested that well-trained individuals could compensate for the negative effects of fatigue when they have to perform cognitive tasks in extremely fatiguing conditions. Athletes have higher resistance to fatigue and are capable of using anaerobic potential more effectively (Edge et al. 2006). Moreover, the fatigue effect could be modified by incentive variables such as an individual's motivation and attentional skills (Voss et al. 2009). These issues, treated by psychologists, "are mainly connected with the particular CNS centers activity and the decision and motivation process assessment" (Klich 2013).

In summary, our findings show a close correlation between the accuracy of visuomotor processing and the intensity of physical exercise in the examined individuals. Future studies should appear necessary in the aim of validating these results and exploring more widely the locus of influence of physical exertion on visuomotor processing.

References

Ando S., Kimura T., Hamada T., Kokubu M., Moritani T., Oda S. Increase in reaction time for the peripheral visual field during exercise above the ventilatory threshold. European Journal of Applied Physiology. 2005; 94 (4): 461–467.

Arcelin R., Delignières D., Brisswalter J. Selective effects of physical exercise on choice reaction processes. Perceptual and Motor Skills. 1998; 87 (1): 175–185.

Brisswalter J., Collardeau M., René A. Effects of acute physical exercise characteristics on cognitive performance. Sports Medicine. 2002; 32 (9): 555–566.

Brisswalter J., Durand M., Delignieres D., Legros P. Optimal and non-optimal demand in a dual-task of pedaling and simple reaction time: Effects on energy expenditure and cognitive performance. Journal of Human Movement Studies. 1995; 29: 15–34.

Chmura J., Krysztofiak H., Ziemba A.W., Nazar K., Kaciuba-Uscilko H. Psychomotor performance during prolonged exerciseabove and below the blood lactate threshold. Eur J ApplPhysiol Occup Physiol. 1998; 77 (1–2): 77–80.

Chmura J., Nazar K., Kaciuba-Uscilko H. Choice reaction time during exercise in relation to blood lactate and plasma catecholamine threshold. International Journal of Sports Medicine. 1994; 15 (4):172–176.

Cian C., Barraud P.A., Melin B., Raphel C. Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. International Journal of Psychophysiology. 2001; 42 (3): 243–251.

Clark C.R., Geffen G.M., Geffen L.B. Catecholamines and the covert of attention in humans. Neuropsychology. 1989; 27 (2): 131–139.

Davranche K., Audiffren M. Facilitating effects of exercise on information processing. Journal of Sports Sciences. 2004; 22 (5): 419–428.

Davranche K., Burle B., Audiffren M., Hasbroucq T. Information processing during physical exercise: a chronometric and electromygraphic study. Experimental Brain Research. 2005; 165 (4): 532–540.

Edge J., Bishop D., Hill-Haas S., Dawson B., Goodman C. Comparisonof muscle buffer capacity and repeated-sprint ability of untrained, endurance-trained and team-sport athletes. European Journal of Applied Physiology. 2006; 96 (3): 225–234.

Fadiga L., Fogassi L., Gallese V., Rizzolatti G. Visuomotor neurons: Ambiguity of the discharge or "motor" perception? International Journal of Psychophysiology. 2000; 35: 165–177.

Hasbroucq T., Tandonnet C., Micallef-Roll J., Blin O., Possamai C.A. An electromyographic analysis of the effect of levodopa on the response time of healthy subjects. Psychopharmacology (Berl). 2003; 165 (3): 313–316.

Kamijo K., Nishihira Y., Hatta A., Kaneda K., Wasaka T., Kida T., Kuroiwa K. Differential influences of exercise intensity on information processing in the central nervous system. Eur J App Physiol. 2004; 92 (3): 305–311.

Klich S. Fatigue development mechanisms during increased intensity exertion. Centr Eur J Sport Sci Med. 2013; 1: 39–45.

Lambourne K., Tomporowski P.D. The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. Brain Research. 2010; 1341: 12–24.

Luk'janowa L.D. Bioenergetic hypoxia: definition, mechanisms, and methods of correction. Biull Eksp Biol Med. 1997; 124 (9): 244–254.

McMorris T., Graydon J. The effect of exercise on cognitive performance in soccer specific test. J Sports Sci. 1997; 15 (5): 459–468.

McMorris T., Sproule J., Delves S., Child R. Performance of a psychomotor skill following rest, exercise at the plasma epinephrine threshold and maximal intensity exercise. Perceptual and Motor Skills. 2000; 91 (2): 553–562.

McMorris T., Graydon J. The effect of incremental exercise on cognitive performance. International Journal of Sport Psychology. 2000; 31 (1): 66–81.

McMorris T., Hale B.J. Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: A meta-analytical investigation. Brain and Cognition. 2012; 80 (3): 338–351.

Royal K.A., Farrow D., Mujika I., Halson S.L., Pyne D., Abernathy B. The effects of fatigue on decision making and shooting skill performance in water polo players. Journal of Sports Sciences. 2006; 24 (8): 807–815.

Tomporowski P.D., Ellis N.R. Effects of exercise on cognitive process: a review. Psychol Bull. 1986; 99 (3): 338–346.

Tomporowski P.D. Effects of acute bouts of exercise on cognition. Acta Psychologica. 2003; 112 (3): 297–324.

Voss M.W., Kramer A.F., Basak C., Prakash R.S., Roberts B. Are expert athletes “expert” in the cognitive laboratory? A meta-analytic review of basic attention and perception and sport expertise. Applied Cognitive Psychology. 2009; 24 (2): 812–826.

Wilmore J.H., Costill D.L. Physiology of sport and exercise. Human Kinetics, USA 2004.

Yagi Y., Coburn K.L., Estes K.M., Arruda J.E. Effects of aerobic exercise and gender on visual and auditory P300, reaction time, an accuracy. European Journal of Applied Physiology. 1999; 80 (5): 402–408.

Zwierko T., Czepita D., Lubiński W. The effect of physical effort on retinal activity in the human eye: rod and cone flicker electroretinogram studies. Graefe’s Archive for Clinical and Experimental Ophthalmology. 2010; 248 (5): 659–666.

Cite this article as: Zwierko T., Lesiakowski P. Visuomotor processing after progressiveley increased physical exercise. Centr Eur J Sport Sci Med. 2014; 5 (1): 27–34.