Research Paper

Investigating the Effects of Combined Physical-cognitive Exercises on Executive Functions: A Home-based Exercise Approach

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ABSTRACT

Purpose: Improving brain functions through physical exercises has been the focus of research in recent years. Accordingly, it is important to examine the kind of physical exercises and brain functions that are affected. This study aims to examine the effect of integrated physical cognitive exercises at home on the executive functions of adults.

Methods: This was a field trial study, in which 28 people were examined in 2 groups. People in the experimental group participated in combined cognitive and physical exercises for 16 sessions, while the control group did their daily routines. Inhibition components were evaluated by the go/no-go test and working memory through the N-back test at the beginning and end of the training period. The data were analyzed via factorial analysis of variance through the SPSS software, version 19.

Results: The findings indicated that the experimental condition, compared to the control condition, caused a significant improvement in the correct inhibition (P=0.002) and total correct response (P=0.047) components in the go/no-go test, along with the commission errors in the N-back test (P=0.003).

Conclusion: The results showed that the combined physical and cognitive exercise had a positive effect on the core executive functions (attentional inhibition and working memory) and could prevent the performance decrement caused by quarantine and the reduction of daily activities that people were facing.

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Highlights

• The combination of physical and cognitive exercises prevented the decline in the performance of executive functions because of quarantine.

• Using the online cognitive physical exercises method demonstrated a positive effect.

• The executive functions improvement was observed more in the components related to inhibitory control.

• Although previous studies observed the improvement of executive functions through physical-cognitive exercises in childhood and old age, the current research observed this effect in young adults as well.

Plain Language Summary

Executive functions are one of the most important brain functions that are related to a higher level of information processing. By relying on these functions, people can maintain information in mind, pay attention to it, analyze information, and finally make a decision. These functions are essential in many aspects of human life, including academic performance and career success, as well as increasing the quality of life (QoL). There are many ways to improve these functions, such as physical exercises. Although most people are familiar with the role of physical exercises on physical health, such exercises can also improve brain functions, such as attention and information processing. To improve the effect of physical exercises on brain functions, it is better to combine these exercises with cognitive challenges. The present findings showed that by using the online combined cognitive-physical exercise method during the quarantine period, the decline of brain functions due to the reduction of physical and daily activities can be prevented.

Introduction

Previous research has demonstrated the importance of physical fitness for brain health and cognitive functions throughout the lifespan [1]; therefore, the reports about the decrease in the level of physical activity at the same time as the decrease in physical fitness are worrying [2] and studies show that these trends may affect the metabolic, along with cognition and brain health [3-5]. Executive functions are one of the most important functions of the human brain and refer to top-down and purposeful behaviors [6]. Inhibitory control (the ability to ignore distracting information and focus on work-related information) and working memory (the ability to maintain and manipulate information for a short period are two important components of executive functions [6]. Accordingly, given the importance of these components, the study of cognitive enhancement methods has expanded [7, 8]. The logic of cognitive training derives largely from the concept of neuroplasticity, which asserts that the brain, similar to a muscle, can change and adapt to challenges, and targeted training produces sustained growth in the brain's structure or functional capacity [9]. Such adaptation is evident in both the young and the elderly and can facilitate a wide range of benefits that appear to accrue through cognitive training, including memory, attention, problem-solving, and learning ability [10].

Some studies have shown that exercise can positively affect cognitive performance [3, 4, 11], although these studies have examined the effects of exercise on different cognitive components and used different training methods [12]. While some research emphasizes the influence of exercise on biological factors related to cognition, such as structural and functional changes in the brain, other researchers consider the effects of exercise on behavioral variables to be important [9, 13-15]. However, the concept that is emphasized is the type of physical exercise [8, 16, 17]. In this regard, a factor called the cognitive need for physical exercises the effectiveness of exercises in improving cognitive functions increases with the increment in the level of complexity of the exercises and their cognitive challenges [18]. Therefore, in the current research, to increase the cognitive challenges and the possible effects, a combination of cognitive and physical exercise was used. Most of the studies on fitness, cognition, and brain health have focused on age boundaries (e.g. children and the elderly), while less attention has been paid to studies of adulthood [19, 20]. Paying attention to cognitive enhancement during adulthood is important since it is the transition period between youth and old age. It is during this period that people can form their habits and stabilize them over time to find the necessary preparation for old age both physically and mentally. Optimum brain function in adulthood is important for two reasons: Firstly, the person is involved in doing important tasks, and secondly, by enhancing brain functions in this period, it is possible to prevent the decline of brain functions because of aging [21].

On the other hand, considering the conditions created during the COVID-19 pandemic, people faced restrictions for doing physical activities in sports clubs, which caused more inactivity. During this period, various protective instructions, including restrictions on social and sports activities, were implemented by the authorities [22]. In this regard, many people followed the official recommendations to stay in quarantines or at home, but these measures affected people's sedentary behaviors. The physical activity decrease during the COVID-19 pandemic is more than before [23, 24]. Some research shows that during the period of COVID-19, many cognitive and physical components have also decreased in healthy people [25]. Although sports activities at home, such as exercising on a bicycle and treadmill, can have positive effects on physical and cognitive components, these activities have low levels of cognitive challenges, which is an important factor in optimal cognitive enhancement [16]; in addition, the motivation to participate in these activities may decrease over time [26]. For these reasons, in this period, considering the limited opportunity to do physical activities outside the house, a home-based physical education program may reduce the negative physiological effects of sedentary behaviors. Accordingly, the present study aims to investigate the effectiveness of a combined home-based physical-cognitive exercises package on the basic core functions of working memory and attentional inhibition during the quarantine period of COVID-19 to answer whether it is possible to prevent possible cognitive functions decline by implementing these exercises.

Materials and Methods

Study participants

The present research was conducted as a field trial study. All procedures were approved by the Research Ethics Committee of Allameh Tabataba'i University. The sample size was calculated using the G*Power software, version 3.1.9.2 (α=0.05, 2 tails, power=0.7) [27]. The participants included 28 male and female adults living in ShahreKord City, Iran, in the age range of 30 to 40 years. The inclusion criteria included being right-handed, being in the age range of 30 to 40 years, having no medical prohibition to exercise, lack of experience in the neuropsychological tests used in this study, and not participating in sports activities and cognitive interventions during the research period. Then, the participants were randomly divided into 2 groups: The experimental group (performing the combined physical-cognitive exercise program) and a control group (performing their routine activities).

Study materials

Go/No-go test

This test was used to evaluate attentional inhibition, in which, several stimuli were shown to subjects and they have to respond to some items and not respond to others. The order of presentation of these stimuli was random and unpredictable. The subjects' task was to respond to the go stimuli as soon as possible. Failure to respond to go stimuli was considered an error of omission and response to no-go stimuli was considered a commission error. In addition to these two types of errors, the total correct answers, correct inhibition, and reaction time were also calculated as other variables of this test [28].

N-back test

This test was measured to evaluate the ability to update information in the working memory. In the execution phase, the subjects should pay attention to a series of numbers that appear randomly on the monitor, and if the current number was the same as the previous two numbers, they must press the space button on the keyboard, however, if it was not the same, they should not react. Given the continuous change of order in the presentation of numbers, the two previous numbers were constantly changing, so the subjects had to keep the new number in mind and remove one of the numbers that were already in mind. The omission and commission errors, reaction time, and the number of correct responses were considered dependent variables [29].

Study procedure

After both groups participated in the pre-test (N-back and go/no-go tests), the experimental group practiced combined physical-cognitive exercise for 16 sessions (4 weeks). The control group was only engaged in routine activities during the same period. After the training sessions, the N-back and go/no-go tests were repeated as the post-test. In the experimental group, training videos were provided to the participants at the beginning of the training sessions. In these videos, the types of exercises

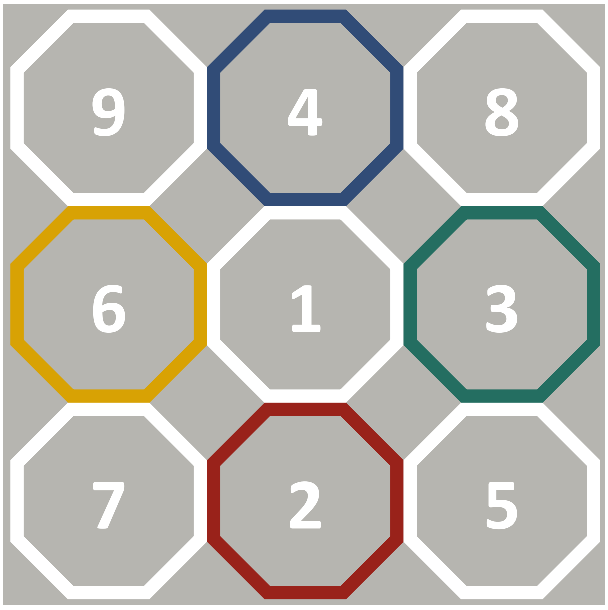

Figure 1. Designed mat for exercise

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that people should perform were shown. After watching the movements, the online trainer asked the subjects to perform these movements in a specific order by adding cognitive challenges at a certain time. The average duration of the exercises was 30 min which included warm-up (5 min), the main part of the exercise (20 min), and cool down (5 min). The main part of the exercise consisted of two parts, namely physical and cognitive challenges. Physical challenges included balance, coordination, and aerobic exercises. Each workout interval consisted of 30 s of exercise along with 30 s of rest. These exercises were performed on a mat designed with numbers (Figure 1).

Cognitive challenges included secondary tasks, such as backward and forward counting (with different intervals and calculations) and digit forward and backward span paradigm. In the dual-task paradigm, the secondary tasks were performed at the same time as the physical exercise but in the digit forward and backward span paradigm, the trainer names a series of numbers, and subjects have to memorize the numbers and perform the exercise on the mat in the order of the numbers mentioned. Over time, these exercises became more complicated, and they needed more coordination in the execution. In each session, the complexity and order of physical and cognitive exercises was different from the previous session and it was more difficult than the previous session. The data in the pre-test and post-tests in the two groups were analyzed by factorial analysis of variance (2×2) through the IBM SPSS software, version 19.

Results

Go/No-go test

Table 1 shows the descriptive statistics of the go/no-go test. The results of omission error revealed that the main effect of the group ($F_{(1, 26)}$=23.71, P=0.001, η^2=0.477) and the main effect of the test ($F_{(1, 26)}$=4.81, P=0.037, η^2=0.156) was significant; however, no statistically significant interaction effect was detected ($F_{(1, 26)}$=3.66, P=0.067, η^2=0.124). The main effect of the test ($F_{(1, 26)}$=1.111, P=0.302, η^2=041), the main effect of the group ($F_{(1, 26)}$=0.077, P=0.784, η^2=0.003), and the interaction effect in commission error were also non-significant ($F_{(1, 26)}$=1.111, P=0.302, η^2=0.041). Based on the reaction time data, the main effect of the group (($F_{(1, 26)}$=0.995, P=0.328, η^2=0.037), and the main effect of the test ($F_{(1, 26)}$=1.000, P=0.327, η^2=0.037) were not significant, and the interaction effect was also non-significant ($F_{(1, 26)}$=1.008, P=0.325, η^2=0.037).

In the component of the total correct answers, the results showed that the main effect of the group ($F_{(1, 26)}$=23.71, P=0.001, η^2=0.477) and the main effect of the test were significant ($F_{(1, 26)}$=4.81, P=0.037, η^2=0.156). In addition, the results revealed a significant difference between groups in the trend of changes from the pre-test to the post-test ($F_{(1, 26)}$=4.35, P=0.047, η^2=0.143). In correct inhibition, the main effect of group ($F_{(1, 26)}$=2.900, P=0.101, η^2=0.100) and the main effect of test ($F_{(1, 26)}$=0.517, P=0.478, η^2=0.020) were not significant. However, the changes from the pre-test to the post-test

Table 1. Mean±SD of the go/no-go subtests

Variables	Mean±SD			
	Pre-test		Post-test	
	Experimental	Control	Experimental	Control
Omission	0.5±0. 8	6.6±3.8	0.29±0.46	3.5±5.1
Commission	6.71±5.9	6.64±3.8	6.7±5.89	7.93±6.6
Reaction time	477.5±56.5	458.69±44.59	466.5±53.4	587.46±66.04
Total correct	206.57±6.44	202.14±5	206.57±3.34	197.7±9.69
Correct inhibition	6.7±5.9	6.6±3.8	6.71±5.95	7.93±6.6

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were significantly different between the two groups ($F_{(1, 26)}$=12.334, P=0.002, η^2=0.322).

N-back test

Table 2 shows the descriptive statistics of the N-back test. The findings of the omission errors indicated that there were significant main effects of the group (($F_{(1, 26)}$=11.235, P=0.002, η^2=0.302), and also test ($F_{(1, 26}$=9.742, P=0.004, η^2=0.273). However, the interaction effect was not significant ($F_{(1, 26)}$=3.145, P=0.088, η^2=0.108). In the commission errors, the main effect of the group was significant ($F_{(1, 26)}$=4.799, P=0.038, η^2=0.156), although the main effect of test stage was not significant ($F_{(1, 26)}$=1.194, P=0.285, η^2=0.044); in addition, the results revealed that there was a significant interaction effect ($F_{(1, 26)}$=10.511, P=0.003, η^2=0.288).

In the true answers, the main effect of the group ($F_{(1, 26)}$=11.283, P=0.002, η^2=0.303) and the main effect of the test ($F_{(1, 26)}$=9.531, P=0.005, η^2=0.268) was significant; however, the results indicated that the interaction effect was not significant ($F_{(1, 26)}$=3.653, P=0.067, η^2=0.123). Accordingly, both groups in this component showed the same alteration trend. Finally, in the reaction time, the main effect of the group ($F_{(1, 26)}$=1.219, P=0.280, η^2=0.045), the main effect of the test ($F_{(1, 26)}$=3.350, P=0.079, η^2=0.114), as well as the interaction between test and group were not significant ($F_{(1, 26)}$=3.350, P=0.079, η^2=0.114).

Discussion

The combined physical-cognitive exercises package could improve some sub-components of working memory and inhibition and it prevented the decline of the function because of the inactivity during the quarantine period. In the go/no-go test, the results indicated no significant drop in the experimental group in the component of the total correct answers, which indicates the performance accuracy in the stimuli that had to be answered; therefore, it can be considered a component of vigilance [30]. On the other hand, the number of correct inhibitions in the experimental group increased significantly, which indicates the accuracy of the individual not responding to the no-go stimuli. This scale can be considered a component of attentional inhibition [6]. The sum

Table 2. Mean±SD of the N-back subtests

Variables	Mean±SD			
	Pre-test		Post-test	
	Experimental	Control	Experimental	Control
Omission	5.64±4.4	9.79±7.6	0.7±0.8	8.43±6
Commission	7.36±6.9	7.21±6.7	3.07±5.03	15.8±14.9
Reaction time	666.99±144	584.4±134.7	666.9±143.5	639.8±124.5
True answers	29.57±4.45	25.5±7.5	34.43±0.93	26.64±5.7

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of these results in the go/no-go test showed that the present package, in addition to preventing the performance decrement in attention and vigilance as a result of inactivity during quarantine has also improved the inhibitory control. In the N-back test, the results showed that the number of commission errors in the experimental group had improved compared to the control group. Since the N-back test measures the ability to update information in the working memory and the commission errors indicate the ability of response inhibition [6], this result can be interpreted as the improvement of inhibition ability in updating working memory information. Considering the close relationship between the two components of working memory and inhibition [6], this seems logical. In this regard, research has shown that attentional inhibition (resistance to distracting interference) and action inhibition (inhibition of a prepared response) are strongly related and are placed together as a single factor [31]. The pattern of current results in both inhibition and working memory components showed that these exercises were more effective on the response accuracy and the response speed was less affected. In examining the effect of exercise on cognitive functions, some studies have shown that the effect of exercise is observed more on the speed component and the accuracy is less affected [32]. However, the current findings revealed that an improvement was observed in performance accuracy. Therefore, by combining physical and cognitive exercises, the effect can be observed in different components.

Another concept that can be discussed in this regard is cognitive training. This training, such as computer-based training that trains memory, attention, and visual and auditory processing, is associated with increased cognition [10]. Although some studies have shown that brain training games are effective in cognitive functions (such as working memory and processing speed) in healthy adults [33], some studies show that the effect size for cognitive interventions is small [34]. On the other hand, some studies show that physical exercises sometimes cannot be effective enough to improve brain functions [8, 16, 17]. Therefore, according to the present findings, it may be possible to confirm this hypothesis that by combining cognitive and physical exercises, its effectiveness in improving cognitive functions can be increased. Evidence suggests that cognitive and physical exercise may complement each other and help improve brain structure and function and cognition [35].

Physical exercises with low cognitive demand can less affect cognitive performance [36]. In the context of how to increase the cognitive demand for exercise, there are several methods that, according to the present findings, adding movement challenges, such as balance and coordination movements to aerobic exercises has increased the cognitive demand for exercise and the subsequent beneficial effects can be observed [37]. In addition, it is possible that the paradigms of cognitive training combined with physical exercises would double this effect. On the other hand, there is also the possibility that physical exercises act as a trigger to prepare a person for the effectiveness of subsequent cognitive training [38]. In this regard, the effects of physical exercise with cognitive challenges used in the present study have been synergistic and increased effectiveness.

The effectiveness of the current exercises can be discussed from the point of view of the movement skills used in this research. In the dimension of balance exercises, the role of the prefrontal cortex and the dorsolateral prefrontal cortex in balance task performance has been shown [39]. Accordingly, by performing the balancing task, these areas that play a role in the executive functions, such as inhibition and working memory, are activated. Hence, balance exercises can affect the improvement of executive functions by activating these parts of the brain [40]. In terms of the coordination exercises used in this research, with the increase in the number of components of motor skills and as a result of the increase in task complexity, the need for cognitive processes also increases. Consequently, by performing these exercises, compared to simple exercises, more useful effects can be obtained in the field of improving cognitive functions [41]. These findings have been observed by studies in different samples, such as the elderly and children, in which changes in the level of behavioral variables, cognitive tests, as well as structural and functional changes in the brain have been observed [35, 42].

In combining cognitive challenges with physical exercises, the following points should be considered. cognitive and motor exercises are paired with each other and enhance each other's relative effects, and more importantly, most of the activities that people perform in their daily lives require movement and cognition at the same time; meanwhile, there is little activity that can be done in an isolated environment. Another point that can be mentioned in the context of this study is the issue of controlling training sessions, which although it was tried to be controlled online, in any case, such exercises cannot be controlled as much as face-to-face exercises. However, in conditions such as quarantine, this limitation can probably be ignored because of the beneficial effects of this type of exercise. In this regard, the comparison of online with face-to-face exercise and its beneficial effects could be investigated in future research. In addition, future studies can use measurements such as brain imaging to compare these two types of exercise.

Conclusion

The present results showed that the combined physical-cognitive exercises package can prevent the decline in cognitive functions of people during the quarantine period and also improve core executive functions, especially inhibition. In this regard, due to the use of a home-based approach and online control of exercises, these exercises can be used in special periods, such as the COVID-19 pandemic, during which it is not possible to access gyms. Thus, trainers are advised to use this type of exercise.

Ethical Considerations

Compliance with ethical guidelines

The research procedures were approved by the Research Ethics Committee of Allameh Tabataba'i University (Code: IR.ATU.REC.1399.041). After giving the initial instruction about the study, informed written consent was obtained from all participants. All subjects participated in this study voluntarily.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Chaddock-Heyman L, Erickson KI, Voss MW, Knecht AM, Pontifex MB, Castelli DM, et al. The effects of physical activity on functional MRI activation associated with cognitive control in children: A randomized controlled intervention. Frontiers in Human Neuroscience. 2013; 7:72. [DOI:10.3389/fnhum.2013.00072] [PMID] [PMCID]

[2] Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U, et al. Global physical activity levels: Surveillance progress, pitfalls, and prospects. The Lancet. 2012; 380(9838):247-57. [DOI:10.1016/S0140-6736(12)60646-1] [PMID]

[3] Westfall DR, Gejl AK, Tarp J, Wedderkopp N, Kramer AF, Hillman CH, et al. Associations between aerobic fitness and cognitive control in adolescents. Frontiers in Psychology. 2018; 9:1298. [DOI:10.3389/fpsyg.2018.01298] [PMID] [PMCID]

[4] Raine LB, Kao SC, Pindus D, Westfall DR, Shigeta TT, Logan N, et al. A large-scale reanalysis of childhood fitness and inhibitory control. Journal of Cognitive Enhancement. 2018; 2:170-92. [Link]

[5] Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: Exercise effects on brain and cognition. Nature Reviews Neuroscience. 2008; 9(1):58-65. [DOI:10.1038/nrn2298] [PMID]

[6] Diamond A. Executive functions. Annual Review of Psychology. 2013; 64:135-68. [DOI:10.1146/annurev-psych-113011-143750] [PMID] [PMCID]

[7] Novick JM, Engle R , Bunting MF, Dougherty MR. Cognitive and working memory training: Perspectives from psychology, neuroscience, and human development. Oxford: Oxford University Press; 2019. [Link]

[8] Diamond A, Ling DS. Review of the evidence on, and fundamental questions about, efforts to improve executive functions, including working memory. In: Novick JM, editor.Cognitive and working memory training: Perspectives from psychology, neuroscience, and human development. Oxford: Oxford Academic; 2019. [DOI:10.1093/oso/9780199974467.003.0008]

[9] Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, et al. Exercise training increases size of hippocampus and improves memory. Proceedings of the national academy of sciences. 2011; 108(7):3017-22. [DOI:10.1073/pnas.1015950108] [PMID] [PMCID]

[10] Harris DJ, Wilson MR, Vine SJ. A systematic review of commercial cognitive training devices: Implications for use in sport. Frontiers in psychology. 2018:709. [DOI:10.3389/fpsyg.2018.00709] [PMID] [PMCID]

[11] Hillman CH, McAuley E, Erickson KI, Liu-Ambrose T, Kramer AF. On mindful and mindless physical activity and executive function: A response to Diamond and Ling (2016). Developmental cognitive neuroscience. 2018:100529. [DOI:10.1016/j.dcn.2018.01.006] [PMID] [PMCID]

[12] Vazou S, Pesce C, Lakes K, Smiley-Oyen A. More than one road leads to Rome: A narrative review and meta-analysis of physical activity intervention effects on cognition in youth. International Journal of Sport and Exercise Psychology. 2019; 17(2):153-78. [DOI:10.1080/1612197X.2016.1223423] [PMID] [PMCID]

[13] Beavon P. Improving memory using N-back training. Perth: Edith Cowan University; 2012. [Link]

[14] Erickson KI, Hillman CH, Kramer AF. Physical activity, brain, and cognition. Current opinion in behavioral sciences. 2015; 4:27-32. [DOI:10.1016/j.cobeha.2015.01.005]

[15] Hillman CH, McAuley E, Erickson KI, Liu-Ambrose T, Kramer AF. On mindful and mindless physical activity and executive function: A response to diamond and ling (2016). Developmental Cognitive Neuroscience. 2019; 37:100529. [DOI:10.1016/j.dcn.2018.01.006] [PMID] [PMCID]

[16] Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. Developmental Cognitive Neuroscience. 2016; 18:34-48. [DOI:10.1016/j.dcn.2015.11.005] [PMID] [PMCID]

[17] Diamond A, Ling DS. Aerobic-exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. Developmental Cognitive Neuroscience. 2019; 37:100572. [DOI:10.1016/j.dcn.2018.05.001] [PMID] [PMCID]

[18] Carey JR, Bhatt E, Nagpal A. Neuroplasticity promoted by task complexity. Exercise and Sport Sciences Reviews. 2005; 33(1):24-31. [PMID]

[19] Fabel K, Kempermann G. Physical activity and the regulation of neurogenesis in the adult and aging brain. Neuromolecular Medicine. 2008; 10(2):59-66. [DOI:10.1007/s12017-008-8031-4] [PMID]

[20] Baniqued PL, Gallen CL, Kranz MB, Kramer AF, D'Esposito M. Brain network modularity predicts cognitive training-related gains in young adults. Neuropsychologia. 2019; 131:205-15. [DOI:10.1016/j.neuropsychologia.2019.05.021] [PMID] [PMCID]

[21] Cheng ST. Cognitive reserve and the prevention of dementia: The role of physical and cognitive activities. Current Psychiatry Reports. 2016; 18(9):85. [DOI:10.1007/s11920-016-0721-2] [PMID] [PMCID]

[22] Acuto M, Larcom S, Keil R, Ghojeh M, Lindsay T, Camponeschi C, et al. Seeing COVID-19 through an urban lens. Nature Sustainability. 2020; 3(12):977-8. [DOI:10.1038/s41893-020-00620-3]

[23] Ammar A, Brach M, Trabelsi K, Chtourou H, Boukhris O, Masmoudi L, et al. Effects of COVID-19 home confinement on eating behaviour and physical activity: Results of the ECLB-COVID19 international online survey. Nutrients. 2020; 12(6):1583. [DOI:10.3390/nu12061583] [PMID] [PMCID]

[24] Hammami A, Harrabi B, Mohr M, Krustrup P. Physical activity and coronavirus disease 2019 (COVID-19): Specific recommendations for home-based physical training. Managing Sport and Leisure. 2022; 27(1-2):26-31. [DOI:10.1080/23750472.2020.1757494]

[25] Tabacof L, Tosto-Mancuso J, Wood J, Cortes M, Kontorovich A, McCarthy D, et al. Post-acute COVID-19 syndrome negatively impacts physical function, cognitive function, health-related quality of life, and participation. American Journal of Physical Medicine & Rehabilitation. 2022; 101(1):48-52. [DOI:10.1097/PHM.0000000000001910] [PMID] [PMCID]

[26] Diamond A. Effects of physical exercise on executive functions: Going beyond simply moving to moving with thought. Annals of Sports Medicine and Research. 2015; 2(1):1011. [PMID]

[27] Cunningham JB, McCrum-Gardner E. Power, effect and sample size using GPower: Practical issues for researchers and members of research ethics committees. Evidence-Based Midwifery. 2007; 5(4):132-6. [Link]

[28] Riccio CA, Reynolds CR, Lowe PA. Clinical applications of continuous performance tests: Measuring attention and impulsive responding in children and adults. New Jersey: John Wiley & Sons Inc; 2001. [Link]

[29] León-Domínguez U, Martín-Rodríguez JF, León-Carrión J. Executive n-back tasks for the neuropsychological assessment of working memory. Behavioural Brain Research. 2015; 292:167-73. [DOI:10.1016/j.bbr.2015.06.002] [PMID]

[30] Mueller ST, Alam L, Funke GJ, Linja A, Ibne Mamun T, Smith SL. Examining methods for combining speed and accuracy in a go/no-go vigilance task. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2020; 64(1):1202–6. [DOI:10.1177/1071181320641286]

[31] Friedman NP, Miyake A. The relations among inhibition and interference control functions: A latent-variable analysis. Journal of Experimental Psychology: General. 2004; 133(1):101-35. [DOI:10.1037/0096-3445.133.1.101] [PMID]

[32] McMorris T, Sproule J, Turner A, Hale BJ. Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. Physiology & Behavior. 2011; 102(3-4):421-8. [DOI:10.1016/j.physbeh.2010.12.007] [PMID]

[33] Gajewski PD, Freude G, Falkenstein M. Cognitive training sustainably improves executive functioning in middle-aged industry workers assessed by task switching: A randomized controlled ERP study. Frontiers in Human Neuroscience. 2017; 11:81. [DOI:10.3389/fnhum.2017.00081] [PMID] [PMCID]

[34] Sala G, Gobet F. Cognitive training does not enhance general cognition. Trends in Cognitive Sciences. 2019; 23(1):9-20. [DOI:10.1016/j.tics.2018.10.004] [PMID]

[35] Joubert C, Chainay H. Aging brain: The effect of combined cognitive and physical training on cognition as compared to cognitive and physical training alone-a systematic review. Clinical Interventions in Aging. 2018; 13:1267-301. [DOI:10.2147/CIA.S165399] [PMID] [PMCID]

[36] Schmidt M, Jäger K, Egger F, Roebers CM, Conzelmann A. Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: A group-randomized controlled trial. Journal of Sport and Exercise Psychology. 2015; 37(6):575-91. [DOI:10.1123/jsep.2015-0069] [PMID]

[37] 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]

[38] Ward N, Paul E, Watson P, Cooke GE, Hillman CH, Cohen NJ, et al. Enhanced learning through multimodal training: Evidence from a comprehensive cognitive, physical fitness, and neuroscience intervention. Scientific Reports. 2017; 7(1):5808. [DOI:10.1038/s41598-017-06237-5] [PMID] [PMCID]

[39] Mihara M, Miyai I, Hatakenaka M, Kubota K, Sakoda S. Role of the prefrontal cortex in human balance control. Neuroimage. 2008; 43(2):329-36. [DOI:10.1016/j.neuroimage.2008.07.029] [PMID]

[40] Diamond A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. Child Development. 2000; 71(1):44-56. [DOI:10.1111/1467-8624.00117] [PMID]

[41] Voelcker-Rehage C, Niemann C. Structural and functional brain changes related to different types of physical activity across the life span. Neuroscience & Biobehavioral Reviews. 2013; 37(9 Pt B):2268-95. [DOI:10.1016/j.neubiorev.2013.01.028] [PMID]

[42] Biino V, Tinagli V, Borioni F, Pesce C. Cognitively enriched physical activity may foster motor competence and executive function as early as preschool age: A pilot trial. Physical Education and Sport Pedagogy. 2021; 1-19. [DOI:10.1080/17408989.2021.1990249]

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