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ABSTRACT

The immediate aftereffects of one hour submaximal steady-state aerobic exercise of high- and low-fit individuals in a random number generation task were assessed. Twelve male university students ($M_{\text{age}} = 22.35$ years) volunteered to participate in the study and were separated into fit ($VO_2 \text{ max} > 55 \text{ ml/kg/min}$) and unfit individuals ($VO_2 \text{ max} < 45 \text{ ml/kg/min}$) based on their $VO_2 \text{ max}$ values. They performed the Random Number Generation test of attentional deployment before and after ergometer cycling exercise at a resistance equivalent to 55% of individual $VO_2 \text{ max}$ values. The results of the 2 (Fitness level) by 2 (Experimental Conditions) by 2 (Measures) analysis of variance with Fitness Level as the between factor and Experimental Conditions and Measures as the within subjects factors revealed that one hour of moderate exercise facilitated attentional process as were estimated by Random Number Generation index scores, independently of participants' level of fitness.

KEY WORDS: *aerobic exercise, fitness, cognitive performance, attention, RNG.*

INTRODUCTION

Researchers attempting to study cognitive performance during moderate intensity steady-state aerobic exercise (lasting less than 60 minutes in duration) provided evidence of positive effects of exercise on attentional processes (1, 37), creativity (20), stimulus detection and coincidence-timing tasks (18, 19), simple reaction time tasks (14, 26), choice reaction time tasks (2, 3, 12, 13, 51), and problem-solving tasks (25, 48). However, Tomporowski et al (47) and Travlos and Marisi (49) indicated that 50 minutes of aerobic exercise did not affect cognitive performance, while Cian et al (9, 10) claimed that more than 2 hours aerobic exercise had no effect or impaired performance on cognitive tasks.

Research on cardiovascular fitness and cognitive aging indicated that higher levels of fitness are correlated with better cognitive performance (30, 34, 35). Moreover, it appears that high-fit individuals performed better than low-fit individuals on effortful memory task (e.g. free recall tasks) (11) and on simple reaction time, attention, working memory and processing speed (36). Similarly, a number of studies on fitness levels and cognitive performance demonstrated that highly physically fit individuals performed better than poorly physically fit individuals on cognitive tasks (23, 25, 40, 50). However, Tomporowski et al (47), and Travlos and Marisi (49) failed to demonstrate any relationship between fitness level and cognitive performance. The inconsistency among the studies can be due to several factors, such as the use of different (a) experimental protocols including type of exercise, exercise intensity and duration, (b) mental tasks, and (c) definitions of physical fitness.

The theoretical explanations for interpreting the effects of exercise-induced activation on cognition was provided by the inverted –U hypothesis (52), Hull's early drive theory (27), the functional relationship between anxiety and performance as is explained by catastrophe theory (7, 24), and Sanders' (38, 39) cognitive-energetical model. For an application and a detailed description of the model, see Davranche & Audiffren (12). The theoretical explanation of Sanders' four information-processing stages model is based on experimental findings obtained using Sternberg's additive factors model (41). According to the model, environmental information is processed through a series of four non-overlapping stages (stimulus preprocessing, feature extraction, response choice, motor adjustment). Each one of them interacts with three energetic attention control mechanisms (arousal, activation, effort) and one evaluation mechanism. Incoming stimuli at the preprocessing stage energize the arousal mechanism which supplies with resources the feature extraction stage. The activation mechanism interacts with arousal and provides the necessary resources in the motor adjustment stage. Both mechanisms inform the evaluation mechanism about their resource state. The evaluation mechanism passes the information about the state of the available resources to the effort mechanism. The effort mechanism controls and supplies these resources in

the response choice stage when complex cognitive tasks have to be processed (12). According to the literature, the facilitating effects of sub-maximal physical exercise on cognitive performance can be attributed to the increase in arousal and activation levels that permit higher involvement of attentional resources to the performed cognitive task (8, 12, 22).

Research on the interaction between exercise-induced activation and random number generation tasks did not demonstrate a clear pattern of results. Travlos and Marisi (49) separated participants into high and low fitness groups according to their VO_2 max values. The participants required to perform the Random Number Generation (RNG) test of attentional deployment after every 10 min of continuous cycling at workload intensities corresponding to 40%, 50%, 60%, 70%, and 80% of individual VO_2 max values. The results of this study indicated that 50 minutes of progressively increased exercise and 15 minutes of recovery did not produce significant differences among fitness levels and exercise intensities on RNG index scores. Similarly, McMorris et al (33) claimed that increases of norepinephrine and dopamine during a 6-min exercise at 40% and 80% maximum power output did not demonstrate significant changes in RNG index scores. Moreover, Audiffren, Tomporowski & Zagrodnik (4) indicated that a 35-min steady-state aerobic exercise at 90% of participant's ventilatory threshold resulted in less effortful random number generation strategy during exercise that was "ceased immediately with the termination of exercise" (p. 93).

Accordingly, the purpose of this study was to investigate whether fitness level and one hour of submaximal exercise at the 55% of individual VO_2 max values on a bicycle ergometer were related to changes on cognitive performance. Cognitive performance was assessed by the RNG test of attentional deployment (16, 17, 31). RNG is a task that involves a number of highly controlled processes (6) that require considerable allocation of attention (28).

METHODS

Participants

Twelve male university students volunteered ($M_{age} = 22.35$ years) to participate in the study and they were defined as fit (VO_2 max > 55 ml/kg/min) and unfit (VO_2 max < 45 ml/kg/min) on the bases of their VO_2 max values. Informed consent was obtained from each individual prior to testing. The individuals were free to withdraw from the study without any repercussion.

Random Number Generation test of attentional deployment

The Random Number Generation test of attentional deployment was used to evaluate the effects of submaximal steady-state exercise on concentration.

RNG index seems to be a sensitive measure to attentional process (16, 17, 21) and is a reliable instrument for test-retest evaluation when the first trial is excluded (16, 31, 49). In this task, participants are required to generate numbers from 1 to 10 in a random fashion, within a period of 100 seconds at a rate of 1 number per second. The concept of randomness was explained to all participants (5). Random number generation index was calculated based on the formulas provided by Evans (16). RNG index can range from zero (perfect randomness) to one (each number is completely predictable from the previous one). For statistical and interpretative purposes, RNG indexes were multiplied by 100 to reflect a range from zero (perfect concentration) to 100 (lack of concentration).

Procedures

Each individual was tested over three sessions. During the first session, the weight of each individual dressed in shorts and socks was determined by a balance beam medical scale (Detect Scale Inc.). A cardiorespiratory endurance test of a continuous, progressive cycle ergometer test to volitional exhaustion was used to assess individual VO_2 max values and to separate individuals in fit and unfit participants. Individual VO_2 max values were used to establish the 55% oxygen uptake values and the corresponding workloads (for a detailed description of instrumentation and VO_2 max estimation, see Travlos & Marisi, (49)). For the following two sessions, each participant returned to the laboratory each week for two consecutive weeks and on each session was given one of the two particular experimental conditions according to a random sequence.

Experimental conditions

The experimental conditions included exercise (exercise condition) and no exercise (control condition). The *exercise condition* required subjects to pedal on a MONARK cycle ergometer for 60 minutes at a resistance equivalent to 55% of individual maximal VO_2 values. An electric metronome was set to allow pedaling at a rate of 60 revolutions per minute (rpm). RNG task was given before the individual mounted the bicycle. This trial was given as a practice trial and was omitted from further analysis. When mounted the bicycle, participants achieved a pedal frequency of 60 rpm at zero resistance and RNG test was given and used as a pretest trial. Within the following minute the resistance setting on the cycle ergometer was adjusted to a workload corresponding to 55% of individual VO_2 max values. Participants continued pedaling at this resistance for one hour and RNG test was given to all participants at the 58th minute of exercise (posttest trial). At the *control condition* the same individuals sat for 60 minutes. They had to mount the bicycle and

achieve a pedal frequency of 60 rpm at zero resistance at the same time periods that undertook the RNG test.

Statistical design and analysis

Univariate procedures were used to analyze random number generation (RNG) index scores. The experimental design used was a 2 (Fitness level) by 2 (Experimental Conditions) by 2 (Measures) with Fitness Level as the between factor and Experimental Conditions and Measures as the within subjects factors. Bonferroni post hoc analyses were used to identify significant differences (29). Partial Eta squared (η^2) was estimated for significant main effects and interactions. The alpha level of significance was set at .05 for ANOVA and *post hoc* analyses.

RESULTS

The $2 \times 2 \times 2$ (Fitness Level x Experimental Conditions x Measures) analysis of variance for RNG index scores revealed significant main effects for Experimental Conditions ($F_{1,10} = 10.35$, $p < .01$, $\eta^2 = .509$) and Measures ($F_{1,10} = 13.13$, $p < .005$, $\eta^2 = .568$) and a significant interaction between Experimental Conditions and Measures ($F_{1,10} = 12.08$, $p < .01$, $\eta^2 = .547$). The main effect of Fitness Level ($F_{1,10} = 2.08$, $p > .05$) and the interactions Fitness Level by Experimental Conditions ($F_{1,10} < 1$, $p > .05$), Fitness Level by Measures ($F_{1,10} < 1$, $p > .05$), and Fitness Level by Experimental Conditions by Measures ($F_{1,10} < 1$, $p > .05$) did not reach statistical significance. The means and standard deviations between individuals high and low in fitness for exercise and control conditions across time on random number generation index scores are presented in Table 1.

Table 1. Means and standard deviations between individuals high and low in fitness for exercise and control conditions across time on random number generation index scores

		Pretest	Posttest
Exercise	High Fit	31.37 ± 1.31	28.29 ± 2.32
	Low Fit	32.61 ± 2.11	29.26 ± 3.35
Control	High Fit	31.71 ± 1.99	32.15 ± 2.29
	Low Fit	33.28 ± 1.32	33.30 ± 2.27

The significant main effect of Experimental Conditions was due to lower RNG index scores for exercise condition ($M = 30.38 \pm 1.93$) as compared to control condition ($M = 32.61 \pm 1.92$). Measures significant main effect can be attributed to lower RNG index scores at posttest ($M = 30.75 \pm 1.79$) as compared to pretest scores ($M = 32.24 \pm 1.59$).

Bonferroni post hoc analysis of Experimental Conditions by Measures interaction indicated that for exercise condition, RNG index scores decreased significantly from pretest ($M = 31.99 \pm 1.79$) to posttest measures ($M = 28.77 \pm 2.80$). Moreover, at posttest measures, exercise condition RNG index scores were significantly lower ($M = 28.77 \pm 2.80$) than control condition indexes ($M = 32.72 \pm 2.26$). The rest of paired comparisons did not reach statistical significance ($p > .05$). The means and standard deviations of RNG index scores for Experimental Conditions and Measures are plotted in Figure 1.

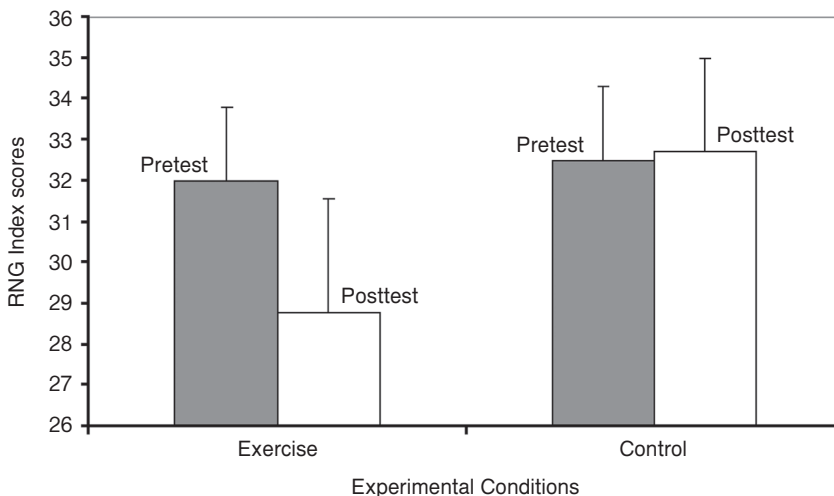


Figure 1: Means and standard deviations for RNG index scores at pretest and posttest measures for exercise and control conditions.

DISCUSSION

The experiment was designed in accordance with the recommendations of Travlos and Marisi (49) and Marisi and Travlos (31) and allowed the investigation of the effects of a steady-state aerobic exercise on RNG test of attentional deployment as a function of high- and low-fitness level. In line with previous research (1, 37), the present study indicated that one hour of exercise at 55% of individual VO_2 max values facilitated attentional process as was estimated by RNG index scores. However, these findings are in disagreement with studies reporting no effect of aerobic exercise in RNG performance (33,

49). These results suggest that long duration submaximal steady-state exercise allowed participants to increase physiological arousal and activation at levels that induced an improvement in cognitive performance (32).

The results of the present experiment failed to show significant differences among high- and low-fit individuals in random number generation index scores when participants exercise under the same relative workload. These findings are in agreement with Tomporowski et al. (47), and Travlos & Marisi (49) studies and support the notion that moderate levels of activation facilitate attentional processes independently of participants' level of fitness. It appears that one issue of future research is to focus on other cognitive tasks that may be affected by different levels of physical fitness (15) and exercise intensity, duration (43, 46) and age (42, 44, 45).

In conclusion, the results of this study confirm the facilitating effect of sixty minutes steady-state moderate aerobic exercise on cognitive performance as reflected by the random number generation task. It is tenable to suggest that submaximal exercise modulated physiological arousal and activation levels to higher involvement of attention control mechanisms to the random number generation task.

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