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Intensity of Aerobic Exercise and Level of Cognitive Task on Computerized Neurobehavioral System

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ABSTRACT

Aerobic exercise affects cerebral circulation, action of neurotransmitters, glucose, oxygen, and energetic substances and influence on the central nervous system for cognition. This study suggests that both the intensity of exercise and the level of cognitive task need to be considered. Computerized neurobehavioral testing is a more effective method, compared to conventional methods, of neuropsychological testing when measuring cognition objectively, in cases that we found. The intensity of 80% max HR had effect on more complex tasks such as 3 Digit Addition and Digit Span Backward, and the intensity of 65% max HR had an effect on more simple tasks such as Color Word Vigilance and Digit Span Forward. We can assume that different intensity of aerobic exercise might involve specific areas of the brain as they could have different sensitivities, so further studies measuring regional cerebral blood flow or electroencephalogram are needed to confirm the results.

Keywords: *aerobic exercise, attention, memory, cognition*

1. INTRODUCTION

Several studies suggest the activation of the autonomic nervous system by aerobic exercise and influence on the central nervous system [1]. Glenister [2] suggested that aerobic exercise affects change of hormones and increase of cerebral activity and Sharmara [3] proposed that cerebral blood flow increased by aerobic exercise, such as jogging, swimming, cycling, walking and gardening, increases influence on the hypothalamic-pituitary-adrenal axis which interacts with the limbic systems. The limbic system has a role of controlling motivation, mood, stress and memory formation [4].

Recent studies report that aerobic exercise had a positive impact on cognition. Pontifex [5] performed an experiments for twenty-one young adult participants to complete 30 min of aerobic exercise on a treadmill at an intensity of 80% of VO_{2max}(maximal oxygen uptake). Reaction time and a modified Sternberg working memory task were used to evaluate cognition before, immediately after, and then again 30 min after 30 min of either, resistance or aerobic exercise followed by a seated rest control. The results suggested that working memory increased with the aerobic condition but there was no effect observed in the resistance exercise or the seated rest conditions ($F(2,19)=112.8$, $p<0.001$). Park [6] studied seven elderly people with cognitive impairments. The intensity of exercise was maintained at 60% of the maximum heart rate, lasting 45min for 6 weeks. The scores of Cognitive Scale for Older Adults showed significant improvements in attention ($p=0.05$), memory ($p=0.01$), language ($p=0.02$), visuospatial function ($p=0.03$), and global cognition ($p=0.04$).

The intensity of exercise interacts with the level of cognitive task. High intensity exercises can disturb one's performance of some cognitive tasks but it can facilitate other tasks [7].

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Therefore we suggest that both the intensity of exercise and the level of cognitive task should be considered. Yoo et al. [8] studied 200 university students performing a cycle ergometer for 20 min at 95% VO_{2max}, 80% VO_{2max} and 50% VO_{2max}. After the exercise, simple and complex cognitive tests were evaluated for the participants. There was no difference among the 3 groups in the simple tasks (simple reaction time) but the group of 80% VO_{2max} showed the shortest reaction time in complex tasks (choice reaction time). Quaney et al. [9] divided 38 stroke patients into 2 groups, one with aerobic exercise at 70% maximal heart rate and the other with stretching exercise at the same maximal heart rate. In the result, the group with aerobic exercise significantly improved information processing speed on the serial reaction time task compared with the stretching exercise group (p=.024) but there were no differences between groups in the simple reaction time task.

The earlier researchers such as Park [6], Yoo et al. [8] and Quaney et al. [9] considered only the intensity of exercise or the level of cognitive task. However, we suggest that two components can interact with each other and should be considered at the same time. Intensity of exercise could be classified with variables such as, percent of maximal oxygen uptake or percent of maximum heart rate but the level of difficulty of cognitive tasks was not easy to objectively classify. The earlier studies had limits that cognitive tasks were simple, cognitive scores were summed up simply and there was no ordering of techniques for the tasks. Thus, it may take an instrument to measure the cognition objectively and order the tasks. Computerized neurobehavioral testing is not only highly effective method to input, process, transform and compare the cognitive behavior but also have the highest reliability in each age, sex or education [10-12]. Furthermore, deficits found by the test provide various neuropsychological information [13]. In our study, we classified intensity of exercise with percent of maximum heart rate and graded cognitive tasks with computerized neurobehavioral systems and we studied the effect of aerobic exercise according to the level of cognitive task.

2. METHOD

2.1. Participants

Participants were recruited from a university by advertisement. All participants were between 19 and 23 years of age, no cardiac problems and healthy, according to an interview. All of them were right-handed and they had no neurological deficit according to a physical examination. All participants received a comprehensive explanation of this study and signed an informed consent document. One occupational therapist checked the radial pulse lying lateral to the flexor carpi radialis tendon on the distal radius before and after a treadmill exercise of 20 minutes at the intensity of either 50% max HR, 65% max HR or 80% max HR (Table 1).

Table 1. Anthropometrical and physiological characteristics (n=30)

Variable	Mean±SD
Age (years)	20.5±1.4
Height (cm)	168.1±9.0
Weight (kg)	62.3±11.6
Resting HR (bpm)	67.8±14.9
Exercise HR (bpm)	125.5±32.4

2.2. Instruments

Computerized neurobehavioral tests were administered with the Korean Computerized Neurobehavioral Test (KCNT). KCNT has the similar structure and content as the Swedish performance evaluation system (SPES), except for the addition of a Korean introduction and its application in a Microsoft Windows environment. Previous studies verified the validity of KCNT for epidemiologic studies [14]. Sakong [15] established a huge norm database through tests for 5,000 health workers. The test system uses the language C++ and consists of the main program and 9 modules for each test. The main program has an interface with pull-down menus where the examiner can record the demographic, past medical history and work related variables then can select the number and duration of test.

We selected 4 tests among the full test battery to compare the effect of aerobic exercise on cognition in the healthy subjects. It took approximately 5–10 min to complete all four tests. 4 tests of the KCNT consisted of Color Word Vigilance (CWV), 3 Digit Addition (3DA), Digit Span Forward (DSF) and Digit Span Backward (DSB) [12]. The purpose of the Color Word Vigilance and the 3 Digit Addition was to evaluate the ability to sustain and focus attention. 3 Digit Addition can classified as a more difficult task because it requires immediate memory and conceptual manipulation as well as attention [16].

For the Color Word Vigilance, the task was to press the space bar when the color of the word coincides with the meaning of the word. For example, the participants should respond only when the color of “Red” is seen in red. If the color of “Red” is seen yellow, he or she should not press the key. When there was no response, the square was cleared from the screen after 1 second. The inter-stimulus interval varied randomly according to a uniform distribution ranging from 2.5 to 5.0 seconds. The performance measures were the mean and variability of the reaction times (Fig.1). For the 3 Digit Addition, a series of calculation tasks were presented on the monitor. The participants pressed the number keys to answer the task. The systems evaluate speed and accuracy to the response. The Digit Span Forward and Digit Span Backward evaluate working memory function. A series of digits were presented on the monitor (Fig.2). After all the digits were displayed, subjects were to press the numeric keys on the keyboard to enter the entire sequence of numbers in the order in which they had been presented. Performance was evaluated as the maximum span length successfully reported [10].

Fig.1. Color Word Vigilance

Fig.2. Digit Span Forward

2.3. Aerobic Exercise Parameters

To train at a percentage of maximum heart rate requires knowledge of what the heart rate would be during near-

exhaustion but such intense exercise needs considerable motivation and could be dangerous. McArdle, Katch and Katch [17] suggested the calculation method. The maximum heart rate of the man calculated (214-0.8*age) and that of the woman estimated (209-0.7*age).

We performed the baseline testing and experimental testing for 2 different days to exclude the testing effect of KCNT. On the first day of visiting the laboratory the participants rested on the chair for 20 minutes and the examiner checked the radial pulse lying lateral to the flexor carpi radialis tendon on the distal radius [18]. And then the baseline evaluation of KCNT was performed. To prevent testing effect, on the first day, the KCNT evaluation was processed and the participants were blinded to whether the performance was practice or a real evaluation.

On the second day of the laboratory visit, the participants performed the treadmill exercise at 50% max HR, 65% max HR or 80% max HR, controlled by the monitor which was displayed in front of the them. Immediately after the exercise, the examiner checked the radial pulse and the participants rested on the chair until the radial pulse decreased to the baseline heart rate, then re-evaluation of KCNT was performed.

2.4. Outcome Measurements

2.4.1. Homogeneity among 3 groups

In the pre-exercise (baseline) results, the 4 tests of the KCNT [Color Word Vigilance (CWV), 3 Digit Addition (3DA), Digit Span Forward (DSF) and Digit Span Backward (DSB)] of all the groups were compared with a one-way ANOVA to confirm the homogeneity among treadmill exercise at 50% max HR, 65% max HR and 80% max HR in the baseline results. Differences were considered statistically significant at $p<0.05$ and we could assume the homogeneity at $p>0.05$.

2.4.2. Reaction Difference between Pre-exercise and Post-exercise

Paired t-tests were used for comparison of the 4 KCNT tests between pre-exercise performance and post-exercise performance. Differences were considered statistically significant at $p<0.05$

2.4.3. Reaction Difference according to Exercise Intensity

In the post-exercise results, the 4 KCNT tests from all the groups were compared to assume the difference among treadmill exercise at 50% max HR, 65% max HR and 80% max HR.

3. RESULT

Table 2 presents the results of KCNT before exercise in the groups of the intensity of 50% max HR, 65% max HR and 80% max HR. There were no significant differences across the groups and we could assume that they are homogeneous in computerized neuro-behavior before the exercise.

Table2. Homogeneity across 3 groups before exercise (Mean±SD)

	G50	G65	G80	F	p
CW(ms)	639.0± 116.3	623.2± 107.0	651.4± 110.0	.16	.85
DA(ms)	2718.7± 815.0	2903.9± 1037.6	3267.9± 982.7	.87	.43
DF(number)	8.5±1.1	7.9±1.5	8.7±1.4	.98	.39
DB(number)	6.9±1.5	7.2±1.2	6.5±1.7	.57	.57

Note: G50=Group of 50% max HR exercise; G65=Group of 65% max HR exercise; G80 =Group of 80% max HR exercise; CW=Color Word Vigilance; DA=3 Digit Addition; DF=Digit Span Forward; DB=Digit Span Backward

Table 3. Reaction time and reaction score at 50% max HR

	Pre-exercise	Post-exercise	t	p
CW	639.0±116.3	631.5±109.0	.16	.87
DA	2718.7±815.0	2838.9 ±818.3	-.83	.43
DF	8.5±1.1	8.5±1.1	.00	1.0
DB	6.9±1.5	6.8±1.1	.16	.88

Note: CW=Color Word Vigilance; DA=3 Digit Addition; DF=Digit Span Forward; DB=Digit Span Backward

Table 4. Reaction time and reaction score at 65% max HR

	Pre-exercise	Post-exercise	t	p
CW	623.2±107.0	566.3±104.7	4.15	.00**
DA	2903.9±1037.6	2821.5±929.0	.53	.61
DF	7.9±1.5	9.2±0.9	-2.62	.03*
DB	7.2±1.2	6.9±1.0	.61	.56

CW=Color Word Vigilance; DA=3 Digit Addition; DF=Digit Span Forward; DB=Digit Span Backward

Table 5. Reaction time and reaction score at 80% max HR

	Pre-exercise	Post-exercise	t	p
CW	651.4±110.0	584.7±97.56	2.54	.03*
DA	3267.9±982.7	2661±536.78	2.80	.02*
DF	8.7±1.4	8.9±1.17	-1.50	.17
DB	6.5±1.7	7.7±1.03	-3.34	.01*

CW=Color Word Vigilance; DA=3 Digit Addition; DF=Digit Span Forward; DB=Digit Span Backward

Figure 3 to figure 6 present the result of KCNT according to the intensity of exercise. The reaction time of Color Word Vigilance as a simple attention task was the lowest with the intensity of 65% max HR. The correct reaction time of 3 Digit Addition as a complex attention task was sequenced with the drop in intensity of 80% max HR, 65% max HR and 50% max HR (p=.02). Digit Span Forward as a simple memory task was the highest in the intensity of 65% max HR. Digit Span Backward as a complex memory task was the highest in the intensity of 80% max HR.

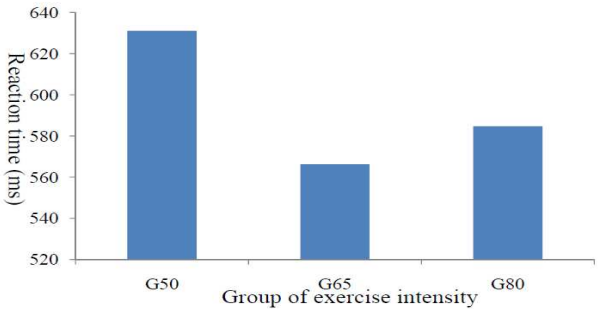

Fig. 3. Color Word Vigilance according to exercise intensity
Note: G50=Group of 50% max HR exercise; G65=Group of 65% max HR exercise; G80 =Group of 80% max HR exercise

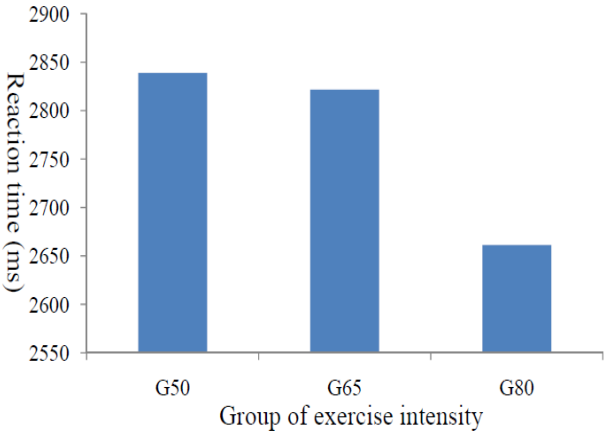

Fig. 4. 3 Digit Addition according to exercise intensity
Note: G50=Group of 50% max HR exercise; G65=Group of 65% max HR exercise; G80 =Group of 80% max HR exercise

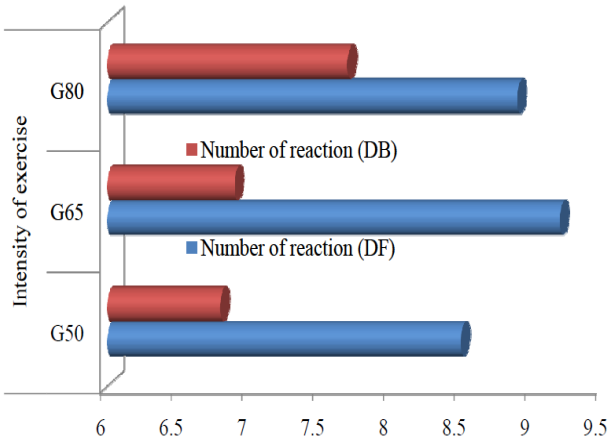

Fig. 5. Digit Span Forward and Backward according to exercise intensity; Note: G50=Group of 50% max HR exercise; G65=Group of 65% max HR exercise; G80 =Group of 80% max HR exercise

4. DISCUSSION

The earlier studies, which were researches about the effects of aerobic exercise on cognition, experimented with the same participants for several times with activities such as: seated rest, mild aerobic exercise, severe aerobic exercise or resistance exercise [5-8]. Chung et al. [14] suggested that a reaction time could decrease or a reaction number could increase when the participants repeat the neuropsychological test across a short period and we should experiment one time to exclude the testing effect of KCNT. Therefore, we performed the baseline testing and experimental testing on 2 different days. The first half of KCNT evaluation was processed for the practice duration and the participants were blinded whether the performance was practice or a real evaluation. We confirmed the homogeneity of the groups by comparing the baseline neuro-behavior of them.

We can consider both the intensity of exercise and the level of the cognitive task on KCNT and we found that the intensity of 80% max HR had effect on more complex tasks such as 3 Digit Addition and Digit Span Backward while the intensity of 65% max HR had effect on simpler tasks such as Color Word Vigilance and Digit Span Forward. Therefore, we can assume that each cognitive component could have a correlation with the optimal intensity of aerobic exercise and there might be different mechanisms of the central nervous system. Past studies about acute exercise-induced changes tap the aspect of inhibitory control [19]-[23]. Executive function such as Color Word Vigilance is controlled by inhibitory control that needs stop-motion in case the color of the literature does not coincide with the meaning of the literature.

Several studies suggest that the cognitive facilitation by moderate exercise is presumably attributable to a direct improvement in cerebral circulation and the alteration of the action of neurotransmitters, glucose, oxygen, and energetic substances [24],[25]. 3 Digit Addition is correlated with the right parietal lobe of the brain and the prefrontal cortex is known to be involved in Digit Span Backward [26]. We can assume that different intensities of aerobic exercise might involve specific areas of the brain and they could have different sensitivity to cerebral circulation, neurotransmitters, glucose, oxygen, or energetic substances.

To confirm our supposition, PET (positron emission computed tomography) scan to measure rCBF (regional cerebral blood flow) or EEG (electroencephalogram) to measure the electric potential of the specific area, may be needed [26]-[29]. PET scans are used to assess blood flow, oxygen or glucose metabolism, and receptor location [4]. rCBF could increase cognition because the cerebral oxygenation measured by near infrared spectroscopy is controlled in both mental and motor tasks [30],[31]. Event-related P300 potentials measured by EEG can evaluate cognitive functions such as stimulus evaluation time (P300 latency) and task relevance (P300 amplitude) [32]. In the study of Nakamura et al., the amplitude of P300 improved significantly after a 30-min jog and Yagi et al. suggested a 10-min aerobic exercise could increase both auditory and visual reaction time [33],[34].

In our study, we did not measure the brain activity by PET or EEG but we used the computerized neurobehavioral system to measure cognition by the activity in various brain areas. It was a more effective method than conventional methods of neuropsychological tests to measure the cognition objectively. Future research should assess the effects of aerobic exercise with the computerized neurobehavioral system and computerized imaging of the brain such as PET, fMRI or EEG and so on.

5. CONCLUSION

We classified the intensity of exercise with the percent of maximum heart rate and grade cognitive tasks with computerized neurobehavioral system and we found that the intensity of 80% max HR had effect on more complex tasks such as 3 Digit Addition and Digit Span Backward while the intensity of 65% max HR had effect on simpler tasks such as, Color Word Vigilance and Digit Span Forward. We concluded that each cognitive component might have a correlation with the optimal intensity of aerobic exercise but further studies using PET, fMRI or EEG need to confirm the results.

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