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The Effect of Aerobic Exercises on Balance, Aerobic Capacity, and Cognitive Functions in Children With Autism Spectrum Disorder

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ABSTRACT

Background: The increasing prevalence of autism spectrum disorder (ASD) worldwide highlights the importance of rehabilitation services, as ASD is often associated with gross motor and cognitive impairments. However, it has not yet been investigated whether aerobic exercise can enhance the effects of conventional physiotherapy on balance, aerobic capacity, and cognitive functions.

Methods: This study included 30 children aged 8–11 years with diagnosed ASD. Fifteen children were assigned to control group who performed conventional physiotherapy, while the other 15 of the experimental group had combined conventional physiotherapy with an additional aerobic exercise. Balance was assessed using the modified Berg Balance Scale, aerobic capacity with the 6-minute run test (modified Cooper test), and cognitive functions were assessed using RehaCom computer system tasks evaluating topological memory and logical reasoning.

Results: The results showed that balance scores and aerobic capacity increased significantly ($p < 0.05$), while no significant changes were observed in the control group. Regarding cognitive functions, the experimental group showed significantly reduced task solving time and memory acquisition time, as well as a shorter reaction time median ($p < 0.05$). No significant changes were found in the control group.

Conclusions: The integration of aerobic exercise into conventional physiotherapy significantly improves balance, aerobic capacity, and cognition in children with autism spectrum disorder, highlighting the efficacy of a combined therapeutic approach.

Keywords: Cognition, aerobic endurance, autism spectrum disorder, postural control

1. INTRODUCTION

The prevalence of autism spectrum disorder (ASD) is constantly increasing worldwide. According to epidemiological data, approximately 1 in 100 children are diagnosed with ASD, and boys are four times more likely to get diagnosed than girls (Zeidan et al., 2022). As children with ASD grow, impairments in executive functions and cognitive functions such as attention, memory, and self-regulation become more apparent (Demetriou et al., 2019). In terms of motor development, balance impairments are most common and are associated with increased fall risk and decreased participation in active play (Date et al., 2024). Deficits in balance and other motor impairments are frequently associated with reduced aerobic capacity, which has been shown to negatively affect cerebral blood flow and contribute to cognitive impairments (Cui et al., 2020). All these factors result in constantly increasing need of effective rehabilitation services.

According to Lippi and co-authors (2020), for past decades this connection between physical activity and cognitive functions is explained through neurobiological perspective, focusing on the neurotrophic hypothesis. It states that physical activity increases metabolic demand and stimulates biochemical changes in the brain, like increasing peripheral cerebral circulation and stimulating brain-derived neurotrophic factor (BDNF) synthesis. Through these processes, physical activity promotes neuroplasticity and neurogenesis in the brain, which plays an important role in child's cognitive functions development (Shao et al., 2025). It is emphasised that aerobic exercise triggers the release of BDNF and tropomyosin receptor kinase B (TrkB), enhancing the synapse formation and improving the efficiency of synaptic transmission. These processes in the brain are important for cognitive flexibility and inhibitory control development in children with ASD (Hou et al., 2024). Previously discussed brain mechanisms are associated with neuroplasticity and the strengthening of synaptic connections, through which authors explain the observed improvements in cognitive and motor development (Mao et al., 2021). Notably, the role of BDNF appears to be particularly important in children with ASD. Zong et al. (2023) reported significantly lower serum levels of BDNF and TrkB in children aged 30–42 months with ASD compared to typically developing controls. Deficiencies in these neurotrophic factors have been linked to ASD pathogenesis, suggesting that physical activity induced modulation of neurobiological mechanisms may represent a potential way for improving motor and cognitive functions and alleviating ASD related symptoms.

Currently, the effect of aerobic exercise on endurance, cognitive functions, and balance is usually studied with healthy children. Existing evidence show that motor and variety of cognitive functions development improve after applying aerobic exercises (Ding et al., 2022; Van Waelvelde et al., 2020), but there is lack of research investigating this effect for children with ASD. Most studies have focused on analysing the effect of exercises during physiotherapy procedures, targeting either motor or cognitive skills separately (Cui et al., 2020; Date et al., 2024), but there is lack of studies investigating the effect of combined conventional physiotherapy programme and aerobic training for balance, aerobic capacity, and cognitive functions all together. Therefore, this study is aimed to determine effects of aerobic exercise on balance, aerobic capacity, and cognitive functions in children with ASD. We hypothesise that aerobic exercises will improve balance, aerobic capacity, and cognitive functions.

2. METHODS

Participants. An a priori power analysis was performed using G*Power software (*version 3.1.9.6; Düsseldorf, Germany*) based on effect size estimates obtained from repeated-measures ANOVA (within–between interaction) conducted in SPSS. Partial eta squared values for the interaction effect (group × time) were calculated separately for balance, aerobic capacity, and cognitive function outcomes. Assuming a significance level of $\alpha = 0.05$ and a statistical power of 0.80, the analysis indicated that a minimum sample size of 15 participants per group ($N = 30$ total) was required.

The study involved 30 children with ASD. The mean age of participants was 9.84 ± 1.08 years. The participants were allocated to one of the two groups, either experimental ($n = 15$) or control ($n = 15$), using blocked randomisation and a computer-generated list of random numbers that had been prepared by an investigator with no involvement in this study. This study employed a single-blinded design in which participating children were unaware of the expected outcomes of the intervention, while the assessor remained unblinded. Each participant had an equal probability of being assigned to either group if they met the inclusion criteria: aged 8–11 years, having a diagnosis of autism spectrum disorder (F84.0) according to the International Classification of Diseases (ICD), impaired balance (scoring less than 50 points on modified Berg balance scale), and a consent form signed by a parent or legal guardian. Participants were excluded from the study if they met any of the following exclusion criteria: discontinued participation in the procedures, the diagnosis of intellectual disability (F70-F79) according to ICD, inability to participate due to severely expressed disorder symptoms (sensory integration issues, increased anxiety, behavioural issues), comorbidities (epilepsy, cardiovascular diseases, respiratory diseases). None of the participants dropped out of the study. The characteristics of the participants are presented in Table 1.

Table 1. **Characteristics of participants**

Data	Experimental group (n = 15)	Control group (n = 15)
Gender (F/M)	5/10	4/11
Age (years)	9.73 ± 1.10	9.94 ± 1.06
Height (cm)	135.87 ± 6.19	137.88 ± 6.17
Weight (kg)	32.87 ± 5.77	36.25 ± 6.13

Note: Female (F), male (M).

Research instruments and primary outcomes. In this study, balance, aerobic capacity, and cognitive functions were considered primary outcomes, as the intervention was designed to target multiple functional domains commonly impaired in children with autism spectrum disorder. The study protocol was structured to evaluate changes across all three domains concurrently using three corresponding assessment methods described below.

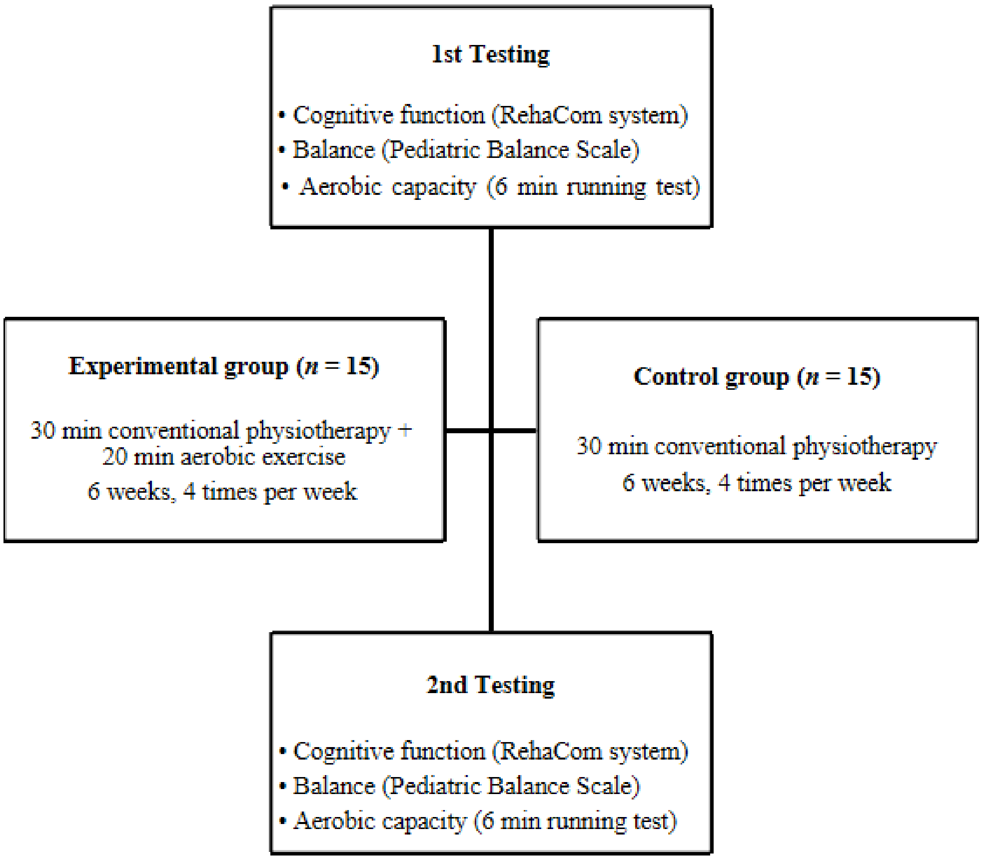
The paediatric balance scale (modified Berg scale) is used to assess children's (aged 5–15) functional balance, according to the everyday task context. The balance skills are evaluated by observing a child's ability to perform movements (independently or with assistance) and maintain a body posture that requires balance skills. Every task can be scored from zero to four points, and the maximum of scored points is 56. A score less than 45 points is clinically considered for balance impairment (Franjoine et al., 2003).

Six-minute running test (a simplified version of the K. Cooper test) is used to evaluate school aged children's aerobic capacity. This test measures the longest possible distance (meters) covered in six minutes. Test procedure: after the verbal or sound command, the child runs around the designated area which is circled with markers. When the time ends, the child stops running and waits until the stopping point is checked. The test is terminated if a child cannot run or walk any longer (the test was approved by the order of the Minister of Health of the Republic of Lithuania, 2019).

RehaCom (Germany), a computer programme designed for the cognitive functions' assessment and training. The testing required: computer, keyboard, computer mouse or a special RehaCom keyboard which is adapted for patients with impaired motor or cognitive skills. The programme provides standardised, objective, and repeatable measures (e.g. reaction time and task completion time) with minimal examiner bias. The computerised format is particularly suitable for children, as tasks are delivered in a consistent manner and allow clear, quantifiable outcomes. In addition, RehaCom tasks can be adapted in difficulty and are presented visually, which helps reduce the complex verbal instructions and supports testing in children with neurodevelopmental illness. Selected tasks can be used for comparison of pre- and post-intervention performance under the same conditions (Kotegawa et al., 2025; Yang et al., 2014). All participants' cognitive functioning abilities met the normative requirements to perform tasks using the RehaCom system. Task difficulty in the RehaCom system was automatically adjusted by the software according to the individual performance level of each child. The programme progressively increased task difficulty based on the participant's abilities, ensuring an individualised yet standardised adaptive training and assessment process across participants. The adaptive adjustment of task difficulty may influence result interpretation, as performance improvements could reflect both genuine gains in cognitive function and increased task demands matched to the participant's abilities. Because the same adaptive procedure was applied consistently at pre- and post-intervention assessments, changes in performance are considered to reflect relative improvements within individuals rather than differences in task difficulty between participants. The first task assessed topological memory and consisted of two phases: the memorisation of a picture and its subsequent recall. After seeing a certain number of pictures (adjusted according to a participant's abilities) and memorising them, the participant has to indicate the previous location of the one image presented on the screen. The second task evaluated logical reasoning. A row of images is shown on the screen, the last image of the row is missing, the participant has to find the correct image that would show a logical sequence continuation. During the study, we collected the reaction time median in seconds and the number of errors data.

Study protocol. The study was approved by the Lithuanian Sports University Bioethics Committee (date: 2025 05 07; No. MI-KIN (M)-2025-787). The study was conducted for six weeks in the Comprehensive Services Center "Family Valley" (Vilnius, Lithuania). A written consent form was obtained from participants' parents or legal guardians. The tests were conducted two times: at the beginning and at the end of the study. Both groups had training sessions for six weeks, four times per week. At the beginning of the study, cognitive functions (topological memory and logical reasoning) were assessed using the RehaCom computer programme, balance was evaluated with a paediatric balance scale (modified Berg scale), and aerobic capacity was measured using a six-minute running test (a simplified version of the K. Cooper test). Participants were assessed at least two hours after their last meal, and all assessments were conducted between 14:00 and 16:00. At the end of the study, participants were tested again using the same methods on the following day after the last training session in order to avoid signs of fatigue. The study protocol is presented in Figure 1.

Figure 1. **Study protocol**



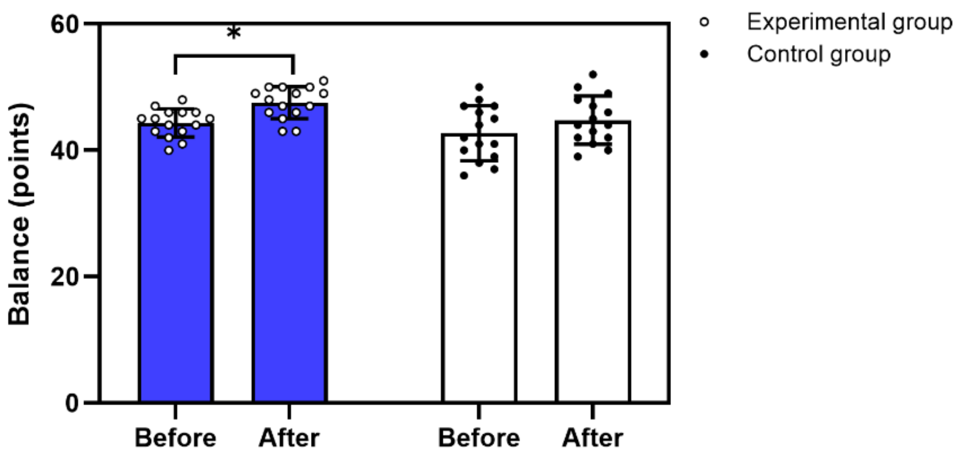
Intervention. The experimental group (n = 15) underwent a conventional physiotherapy programme (30 minutes) combined with aerobic training (20 minutes), whereas the control group participated only in the conventional physiotherapy programme (30 minutes). The intensity and duration of the aerobic training remained constant throughout the six-week intervention period. No progression in training intensity or session duration was applied. The conventional physiotherapy programme consisted of obstacle course-based exercises and muscle strengthening training (resistance band and bodyweight exercises). The aerobic training programme included the use of a treadmill, stationary bicycle, and trampoline exercises, supplemented by other forms of active play. Both groups received a standardised warm-up lasting ten minutes and a cool-down period of five minutes. The main part of the training was 50 min for the experimental group, and 30 min for control group. Before physical activity, participants' resting heart rate was measured for five minutes. The intensity of aerobic training was calculated using the Karvonen formula *(intensity (%) / 100 × (maximum heart rate – resting heart rate) + resting heart rate)*. Aerobic load was applied at 50–60% of the light intensity aerobic zone. Heart rate was measured every five minutes using the "EVOLU" heart rate monitor (*model JPD500G, China*). Warm up exercises (walking, dynamic stretching) were performed before each training session and cool-down exercises (static stretching, breathing exercises) were performed afterwards.

Statistical data analysis. Statistical analysis was performed using IBM SPSS Statistics programme (*version 28.0.1.0 (142)*). In order to determine if the data followed a normal distribution, the Shapiro–Wilk (Shapiro & Wilk, 1965) test was applied. If the data was normally distributed ($p > 0.05$), a repeated-measures ANOVA was applied, and an independent-samples t-test was used to examine differences between groups. If the data were not normally distributed ($p < 0.05$), the nonparametric Wilcoxon matched-pairs test was used, and the Mann–Whitney U test was applied for group comparisons. Most of the data met the assumption of normality; however, reaction time data did not, and therefore nonparametric tests were applied. Results were considered statistically significant when the p-value was less than 0.05. Effect sizes (d) were also calculated using Cohen's d coefficient when statistical differences were observed (Cohen, 1988). The calculated effects were interpreted as: ~0.2 small, ~0.5 medium, ~0.8 large effect (Mangiafico, 2016).

3. RESULTS

The balance results are presented in Figure 2. Combined conventional physiotherapy with aerobic training led to a statistically significant improvement in balance ($p < 0.05$; $d > 0.8$). In contrast, conventional physiotherapy alone produced no statistically significant change in balance following the intervention ($p > 0.05$). Furthermore, no significant differences were observed when comparing balance between the two groups ($p > 0.05$).

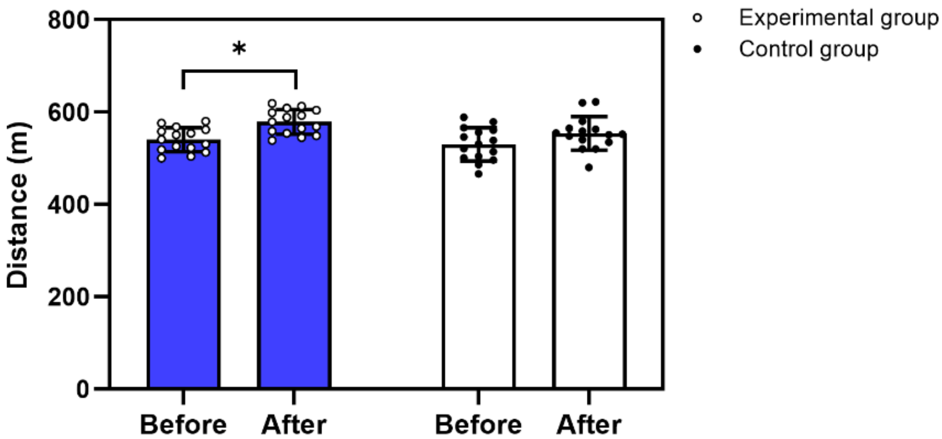
Figure 2**. The effect of different programmes on balance**



Note: * – significant difference compared to baseline values.

The aerobic capacity results are presented in Figure 3. Combined conventional physiotherapy with aerobic training significantly increased the distance during the 6-minute running test ($p < 0.05$; $d > 0.8$). In contrast, conventional physiotherapy alone produced no statistically significant change in aerobic capacity following the intervention ($p > 0.05$). No significant differences were observed when comparing balance between the two groups ($p > 0.05$).

Figure 3**. The effect of different programmes on aerobic capacity**



Note: * – significant difference compared to baseline values.

Table 2 presents data results of the effect of aerobic training on cognitive functions. Combined physiotherapy and aerobic training had significantly reduced task solving and picture memorisation time, reaction time median and the number of errors ($p < 0.05$; $d > 0.8$). In contrast, conventional physiotherapy alone produced no statistically significant change in cognitive functions following the intervention ($p > 0.05$). When comparing the results between groups, the task solving time and reaction time median were significantly better in the experimental group ($p < 0.05$; $d > 0.8$), whereas no significant differences were observed in the number of errors ($p > 0.05$).

Table 2. **The effect of different programmes on cognitive functions**

	Experimental group		**Control group**	
	Before	After	Before	After
Topological memory				
Task solving time (s)	42.8 ± 15.4	25.7 ± 6.4*	40.1 ± 4.6	40.3 ± 4.7#
Picture memorisation time (s)	43.7 ± 18.1	18.5 ± 10.5*	42.3 ± 10.3	43.2 ± 8.5#
Logical reasoning				
Reaction time median (s)	12.0 ± 4.4	6.3 ± 4.4*	12.0 ± 4.4	12.1 ± 4.2#
Number of errors	15.6 ± 3.1	9.6 ± 4.8*	13.7 ± 2.5	9.7 ± 4.5

Notes: * – significant difference compared to baseline values; # – significant difference between groups.

4. DISCUSSION

The aim of this study was to determine effects of aerobic exercise on balance, aerobic capacity, and cognitive functions in children with ASD. The main finding of this study was that six weeks of combining conventional physiotherapy with additional aerobic exercises had improved balance, aerobic capacity, and cognitive functions.

It is widely recognised that conventional physiotherapy can improve balance skills in children across different age groups (Bataweel, 2020; Jabouille et al., 2021). Jouira and co-authors (2024) in previous research show that aerobic training, such as dancing, stimulates visual, proprioceptive, and vestibular sensory systems, which are crucial for good development of balance skills. After eight weeks of applying the training programmes, authors found that the activation of these systems during aerobic exercise determines the ability to maintain balance and perform coordinated movements in response to changing environmental conditions. Our study protocol also emphasised the effect of aerobic exercise on balance skills, and our findings are consistent with those reported by other authors. Similar effects have been reported by Richer and Lajoie (2020), claiming that dualtask exercises are an effective approach to improving postural control skills, as they require increased attention, balance abilities, and cognitive engagement. While the meta-analysis by Saraiva and co-authors (2022) highlighted a variety of dual-task exercise examples, such as maintaining balance while holding a glass of water, balancing a ball on a small wooden board, passing a ball from one hand to the other, and buttoning a shirt.

Kubica and co-authors (2019) also suggest that even basic balancing exercises, if done systemically, can increase BDNF release in the brain and can improve not only balance, but also cognitive skills. During physical activity, contracting muscle fibres make peptides – myokines, which take part in physiological, metabolic, and immunological effects of physical exercise (Laurens et al., 2020). It is important to note that it also enhances neuroplasticity and BDNF synthesis in the brain (Choi & Balakrishnan, 2024) and these effectively promote the improvement of cognitive functions (Seidler & Barrow, 2022). Furthermore, Avgerinos and colleagues (2023) stated that irisin (a myokine) affects not only metabolic processes, but also increases BDNF expression in the cerebellum (necessary for successful balance control) as well as in the cerebral cortex and hippocampus. This theory was further supported by the study conducted by Solianik and co-authors (2021), which demonstrated that after a ten-week Tai Chi programme, older adults exhibited improved balance skills, with outcomes linked to increased levels of BDNF and irisin following the training cycle. In our study, the improvement of balance skills could be linked to the stimulated visual, proprioceptive, and vestibular sensory integration during the aerobic training, as well as the environmental demands that require fast and coordinated movements while maintaining body stability.

Our study findings, indicating that aerobic exercise can improve cognitive functions for children with ASD, are consistent with Hou and co-authors' (2024) study results, in which they report that for neurotypical young individuals aerobic exercise stimulates peripheral blood flow and promotes the release of BDNF and TrkB in the cerebellum. Even simple activities that involve running or ball play can stimulate these processes. The release of BDNF and TrkB activates synapse formation and enhances the efficiency of synaptic transmission. These processes could explain improvements in cognitive flexibility and inhibitory control in children with ASD. These mechanisms are also linked to neuroplasticity and the strengthening of synaptic connections, which are an important part of the development of cognitive and motor functions (Mao et al., 2021).

This study had some limitations. Firstly, residual effects were not assessed, and therefore the long-term impact of the programme cannot be evaluated. Secondly, the specific mechanisms underlying the observed changes remain unclear. Future studies should investigate processes that may explain these outcomes, such as alterations in BDNF and TrkB concentrations, changes in cerebral blood flow, and other neurophysiological indicators. Thirdly, the experimental group completed 50-minute sessions that included aerobic exercise, whereas the control group performed 30 minutes of conventional physiotherapy, resulting in a greater overall physical activity volume in the experimental group. This difference may act as a confounding factor, as the observed improvements could reflect not only the specific effects of aerobic exercise but also increased total activity exposure. Although unequal session duration is a limitation, it is common in exercise-based study designs. For example, Cai et al. (2020) used an add-on approach in autistic children, providing conventional therapy plus an additional 40 minutes of physical activity, a design frequently applied in studies examining physical activity effects (Elwadhi et al., 2025; Stössel et al., 2020). Such protocols inevitably result in higher activity volume in the intervention group, and currently no methodological alternative allows matching both session duration and physiological load. Finally, the spectrum of the autistic traits is broad, thus most of the children have different impairments in motor or cognitive skills. It is important to evaluate how children with varying functional abilities respond to the current programme.

5. CONCLUSIONS

Our hypothesis was confirmed. The integration of aerobic exercise into conventional physiotherapy significantly improves balance, aerobic capacity, and cognition in children with autism spectrum disorder, highlighting the efficacy of a combined therapeutic approach. Future research perspectives could include studies examining effects of aerobic exercises on many other motor skills and a bigger range of cognitive functions in children with ASD. It is also important to investigate the effects of different intervention parameters (duration and intensity) on balance, aerobic capacity, and cognitive skills and to determine if the positive effects persist after the discontinuation of applying aerobic training.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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