Original Article

Vol. 12, No. 2, 89-97
https://doi.org/10.15280/jlm.2022.12.2.89

Journal of Lifestyle Medicine

Changes in Keyboard Typing Accuracy and Spatial Perception after Cardiovascular Fitness Exercise

Myeonggon Moon[1,2,3,†], Dewan Md. Sumsuzzman[2,3,4,5,†], Jeonghyun Choi[2,3,4,‡], Ashura Suleiman Kazema[1,2,3,‡], Zeeshan Ahmad Khan[2,3,4], Yonggeun Hong[1,2,3,4,5,6,*]

[1]Department of Physical Therapy, Graduate School of Inje University, [2]Research Center for Aged-life Redesign (RCAR), [3]Biohealth Products Research Center (BPRC), [4]Department of Physical Therapy, College of Healthcare Medical Science & Engineering, Inje University, [5]Department of Rehabilitation Science, [6]Institute of Digital Anti-aging Healthcare, Graduate School of Inje University, Gimhae, Korea

Background: This study aimed to identify the association between cardiopulmonary exercise and neurological activation by measuring dictation accuracy and the extent of spatial perception.

Methods: First of all, the body composition of subjects was analyzed to verify their physical abnormality. The subjects were given treadmill exercise using modified Bruce protocol. Before and after the treadmill exercise, a spatial perception test and dictation task with auditory and visual stimulation were carried out to identify the changes in neurological activation.

Results: The scores of spatial perception after treadmill exercise were higher than those before treadmill exercise ($p < 0.05$). In addition, the speed of the post-treadmill dictation task with visual stimulation was significantly increased compared to that of the pre-treadmill dictation task ($p < 0.05$). However, the accuracy of the post-treadmill dictation task with visual stimulation was significantly decreased compared to that of the pre-treadmill dictation task ($p < 0.05$).

Conclusion: In this study, it was shown that spatial perception and speed of visual dictation were increased after treadmill exercise. These results suggest that cardiovascular fitness exercise increases spatial perception and typing speed by facilitating neurological activation.

Key Words: Cardiovascular fitness exercise, Treadmill exercise, Cognitive function, Autonomic nervous system, Neurological activation

INTRODUCTION

Plenty of studies have documented the effects of exercise on cognition, however, most of them were theoretical [1,2]. Among them, Davey [3] first reported the theoretical evidence by insisting that exercise is a stressor inducing changes in arousal levels. It has been suggested for more than a decade that both chronic and acute exercise are beneficial to the brain as they may influence neural functioning and cognitive performances [4,5]. These exercise-mediated benefits are attributed to improved neural adaptation caused by increased regional blood flow and brain vascularization

†These authors contributed equally to this work.
‡These authors contributed equally to this work.

Received: March 19, 2022, Accepted: April 3, 2022

*Corresponding author: Yonggeun Hong
Department of Rehabilitation Science, Graduate School of Inje University, 197 Inje-ro, Gimhae, Gyeongsangnam-do 50834, Republic of Korea
Tel: 82-55-320-3681, Fax: 82-55-329-1678
E-mail: yonghong@inje.ac.kr

[6,7], stimulated neurogenesis [8], and augmented nerve growth factor levels such as brain-derived neurotrophic factor (BDNF) [9].

Acute exercise refers to a session of single exercises, which may last for about a few seconds to several hours [10]. Among numerous types of exercise, treadmill training is known to be beneficial to cardiovascular enhancement as well as muscle endurance of the lower extremity [11]. This kind of exercise is generally believed to enhance cognitive performances including attention and memory [12,13]. Especially, it can improve response speed and accuracy, and cognition requiring delicate control involving working memory and response inhibition [14]. Also, improvement in cardiovascular fitness may not only enhance the function of the aged brain but minimize the biological decline of cognitive function [15]. Furthermore, physical exercise has been reported to induce structural and neurophysiological changes in the hippocampus, leading to improvement in spatial perception [16]. In human beings, spatial perception is considered an important sense and is associated with vision. Spatial perception related to vision has a clinical significance since it affects not only the positional relationship of spatial structures and objects in three-dimensional spaces but also the synaptic plasticity and rescue in the brain, especially the hippocampus [17-19].

Despite extensive research, the underlying mechanisms regarding the relationship between exercise and cognitive function have not been fully understood [4]. Moreover, the assessment of brain activity after exercise has only a little evidence since the association between autonomic nervous system response and cognitive performance has poorly been studied. Recently, heart rate variability (HRV), which represents autonomic nervous system function providing an index via different frequency components of sympathetic and parasympathetic activities, was measured to assess autonomic nervous system functioning [20,21]. Also, it has been suggested that changes in HRV may be related not only to cognitive regulation but also to activity in the prefrontal cortex [21].

In general, the activation of the human brain region is measured by functional magnetic resonance imaging (fMRI). A previous study tried to find and compare the activated areas and lateralization following auditory and visual word generation tasks [22]. In their works, left dominant activations were presented, and they were more lateralized following visual tasks. And, both of the tasks activated the frontal lobe and left posterior middle temporal gyrus. Moreover, extensive bilateral temporal activations were noted by the auditory task, while occipital and parietal activations were demonstrated by the visual task [22].

In this study, dictation tasks and embedded figures test (EFT) were conducted before and after the treadmill exercise. The ultimate goal of this study was to elucidate the changes in neurological activation due to treadmill training.

MATERIALS AND METHODS

All subjects who voluntarily participated in this study were male and agreed with the whole procedure of this

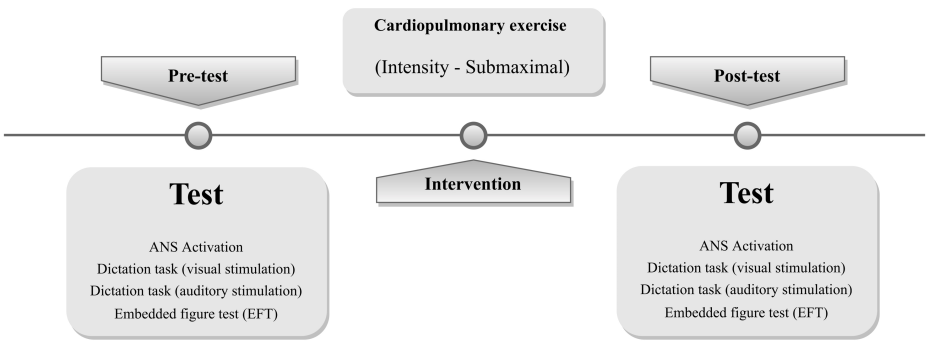

Fig. 1. Schematic procedures of this study. To compare the typing accuracy before and after the treadmill training, subjects were given dictation tasks before and after the treadmill exercise. Likewise, to compare the extent of space perception before and after the treadmill training, subjects were given EFT before and after the treadmill exercise. Also, activation of the autonomic nervous system was measured before and after treadmill exercise.

Table 1. General characteristics of the participating male subjects (N = 14)

General characteristics	Mean ± SD		Range	
Age (year)	22.29 ± 2.02		19-25	
Height (cm)	174.3 ± 5.60		167.6-185.3	
Body weight (kg)	62.25 ± 9.63		56-93	
Blood pressure	Maximal	Minimal	Maximal	Minimal
(mmHg)	122.86 ± 8.85	73.64 ± 7.07	103-135	66-85

study as described in Fig. 1. Exclusion criteria included history or current presence of neurological conditions such as amblyopia, vertigo, and vestibular dysfunction. The general characteristics of the subjects are shown in Table 1. This experiment was approved by the Inje University Faculty of Health Science Human Ethics Committee (Approval No. 2018-05-051-001). All subjects were informed of the experiment details and agreed to participate in the experiment. Supplementary Table 1 describes inclusion/exclusion criteria.

1. Experimental requirements for the subjects

Starting at 9:00 pm on the day before the experiment, subjects were prohibited from taking any foods or caloric beverages. Also, they were noticed not to intake caffeine, and not to perform the vigorous exercise for 24 hrs before the experiment. In addition, the subjects were asked to take at least 7 hrs of sleep the day before testing. Since caloric intake and hunger levels may draw potential differences including cognitive performances [23], subjects were needed to participate in the experiment in a fasting state. These criteria were verbally announced upon arrival, and all participants signed a written informed consent form.

2. Resting and calibration

To exclude the possible effects of physical activity during travel from home to the laboratory, the subjects took a rest for 15 min before the test [24]. At this moment, the subjects were informed of the overall details of the experiment. The performer calibrated the surrounding environments such as computer, atmosphere, humidity, and temperature.

3. Body composition analysis

Body composition analysis was conducted using InBody770

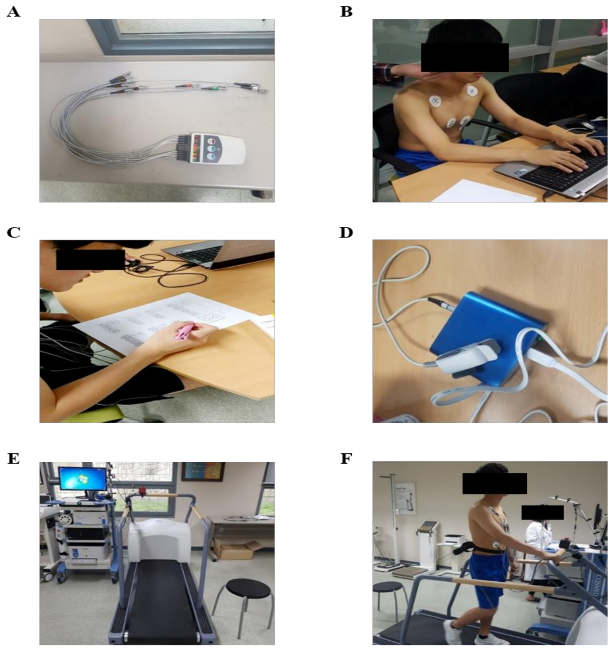

Fig. 2. Experimental instruments. (A) Electrocardiography, (B) Dictation task, (C) Embedded figures test, (D) Instrument for autonomic nervous system measurement, (E) Automated metabolic measurement system, (F) Treadmill exercise.

(InBody Inc., Seoul, Korea). This analyzer was utilized to obtain comprehensive body composition including body weight (kg), body mass index (BMI), body fat percent, and basal metabolic rate (BMR). Since bodily components are closely associated with health status, only the subjects showing normal body composition participated in the experiment. As described in a former study [25], BMI between 18 and 30 was considered a normal body composition. Thus, only the subjects with BMI falling in this range participated in this study.

4. Electrocardiography

Electrocardiography (ECG) was analyzed to monitor the subject's heart rate during treadmill exercise (Fig. 2A). The target heart rate was 85% of the maximum heart rate [26]. To check the subject's real-time heart rate, ECG analysis was required.

5. Dictation task

To assess the neurological changes by treadmill exercise, pre- and post-treadmill, a dictation task was conducted. Keyboard-typing while looking and hearing was conducted before and after the treadmill training, respectively (Fig. 2B). And each paragraph consisted of about exact 300 letters including space [27].

6. Embedded figures test (EFT)

Generally, EFT is widely performed to assess the ability of spatial perception in elderly people and patients with mental retardation [28]. EFT is called the test of a picture puzzle due to subject should find the hidden figures in complex shapes [29]. In this study, we conducted EFT to evaluate the neurobehavioral change following cardiovascular fitness. Therefore, EFT was measured before and after treadmill exercise (Fig. 2C). EFT is composed of a total of 25 questions, also, the time given to subjects is 2.5 min.

7. Measurement of autonomic nervous systems

To measure the activation of the autonomic nervous system before and after treadmill exercise, we used BACS advance (TAOS institute Inc. Japan), which is based on finger plethysmography (Fig. 2D). The non-dominant third finger of the subjects was covered by an airbag, then slight pressure (about 25 mmHg) was put. The finger was maintained at the same height as the heart during measurement. Fingertip pulse from the sensor was converted to an electrical signal, which in turn, was sent to the computer. This electrical signal was monitored and recorded by the computer. Also, the electrical signal based on fingertip pulse was calculated using a band-pass filter with a lower limit of 0.3 Hz and an upper limit of 45 Hz [30].

8. Treadmill exercise training

For the treadmill exercise session, an automated metabolic measurement system (Cosmed Quark CPET, Rome, Italy) was used (Fig. 2E). Among various treadmill protocols, we utilized the 'Modified Bruce Protocol'. It consists of several steps as follows: The first stage is performed at a 1.7 mph and 0% grade. And, the second stage is performed at the same speed and 5% grade. Next, the speed and slope were increased by 0.8-0.9 mph and 2% per every three minutes, respectively. Unlike the conventional Bruce protocol, the modified Bruce protocol is suitable for subjects with lower cardiac function [31]. Therefore, to reduce the risk of the training, we adopted a modified Bruce protocol. The training progressed until the target heart rate (85% of maximum heart rate) is achieved or the subject appeals to stop. Blood pressure was regularly checked by the cardiopulmonary instrument. The subjects were given verbal cues before the slope changes, and when there are possible risk factors. Also, the test was immediately stopped when the subject was likely to show abrupt chest pain, disorders in consciousness, vertigo, and paleness (Fig. 2F).

9. Statistical analysis

All analyses were performed using the SPSS statistical package software (SPSS ver. 25.0, IBM, New York, NY, USA). Statistical significance of data was analyzed with Paired t-test to see if there is a difference between pre- and post-treadmill exercise. Differences were considered statistically significant when the $p < 0.05$.

RESULTS

1. Activation of autonomic nervous systems

The activation of the autonomic nervous system was measured to identify the antagonistic activation of the sympathetic nervous system (SNS) (LF; low frequency) and parasympathetic nervous system (PNS) (HF; high frequency) following treadmill exercise. Before and after treadmill training, subjects were given dictation tasks and EFT. During the task, activation of the autonomic nervous system was measured. Relative activation of the sympathetic nervous system was increased after treadmill exercise (Fig. 3A).

2. Pulse wave measurement before and after treadmill exercise

Pulse can be felt in several regions of the body. Among them, the fingertip pulse was continuously measured for 5 min (Fig. 3B). The fingertip pulse wave was measured before and after the treadmill exercise. The differential values were also visualized. These differential values were calculated based on fingertip pulse waves, enabling the estimation of blood vessel age. Since the fingertip pulse ultimately represents the pulse of the heart, the estimated heart was drawn based on the pulses measured (Fig. 3C). Each image was drawn via the summation of the estimated heart shape acquired for 30 sec.

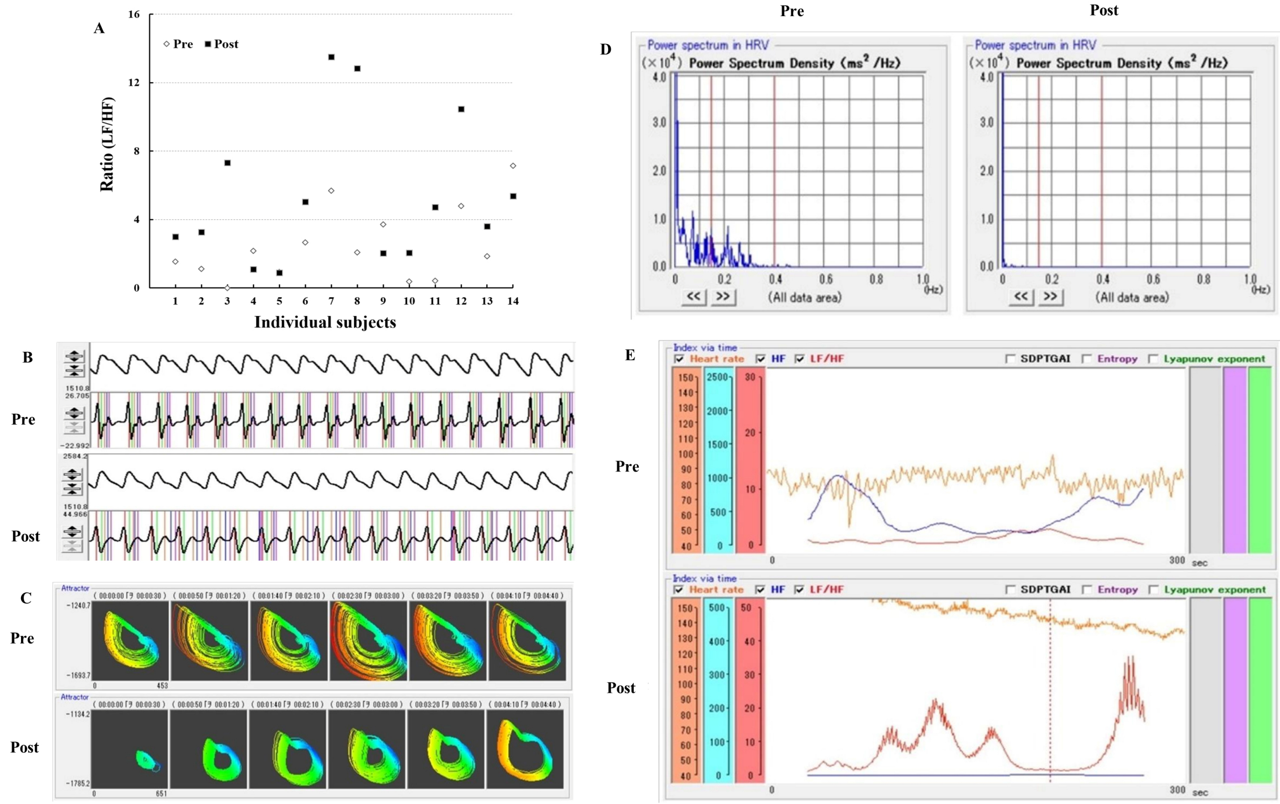

Fig. 3. Characteristics of physiological outcomes. (A) Relative activation of sympathetic compared with the parasympathetic nervous system. Activation of the sympathetic nervous system was increased after treadmill exercise. Most of the changes implied higher sympathetic modulation after treadmill exercise. (B) Fingertip pulse. To measure the activation of the autonomic nervous system, the fingertip pulse was measured for 5 min before and after treadmill exercise. Upper table, fingertip pulse wave measure; lower table, visualized differential value. Pre: before treadmill exercise, Post: after treadmill exercise. (C) Chaotic attractor image. A chaotic attractor is an image of the estimated shape of the heart, which is drawn based on a fingertip pulse wave. (D) Power spectrum in HRV and its alterations owing to stimulation of autonomic nervous system. The graphs represent the extent the sinoatrial node is stimulated by the autonomic nervous system. After treadmill exercise, parasympathetic nerve activation in the Power spectrum in HRV decreased. 0-0.15 Hz: sympathetic nervous system, 0.15-0.4 Hz: parasympathetic nervous system. (E) The ratio between the sympathetic and parasympathetic nervous systems. The data from Figure 3D and E was shown as line graphs. LF: low frequency, HF: high frequency, Pre: before treadmill exercise, Post: after treadmill exercise, Orange line: heart rate, Blue line: parasympathetic nerve (HF), Red line: the ratio of sympathetic (LF) compared to the parasympathetic nervous system (HF). Pre: before treadmill exercise, Post: after treadmill exercise.

3. The ratio of activity between the sympathetic and parasympathetic nervous system by treadmill exercise

After the treadmill exercise, the activation of the parasympathetic nerve system dropped nearly to zero (Fig. 3D). However, activation of the SNS increased although fluctuated. Thus, the activation of the sympathetic compared to the PNS seems to be increased after treadmill exercise. The ratio between them is demonstrated in Figure 3E. The line graphs show that SNS activation (red line in Fig. 3E) rises after treadmill exercise. LF/HF ratio increases, indicating relatively higher activation of the SNS after treadmill exercise. As previously reported [32], increased activation of the SNS during exercise seems to be normalized after the exercise to its original extent.

4. Accuracy and speed of dictation task by treadmill exercise

1) Comparison between the accuracy of pre- and post-treadmill exercise in auditory typing session

Treadmill exercise is generally believed to enhance cognitive performance. Changes in the accuracy of pre- and post-intervention, are listed in Table 2. As previously suggested [33], typing accuracy was decreased after treadmill exercise. Similarly, typing accuracy showed a tendency to decrease, but there was no significant difference ($p < 0.05$) (Fig. 4A).

2) Comparison between the accuracy and speed of pre- and post-treadmill exercise in visual typing session

Although treadmill exercise has been reported to augment neurological activation, typing became inaccurate after

Table 2. The outcome for differences in typing speed and accuracy before and after performing a treadmill exercise

	Auditory session			Visual session (Mean ± SD)		
	Pre	Post	p-value	Pre	Post	p-value
Gross WPM	52	52	-	53.73 ± 6.62	57.91 ± 9.2	.004*
AWPM	-	-	-	47.45 ± 6.36	49.36 ± 9.59	.038*
Accuracy (%)	85.26 ± 9.64	83.33 ± 10.76	.148	88.32 ± 4.65	85.04 ± 6.53	.048*

WPM: words per minute, Gross WPM: Total words typed per minute, AWPM: Gross words − incorrect words (adjusted words per minute). Accuracy, percent of words typed correctly. Both typing accuracy of auditory and visual sessions was reduced compared to the pre-treadmill exercise condition. However, both typing measures of WPM and AWPM showed higher performance in the visual session. A statistical significance test was done by paired t-test. Data are shown as the mean ± SD (*$p < 0.05$ Pre vs. Post). Pre: before treadmill exercise, Post: after treadmill exercise.

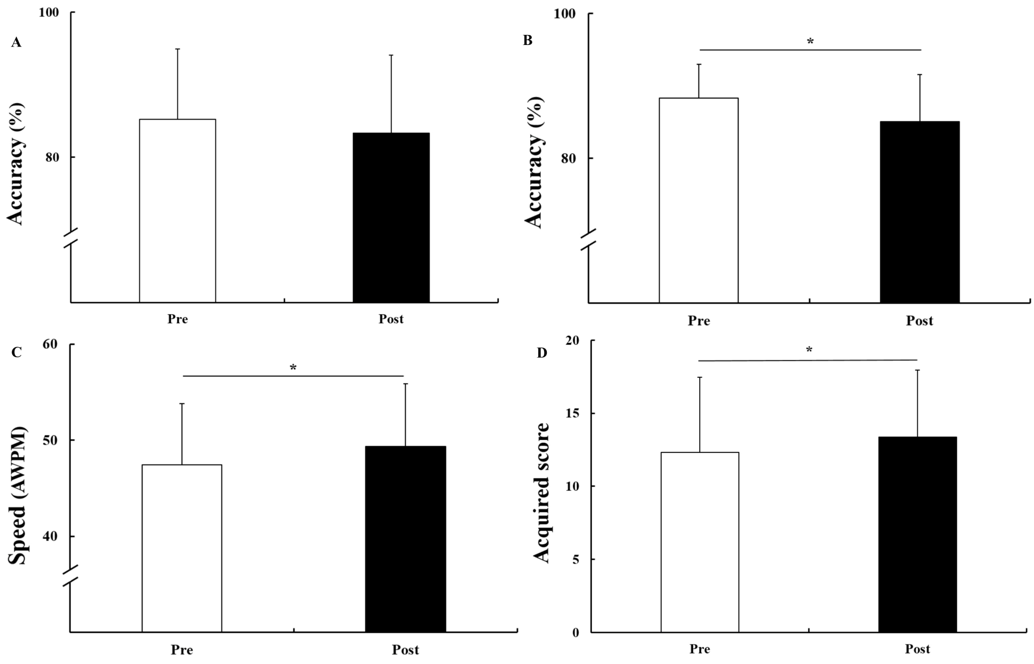

Fig. 4. The accuracy of auditory and visual dictation. (A) Auditory dictation accuracy before and after treadmill exercise. Typing accuracy was reduced after treadmill exercise. However, there was no significant difference between the accuracy of the pre- and post-treadmill exercise conditions for the dictation test in the auditory typing session. (B) Visual dictation accuracy. Typing accuracy was reduced after treadmill exercise. There was a significant difference ($p < 0.05$) between the accuracy of the pre- and post-treadmill exercise conditions for the dictation test in the visual typing session. (C) Speed before and after treadmill exercise. Typing speed was increased after the treadmill exercise. When comparing values between the speed of the pre- and post-treadmill exercise revealed a significant increase ($p < 0.05$) in AWPM. (D) EFT score before and after treadmill exercise. EFT score was increased after treadmill exercise. There was a significant difference ($p < 0.05$) between the EFT score of the pre- and post-treadmill exercise conditions for the spatial perception test. As previously hypothesized, treadmill exercise increased EFT scores, indicating advanced neurological activation. A statistical significance test was done by paired t-test. Data are shown as the mean ± SD (*$p < 0.05$ Pre vs. Post). Pre: before treadmill exercise, Post: after treadmill exercise.

treadmill exercise. As a result, typing accuracy was significantly decreased ($p < 0.05$) after the treadmill exercise (Fig. 4B). However, typing speed was significantly increased ($p < 0.05$) following the treadmill exercise (Fig. 4C, Table 2). This exercise-mediated typing acceleration has been reported previously [34]. In this regard, treadmill exercise seems to contribute to neurological activation.

5. Spatial perception is affected by treadmill exercise

To assess the spatial perception of subjects, EFT was conducted. The EFT score was significantly increased ($p < 0.05$) after treadmill exercise (Fig. 4D, Supplementary Table 2). These results indicate that treadmill exercise makes the spatial perception of participating subjects advanced. In other words, neurological activation, which is proven by advanced EFT score, was improved by treadmill exercise, as previous researchers demonstrated [16].

DISCUSSION

The purpose of the present study was to verify whether aerobic exercise results in improved neurological activation. To identify the changes in neurological activation, subjects were given dictation tasks and EFT. Treadmill exercise was adopted for our study because this aerobic exercise is widely used for its easy manipulation [35]. The submaximal exercise was executed not to cause excessive fatigue. This intensity level of exercise stops when the heart rate of participating subjects reaches 85% of the maximum heart rate [26].

In this study, SNS activity increases after treadmill exercise. The autonomic nervous system has been reported to play a crucial role in homeostasis maintenance [36]. During exercise, the SNS is activated leading to an increase in heart rate. However, the parasympathetic nervous system is activated after exercise to normalize the heart rate increased during exercise. Owing to this alteration in the autonomic nervous system, the increased heart rate due to exercise diminishes its resting rate after exercise.

As previously suggested by several researchers, physical exercise enhances neurocognition [12-14]. However, auditory dictation accuracy decreased after treadmill exercise in this study. Likewise, visual dictation accuracy is also reduced after treadmill exercise. These results opposed our hypothesis that expected improved typing accuracy after treadmill exercise. According to former researchers, treadmill exercise may deteriorate typing accuracy [33]. The interference of upper body motions with arms stability during treadmill exercise may lower the typing accuracy [27]. However, post-treadmill exercise with visual dictation typing showed a significantly increased speed when compared to pre-treadmill exercise. In a previous study, it was argued that exercise-induced increases in neurotransmitters may ensure increased speed of processing, whereas increases in neural noise may negatively affect accuracy [37].

Post-treadmill spatial perception was improved compared to that of pre-treadmill spatial perception. In recent years, many kinds of research regarding fitness and cognition including spatial perception have been reported [17,38] and have revealed the effects of exercise on the hippocampus related to augmented spatial perception in older animals [38]. Cardiopulmonary fitness alters neuroplasticity, which means structural changes in the brain [38,39]. Additionally, treadmill exercise induces alteration of synapse, structure, and neurophysiology in the hippocampus [16]. Cardiopulmonary exercise may alter the speed of cognitive processing by affecting neuroelectric procedures, which are fundamental for motor control [4]. The enhancement of spatial perception is thought to be caused by these neuronal alterations. Especially, several spatial perception-related areas including the hippocampus are possibly activated.

In this present study, although post-treadmill typing accuracy was diminished, neurological activation was thought to be induced by treadmill exercise since typing speed following treadmill exercise was increased. Also, the EFT score was significantly increased after treadmill exercise. Even though we have drawn interesting results, the number of subjects was somewhat small. And, we only conducted EFT among various tests for spatial perception. Also, fMRI was not utilized to analyze the activation of the brain. Further studies would be required to overcome these limitations. Additionally, an extensive analysis of biomarkers including hormones is supposed to be executed to identify the changes in regarding brain activity after treadmill exercise. Furthermore, we will investigate the effects on brain activity and neurobehaviors after the long-term application of various physical activities.

CONCLUSION

Although cardiopulmonary exercise is known to enhance neurological activation, typing accuracy had no differences between pre-and post-treadmill exercise. In this study, dictation accuracy was decreased after treadmill exercise whereas the speed of visual dictation was increased. In addition, the EFT score was increased after the treadmill exercise. Therefore, cardiovascular fitness exercise was proved to increase neurological activation.

CONFLICTS OF INTEREST

None to declare.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the invaluable support and critical comments of members of 'Biological Clock & Aging Control' laboratory. This study was completed as part of the dissertation for Master of Science by M.M. This work also was supported in part by a grant from the National Research Foundation (2017R1D1A1B0302956514 to Y.H.), Korea.

REFERENCES

1. Gutin B, Digennaro J. Effect of one-minute and five-minute step-ups on performance of simple addition. *Res Q* 1968;39:81-5.
2. McAdam RE, Wang YK. Performance of a simple mental task following various treatments. *Res Q* 1967;38: 208-12.
3. Davey CP. Physical exertion and mental performance. *Ergonomics* 1973;16:595-9.
4. Hillman CH, Snook EM, Jerome GJ. Acute cardiovascular exercise and executive control function. *Int J Psychophysiol* 2003;48:307-14.
5. Tomporowski PD, Lambourne K, Okumura MS. Physical activity interventions and childrens's mental function: an introduction and overview. *Prev Med* 2011;52:S3-9.
6. Endres M, Gertz K, Lindauer U, Katchanov J, Schultze J, Schröck H, Nickenig G, Kuschinsky W, Dirnagl U, Laufs U. Mechanisms of stroke protection by physical ativity. *Ann Neurol* 2003;54:582-90.
7. Pereira AC, Huddleston DE, Brickman AM, Sosunov AA, Hen R, McKhann GM, Sloan R, Gage FH, Brown TR, Small SA. An in vivo correlate of exercise-induced neurogenesis in the adult dentate gyrus. *Proc Natl Acad Sci U S A* 2007;104:5638-43.
8. Van Praag H, Kempermann G, Gage FH. Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. *Nat Neurosci* 1999;2:266-70.
9. Neeper SA, Gómez-Pinilla F, Choi J, Cotman C. Exercise and brain neurotrophins. *Nature* 1995;373: 109.
10. Dietrich A, Audiffren M. The reticular-activating hypofrontality (RAH) model of acute exercise. *Neurosci Biobehav Rev* 2011;35:1305-25.
11. Yoo J, Lim KB, Lee HJ, Kwon YG. Cardiovascular response during submaximal underwater treadmill exercise in stroke patients. *Ann Rehabil Med* 2014;38: 628-36.
12. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci* 2003;14:125-30.
13. Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *J Sport Exerc Psychol* 1997;19:249-77.
14. Tomporowski PD. Effects of acute bouts of exercise on cognition. *Acta Psychol* 2003;112:297-324.
15. Colcombe SJ, Kramer AF, Erickson KI, Scalf P, McAuley E, Cohen NJ, Webb A, Jerome GJ, Marquez DX, Elavsky S. Cardiovascular fitness, cortical plasticity, and aging. *Proc Natl Acad Sci U S A* 2004;101: 3316-21.
16. Holzschneider K, Wolbers T, Röder B, Hötting K. Cardiovascular fitness modulates brain activation associated with spatial learning. *Neuroimage* 2012;59:3003-14.
17. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci* 2008;9:58-65.
18. Li Y, Zhao L, Gu B, Cai J, Lv Y, Yu L. Aerobic exercise regulates Rho/cofilin pathways to rescue synaptic loss in aged rats. *PLoS One* 2017;12:e0171491.
19. MacIntosh BJ, Crane DE, Sage MD, Rajab AS, Donahue MJ, McIlroy WE, Middleton LE. Impact of a single bout of aerobic exercise on regional brain perfusion and activation responses in healthy young adults. *PLoS One* 2014;9:e85163.
20. Aubert AE, Seps B, Beckers F. Heart rate variability in athletes. *Sports Med* 2003;33:889-919.
21. Thayer JF, Lane RD. Claude Bernard and the heart-brain connection: further elaboration of a model of neurovisceral integration. *Neurosci Biobehav Rev* 2009;33: 81-8.

22. Ryoo JW, Cho JM, Choi HC, Park MJ, Choi H-Y, Kim JE, Han H, Kim SS, Jeon YH, Khang HS. Functional MRI of language: Difference of its activated areas and lateralization according to the input modality. *J Korean Soc Magn Reson Med* 2011;15:130-8.
23. Cooper SB, Bandelow S, Nevill ME. Breakfast consumption and cognitive function in adolescent schoolchildren. *Physiol Behav* 2011;103:431-9.
24. Mackay N, Hansen S, McFarlane O. Autonomic nervous system changes during Reiki treatment: a preliminary study. *J Altern Complement Med* 2004;10:1077-81.
25. Commissaris DA, Könemann R, Hiemstra-van Mastrigt S, Burford EM, Botter J, Douwes M, Ellegast RP. Effects of a standing and three dynamic workstations on computer task performance and cognitive function tests. *Appl Ergon* 2014;45:1570-8.
26. Lee MS, Yi CH, Cho SH, Kwon OY. Effect of fatigue on hull oscillation by maximum load treadmill motion. *Phys Ther Korea* 2000;7:35-54.
27. Straker L, Levine J, Campbell A. The effects of walking and cycling computer workstations on keyboard and mouse performance. *Hum Factors* 2009;51:831-44.
28. Cribb SJ, Olaithe M, Di Lorenzo R, Dunlop PD, Maybery MT. Embedded figures test performance in the broader autism phenotype: A meta-analysis. *J Autism Dev Disord* 2016;46:2924-39.
29. Seo JY. Comparative study between the group embedded figures test and the cognitive styles analysis [dissertation]. Seoul: Yonsei Univ.; 2003. Korean.
30. Murray NP, Russoniello C. Acute physical activity on cognitive function: a heart rate variability examination. *Appl Psychophysiol Biofeedback* 2012;37:219-27.
31. Ko SH, Kim TH, Jekal Y. Comparative analysis of protocols through a treadmill exercise test. *J Exerc Sport Sci* 2016;22:53-62.
32. Zheng H, Sharma NM, Liu X, Patel KP. Exercise training normalizes enhanced sympathetic activation from the paraventricular nucleus in chronic heart failure: role of angiotensin II. *Am J Physiol Regul Integr Comp Physiol* 2012;303:R387-94.
33. Larson MJ, LeCheminant JD, Hill K, Carbine K, Masterson T, Christenson E. Cognitive and typing outcomes measured simultaneously with slow treadmill walking or sitting: implications for treadmill desks. *PLoS One* 2015;10:e0121309.
34. McMorris T, Hale BJ. Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: a meta-analytical investigation. *Brain Cogn* 2012;80:338-51.
35. Kim W. Guidelines for exercise testing and exercise prescription. (2nd ed). Seoul: Hanmi Medical Center; 2015. Korean.
36. McCorry LK. Physiology of the autonomic nervous system. *Am J Pharm Educ* 2007;71(4):78.
37. McMorris T, Collard K, Corbett J, Dicks M, Swain JP. A test of the catecholamines hypothesis for an exercise-cognition interaction. *Pharmacol Biochem Behav* 2008;89:106-15.
38. van Praag H, Shubert T, Zhao C, Gage FH. Exercise enhances learning and hippocampal neurogenesis in aged mice. *J Neurosci* 2005;25:8680-5.
39. Erickson KI, Prakash RS, Voss MW, Chaddock L, Hu L, Morris KS, White SM, Wójcicki TR, McAuley E, Kramer AF. Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus* 2009;19:1030-9.