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ORIGINAL ARTICLE

Combined aerobic and brain exercise can improve executive function among adolescent girls

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ABSTRACT

Objectives: The aim of this study was to investigate the effectiveness of a training program consisting of aerobic exercise, video games, brain exercises, and combination of all of it on the executive functions among adolescent girls. Methods: The research utilized a semi-experimental design with a mixed design approach, where the training groups were treated as between-group factors and the assessed tests (pre-test and post-test) as within-group factors. A total of 48 female students aged 11 to 17 from Deir city (Ahvaz, Iran) were randomly assigned to four equal groups: video game, brain exercise, aerobic exercise, and combined. Prior to the training sessions, all participants completed tests assessing inhibitory, working memory, and cognitive flexibility in a pre-test. These exercises were conducted three times a week for 20 minutes per session, totaling 12 sessions. Following the intervention, a post-test was administered under the same conditions as the pre-test. Results: The results of the covariance analysis revealed that video games had a significant effect on working memory and inhibitory, brain exercises had an impact on working memory, cognitive flexibility, and inhibitory, and aerobic exercise influenced working memory and inhibitory. However, there was no significant difference between aerobic exercise and video games in terms of cognitive flexibility. Conclusion: In conclusion, conducting an intervention course incorporating video games, brain exercises, and aerobic exercise can improve executive functions such as working memory, selective attention, and cognitive flexibility. Therefore, it is recommended that teachers and sports coaches consider implementing combined training approach to enhance executive functions in teenagers.

Keywords: Physical activity psychology, Adolescence, Physical activity, Cognition, Brain exercise, School.

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INTRODUCTION

During the stage of adolescence, the brain undergoes active development, particularly in the prefrontal cortical areas responsible for executive functioning (Sakurai & Gamo, 2019). Consequently, it is crucial to explore ways of promoting brain health during this phase to optimize cognitive development, academic performance, and vocational achievements (Brigman & Campbell, 2003). Previous research indicates that adolescents exhibit a higher prevalence of risky and impulsive behaviours (Brent et al., 1993). However, improving executive functions can potentially reduce impulsivity in this population (Crews & Boettiger, 2009). Therefore, conducting interventions that address patterns of brain development and associated behaviours holds considerable value.

The detrimental effects of a sedentary lifestyle on health, social interactions, and academic performance are widely acknowledged (Sahoo et al., 2015). Physical exercise is a commonly employed intervention to enhance cognitive and motor functions in adolescents (Herting & Chu, 2017; Williams et al., 2022). For example, Brylka et al. (2021) conducted a study revealing that adolescents who engage in higher levels of physical activity exhibited significantly better mental health and fitness scores. Similarly, Y. Li et al. (2022) demonstrated a positive association between higher mental fitness scores and improved learning, educational attainment, work performance, and psychological well-being. Therefore, it is crucial to prioritize physical activity as a means of enhancing academic achievements among adolescents.

Previous studies on physical training aimed at enhancing cognitive functioning have primarily focused on manipulating the quantitative aspects of exercise to establish a dose-response relationship between physical activity and cognitive performance (Loprinzi et al., 2018). Maintaining an inactive lifestyle has been linked to decreased cognitive and motor performance in adolescents (Esteban-Cornejo et al., 2015). However, physical activity and combined exercise such as video game have been associated with improved cognitive function, body composition, and reaction time (Gomez-Pinilla & Hillman, 2013; Zhao et al., 2022). Despite this evidence, the majority of studies on improving cognition among adolescents do not consider combined video game and most importantly brain exercise (Toth et al., 2020). Furthermore, in intervention studies, there has been less emphasis on examining brain exercise, with a greater focus on aerobic exercises (Ferrer-Uris et al., 2022).

The video games dates back to 1982 with the introduction of "*Pong*," a computerized table tennis game. Maillot et al. (2012) evaluated the effectiveness of active video games on cognitive performance and result demonstrated significant benefits on cognitive function. In addition to video games, research has shown the potential of brain training exercises to stimulate all parts of the brain and the nervous system equally, reducing one-sided and negative brain responses, thereby alleviating stress and enhancing memory (Smirni et al., 2021). Brain exercise, recognized as cognitive movement therapy, can lead to rapid progress and improvements in motor skills, concentration, memory, reading and writing, organization, listening and physical coordination (Sepehrikia et al., 2023; Zeng et al., 2017). Brain exercise interventions focus on engaging adolescents in neuroplastic activity and executive brain functioning, which exclusively lead to improvements in working memory and life skills (Ismayenti et al., 2021; Zhang et al., 2017). Brain training exercises facilitate the development of neural pathways in the brain through movement (Ismayenti et al., 2021).

The executive functions component encompasses inhibitory control, working memory, and divided attention (cognitive flexibility)(Diamond, 2013). Engaging in aerobic exercise and video game training to practice these functional components could be a crucial strategy in preventing impulsivity disorders among adolescents

(Chan et al., 2022). In contrast to video game and brain exercise, which has yielded inconsistent results in studies examining its effects on cognitive function (Sepehrikia et al., 2023; Smirni et al., 2021; Zhao et al., 2022), aerobic exercise has been associated with enhanced overall cognitive function (Gomez-Pinilla & Hillman, 2013). However, there is a scarcity of combined physical activity and video game interventions specifically targeting adolescents. Furthermore, previous studies have indicated the brain's plasticity and its correlation with executive functions and motor performance as potential factors contributing to the cognitive enhancement following exercise (Brylka et al., 2021). However, the optimal design of intervention to achieve greater improvements in cognitive performance, especially in adolescents, remains unclear (Brent et al., 1993).

The relationship between higher-order cognition, specifically executive functioning, and various health-related outcomes is well-established across different age groups (Esteban-Cornejo et al., 2015; Y. Li et al., 2022). Although the available evidence is limited, current research suggests that aerobic exercise can have positive immediate and long-term effects on executive functions (Gomez-Pinilla & Hillman, 2013; Shi et al., 2022). However, there is still a lack of knowledge regarding the effectiveness of specific combined aerobic and brain exercise programs for different populations and age groups (Esteban-Cornejo et al., 2015; Zhao et al., 2022). Specifically, the impact of combined aerobic and brain exercise on executive function in children and adolescents remains unclear (Smirni et al., 2021). This study aims to investigate the effects of moderate-intensity aerobic exercise, video game and brain exercise on executive functions among adolescent students.

METHODS

Study design
Our study employed a randomized controlled trial design. Data were collected at baseline and 4 weeks after the intervention.

Participants
A power analysis using G*Power 3.1 software determined that a minimum of 38 participants was needed to detect a moderate effect size (f = .25) in analyses of variance (ANOVAs) with an alpha error of .05, power of .80, four groups, two measurements, and a correlation of .50 among repeated measures. Due to the possibility of falling, we recruited a total of 48 adolescent girls from secondary schools to participate in the study.

Eligibility was determined through an initial screening process. Inclusion criteria for the study were as follows: (1) age between 11 and 17 years, (2) enrolment as a student in an Iranian secondary school, (3) normal vision based on the Snellen chart test, and (4) self-reported normal hearing. Participants with the following conditions were excluded from the study: (1) psychiatric issues, as determined by a brief psychiatric interview, (2) neuromuscular, motor, or sensory disorders, and (3) use of medications affecting mood or alertness. The study procedures were in accordance with the Declaration of Helsinki and were approved by the university's institutional review board. All participants provided written informed consent to participate in the study.

Measure
Working memory
The assessment of working-memory performance was conducted using the N-back task, which involved displaying a sequence of letters and numbers (Bayramova et al., 2021). Adolescent students were required to determine whether the current numbers/letters matched those presented in the series one or two trials earlier. Their responses were recorded by pressing a button corresponding to "*yes*" or "*no*" for each trial. The

task included two levels of difficulty: one-back and two-back. The stimuli consisted of blue letters (vertical visual angle = 0.7°) presented against a light black background. Each number/letter in the sequence was shown for 1000 ms, with a response window of 2500 ms provided. The inter-stimulus interval was set at 2000 ms. In each block, the probability of letters matching those presented N trials earlier (targets) was 25%. Scores were determined by averaging the mean reaction time for correct responses. The test-retest reliability of the measure was confirmed (one-back, r = .79; two-back, r = .72).

Inhibitory control

The Stroop Test is a cognitive assessment tool used to measure inhibitory control. It is a software developed by the Sina Institute of Cognitive Sciences. The test consists of three stages. In the first stage, participants familiarize themselves with the location of buttons on the computer keyboard. The screen displays red, blue, yellow, and green circles, and participants are required to press the corresponding button for the displayed colour. Feedback is provided for each response indicating its correctness. The second stage is similar to the actual test but serves only to familiarize participants with the testing procedure and does not impact the final results. In the third stage, participants are presented with 48 congruent colour words and 48 incongruent colour words, displayed in blue, red, green, and yellow colours. Congruent words refer to colour words that match the ink colour they are written in, while incongruent words involve different ink colours than the written meaning or word. Participants respond randomly to the 96 stimuli, which consist of congruent and incongruent words. Each stimulus is presented for 2 seconds, with an 800-millisecond interval between stimuli. The response time of participants is measured from the onset of stimulus presentation until they press the corresponding coloured button. The keyboard buttons are labelled with green, yellow, blue, and red colour labels.

Cognitive flexibility

The Wisconsin Card Sorting Task was utilized to assess cognitive flexibility. This task measures cognitive flexibility by evaluating changes in accuracy and/or response speed when the correct way of responding is modified (switch cost). The adolescent is presented with a set of stimulus cards and instructed to match the cards but not specifically told how to match them. However, they are informed whether a particular match is correct or incorrect. The test is administered using paper cards, with the experimenter and the adolescent positioned on opposite sides of a desk. The administration of the test typically takes between 12 to 20 minutes and produces various psychometric scores, including the number of trials, errors, and perseverative errors (Bishara et al., 2010).

Procedure

Participants were randomly assigned to one of four groups (Video game, Brain exercise, Aerobic exercise, and Combined) using block randomization. Outcome assessors and data analysts were blinded to group allocation. Participants underwent a series of tests to assess working memory, inhibitory control, and cognitive flexibility. The interventions involved three 20-minute group sessions per week for 4 consecutive weeks. The intervention protocol was selected based on evidence suggesting that short-duration, moderate-intensity exercise performed up to three times weekly is effective in improving cognitive function, while also minimizing participant fatigue and dropout rates (Zhang et al., 2022; Vera-Garcia et al., 2017).

Organization and content of the interventions

Aerobic exercise

The aerobic exercise intervention consisted of walking and running exercises conducted three times per week. Adolescent students were instructed to perform multi-joint aerobic exercises targeting major muscle groups. Each session involved aerobic exercise, at 60-75% of their maximum heart rates. Prior to each session, participants engaged in a warm-up protocol that included stretching. Trained clinical sport scientists supervised the training sessions, which lasted approximately 20 minutes.

Jump rope video game

Game was installed on the participants' mobile phones by the experimenter. The exercise period involved playing the game for 12 days. After providing a detailed explanation of how to play the game and conducting two trial attempts by the participants, each individual in this group spent 20 minutes playing the game in each session (Comeras-Chueca et al., 2021).

Brain exercises

Prior to commencing the exercises, three warm-up activities were performed, including drinking water, performing brain button exercises, and cross-lateral movements. Drinking water before the exercises was essential as approximately 85% of the brain's weight is composed of water. The brain exercise included 1) Brain Button Exercises 2) Breathe through the nose for 30 to 60 seconds, 3) Cross-Lateral Movements, 4) Owl Exercise, 5) Elephant Exercise, 6) Lazy Eight Exercise, 7) Up-Down-Left-Right and 8) Straight Line Exercise.

Combined group

In the combined condition, aerobic exercise, video game and brain exercise were combined. Again, the duration of each session was 20 minutes included 7 minutes of aerobic exercise, 7 minutes of video game, and 6 minutes of brain exercises. Heart rate monitors were used to ensure exercise intensity was maintained at 60-75% of maximum heart rate. Participants received general guidance on the task. In summary, the combined condition provided the visual (video game screen), aerobic exercise and motor control training. This sensory feedback helped participants to compensate their motor control.

Data analysis

The mean and standard deviation were used to describe the collected data. The Shapiro-Wilk test was used to examine the normality of the data distribution. The Levene's test was employed to assess the equality of variances. To compare pre-test and post-test measures, analysis of covariance (ANCOVA) was utilized. All data analyses were conducted using SPSS software version 22, with a significance level set at $p \leq .05$. Effect size measures, including eta-squared (η^2) and Cohen's d, were used.

RESULTS

All 48 students successfully completed the initial assessment, post-intervention assessment. The intervention group, consisting of 12 adolescence, actively participated in the planned 12 aerobic sessions, while the video game, brain exercise and combined groups, also comprising 12 participants, attended the intervention sessions as planned. The sociodemographic characteristics of the groups are summarized in Table 1. Additionally, inferential statistics were conducted to determine if there were any significant differences between the four groups in terms of the assessed sociodemographic variables at baseline. The descriptive statistics for the outcome variables (inhibitory control, working memory, and cognitive flexibility) are presented in Table 2, separately for groups, and across the two measurement occasions (baseline, post-intervention). Furthermore, Table 2 provides the results of ANCOVA to examine potential differences in the development of the assessed outcome variables between the groups.

Sample characteristics

Table 1 presents details regarding the sociodemographic characteristics of the participants. The inferential statistics indicate that there were no significant differences between the two groups in terms of age and BMI.

Table 1. Descriptive statistics and overview of sociodemographic background, separately for groups.

Dimension	Group				Statistics
	Aerobic exercise	Brain exercise	Video game	Combined	
N	12	12	12	12	
Age (years): M (SD)	13.33 (1.2)	12.66 (1.6)	12.33 (1.1)	14.83 (1.6)	t(44) = 0.93, *p* = .38
Age range (years)	11-17	10-17	10-17	11-17	
Weight (kg) M (SD)	44.32 (1.88)	43.29 (2.01)	42.29 (2.01)	42.89 (2.01)	t(44) = 0.92, *p* = .19
Body mass index (kg/m^2): M (SD)	19.92 (4.6)	21.72 (3.2)	18.02 (2.7)	18.08 (3.4)	

Note: M: Mean; SD: Standard deviation.

Differences between the intervention and control groups over time

Table 2 presents the means and standard deviations of all outcome measures at baseline and post-intervention for all groups.

Table 2. Descriptive statistics for working memory, inhibitory control and cognitive flexibility, separately for groups and for each measurement point (baseline, post-intervention) and tests for time x group interaction effects.

	Groups				Factors					
	Aerobic exercise	Brain exercise	Video game	Combined	Group		Time		Time × Group interaction	
N	12	12	12	12						
	M (SD)	**M (SD)**	**M (SD)**	**M (SD)**	**F**	**ηp²**	**F**	**ηp²**	**F**	**ηp²**
Working memory					1.19	.07	27.70**	.38	.17	.01
Baseline	559.41 (103.17)	616.25 (161.84)	614.08 (180.87)	560.58 (123.13)						
Post-intervention	442.16 (91.61)	137.01 (422.41)	435.75 (104.33)	472.16 (110.61)						
Inhibitory control					1.25	.07	26.21**	.37	1.21	.07
Baseline	843 (96.42)	920.16 (111.33)	980.83 (127.08)	966.91 (123.62)						
Post-intervention	882.91 (97.21)	962.66 (131.50)	1024.66 (139.09)	1010.91 (155.38)						
Cognitive flexibility					5.40**	.27	411.96**	.90	4.24*	.22
Baseline	41.83 (3.51)	42.91 (2.57)	43.33 (3.39)	41.66 (4.31)						
Post-intervention	41.66 (2.70)	41.16 (3.45)	41.33 (4.24)	41.16 (4.06)						

*Note. Note: M: Mean; SD: Standard deviation; * indicates p < .05; ** indicates p < .001.*

Working memory

The analysis of covariance (ANCOVA) revealed that across the entire sample, there was a significant increase in working memory scores from baseline to intervention completion (significant Time effect; see Table 2). Post hoc calculations indicated that within the aerobic exercise group (t = 4.52, *p* = .001, effect size = 1.30), video game group (t = 3.74, *p* = .003, effect size = 1.08) and combined group (t = 3.56, *p* = .004, effect size = 1.03) working memory scores significantly increased from baseline to post-intervention. In contrast, within the brain exercise group, working memory scores showed minimal changes from baseline to post-intervention (t = 2.88, *p* = .015, effect size = .83).

Inhibitory control

The analysis of covariance (ANCOVA) revealed that across the entire sample, there was a significant increase in inhibitory control scores from baseline to intervention completion (significant Time effect; see Table 2). Post hoc calculations indicated that within the aerobic exercise group (t = -2.13, *p* = .005, effect size = -0.61), video game group (t = -3.94, *p* = .002, effect size = -1.14), the brain exercise group (t = -3.16, *p* = .009, effect size = -0.91), and combined group (t = -2.59, *p* = .02, effect size = -0.74) inhibitory control scores significantly increased from baseline to post-intervention.

Cognitive flexibility

The results of the ANCOVA indicate that across the entire sample, there was a significant decrease in cognitive flexibility error from baseline to post-intervention (significant Time, Group and interaction effect; see Table 2). This decrease in error was primarily driven by improvements in all intervention group. Post hoc calculations indicated that within the aerobic exercise group (t = -11.99, *p* = .001, effect size = -30.46), video game group (t = -9.94, *p* = .001, effect size = -2.87), the brain exercise group (t = -9.26, *p* = .001, effect size = -2.67), and combined group (t = -10.14, *p* = .001, effect size = -2.93) cognitive flexibility scores significantly increased from baseline to post-intervention.

DISCUSSION

The main results of this study indicate that participation in a 4-week aerobic and brain exercise program led to enhanced executive functions in adolescent students. These findings make a significant contribution to the existing literature by demonstrating the successful implementation of combined video game and aerobic exercise in improving executive functions among adolescent students.

There is a substantial body of evidence demonstrating the positive effects of physical activity on cognitive enhancement (Chan et al., 2022; Herting & Chu, 2017; Shi et al., 2022). In line with these findings, our study provides further support by showing that aerobic exercise can also improve executive functions, a cognitive domain, in adolescent students. This finding aligns with the results of Gilbert et al. (2023), who reported cognitive function improvements in adolescents following engagement in games-based physical education lesson. It is likely that the observed improvements in psychological well-being among the physical activity group can be attributed to the enhancement of psychological resources such as self-esteem and self-concept (Fernández-Bustos et al., 2019).

Previous research has consistently demonstrated the positive impact of environmental factors, such as physical activity and video game training, on cognitive development during childhood (Zeng et al., 2017; Zhao et al., 2022). Engaging in physical activity promotes the formation of synapses and enhances memory in the brain. For instance, Firth et al. (2018) conducted a study that revealed an increase in hippocampal volume as a result of physical activity intervention. This highlights the crucial role that physical activity plays in promoting cognitive function and academic achievement. Supporting these findings, a review study by Jackson et al. (2016) based on sixteen studies reported a significant and positive relationship between physical activity, learning, and academic performance in children. Additionally, physical activity and brain exercise has been shown to bring about structural and functional changes in the brain (Esteban-Cornejo et al., 2015; Zhang et al., 2017). Furthermore, improving basic motor skills through physical activity can enhance cognitive and brain functions. As a result, physical activity not only strengthens social relationships with peers, parents, and teachers but also plays a significant role in improving mental health and cognitive function (Zuo et al., 2021).

The present study's findings provide evidence that combined aerobic and brain exercise plus video game based intervention can enhance inhibitory control in adolescent girls. These results are consistent with previous studies conducted by Dhir et al. (2021) and (Diamond & Ling, 2016). X. Li et al. (2022) reported similar findings, demonstrating that a physical activity intervention improved inhibitory control in adolescents. It is well-documented that higher levels of inhibitory control are associated with reduced impulsive behaviours (Roberts et al., 2011), which are commonly observed among adolescents. Impulsivity encompasses various cognitive impairments, including reduced attention and diminished control and inhibition. Thus, addressing impulsivity is crucial for improving mental health. Romer (2010) highlighted the importance of interventions targeting impulsivity and inhibitory control in reducing antisocial behaviours among adolescents.

Furthermore, there exists a relationship among physical health, cognitive function, and academic performance in children and adolescents. Research has consistently shown that physical activity can enhance academic performance (Behringer et al., 2022). Additionally, the present study's findings align with the results of a review conducted by Boat and Cooper (2019), which demonstrated the positive effects of physical activity on self-control. Increased self-control and regulation is associated with higher engagement in school and a greater willingness to learn. Moreover, physical activity in the school setting is linked to improved discipline, creativity, and motivation. Consequently, physical activity offers numerous positive effects on social, cognitive, and academic performance.

Despite the novel findings, it is important to consider several limitations that caution against generalizing the results. Firstly, the absence of a control group in the initial design limited the ability to attribute improvements solely to the interventions. Future studies should include a no-intervention control group. Also a significant limitation of the present study was the small sample size. However, the use of effect sizes in statistical calculations helps mitigate the impact of sample size. Secondly, the study did not assess biomarkers such as cortisol, which can provide insights into perceived stress, or BDNF, which can indicate neural plasticity. The absence of these biomarkers limits our understanding of underlying physiological mechanisms. Thirdly, there is a possibility that unmeasured latent factors could have influenced multiple variables in different directions, potentially biasing the observed results. Fourthly, the study included adolescent girls aged 11-17 years, making it unclear whether the findings can be generalized to male students and the extent to which they may differ. However and in general, this planned research is novel as it has the potential to offer new insights into how cognitive development, academic achievement, and vocational attainment can be influenced in adolescent girls. The proposed training program can provide valuable guidance for physical education teachers, parents, and adolescent girls themselves seeking to enhance their cognitive function.

AUTHOR CONTRIBUTIONS

M. M.: methodology, investigation, formal analysis, writing−original draft. R. A.: conceptualization, methodology, supervision, formal analysis, review, and editing−original draft. S. A. B.: review, and editing−original draft.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Prior to participation, parents of the participants were provided with an informed consent form. This study was approved by the local ethics board of Shahid Chamran University of Ahvaz. All experiments were performed in accordance with the Declaration of Helsinki.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated during the current study are available upon request from corresponding author.

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