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Research Article

Improving Physical Fitness in Children with ADHD Through Virtual Physical Activity: A Randomized Controlled Trial

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Abstract

Background: Attention-deficit hyperactivity disorder (ADHD) is a chronic condition that causes impairment in executive function.

Objectives: The present randomized controlled trial aimed to assess how virtual physical activity (VPA) affected physical fitness metrics in children with ADHD.

Methods: Eighty boys with ADHD, aged 7 to 10, were randomly assigned using a 1:1 allocation ratio via computer-generated block randomization to either a non-active control group (n = 40) or a 12-week VPA intervention group (n = 40). A third, typically developing (TD) comparison group (n = 40) was also included. Twice-weekly online workouts that focused on locomotor, manipulative, and stability abilities were part of the intervention. Physical fitness outcomes were assessed at baseline, immediately post-intervention, and at 12-week follow-up using standardized measures of physical fitness. Data analysis was conducted using descriptive statistics and a series of combined two-way variance analyses with repeated measurements at a significance level of 0.05, using SPSS23 software.

Results: The results demonstrated that children in the VPA group outperformed children in the control group in terms of aerobic capacity, muscle strength, and flexibility ($P < 0.01$, η^2 from 0.28 to 0.34). At the follow-up, these increases persisted. The indices of physical fitness showed significant impact sizes. The control group showed no discernible gains. According to research, structured VPA programs provide children with ADHD with a non-pharmacological, useful, pleasurable, and efficient means of promoting their physical development.

Conclusions: These findings have significant ramifications for how educational and therapeutic approaches are developed and applied in environments that assist people with developmental disabilities.

Keywords: ADHD, Virtual Education, Physical Health, Neurodevelopmental Disorders

1. Background

It is believed that approximately 5% of children and adolescents worldwide suffer from attention-deficit hyperactivity disorder (ADHD), a common neurodevelopmental disorder (1, 2). It is characterized by persistent signs of impulsivity, hyperactivity, and inattention that significantly impair social interactions, behavioral self-regulation, and academic performance (1, 3). There are numerous advantages to physical activity (PA) in general, including increased cardiovascular health (4), enhanced motor abilities (5), and decreased risk of obesity (6). Physical activity also improves neurocognitive function (7), behavioral management (8), and quality of life (9) in children with ADHD. However, children with ADHD may not necessarily find traditional physical activities interesting, which can make it challenging to maintain exercise regimens (5). There are hazards associated with existing treatment choices, such as pharmacological therapies (10), and behavioral interventions require a significant amount of time and effort from parents and doctors (11). Virtual physical activity (VPA) blends technology and exercise, offering a unique solution that provides interactive and engaging environments to capture the attention of children with ADHD (12). This strategy makes exercise

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more appealing and, thus, more successful for kids by utilizing digital gadgets and game technology to promote movement (12, 13). The VPA has the potential to offer structured, engaging, and personalized fitness programs for kids with ADHD, thereby increasing program adherence (14, 15).

Despite these encouraging characteristics, there is little empirical data on how virtual physical activities affect children with ADHD's physical fitness. Most research has evaluated the general advantages of PA without considering the distinction between traditional and virtual approaches (16, 17). For example, Liang et al. demonstrated that structured aerobic activity can improve executive function in children with ADHD (18), while Sun et al. reported that game-based virtual high-intensity interval training significantly enhanced working memory and task-switching skills in a similar population (19). The VPA platforms often incorporate gamification, immediate feedback, and sensory-rich environments, all of which are designed to sustain attention and reduce task monotony (12, 13). These elements are particularly beneficial for children with ADHD, who tend to perform better in dynamic and visually stimulating environments (12). Furthermore, VPA can be delivered remotely, allowing for higher accessibility and parent-led implementation (14).

Executive functioning deficiencies, such as difficulties with planning, maintaining focus, and controlling emotions, are common in children with ADHD diagnoses. These challenges frequently make it difficult for them to participate successfully in traditional sporting environments (3, 8). The VPA can be created to meet these requirements and offer a disciplined, interesting, and distraction-free setting (14). Additionally, because VPA is adjustable, it can be used to address the impulsivity and fluctuating attention span of kids with ADHD, which are easier to manage in kids in good health (12, 15). Children with ADHD typically have lower levels of physical fitness, which affects their ability to breathe, their muscle strength, and their flexibility — all of which are critical for good health (4, 20). The precise effects of VPA on these outcomes have not been as well studied, but PA has been shown to improve many aspects of physical fitness, which may improve cognitive functioning and reduce behavioral symptoms commonly associated with ADHD (8, 20). It also has positive effects on reducing aggression and increasing social skills (5, 21).

Mechanistically, PA is known to enhance prefrontal cortex activity, improve dopaminergic signaling, and regulate catecholamine levels — neurobiological systems frequently dysregulated in ADHD (22). The VPA may additionally stimulate the vestibular system and sensorimotor networks, improve motor skill automation, and increase self-efficacy through structured progression and achievement-based feedback (14, 23). These neurophysiological and psychological mechanisms collectively contribute to improved attention regulation, emotional control, and physical fitness (12). Despite the theoretical advantages of VPA, there is limited empirical research assessing its effectiveness compared to non-active or traditional PA controls. Furthermore, the specific impact of VPA on key components of physical fitness — such as aerobic capacity, muscle strength, and flexibility — remains underexplored in children with ADHD.

This investigation offers a chance to learn more about how VPA may specifically improve the physical characteristics of kids with ADHD. Accordingly, the present study aimed to investigate the effects of a 12-week VPA program on physical fitness factors in boys with ADHD. A group of typically developing (TD) children was also included for comparison as a normative standard. The role of VPA was highlighted as an effective and practical solution for controlling ADHD symptoms in limited settings, by filling these research gaps. Therefore, the hypothesis of the present study was that children participating in the VPA program would show significant improvements in physical fitness (aerobic capacity, muscle strength, and flexibility) compared to an inactive control group.

The results of this study could influence public health policies and educational initiatives from a societal perspective. Given the high cost of ADHD treatment and the burden this disease places on society, finding accessible and successful treatments is of great importance. Furthermore, the findings of this study could help parents, teachers, and healthcare professionals support children with ADHD in realizing their full potential and provide a framework for further research into the long-term benefits of VPA in ADHD management in various contexts.

2. Objectives

The present study was conducted to investigate the effect of VPA on physical fitness factors in children with ADHD.

3. Methods

3.1. Study Design and Participants

This study used a randomized controlled trial with a parallel group design. Participants were assessed at three time points: Pretest, posttest, and follow-up. Participants were initially selected based on prespecified criteria and then matched for important variables such as age, ADHD subtype, and comorbidity to ensure initial homogeneity between groups. After the matching process, participants were randomly assigned in a 1:1 ratio to one of two intervention groups (recipients of VPA) or inactive control. Randomization was performed using a block design with four blocks and a random number generation algorithm by an independent researcher who was not involved in the data collection process. Opaque, sealed envelopes were used to maintain allocation concealment. Additionally, to compare the results of children with ADHD with healthy children, a third group including children with normal development (healthy control group) was also included in the study as a comparison reference. G*Power software (version 3.1.9.2) was used to calculate the sample size, which was based on a statistical power of 80%, an effect size of 0.3, and a significance level of 5%. According to the analysis, a minimum of fifty people would be required. The sample size was expanded to 80 participants (40 in each group) to account for possible attrition.

3.2. Participants and Procedure

The study sample consisted of male students aged 7 to 10 who were enrolled in elementary schools in Shiraz, Iran, in 2025. The all-male selection was consistent with national educational regulations that mandate male teachers for male students. The following were the requirements for inclusion: (1) A child between the ages of 7 and 10; (2) a Conners Rating Scale (1979) result and a clinical diagnosis of ADHD verified by a child psychiatrist or developmental psychologist; (3) a formal recommendation from a healthcare provider to participate in the study; and (4) an IQ greater than 80 as determined by the Wechsler Intelligence Scale for Children, Fourth Edition (24). The exclusion criteria included a parent's reported inability to participate in physical activities, the presence of acute or chronic medical conditions that limit PA, a history of seizures, or a diagnosis of another psychiatric or neurodevelopmental disorder (e.g., autism spectrum disorder or intellectual disability). Out of the forty Shiraz elementary schools for boys, ten were selected at random. A total of 800 Conners questionnaires (25) were distributed to parents and teachers of first- through fourth-grade pupils; 580 of these were completed and returned. Based on the results of the questionnaire and subsequent clinical evaluations, 86 children were deemed qualified. Six children withdrew, leaving 80 youngsters in the final sample. A matched, non-random process was then used to separate them into experimental and control groups, each consisting of 40 participants. In order to confirm that they were developing normally, a psychiatrist also evaluated 40 TD children who were selected from two different schools and demographically matched with the ADHD groups. The healthy control group was subsequently included. Assessments of physical fitness were carried out three times: A week before the intervention (pre-test), right after the 12-week intervention (post-test), and twelve weeks after the intervention's conclusion (follow-up). Each child's assessment session lasted roughly sixty minutes. The Declaration of Helsinki's (1975) ethical guidelines were strictly followed during the study's execution. The Research Ethics Committee of Shahid Chamran University of Ahvaz granted ethical approval (IR.SCU.REC.1404.035). After being thoroughly informed about the study's objectives, potential benefits, duration, and data confidentiality protocols, all participant parents provided their written informed consent.

3.3. Measuring Instruments

Three time points were used to measure physical fitness indicators: Before the intervention (time 1), just after the 12-week intervention period (time 2), and at a 12-week follow-up (time 3). To reduce bias, all evaluations were carried out by qualified research personnel who were blind to group assignment. Standardized measurement training and comprehensive protocol instructions covering the administration of all evaluations were provided to the research team in order to guarantee data consistency and reliability. To ensure procedural fidelity, a senior researcher oversaw each testing session. Fitness evaluations were performed under carefully monitored experimental conditions, and all physical examinations were performed with tact and consideration. To minimize confounding variables, participants were permitted to consume only distilled water before testing and were advised to follow regular dietary guidelines on the main testing days.

3.3.1. Physical Fitness

A series of standardized tests, such as the 20-meter progressive aerobic cardiovascular endurance run (PACER), isometric push-up, curl-up, and step-back tests, were used to evaluate the physical fitness levels of children (26). Furthermore, anthropometric measurements were made using a bioelectrical impedance analyzer (MFBIA8, InBody 720, Biospace) to determine height and weight with a precision of 0.1

units. Multi-step running was used to evaluate cardiovascular fitness. To perform the PACER test, a distance of 20 meters was measured. In the test, a straight path of 20 meters was marked and measured in a suitable space. Participants were required to run a distance of 20 meters in a round-trip manner and in time with pre-recorded audio beeps. The time interval between beeps was reduced every minute to gradually increase the running speed. The test continued until the participant could not reach the opposite line in the prescribed time for two consecutive times. In this case, the test was stopped, and the total number of successful crossings of the 20-meter path was recorded as a Performance Index. The main criterion of this test was the total number of successful laps (number of round trips), which is considered a valid index of maximum oxygen consumption (VO_2max). This test is known as an indirect, standardized, and highly valid and reliable tool for assessing cardiovascular endurance in children (27, 28).

The isometric push-up test was used to measure muscle strength and endurance in the upper body of the participants. During the test, participants were asked to maintain a standard static isometric swimming position. In this position, the arms were positioned vertically under the shoulders, the body was held in a straight line from head to heel, and the toes were in direct contact with the floor. The primary evaluation criterion was the length of time the participant was able to maintain the correct position without loss of form. The test was timed immediately after the participant was positioned in the correct position, and if there was any loss of form (such as hip drop or knee bend), the test was stopped, and the time was recorded. The maximum time allowed to maintain the position was 40 seconds. If the participant maintained this time without loss of form, they were given a full score; otherwise, the exact time they could tolerate maintaining the position was recorded as their performance score (29).

Using the curl-up test, the strength and endurance of the participants' abdominal muscles were evaluated. Participants lay supine on a mat, with their knees bent at approximately 140 degrees and their feet flat on the floor. Hands were placed on their thighs with fingertips touching the upper thighs. Participants were instructed to perform sit-ups at a rate of one repetition every 3 seconds, with a maximum of 75 repetitions. With each repetition, the participant had to raise their upper body until their fingertips touched the kneecap. They then returned to the starting position. The primary outcome measure was the number of correct repetitions of the sit-up. A valid repetition was considered to be completed when the movement was completed without using the arms, with a full and controlled range of motion. The test ended either after reaching 75 repetitions or when the participant was unable to continue the movement with correct form. This test has been recognized in previous research as a valid tool for assessing abdominal muscle endurance in children and has shown good validity in various studies (29, 30).

The sit-and-reach test is a common method for assessing flexibility, particularly in the back and hamstring muscles. During the test, participants sat on a flat surface with their legs completely straight and shoulder-width apart, without shoes. The knees were to remain fully extended and locked, and the soles of the feet were placed perpendicular to the test box. A standard sit-and-reach box measuring approximately 30 × 30 cm was used, which was placed flat against the soles of the feet. A measuring tape was attached to the top of the box, with the zero point set at the level tangent to the soles of the feet. Participants were asked to extend their arms forward and place their hands on top of each other or to place their palms together and facing downward. Participants slowly leaned forward and attempted to walk as far as possible along the measuring line without bending their knees. The examiner made sure that the hand movements were performed symmetrically and simultaneously, and that one hand did not move forward in relation to the other. The main criterion of the test was the greatest distance (in centimeters) that the participant could maintain. The participant had to remain in the final position for at least 1 to 2 seconds for the number to be recorded. Each participant performed the test twice, and the highest recorded value was considered the final score. Before the main test, a short practice phase was performed to familiarize themselves with the method of execution and to prevent possible injuries. Also, rapid or jumping movements were avoided to prevent errors or injuries (29).

3.4. Ethical Considerations

Informed consent was obtained from all participants. Confidentiality and anonymity of the rejected subjects were observed and controlled throughout the study.

3.5. Intervention

The experimental group (n = 40 ADHD children) practiced the created program online for 12 weeks after finishing the pre-test. Sessions were delivered via Google Meet, and the exercise routines were hosted on WhatsApp. The digital content included pre-recorded video modules, interactive live coaching, and movement-based games, all of which were accessible using a laptop, tablet, or smartphone. The control group, which consisted of 40 children with ADHD, went about their regular lives during this time without engaging in any medical therapies or a structured activity program. The curriculum utilized in this study is founded on the ideas put out for instructing kids in physical education (31). The program was put together using the frequency, intensity, time, and type (FITT) technique. An online workout program lasting 12 weeks was administered to the experimental group in two sessions per week, on Saturday and Tuesday, lasting 60 minutes each, from 10 to 11 A.M. There were five minutes of warm-up and cool-down (both movement games), forty-five minutes of main training, and five minutes of pre-class preparation throughout each training session. Each of the three 15-minute segments that made up the major exercises focused on one of the three basic motor skills: Locomotor, manipulation, and stability. Movement concepts served as the foundation for the design of the activities; in other words, the degree of difficulty of the movement tasks was modified by manipulating movement concepts, such as body perception, space perception, execution quality, and relationships. In addition to the standard instruments used in games and sports programs, such as balls, cones, and hula hoops, the equipment also included items that could be acquired at home. The instructional content was delivered through a combination of live coaching and pre-recorded videos. The coaches had previous experience in children's physical education and followed a standardized curriculum to ensure consistency.

3.6. Statistical Analysis

SPSS software (version 23, USA) was used for all statistical analyses, and $P < 0.01$ was chosen as the significance level. To compare groups, demographic factors such as age, height, weight, Body Mass Index (BMI), and IQ were examined using independent *t*-tests. Physical fitness tests (20-meter PACER test, isometric swimming test, sit-up test, and goal-reaching test) were among the dependent variables examined in this study. A series of combined two-way variance analyses [3 (times) × 3 (groups)] with repeated measurement used for physical fitness outcomes were used to evaluate the intervention's effects. Simple main effects were identified if any interaction was deemed substantial. For analyses of variance (ANOVA), effect sizes were expressed using eta squared (η^2), which gives an estimate of the percentage of variance that the independent variable accounts for. Cohen's d was computed for paired *t*-tests in order to evaluate the extent of within-group variations over time. Specifically, the intervention's potential maintenance effects at different time points were evaluated using paired *t*-tests. The following presumptions were investigated and confirmed prior to data analysis: Mauchly's sphericity, linearity, homogeneity, normalcy, and homogeneity of regression slopes.

4. Results

Demographic factors did not differ among the groups (Table 1). It is important to note that at time 1, one child left the ADHD training group. Additionally, nine children in the ADHD non-training group and one child in the ADHD training group withdrew and did not take part in the study at time 3. Measurements of heart rate and exercise duration were made to assess the degree of PA (intervention). Moderate to vigorous PA was indicated by the training intensity of 80 heartbeats per minute and the average training length of 53.20 ± 2.80 minutes per session.

4.1. Group Comparability

- Pre-training: Table 2 displays the results pertaining to the subscales of physical fitness components. In the 20-meter PACER exam, a physical fitness subtest, the results showed substantial group differences (Table 2). Both ADHD subgroups significantly underperformed the TD group on the 20-meter PACER, according to post hoc pairwise comparisons. The isometric push-up, curl-up, and sit-and-reach tests, among other physical fitness assessments, did not reveal any noteworthy variations between the groups.

- Post-training: Table 3 summarizes the results of the post-training of the physical fitness factors subscales. After controlling for baseline differences, analysis of physical fitness outcomes revealed significant group effects in the 20-meter PACER test (partial $\eta^2 = 0.28$), isometric push-up (partial $\eta^2 = 0.34$), curl-up (partial $\eta^2 = 0.25$), and sit-and-reach tests for both the right (partial $\eta^2 = 0.32$) and left legs (partial $\eta^2 = 0.31$). Compared to the ADHD training group, both the ADHD non-training and TD groups demonstrated significantly lower levels of physical fitness across these measures.

- Follow-up stage: Table 4 summarizes the results of the follow-up training of the physical fitness factors. After controlling for baseline differences, significant group differences were observed in physical fitness outcomes, including the 20-meter PACER test (partial $\eta^2 = 0.29$), isometric push-up (partial $\eta^2 = 0.36$), curl-up

Table 1. Participant Descriptive Characteristics [a]

Variables	ADHD Training (n = 40)	ADHD Non-training (n = 40)	TD Non-training (n = 40)	*t*	P-Value
Age (y)	8.27 ± 1.40	8.32 ± 1.46	8.38 ±1.25	0.38	0.75
Height (cm)	132.20 ± 3.45	131.50 ± 3.60	130.39 ± 3.80	0.76	0.46
Weight (kg)	30.65 ± 4.40	29.75 ± 4.69	30.50 ± 4.32	0.56	0.52
BMI	17.30 ± 3.29	17.40 ± 3.20	17.60 ± 3.23	0.86	0.39
IQ	93.50 ± 8.60	92.80 ± 7.93	94.65 ± 8.33	0.98	0.32
ADHD Symptoms					
ADHD-I	20 (50)	18 (45)	-	-	-
ADHD-HI	11 (28)	8 (20)	-	-	-
ADHD-C	9 (22)	14 (35)	-	-	-

Abbreviations: ADHD, attention-deficit hyperactivity disorder; TD, typically developing; BMI, Body Mass Index; ADHD-I, attention-deficit hyperactivity disorder- inattentive subtype; ADHD-HI, attention-deficit hyperactivity disorder-hyperactive/impulsive subtype; ADHD-C, attention-deficit hyperactivity disorder-combined subtype.

[a] Values are expressed as No. (%) or mean ± SD.

Table 2. An Overview of the Variations in Physical Fitness Subscales Prior to Training [a]

Variables	ADHD Training (n = 40)	ADHD Non-training (n = 40)	TD Non-training (n = 40)	F	Post hoc
20-m PACER	15.35 ± 2.50	15.20 ± 2.58	22.40 ± 3.95	3.68 [b]	1, 2 < 3
Isometric push-up (s)	34.65 ± 5.20	33.73 ± 6.42	37.20 ± 4.40	1.76	-
Curl-up	3.88 ± 8.60	4.60 ± 7.87	5.55 ± 7.43	0.67	-
Sit and reach (cm)					
Right leg	26.34 ± 7.89	25. 43 ± 6.67	23.77 ± 5.66	0.58	-
Left leg	27.10 ± 5.23	26.44 ± 6.30	24.80 ± 6.32	0.43	-

Abbreviations: ADHD, attention-deficit hyperactivity disorder; TD, typically developing; PACER, progressive aerobic cardiovascular endurance run.

[a] Values are expressed as mean ± SD.

[b] A P-value < 0.0 is considered statistically significant.

(partial η^2 = 0.27), and sit-and-reach tests for both the right (partial η^2 = 0.33) and left legs (partial η^2 = 0.32). The findings further indicate that the beneficial effects of the intervention observed at post-training were maintained during the retention phase. Compared to the ADHD training group, both the ADHD non-training and TD groups demonstrated significantly lower levels of physical fitness across these measures.

4.2. Disparities Within Groups Before and After Training

Table 5 displays Cohen's d values for within-group comparisons between pre- and post-training outcomes.

- Attention-deficit hyperactivity disorder training group: Following instruction, the ADHD training group's physical fitness subscales showed a notable improvement. All four of the physical fitness factor scores showed large effect sizes.

- Attention-deficit hyperactivity disorder non-training group: Neither physical fitness metric showed any appreciable gains in the ADHD non-training group.

- Typically developing non-training group: The 20-meter PACER test showed middling effect sizes after the intervention. The curl-up and sit-and-reach scores showed small impact sizes.

5. Discussion

The present study evaluated the effects of a 12-week VPA program on various physical fitness components in children with ADHD. The results demonstrated that the VPA group exhibited statistically significant and practically meaningful improvements in aerobic capacity, muscular strength, and flexibility compared to both the ADHD control group and TD peers. Importantly, the magnitude of improvements in the intervention group was substantial. For instance, a large effect size (Cohen's d > 1.2) was observed for the 20-meter PACER test, indicating significant enhancement in aerobic endurance. Similarly, effect sizes for isometric push-up and sit-and-reach tests were in the large range (d = 1.83

Table 3. Summary of Post-training Differences in Physical Fitness Subscales [a]

Variables	ADHD Training (n = 40)	ADHD Non-training (n = 40)	TD Non-training (n = 40)	F [b]	Post hoc
20-m PACER	19.20 ± 1.23	15.98 ± 2.79	23.65 ± 3.80	7.55	1 > 2
Isometric push-up (s)	38.66 ± 5.21	33.95 ± 5.40	37.69 ± 4.23	8.45	2, 3 < 1
Curl-up	7.80 ± 6.95	4.85 ± 5.80	6.45 ± 5.40	4.50	2, 3 < 1
Sit and reach (cm)					
Right leg	30.44 ± 6.43	25. 76 ± 6.60	24.66 ± 5.65	7.99	2, 3 < 1
Left leg	31.23 ± 6.50	26.20 ± 6.45	25.75 ± 5.30	7.95	2, 3 < 1

Abbreviations: ADHD, attention-deficit hyperactivity disorder; TD, typically developing; PACER, progressive aerobic cardiovascular endurance run.

[a] Values are expressed as mean ± SD.

[b] A P-value < 0.0 is considered statistically significant.

Table 4. Summary of retention stage (follow-up) differences in Physical subscales [a]

Variables	ADHD Training (n = 40)	ADHD Non-training (n = 40)	TD Non-training (n = 40)	F [b]	Post hoc
20-m PACER	19.45 ± 1.20	15.10 ± 2.70	25.68 ± 3.69	7.61	1 > 2
Isometric push-up (s)	39. 50 ± 5.20	33.10 ± 5.23	38.20 ± 4.15	8.63	2, 3 < 1
Curl-up	7.93 ± 6.88	4.80 ± 5.43	6.87 ± 5.13	5.33	2, 3 < 1
Sit and reach (cm)					
Right leg	31.20 ± 6.32	26. 10 ± 6.09	24.87 ± 5.39	8.07	2, 3 < 1
Left leg	32.07 ± 6.19	27.20 ± 5.55	26.44 ± 5.67	7.99	2, 3 < 1

Abbreviations: ADHD, attention-deficit hyperactivity disorder; TD, typically developing; PACER, progressive aerobic cardiovascular endurance run.

[a] Values are expressed as mean ± SD.

[b] A P-value < 0.0 is considered statistically significant.

and 1.89, respectively), emphasizing the considerable improvement in upper-body strength and flexibility. These findings confirm that even a relatively low-frequency, home-based VPA intervention (twice weekly) can yield robust gains in key physical fitness domains in children with ADHD.

Although a retention test was not administered in this study, the inclusion of a 12-week follow-up evaluation provides some insight into the maintenance of intervention effects. The sustained performance observed at follow-up suggests the potential for long-term benefits. However, future studies should incorporate formal retention testing several months post-intervention to determine whether physical gains translate into enduring physiological or behavioral changes. This could also clarify whether booster sessions or ongoing activity are necessary to maintain benefits.

These findings are in line with earlier studies that demonstrate how less mobile and physically fit kids with ADHD are (29, 32-34) and have more behavioral issues (35-38) than children with TD. Negative psychosocial consequences, such as a lowered self-concept, increased anxiety, and trouble interacting with others, have been connected to poor motor performance in children with ADHD (29, 36). Furthermore, a higher incidence of childhood obesity is linked to motor impairments (29, 33). Additionally, recent research shows that children with ADHD are significantly more likely to be obese than their TD peers, highlighting the significance of improving motor skills and physical exercise in this population (34, 36).

There are a number of reasons why children with ADHD benefit from PA in terms of their physical condition. Generally speaking, children with ADHD have motor skills that are much below average for their age and level of cognitive functioning (23, 29, 39). In addition to improving physical conditioning, organized sports training offers constructive distractions from stressful or anxiety-inducing circumstances (18, 24, 32). Additionally, exercise improves higher-order brain processes, including motor abilities and sensorimotor integration, and activates the vestibular nerve system. These enhancements encourage greater self-efficacy and self-confidence, which can reduce symptoms of ADHD and improve physical fitness outcomes (21, 39).

Table 5. An Overview of the Effect Sizes for Pairwise Comparisons Between Each Group Before and After the Test [a]

Variables	ADHD Training (n = 20)		ADHD Non-training (n = 20)		TD Non- training (n = 40)	
	Change	ES [b]	Change	ES	Change	ES
20-m PACER	3.85	1.22	0.78	0.19	1.25	0.58 [c]
Isometric push-up (s)	4.01	1.83	0.22	0.11	0.49	0.12
Curl-up	3.92	1.34	0.25	0.13	0.90	0.41 [d]
Sit and reach (cm)						
Right leg	4.10	1.89	0.33	0.15	0.89	0.29 [d]
Left leg	4.13	1.94	-0.24	-0.29	0.95	0.43 [d]

Abbreviations: ADHD, attention-deficit hyperactivity disorder; TD, typically developing; ES, effect size (Cohen's d); PACER, progressive aerobic cardiovascular endurance run.

[a] Positive values indicate improvements, while negative values indicate reductions in targeted behaviors.

[b] Cohen's d ≥ 0.8 denotes a large effect size.

[c] Cohen's d ≥ 0.5 and < 0.8 denotes a medium effect size.

[d] Cohen's d ≥ 0.2 and < 0.5 denotes a small effect size.

Neuroanatomical alterations may be intimately related to the fundamental processes by which exercise interventions improve physical fitness (22, 40). By altering brain neural circuits, exercise can trigger a series of physiological reactions in muscles and organs that support neural adaptation and neuroprotection, favorably impacting both structural brain growth and functional neurocognitive processes (21, 39, 40). Exercise may also help the prefrontal cortex develop and improve tasks involving motor and perceptual abilities. Overall motor performance is improved by the gradual automation of motor skills, which is made possible by the prefrontal cortex, which is in charge of cognitive and adaptive processes (22, 32, 37). The impacts of growth hormone and insulin-like growth factor-1, which affect different physiological reactions to children's physical fitness, may also be responsible for the intervention effects seen in this study (19, 40). The effects of neurotransmitter deficits, including epinephrine, can be lessened by PA (21, 22). The adrenal medulla secretes epinephrine, which is especially crucial for tasks demanding sudden muscle strength and power because it activates the central motor system, causes peripheral vasodilation, and enhances muscle enzyme activity (29, 39, 40).

In addition to the type of intervention, the timing, duration, and frequency of the intervention can affect motor skills and physical fitness results (19, 21). The most successful sports therapies for improving motor skills in children with ADHD are 60-minute sessions held twice a week for a minimum of 12 weeks, according to review studies (21, 22, 41). Due to their generally lower levels of physical and motor preparedness compared to their TD peers, extensive training may not be suitable for these children; therefore, the frequency of interventions should be in line with their developmental capacities (21, 40). Last but not least, enhancing the developmental environment for kids' growth and learning requires offering practice opportunities (42). According to the findings of research on children with developmental disorders, these kids have no enough space for play or PA at home, which might negatively impact their overall growth factors (32, 40, 43). Therefore, the kinds of special physical exercises that were used in this research increased the physical fitness factors of ADHD children. Additionally, the lack of appropriate and effective supplies and equipment, particularly the structure and educational program for PA or movement experience, affects their movement development (18, 21, 22).

A significant limitation of this study was the inclusion of only male participants. Gender differences in motor coordination, hormonal development, and interest in PA may influence baseline performance and response to intervention (9). Some studies have shown that girls may initially have lower levels of physical fitness but show higher adherence to group-structured or socially interactive activities (10, 17). Therefore, it is suggested that future research examines the differential responses of girls and boys to in-person and virtual exercise interventions and, if necessary, adjust program designs according to gender characteristics.

The results of this study open new avenues for future studies. First, comparing VPA with traditional in-person PA could determine how the type of delivery (virtual or in-person) affects participation and outcomes. Second, expanding the sample to include children from diverse cultural, social, and geographic backgrounds would increase the generalizability of the results. Third, examining different types of PA — including team games, yoga, or dance — could help identify approaches that are more appropriate for children's interests, attention profiles, or motor abilities. Also, examining the role of parental involvement, the use of gamification, and new technologies such as augmented reality or biofeedback could play a significant role in improving program adherence and maximizing outcomes.

5.1. Conclusions

Based on the findings of this study, movement-based activities can significantly improve fitness in children with ADHD. These results underscore the importance of active participation in structured physical activities, whether in a group or individually, for these children. In this context, the supportive role of parents and schools in facilitating access to and motivating participation in such programs is fundamental. However, it is important to consider that external factors such as nutritional status, socioeconomic conditions, and access to technology may influence the outcomes of these interventions. Careful control or assessment of these factors could enhance the accuracy of the results. Improvements in motor performance can lead to increased classroom participation, enhanced self-regulation, and improved social relationships, all of which contribute to academic achievement and social functioning. Integrating physical activity into school-based or distance learning models can provide a comprehensive approach to promoting neurodevelopmental health and academic success.

5.2. Limitations

The present study has several limitations. It did not include both genders and lacked a retention test. Additionally, there was an inability to control for daily activity levels, weather conditions, sleep quantity and quality, nutrition, and rest of the subjects. Furthermore, the study did not assess potential moderating variables such as socioeconomic status or parental involvement, which could influence children's access to digital tools and their engagement in the intervention.

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Footnotes

Authors' Contribution: Study concept and design: A. S.; Analysis and interpretation of data: A. H. and A. S.; Drafting of the manuscript: A. H. and E. S.; Critical revision of the manuscript for important intellectual content: A. S. and A. H.; Statistical analysis: E. S.

Clinical Trial Registration Code: The clinical trial code of the present study is IR.SCU.REC.1404.035 .

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Data Availability: The collected and analyzed data are available and the researchers can contact the corresponding author upon request.

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