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Effects of a Single Bout of Low and Moderate Intensity Aerobic Exercise on Cognitive Function in Young Adults

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Abstract Regular exercise is proven to improve cognitive function. However, the effect of acute exercise on cognitive function in young adults has not been established, especially exercise intensity that provides the most benefit for cognitive performance. Therefore, this study aimed to assess the effect of a single bout of low and moderate-intensity aerobic exercise on cognitive function in young adults. Thirty volunteers (aged 21.08 ± 0.41 years) were randomized into a control (n=10), low (n=10), or moderate (n=10) intensity aerobic exercise group. Stroop color and word test, digit span forward (DSF), and digit span backward test (DSB) were used to determine cognitive function at baseline and after exercise for both exercise groups, or after watching the video of aerobic exercise for the control group. After the intervention, all 3 parts of the Stoop color and word test were significantly improved from baseline in all 3 groups ($p < 0.05$) while only the moderate-intensity aerobic exercise group had significant improvement in DSF ($p < 0.05$). In addition, part 1 and part 3 of the Stoop color and word test, and DSF were significantly improved in the moderate-intensity aerobic exercise group when compared with the control group ($p<0.05$). In conclusion, a single bout of exercise can improve cognitive function in young adults. In addition, the moderate-intensity aerobic exercise had greater improvement in cognitive function which was evaluated by Stroop color and word test, and DSF compared to the low-intensity exercise.

Keywords Exercise, Cognitive Function, Exercise Intensity

1. Introduction

Cognitive function is one of the important factors that influence quality of life. People with cognitive decline had lower ability to perform activities of daily living [1], and decreased quality of life [2]. Previous studies suggested that cognitive function, particularly memory and executive function were both associated with instrumental activities of daily living impairment, which consisted of preparing meals, managing medications, and housekeeping [3]. In addition, cognitive impairment was associated with an increased risk of mortality [4].

Exercise has been shown to have positive effects on cognitive function in older adults [5, 6]. Interestingly, previous literature reported that physical activity was related to brain activity, cognitive function, and academic performance in adolescents [7]. Physical activity at a young age correlated with better cognitive function in later life. It can be suggested that exercise at an early age may enhance cognitive reserve, and then reduce age-related cognitive decline [8].

The study by Kaya et al. [9] showed that regular exercise 3 days a week for 4 weeks improved selective attention, verbal fluency, and executive control in young adults. Although regular exercise is proven to improve cognitive function, the effect of single-bout exercise on cognitive function in young adults has not been established, especially exercise intensity that provides the

most benefit for cognitive performance. Previous literature suggested that low-intensity exercise improved cognitive health in older adults [10]. Wu et al. [11] found that mild and moderate physical activity improved cognitive function, rather than high-intensity physical activity. Smith et al. also showed treadmill running at high-intensity exercise (90% of heart rate reserve: HRR) was significantly slower in reaction time than moderate-intensity exercise (70%HRR) and rest [12]. On the contrary, Shah et al. [13] reported that one bout of moderate and high-intensity exercise significantly enhanced BDNF and working memory in young adults. However, Davranche et al. [14] suggested that cognitive performance may not be affected by exercise intensity. The intensity of exercise is one of the important factors affecting physiological response to exercise [15]. Nevertheless, the optimized exercise intensity on cognitive function is still unclear, so the objective of this study was to compare the effects of a single bout of low and moderate-intensity aerobic exercise on cognitive function in young adults. Exercise with optimized intensity may improve cognitive function in early age, and contribute to reduce cognitive decline with age.

2. Materials and Methods

2.1. Subjects

The sample size was calculated with an alpha level being 0.05 and the power of test being 0.80. Based on the data of the Stroop test from the previous study [16], the calculated sample size was 8/group. In addition, 20% of the drop-out rate was added so the total number of participants was 10/group. Inclusion criteria were male and female young adults who aged between 18 and 22 years, and were willing to participate in this study. The participants were excluded if they 1) had any medical condition, i.e., infectious conditions, neurological, cardiovascular, respiratory, and orthopedic problems, 2) engaged in any regular exercise during the last three months, and 3) had contraindications to perform an exercise. The participants were recruited in this study through face-to-face contact. All of them were informed of the study protocol and possible risks before signing the consent form. The study protocol was approved by University of Phayao Human Ethics Committee, reference number 2/103/61.

2.2. Procedures

Thirty healthy volunteers were simply randomly assigned into 3 groups by drawing lots, control (n=10), low (n=10), or moderate (n=10) intensity aerobic exercise group. The aerobic exercise started with general stretching for five minutes as a warm-up. After that, the participants performed 30 minutes of aerobic dance exercise followed by cool down with general stretching for five minutes. Warm-up and cool-down involved upper body and lower body major muscle groups stretching. The movements of aerobic dance exercises were applied from Thai dance and Thai boxing including raising arms sideward, upward, and downward, step touch, cross punch, uppercut punch, horizontal elbow strike, knee strike, and kick. The participants were required to maintain exercise intensity at 57-63 % of maximum heart rate (HR_{max}) and 64-70% HR_{max} for low-intensity exercise and moderate-intensity exercise group, respectively [17]. Heart rate was monitored throughout the experiment using Polar M430. The participants in the control group did not perform any exercises but they were asked to watch a video of aerobic dance exercise for 30 minutes. All participants took at least 8 hours of sleep and abstained from caffeine, alcohol, and smoking at least 24 hours before the investigation.

2.3. Measurements

Executive and memory function were used to determine cognitive function at baseline and after a single bout of aerobic exercise for both exercise groups, or after watching the exercise video for the control group.

2.3.1. Executive Function

Executive function was measured by Stroop color and word test. Participants were required to 1) read a list of color words printed in back ink, 2) name the colors printed in "XXXX", and 3) name the colors printed in inconsistent color ink. Participants were asked to read words or name of the ink colors of each condition as quickly as possible within 45 seconds, and the number of items correctly read aloud was recorded [18, 19].

2.3.2. Short-Term Memory and Working Memory

Short-term memory was evaluated by the digit span forward test, which requires the participants to repeat a string of digits in the same order. The digit span backward test (DSB) was used to determine working memory. The test requires participants to repeat a string of digits in the reverse order [20].

2.4. Statistical Analyses

The normality of each variable was checked using Shapiro-Wilk test. The differences within group were compared using Wilcoxon for non-parametric data, and the differences in outcomes among the three groups were analyzed using Kruskal-Wallis test. The data were presented as mean ± SD. A p-value of ≤ 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 21.

3. Results

3.1. Descriptive Data of the Participants

Thirty participants completed the study, and no adverse

events were reported. All of them were studying in the fourth year of their bachelor's degree, aged between 21 and 22 years, and had normal body mass index (BMI). No significant differences were found among the three groups in age, height, body mass, and BMI ($p \leq 0.05$, Table 1).

3.2. Executive Function

There was no significant difference among the three groups in Stroop color and word score at baseline. After the intervention, all three groups showed significant pre-to-post-intervention improvement in Stroop color and word test ($p \leq 0.05$). Interestingly, only the moderate-intensity group showed significantly higher scores in conditions 1 and 3 than the control group after exercise ($p \leq 0.05$) (Table 2).

3.3. Short-Term Memory and Working Memory

No significant differences in DSF and DSB were found at the baseline among the three groups. A significant pre-to-post-intervention improvement in DSF was observed only in the moderate-intensity group ($p \leq 0.05$). In addition, the moderate group showed greater improvement in DSF relative to the control group at post-exercise ($p \leq 0.05$) (Table 3).

Table 1. Descriptive data of the subjects

Variables	Groups		
	Control (n = 10)	**Low- intensity (n = 10)**	**Moderate-intensity (n = 10)**
Age (yrs)	21.70 ± 0.48	21.70 ± 0.48	21.40 ± 0.52
Height (cm)	57.80 ± 4.37	162.60 ± 6.22	160.00 ± 6.16
Body mass (kg)	53.90 ± 10.27	54.20 ± 9.57	58.00 ± 44.24
BMI ($kg \cdot m^{-2}$)	21.57 ± 3.77	20.54 ± 3.68	22.52 ± 4.70

Data are represented as mean ± SD; BMI = body mass index

Table 2. Executive function (Stroop color and word test)

Test		Groups			*p*-value
		Control (n=10)	**Low-intensity (n=10)**	**Moderate-intensity (n=10)**	
Condition1	Pre-test	96.70 ± 10.65	94.10 ± 7.99	101.30 ± 8.20	ns
	Post-test	102.90 ±10.87	106.00 ± 8.63	114.10 ±12.70	0.02#
p-value		0.01*	<0.001*	<0.001*	
Condition 2	Pre-test	72.30 ± 10.65	72.40 ± 7.07	81.70 ± 14.16	ns
	Post-test	75.50 ±12.14	80.60 ± 7.99	88.00 ± 15.51	ns
p-value		0.01*	<0.001*	<0.001*	
Condition 3	Pre-test	40.70 ± 8.77	45.20 ± 5.70	49.20 ± 8.46	ns
	Post-test	46.60 ±10.48	52.60 ± 6.29	60.50 ± 15.39	0.03#
p-value		0.01*	0.01*	0.02*	

Data are represented as mean ± SD; ns= non-significant * A significant pre-to-post-intervention at $p \leq 0.05$. #A significant difference between the moderate-intensity and the control group at $p \leq 0.05$.

Table 3. Short-term memory (DSF) and working memory (DSB)

Tests		Groups			*p*-value
		Control (n = 10)	**Low-intensity (n = 10**	**Moderate-intensity (n = 10)**	
DSF	Pre-test	9.60 ±2.95	9.00 ±2.87	12.70 ±3.09	ns
	Post-test	10.10 ±3.73	10.60 ±2.72	14.40 ±2.55	0.03[#]
p-value		ns	ns	0.02*	
DSB	Pre-test	9.60 ±2.95	9.00 ±2.87	11.04 ±4.20	ns
	Post-test	10.10 ±3.73	10.60 ±2.72	11.40 ±3.84	ns
p-value		ns	ns	ns	

Data are represented as mean ± SD; DSF = digit span forward test; DSB =digit span backward test; ns= non-significant [*]A significant pre-to-post-intervention at p≤0.05. [#]A significant difference between the moderate-intensity and the control group at p ≤0.05.

4. Discussion

The present study aimed to evaluate the acute effects of low and moderate-intensity aerobic exercise on cognitive function in young adults. After single-bout exercise, both low- and moderate-intensity exercises had a significant improvement in executive function measured by Stroop color and word test. Specifically, the moderate-intensity group showed a significant pre- to post-exercise improvement in short-term memory measured by DSF, and greater improvement than the control group in executive function and short-term memory after one bout of exercise.

4.1. Executive Function

Although the three groups improved significantly in Stroop color and word test post-intervention, only the moderate-intensity group showed a significantly higher score than the control group after the intervention. These results suggested that a single-bout exercise with moderate intensity had greater improvement in executive function than the low-intensity group. The finding of the present study is consistent with the previous study which reported a linear improvement in cognition with increasing exercise intensity [21]. On the contrary, previous research found that one session of treadmill exercise at 70%HRR did not improve cognitive function compared with the control condition [22].

Ferris et al. reported a significant increase in the color–word performance after the acute high-intensity exercise (10% above the ventilatory threshold), whereas the low intensity (20% below the ventilatory threshold) did not. Interestingly, the authors found that the higher-intensity group significantly improved in BDNF concentration relative to baseline while the low-intensity group did not show a significant pre- to post-exercise improvement [23]. Although the mechanism of acute exercise on cognitive function is still unclear, previous reviews suggested that brain-derived neurotrophic factor (BDNF) [24] may play a role in the effects of acute exercise on cognitive function. BDNF is a neurotrophic factor involved in neuroplasticity, neuronal growth and survival, and neuronal transmission [25]. El-Sayes et al. [26] suggested that acute aerobic exercise increased BDNF and neurotransmitter concentrations, which contributed to increased receptor activity. Additionally, acute exercise may increase neural activity by increasing cerebellar blood flow, glucose and oxygen metabolism. All of these may lead to improved cognitive function. The authors also suggested that neuroplasticity was affected by the exercise intensity. BDNF is elevated during exercise, and the increase is exercise intensity dependent. The higher-intensity exercise was greater increase BDNF level compared to lower intensity exercise [23, 26].

Another potential mechanism explaining cognitive improvements after acute exercise was increased cerebral blood flow (CSF) which contributes to improving oxygen and glucose for metabolic functions, and metabolic waste clearance [25]. Tsubaki et al., also found that cerebral oxyhemoglobin concentration increased during a single bout of moderate-intensity aerobic exercise, at least 15 min after exercise cessation [27].

A single bout exercise initiates the neuroplasticity pathway, while regular exercise stimulates brain structural, and functional changes [26], which may lead to improved cognitive function in young adults, and have a beneficial effect on academic performance, ADL, and decreased cognitive decline with age.

4.2. Short-Term Memory and Working Memory

The current study found that moderate-intensity aerobic exercise improved short-term memory whereas low aerobic intensity exercise did not. This finding corresponds with a previous study that indicated that one bout of moderately intense running improved verbal short-term memory in young adults [28]. Additionally, Wohlwend et al. suggested that cognitive improvement after a single bout of exercise is intensity-dependent [21].

These were inconsistent with the study by Zuniga [29] which reported that both low and high-intensity acute exercise can improve memory in college students. Previous studies showed that a single bout of higher-intensity exercise had a better effect on 24-hour memory recall than the lower-intensity exercise group. Although a single session of exercise increases BDNF level, the results did not find a significant association between BDNF and memory [30].

A single-bout exercise has been shown to improve cognitive function. Nevertheless, the biological mechanisms underlying this effect are still unclear. Future research should explore the mechanisms underlying this effect to better understand how acute exercise improves cognitive function.

In the present study, a single-bout exercise with low or moderate intensity did not show a clear effect on working memory. This finding is well in agreement with the previous study which demonstrated that working memory was not improved by acute mild or moderate exercise aerobic exercise [31]. In contrast, Shah et al. [13] found that a single bout moderately increased working memory and BDNF levels in young adults. The discrepancy may be explained by difference in exercise duration. The exercise intervention in the present study was 30 minutes while the study of Shah was 15 minutes. It has been suggested that exercise-induced cognitive improvement was affected by exercise duration [32]. Prolonged exercise may result in fatigue and dehydration, and could lead to decreased cognitive performance [33]. However, exercise duration for the most beneficial effect on cognitive improvement is still controversial. Short-duration exercise has shown no effect on working memory, while 16–30 min exercise showed mixed results, no changes, or improved working memory [34]. Exercise intensity and duration are the important factors affecting cognitive improvement after exercise. Therefore, future research on dose-response between exercise and cognition should focus on both exercise intensity and duration.

4.3. Limitations

Since a major limitation of the present study is a lack of the high-intensity aerobic exercise group, it cannot conclude that the relationship between exercise intensity and cognitive function is a linear improvement, or inverted-U shaped. Another limitation is a small sample size although it was based on power calculation. Nevertheless, the present study found that the moderate-intensity group showed a significant pre- to post-exercise improvement in executive function and short-term memory while the low-intensity group only significantly improved in executive function after the intervention. Further investigations with high-intensity exercise, and larger sample sizes are required to confirm the optimal exercise intensity for improving cognitive function in young adults.

5. Conclusions

In conclusion, the present study revealed that a single bout of exercise can enhance young adults' cognitive function. In addition, the acute moderate-intensity aerobic exercise group showed a greater improvement in executive function and short-term memory relative to the low-intensity group.

Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

REFERENCES

[1] Demir Akca A.S., Saracli O., Emre U., Atasoy N., Gudul S., Ozen Barut B., Senormanci O., Buyukuysal M.C., Atik L., Atasoy H.T., “Relationship of Cognitive Functions with Daily Living Activities, Depression, Anxiety and Clinical Variables in Hospitalized Elderly Patients,” Noro Psikiyatr Ars, vol. 51, no. 3, pp. 267-274, 2014. DOI:10.4274/npa.y 7053

[2] Pusswald G., Tropper E., Kryspin-Exner I., Moser D., Klug S., Auff E., Dal-Bianco P., Lehrner J., “Health-Related Quality of Life in Patients with Subjective Cognitive Decline and Mild Cognitive Impairment and its Relation to Activities of Daily Living,” J Alzheimers Dis, vol. 47, no. 2, pp. 479-486, 2015. DOI:10.3233/jad-150284

[3] Overdorp E.J., Kessels R.P., Claassen J.A., Oosterman J.M., “The Combined Effect of Neuropsychological and Neuropathological Deficits on Instrumental Activities of Daily Living in Older Adults: a Systematic Review,” Neuropsychol Rev, vol. 26, no. 1, pp. 92-106, 2016. DOI:10.1007/s11065-015-9312-y

[4] Duan J., Lv Y.-B., Gao X., Zhou J.-H., Kraus V.B., Zeng Y., Su H., Shi X.-M., “Association of cognitive impairment and elderly mortality: differences between two cohorts ascertained 6-years apart in China,” BMC Geriatrics, vol. 20, no. 1, pp. 29, 2020. DOI:10.1186/s12877-020-1424-4

[5] Falck R.S., Davis J.C., Best J.R., Crockett R.A., Liu-Ambrose T., “Impact of exercise training on physical and cognitive function among older adults: a systematic review and meta-analysis,” Neurobiology of Aging, vol. 79, pp.119-130, 2019. DOI:10.1016/j.neurobiolaging.2019.03. 007

[6] Yu A.P., Chin E.C., Yu D.J., Fong D.Y., Cheng C.P., Hu X., Wei G.X., Siu P.M., “Tai Chi versus conventional exercise for improving cognitive function in older adults: a pilot randomized controlled trial,” Scientific Reports, vol. 12, no. 1, pp. 8868, 2022. DOI:10.1038/s41598-022-12526-5

[7] Herting M.M., Chu X., “Exercise, cognition, and the adolescent brain,” Birth Defects Res, vol. 109, no. 20, pp. 1672-1679, 2017. DOI:10.1002/bdr2.1178

[8] Reas E.T., Laughlin G.A., Bergstrom J., Kritz-Silverstein D., Richard E.L., Barrett-Connor E., McEvoy L.K.,

"Lifetime physical activity and late-life cognitive function: the Rancho Bernardo study," Age Ageing, vol. 48, no. 2, pp. 241-246, 2019. DOI:10.1093/ageing/afy188

[9] Kaya B.K., Alpozgen A.Z., "Comparing the Cognitive Functioning Effects of Aerobic and Pilates Exercises for Inactive Young Adults: A Randomized Controlled Trial," Perceptual and Motor Skills, vol. 129, no. 1, pp. 134-152, 2022. DOI:10.1177/00315125211051178

[10] Tse A.C., Wong T.W., Lee P.H., "Effect of Low-intensity Exercise on Physical and Cognitive Health in Older Adults: a Systematic Review," Sports Med Open, vol. 1, no. 1, pp. 37, 2015. DOI:10.1186/s40798-015-0034-8

[11] Wu Z., Zhang H., Miao X., Li H., Pan H., Zhou D., Liu Y., Li Z., Wang J., Liu X., Zheng D., Li X., Wang W., Guo X., Tao L., "High-intensity physical activity is not associated with better cognition in the elder: evidence from the China Health and Retirement Longitudinal Study," Alzheimer's Research & Therapy, vol. 13, no. 1, pp. 182, 2021. DOI:10.1186/s13195-021-00923-3

[12] Smith M., Tallis J., Miller A., Clarke N.D., Guimaraes-Ferreira L., Duncan M.J., "The effect of exercise intensity on cognitive performance during short duration treadmill running," J Hum Kinet, vol. 51, pp. 27-35, 2016. DOI:10.1515/hukin-2015-0167

[13] Shah Z., Ahmad F., Zahra M., Zulfiqar F., Aziz S., Mahmood A., "Effect of Single Bout of Moderate and High Intensity Interval Exercise on Brain Derived Neurotrophic Factor and Working Memory in Young Adult Females," Brain Plasticity, vol. 8, pp. 35-42, 2022.DOI:10.3233/BPL-210130

[14] Davranche K., Brisswalter J., Radel R., "Where are the limits of the effects of exercise intensity on cognitive control?," J Sport Health Sci, vol. 4, no. 1, pp. 56-63, 2015. DOI:10.1016/j.jshs.2014.08.004

[15] Burton D.A., Stokes K., Hall G.M., "Physiological effects of exercise," Continuing Education in Anaesthesia Critical Care & Pain, vol. 4, no. 6, pp. 185-188, 2004. DOI:10.1093/bjaceaccp/mkh050

[16] Cooper S.B., Bandelow S., Nute M.L., Dring K.J., Stannard R.L., Morris J.G., Nevill M.E., "Sprint-based exercise and cognitive function in adolescents," Prev Med Rep, vol. 4, pp. 155-161, 2016. DOI:10.1016/j.pmedr.2016.06.004

[17] Gonçalves C., Raimundo A., Abreu A., Bravo J., "Exercise Intensity in Patients with Cardiovascular Diseases: Systematic Review with Meta-Analysis," International Journal of Environmental Research and Public Health, vol. 18, pp. 3574, 2021. DOI:10.3390/ijerph18073574

[18] Scarpina F., Tagini S., "The Stroop Color and Word Test," Front Psychol, vol. 8, pp. 557, 2017. DOI:10.3389/fpsyg.2017.00557

[19] Sisco S.M., Slonena E., Okun M.S., Bowers D., Price C.C., "Parkinson's disease and the Stroop color word test: processing speed and interference algorithms," Clin Neuropsychol, vol. 30, no. 7, pp. 1104-1117, 2016. DOI:10.1080/13854046.2016.1188989

[20] Nouchi R., Taki Y., Takeuchi H., Hashizume H., Nozawa T., Sekiguchi A., Nouchi H., Kawashima R., "Beneficial effects of short-term combination exercise training on diverse cognitive functions in healthy older people: study protocol for a randomized controlled trial," Trials, vol. 13, pp. 200, 2012. DOI:10.1186/1745-6215-13-200

[21] Wohlwend M., Olsen A., Haberg A.K., Palmer H.S., "Exercise Intensity-Dependent Effects on Cognitive Control Function during and after Acute Treadmill Running in Young Healthy Adults," Front Psychol, vol. 8, pp. 406, 2017. DOI:10.3389/fpsyg.2017.00406

[22] Ploughman M., McCarthy J., Bosse M., Sullivan H.J., Corbett D., "Does treadmill exercise improve performance of cognitive or upper-extremity tasks in people with chronic stroke? A randomized cross-over trial," Arch Phys Med Rehabil, vol. 89, no. 11, pp. 2041-2047, 2008. DOI:10.1016/j.apmr.2008.05.017

[23] Ferris L.T., Williams J.S., Shen C.L., "The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function," Med Sci Sports Exerc, vol. 39, no. 4, pp. 728-734, 2007. DOI:10.1249/mss.0b013e31802f04c7

[24] Piepmeier A.T., Etnier J.L., "Brain-derived neurotrophic factor (BDNF) as a potential mechanism of the effects of acute exercise on cognitive performance," Journal of Sport and Health Science, vol. 4, no. 1, pp. 14-23, 2015. DOI:10.1016/j.jshs.2014.11.001

[25] Borror A., "Brain-derived neurotrophic factor mediates cognitive improvements following acute exercise," Medical Hypotheses, vol. 106, pp. 1-5, 2017. DOI:10.1016/j.mehy.2017.06.024

[26] El-Sayes J., Harasym D., Turco C.V., Locke M.B., Nelson A.J., "Exercise-Induced Neuroplasticity: A Mechanistic Model and Prospects for Promoting Plasticity," The Neuroscientist, vol. 25, no. 1, pp. 65-85, 2018. DOI:10.1177/1073858418771538

[27] Tsubaki A., Morishita S., Tokunaga Y., Sato D., Tamaki H., Yamazaki Y., Qin W., Onishi H., "Changes in Cerebral Oxyhaemoglobin Levels During and After a Single 20-Minute Bout of Moderate-Intensity Cycling," Adv Exp Med Biol, vol. 1072, pp. 127-131, 2018. DOI:10.1007/978-3-319-91287-5_20

[28] Ludyga S., Gerber M., Brand S., Puhse U., Colledge F., "Effects of Aerobic Exercise on Cognitive Performance Among Young Adults in a Higher Education Setting," Res Q Exerc Sport, vol. 89, no. 2, pp. 164-172, 2018. DOI:10.1080/02701367.2018.1438575

[29] Zuniga K.E., Mueller M., Santana A.R., Kelemen W.L., "Acute aerobic exercise improves memory across intensity and fitness levels," Memory, vol. 27, no. 5, pp. 628-636, 2019. DOI:10.1080/09658211.2018.1546875

[30] Etnier J.L., Wideman L., Labban J.D., Piepmeier A.T., Pendleton D.M., Dvorak K.K., Becofsky K., "The Effects of Acute Exercise on Memory and Brain-Derived Neurotrophic Factor (BDNF)," J Sport Exerc Psychol, vol. 38, no. 4, pp. 331-340, 2016. DOI:10.1123/jsep.2015-0335

[31] Yamazaki Y., Sato D., Yamashiro K., Tsubaki A., Takehara N., Uetake Y., Nakano S., Maruyama A., "Inter-individual differences in working memory improvement after acute mild and moderate aerobic exercise," PLoS One, vol. 13, no. 12, pp. e0210053, 2018. DOI:10.1371/journal.pone.0210053

[32] Chang Y.-K., Chu C.-H., Wang C.-C., Wang Y.-C., Song

T.-F., Tsai C.-L., Etnier J.L., “Dose–Response Relation between Exercise Duration and Cognition,” Medicine & Science in Sports & Exercise, vol. 47, no. 1, pp. 159-165, 2015.

[33] Brisswalter J., Collardeau M., René A., “Effects of Acute Physical Exercise Characteristics on Cognitive Performance,” Sports Medicine, vol. 32, no. 9, pp. 555-566, 2002. DOI:10.2165/00007256-200232090-00002

[34] Cantelon J.A., Giles G.E., “A Review of Cognitive Changes During Acute Aerobic Exercise,” Front Psychol, vol. 12, pp. 653158, 2021. DOI:10.3389/fpsyg.2021.653158