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Original Article

The Effect of an Acute Aerobic Exercise with Different Intensities on the Executive Functions of 9-10-year-old Children

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Abstract

Background: It is well-established that executive function can be affected by a session of aerobic training. Our study aimed to determine how acute aerobic exercise affect executive function at different intensities in 9-10-year-old children.
Methods: The participants in this quasi-experimental study were 36 children (9.58 years±0.50) in Saqqez, Kurdistan Province, Iran in the first half of 2022. They were randomly assigned into 60% and 80% heart rate reserve (HRR) and a control group. All groups performed the Progressive Aerobic Cardiovascular Run (PACER) test in the first stage of study to ensure homogeneity. Then, in the pretest- posttest design, inhibitory control and working memory were assessed using the Stroop and N-back tests. During the 15-minute exercise session, participants exercised on a treadmill at different intensities of 60% and 80% of their HRR. One-way Analysis of Variance (ANOVA) and paired t-test were employed to analyze between-group and within-group differences in control and intervention groups.
Results: According to the results, working memory scores of children improved significantly in 60% and 80% HRR groups (65.44±9.51 vs. 44.69±17.76) compared with the control group (31.00±2.02) (P<0.0001). Different exercise intensities; however, did not show any advantage over a control group in the interference score of correct answers, or reaction time (RT) of inhibition control (60% HRR: 4.08±3.77, 80% HRR: 1.16±3.32, Control: 4.25±3.62, P=0.074), (60% HRR: 52.00±65.91, 80% HRR: 85.66±59.75, Control: 27.16±106.46, P=0.215).
Conclusions: The study findings revealed that working memory in pre-adolescents can be improved by a 15-minute session of moderate or high-intensity aerobic exercise. However, there were no significant differences between the groups in terms of inhibitory control.

Keywords: Executive function, Acute exercise, Working memory, Inhibitory control, Students

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1. Introduction

A higher-level cognitive process, called the executive function, is responsible for regulating and organizing behaviors directed toward specific goals. They enable individuals to respond to novel events and adapt to new environments or contexts by overriding habitual or automatic actions (1). The results of Contreras-Osorio and colleagues, analyzing the relationship between cognitive performance and aerobic fitness, showed that children's cognitive performance can be improved by increasing aerobic fitness (2). Also, the results of previous review and meta-analysis studies revealed that physical activity, both acute and chronic, can influence specific aspects of cognitive function, especially executive function (3-8). Most of the research on acute exercise and cognitive performance was focused on adults, middle-aged and older adults (6, 9, 10). These studies found that aerobic exercise for 30 minutes at a moderate intensity facilitates cognitive function (5, 11). In comparison with adult studies, very limited research has been done on children, especially those who are pre-adolescent. However, some studies reported improvements in cognitive function following an acute training (12, 13). Chen and colleagues analyzed the influence of aerobic exercise based on basketball dribbling training with the moderate-intensity (65%) on the cognitive function of 4^{th} grade students in elementary school and found that aerobic exercise for 30 minutes had a significant improvement on children's cognitive performance (14). Hillman and co-workers examined the effect of an acute aerobic training on the executive functions of children (mean age=9.6 years). They showed that an acute aerobic training with moderate-intensity (60% maximum HR) has a significant effect on executive functions (15).

Recently, researchers have been interested in studying the influence of acute exercise on memory. The limited research conducted on the effect of aerobic training on children's memory showed its positive effects (4, 16). A study conducted on the influence of high intensity interval training on the executive functions of 11 to 13-year-old children revealed that a 60-minute aerobic training (60%-70% MHR) significantly improved working memory (17). Other studies indicated a single session of exercise improves memory in healthy children (18, 19). In contrast, some studies, such as Stroth and colleagues indicated that aerobic exercise with an intensity of 60% of the maximum HR does not affect the control of attention and memory of 13-14-year-old teenagers (20).

An important point here is that the level of cognitive development and the components of executive functions may moderate the influence of an exercise session on executive function. In other words, at certain stages of development, executive functions may be more sensitive to aerobic training, and one component of executive functions may respond differently to acute aerobic exercise (6, 20). Children; however, follow different developmental schedules for these components, despite the fact that they are correlated (21).

A meta-analysis of 40 studies examining the effect of acute exercise on cognitive function revealed that exercise intensity was an important moderator of the effect of acute exercise on cognitive performance (6). It is important to consider how physical activity dose affects cognitive changes after acute physical activity. The absence of sufficient background on how exercise affects executive functions and working memory in pre-adolescent children, led us to examine whether different intensities of aerobic exercise affect working memory and inhibitory control differently.

2. Methods

2.1. Participants

This quasi-experimental study employed a pretest-posttest design with a control group. The participants were 9 to 10-year-old elementary school students. After checking their health status using a health questionnaire, 36 volunteers (18 girls) (9.58±0.5) were included in the study. Participants were recruited from elementary schools in an urban area of Saqqez, Kurdistan Province, Iran in the first half of 2022. Parents of all children signed a written consent form and verbal assent was obtained from all study participants.

Using a priori power analysis, the sample size was determined for working memory (Moderate-intensity group: pre-test: 88.19±1.45, post-test: 93.61±1.23; Control group: pre-test: 90.67±1.51, post-test: 92.25±1.55) (22), and for inhibition control (High-intensity group: baseline: 573±58, post-test: 545±65; Moderate-intensity group: baseline: 560±63, post-test: 523±54; Control group: baseline: 542±59, post-test: 543±74) (23), with the estimate of the minimum required sample size being 33.

2.2. Apparatuses and Task

2.2.1. Progressive Aerobic Cardiovascular Run test (PACER)

Before performing the executive function tests, the PACER test was conducted to homogenize the cardiovascular fitness of the study participants. PACER is a multistage test for assessing aerobic capacity which gradually increases difficulty as it progresses. Runners run back and forth as many laps as they can; each lap is signaled by a beep. As each minute passes, participants run faster back and forth across the 20m distance. The test ends when the participant is unable to complete the distance of 20 meters twice in a row within the set time. Number of completed laps is recorded as the score of the participants. A significant correlation (R=0.72) was found between PACER scores and measured VO2peak, indicating good validity for the test (24).

2.2.2. The N-Back Test

To measure working memory in this study, the computer N-Back test was employed during both the pre-and post-tests. In this test, a series of stimuli are sequentially presented to participants. They must decide if the presented stimulus is similar to the previous N trials. In our study, a sequence of random numbers was displayed on the screen, and three stages (1 to 3-Back) were included. During a 10-minute test, the number of correct answers, wrong answers, and unanswered cases was recorded. Participants' final scores were calculated based on their percentage of correct responses.

2.2.3. The Stroop Test

An important neuropsychological test for assessing inhibitory control is the Stroop Color and Word Test. This task assesses the participant's ability to inhibit cognitive interference. It happens when one stimulus attribute interferes with the simultaneous processing of another. The present study included a total of 96 trials, with 48 trials having congruent word and color combinations and the remaining 48 trials having incongruent word and color combinations. The reaction time for correct answers and the number of correct answers were analyzed. The score of the test, called the interference score, is as follows:

Congruent integer - Incongruent integer= interference score

2.3. Procedure

Following the homogenization of cardiovascular fitness using the PACER test, all participants completed the N-Back and Stroop tasks which were employed to assess executive function in the present study. First, the participants were stratified by gender and PACER score. Then, they were randomly assigned to two experimental groups with intensities of 60% and 80% HRR and a control group. Modified random assignment is the standard practice to ensure that each group has a similar number of participants. One method is block randomization, which repeats all conditions once before repeating the rest. In the present study, stratified and blocked randomization resulted in the placement of 12 participants in each group, with an equal representation of both genders.

At least 48 hours after the PACER test, the participants were invited to participate in the main intervention. As part of the acute aerobic training program, and before starting the training session, the participants Walked 1.5 km/h on the treadmill to warm up. In 5 minutes, the participants reached the target intensity. Then, for 15 minutes, each group participated in an aerobic exercise program at a target intensity. The heart rate monitor (Polar model, made in Finland) was employed to control the intensity of the exercise. The maximum heart rate (HR max) was estimated using the method of Tanaka and co-workers; HR max=208 - (age×0.7) (25). Then, the HRR for each intensity was determined using the formula below.

HRR=[(Max HR-Resting HR)×target intensity]+ Resting HR

This number represents the intensity at which the participants started training. If the heart rate of the participants changed, the treadmill speed was increased or decreased in the same proportion until the heart rate returned to the desired range. This intensity was maintained for 15 minutes.

The cool-down duration was 5 minutes. When the child's HR returned to 10% of the pre-intervention value, executive function post-tests were carried out. The order of executive function tests was counterbalanced.

2.4. Data Analysis

Paired sample t-test and one-way ANOVA were employed to examine within and between-group differences in intervention and control groups. Least Significant Difference (LSD) post-hoc test was used if a significant difference was detected. The data were analyzed using SPSS version 22. The level of significance was set at 0.05.

3. Results

Based on the Shapiro-Wilk and Leven tests, the normality and equality of variances were both confirmed (P>0.05). Also, one-way ANOVA indicated that there was no significant difference among the groups at the beginning of this study in terms of cardiovascular fitness measured by PACER (P=0.647). The test also revealed no significant differences among groups for age, P=0.379; height, P=0.631; weight, P=0.472; and BMI, P=0.590. Table 1 presents the participants' demographics.

Using one-way ANOVA, baseline scores for executive function were also analyzed between the groups. The groups were not significantly different from each other before the intervention in terms of the performance of the Stroop (interference score for number of correct answers (P=0.200), reaction time (P=0.896)) and working memory (P=0.370) tests. Table 2 presents means (±SD) of Stroop and working memory performance in pre and post-test for each group.

Table 1: Demographic characteristics of the participants				
Variables	**60% HRR**	**80% HRR**	**Control**	**P value**
n	12	12	12	
Female/Male	6/6	6/6	6/6	
Age (yrs)	9.75±0.45	9.50±0.52	9.50±0.52	0.379
Height (cm)	127.58±12.97	132.00±8.51	130.58±12.31	0.631
Weight (kg)	27.50±5.21	31.00±8.68	28.08±7.89	0.472
BMI (kg/m^2)	17.02±3.14	17.47±3.13	16.24±2.89	0.590

HRR: Heart Rate Reserve; BMI: Body Mass Index

Table 2: Mean (±SD) of group measures during pre and post-exercise

Groups	**60% HRR**			**80% HRR**			**Control**			**Between group P value**	
Variables	**Pre-test Mean (SD)**	**Post-test Mean (SD)**	**Within-group P value**	**Pre-test Mean (SD)**	**Post-test Mean (SD)**	**Within-group P value**	**Pre-test Mean (SD)**	**Post-test Mean (SD)**	**Within-group P value**	**Pre-test**	**Post-test**
Working memory	29.63 (3.69)	65.44 (9.51)	<0.0001	28.94 (3.66)	44.69 (17.76)	0.013	30.86 (2.43)	31.00 (2.02)	0.855	0.370	<0.0001
Inhibition control (no. correct answers)	5.75 (6.25)	4.08 (3.77)	0.408	2.33 (5.82)	1.16 (3.32)	0.541	7.53 (8.83)	4.25 (3.62)	0.261	0.200	0.074
Inhibition control (RT)	48.08 (63.88)	52.00 (65.91)	0.905	49.75 (76.39)	85.66 (59.75)	0.022	37.08 (74.18)	27.16 (106.46)	0.871	0.896	0.215

HRR: Heart Rate Reserve; SD: Standard Deviation; RT: Reaction Time

Table 3: Pairwise comparison of the LSD test of the working memory variable between different groups

Source	**Group 1**	**Group 2**	**P value**
Working Memory	60% HRR	80% HRR	<0.0001
	60% HRR	Control	<0.0001
	80% HRR	Control	0.007

HRR: Heart Rate Reserve; LSD: Least Significant Difference

The main effect of post-intervention outcome of working memory showed significant differences between groups (P<0.0001). A pairwise post-hoc LSD test revealed that participants in the 60% HRR (M=65.44, SD=9.51) improved their working memory significantly as compared with 80% HRR (M=44.69, SD=17.76) and control group (P<0.0001). In comparison with the control group (M=31.00, SD=2.02), the scores of the 80% HRR training group increased statistically (P=0.007) (Table 3). It can therefore be concluded that an acute aerobic exercise session with an intensity of 60% and 80% HRR training positively affected the working memory of 9-10-year-old children.

Paired sample t-test showed that the working memory score was significantly better in the post-test (M=47.04, SD=18.30) as compared with the pre-test (M=29.81, SD=3.32); (P<0.0001).

The results of one-way ANOVA for two sub-variables of the inhibition control, the interference score of the reaction time (RT) of the correct answer (60% HRR: M=52.00, SD=65.91, 80% HRR: M=85.66, SD=59.75, Control: M=27.16, SD=106.46) (P=0.215), and the interference score of the number of correct answers (60% HRR: M=4.08, SD=3.77, 80% HRR: M=1.16, SD=3.32, Control M=4.25, SD=3.62) (P=0.074) showed no significant differences between the groups.

The results of paired sample t-test showed no significant difference for the post-test as compared with the pre-test in both interference scores of inhibition control (interference score of RT: pre-test (M=44.97, SD=69.85); post-test (M=54.94, SD=81.94), (P=0.582), interference score of number of correct answers: pre-test (M=5.22, SD=7.23); post-test (M=3.16, SD=3.76), (P=0.114)).

4. Discussion

The study results showed that the 60% and 80% HRR group significantly improved children's working memory scores as compared with the control group. However, there were no significant differences between the groups in terms of inhibitory control.

The study primarily showed that moderate and high-intensity physical activity improved working memory performance in pre-adolescent children, which was consistent with previous findings (18, 26). Using the functional magnetic resonance imaging (fMRI) technique, researchers investigated the activation of different brain regions following 30 minutes of moderate-intensity aerobic exercise in 10-year-old children (18). Results showed that aerobic exercise improved the execution of the N-Back test in comparison with the pre-test and increased activities of brain in the bilateral cerebellum, left hippocampus and bilateral parietal cortex (18). This study only examined moderate-intensity aerobic activity. Mou and colleagues evaluated the working memory of young people (average age of about 20 years) by comparing high-intensity interval training and moderate-intensity training. This study demonstrated that both types of exercise improved working memory significantly, but the high-intensity interval training had more lasting effects (27).

Various neural mechanisms have been proposed to explain executive function improvement after physical activity. These mechanisms include the increase in blood lactate levels, release of catecholamines, expression of human growth factors, and importance of brain-derived neurotrophic factor (BDNF) (28-30). The arousal theory is one of the most widely used theories that attempts to give an explanation of the mechanism of how acute training affect cognitive functions. An arousal state is a physiological and psychological state of wakefulness in which the sensory organs are stimulated to the point of perception, which is important to attention regulation and the storage of memories (9).

As the second finding of this study indicated, no significant differences were observed between the groups in terms of inhibitory control. This finding was consistent with the finding of Stroth and colleagues which showed the inhibitory control improves due to physical fitness rather than acute training (20). Other studies; however, showed different results (15, 26). One potential reason for this discrepancy may stem from the varying research conditions in the two separate studies. While the Flanker test was used to investigate inhibitory control, the Stroop test was employed in this study. According to Moreau and Chou, the cognitive-task characteristics is one of the moderators in the relationship between cognitive performance and acute exercise (31).

In order to obtain more consistent results, age and fitness were controlled as moderating variables. The participants' age range was reduced to one year, and their cardiovascular endurance was assessed using the PACER test. Another strength of this study was using a treadmill for aerobic exercise, which creates a uniform intensity for the participants, and has been used in most studies (5, 15).

4.1. Limitations

The present study had certain limitations; bringing up these restrictions could offer valuable insights for future studies. One of main limitations of the present study was the lack of post-test follow-up with a longer time interval that could investigate the difference between the groups in a long time. Because all phases of training and test interventions were performed by one person, this person may have consciously or unconsciously given information (such as voice tone, instructions, or encouragement) to participants differently. Therefore, using double-blind techniques, in which the examiner is not the person who intervened, seem to give more reliable results and prevent bias.

5. Conclusions

Our results suggested that training with an intensity of 60% and 80% HRR can have positive effects on the working memory. Those involved in school sports are recommended to try aerobic exercises with moderate or high-intensity during school breaks in order to improve their working memory in their upcoming classes. Further research is required because acute exercises have different effects on components of executive functions, including inhibitory control and working memory. Research with cross-over designs, manipulation of different intensities, and using high-intensity interval training appears to provide us with more information. Other groups with disabilities and disorders may also benefit from acute exercise interventions.

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Authors' Contribution

Bayan Amani: Study concept and design, acquisition of data, drafting the manuscript. Arezo Ahmadpour: Study concept and design, analysis and interpretation of data, drafting the work and reviewing it critically for important intellectual content. Mohammad Rahman Rahimi: Study concept and design, reviewing the work critically for important intellectual content. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work, such that the questions related to the accuracy or integrity of any part of the work.

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Ethical Approval

The Ethics Review Board of the University of Kurdistan, Sanandaj, Iran, approved the present study with the code of IR.UOK.REC.1400.043. Also, written informed consent was obtained from the participants.

References

1. Pontifex MB, McGowan AL, Chandler MC, Gwizdala KL, Parks AC, Fenn K, et al. A primer on investigating the after effects of acute bouts of physical activity on cognition. Psychology of Sport and Exercise. 2019;40:1-22. doi: 10.1016/j.psychsport.2018.08.015.
2. Contreras-Osorio F, Guzmán-Guzmán IP, Cerda-Vega E, Chirosa-Ríos L, Ramírez-Campillo R, Campos-Jara C. Anthropometric parameters, physical activity, physical fitness, and executive functions among primary school children. Int J Environ Res Public Health. 2022;19(5):3045. doi: 10.3390/ijerph19053045. PubMed PMID: 35270736; PubMed Central PMCID: PMC8910200.
3. Jasim SA, Singh M, Al-Dhalimy AMB, Zwamel AH, Jawad IA, Shalaby NS. The impact of chronic exercise on cognitive function: an overview of reviews. Iranian Journal of Psychiatry. 2024;19(4):1-10. doi: 10.18502/ijps.v19i4.16561.
4. Liu S, Yu Q, Li Z, Cunha PM, Zhang Y, Kong Z, et al. Effects of acute and chronic exercises on executive function in children and adolescents: a systemic review and meta-analysis. Front Psychol. 2020;11:554915. doi: 10.3389/fpsyg.2020.554915. PubMed PMID: 33391074; PubMed Central PMCID: PMC7773601.
5. Lambourne K, Tomporowski PD. The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. Brain Res. 2010;1341:12-24. doi: 10.1016/j.brainres.2010.03.091. PubMed PMID: 20381468.
6. Ludyga S, Gerber M, Brand S, Holsboer-Trachsler E, Pühse U. Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups: A meta-analysis. Psychophysiology. 2016;53(11):1611-1626. doi: 10.1111/psyp.12736. PubMed PMID: 27556572.
7. Tomporowski PD, McCullick B, Pendleton DM, Pesce C. Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. Journal of Sport and Health Science. 2015;4(1):47-55. doi: 10.1016/j.jshs.2014.09.003.
8. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. Med Sci Sports Exerc. 2016;48(6):1197-222. doi: 10.1249/MSS.0000000000000901. PubMed PMID: 27182986; PubMed Central PMCID: PMC4874515.
9. Cantelon JA, Giles GE. A review of cognitive changes during acute aerobic exercise. Front Psychol. 2021;12:653158. doi: 10.3389/fpsyg.2021.653158. PubMed PMID: 34975602; PubMed Central PMCID: PMC8716584.
10. Falck RS, Davis JC, Best JR, Crockett RA, Liu-Ambrose T. Impact of exercise training on physical and cognitive function among older adults: a systematic review and meta-analysis. Neurobiol Aging. 2019;79:119-130. doi: 10.1016/j.neurobiolaging.2019.03.007. PubMed PMID: 31051329.
11. Wei J, Hou R, Xie L, Chandrasekar EK, Lu H, Wang T, et al. Sleep, sedentary activity, physical activity, and cognitive function among older adults: The National Health and Nutrition Examination Survey, 2011–2014. J Sci Med Sport. 2021;24(2):189-194. doi: 10.1016/j.jsams.2020.09.013. PubMed PMID: 33032913.
12. Hillman CH, Logan NE, Shigeta TT. A review of acute physical activity effects on brain and cognition in children. Translational Journal of the American College of Sports Medicine. 2019;4(17):132-6. doi: 10.1249/TJX.0000000000000101.

13. De Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E. Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. J Sci Med Sport. 2018;21(5):501-507. doi: 10.1016/j.jsams.2017.09.595. PubMed PMID: 29054748.
14. Chen A, Fu L, Zhu L. Effects of medium-intensity basketball with different durations on children's executive function. J Capital Ins Phys Educ. 2015;27:223-227. doi: 10.14104/j.cnki.1006-2076.2017.01.015.
15. Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer A. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. Neuroscience. 2009;159(3):1044-54. doi: 10.1016/j.neuroscience.2009.01.057. PubMed PMID: 19356688; PubMed Central PMCID: PMC2667807.
16. Zhu Q, Deng J, Yao M, Xu C, Liu D, Guo L, et al. Effects of physical activity on visuospatial working memory in healthy individuals: A systematic review and meta-analysis. Front Psychol. 2023;14:1103003. doi: 10.3389/fpsyg.2023.1103003. PubMed PMID: 36874874; PubMed Central PMCID: PMC9974834.
17. Cooper SB, Dring KJ, Morris JG, Sunderland C, Bandelow S, Nevill ME. High intensity intermittent games-based activity and adolescents' cognition: Moderating effect of physical fitness. BMC Public Health. 2018;18(1):603. doi: 10.1186/s12889-018-5514-6. PubMed PMID: 29739386; PubMed Central PMCID: PMC5941716.
18. Chen A-G, Zhu L-N, Yan J, Yin H-C. Neural basis of working memory enhancement after acute aerobic exercise: fMRI study of preadolescent children. Front Psychol. 2016;7:1804. doi: 10.3389/fpsyg.2016.01804. PubMed PMID: 27917141; PubMed Central PMCID: PMC5116552.
19. BB, Vallejo AP, Román PÁL. Acute effect of two different physical education classes on memory in children school-age. Cognitive Development. 2019;50:98-104. doi: 10.1016/j.cogdev.2019.03.004.
20. Stroth S, Kubesch S, Dieterle K, Ruchsow M, Heim R, Kiefer M. Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. Brain Res. 2009;1269:114-24. doi: 10.1016/j.brainres.2009.02.073. PubMed PMID: 19285042.
21. Best JR. Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. Dev Rev. 2010;30(4):331-551. doi: 10.1016/j.dr.2010.08.001. PubMed PMID: 21818169; PubMed Central PMCID: PMC3147174.
22. Weng TB, Pierce GL, Darling WG, Voss MW. Differential effects of acute exercise on distinct aspects of executive function. Med Sci Sports Exerc. 2015;47(7):1460-9. doi: 10.1249/mss.0000000000000542. PubMed PMID: 25304335.
23. Brown DM, Bray SR. Acute effects of continuous and high-intensity interval exercise on executive function. Journal of Applied Biobehavioral Research. 2018;23(3):e12121. doi: 10.1111/jabr.12121.
24. Mayorga-Vega D, Aguilar-Soto P, Viciana J. Criterion-related validity of the 20-m shuttle run test for estimating cardiorespiratory fitness: a meta-analysis. J Sports Sci Med. 2015;14(3):536-47. PubMed PMID: 26336340; PubMed Central PMCID: PMC4541117.
25. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001;37(1):153-6. doi: 10.1016/s0735-1097(00)01054-8. PubMed PMID: 11153730.
26. Chen A-G, Yan J, Yin H-C, Pan C-Y, Chang Y-K. Effects of acute aerobic exercise on multiple aspects of executive function in preadolescent children. Psychology of Sport and Exercise. 2014;15(6):627-636. doi: 10.1016/j.psychsport.2014.06.004.
27. Mou H, Tian S, Fang Q, Qiu F. The immediate and sustained effects of moderate-intensity continuous exercise and high-intensity interval exercise on working memory. Front Psychol. 2022;13:766679. doi: 10.3389%2Ffpsyg.2022.766679. PubMed PMID: 35242075; PubMed Central PMCID: PMC8887601.
28. Szuhany KL, Bugatti M, Otto MW. A meta-analytic review of the effects of exercise on brain-derived neurotrophic factor. J Psychiatr Res. 2015;60:56-64. doi: 10.1016/j.jpsychires.2014.10.003. PubMed PMID: 25455510; PubMed Central PMCID: PMC4314337.
29. Moriarty TA, Mermier C, Kravitz L, Gibson A, Beltz N, Zuhl M. Acute aerobic exercise based cognitive and motor priming: practical applications and mechanisms. Front Psychol. 2019;10:2790. doi: 10.3389/fpsyg.2019.02790. PubMed PMID: 31920835; PubMed Central PMCID: PMC6920172.
30. El-Sayes J, Harasym D, Turco CV, Locke MB, Nelson AJ. Exercise-induced neuroplasticity: a mechanistic model and prospects for promoting plasticity. Neuroscientist. 2019;25(1):65-85. doi: 10.1177/1073858418771538. PubMed PMID: 29683026.
31. Moreau D, Chou E. The acute effect of high-intensity exercise on executive function: a meta-analysis. Perspect Psychol Sci. 2019;14(5):734-764. doi: 10.1177/1745691619850568. PubMed PMID: 31365839.