



# Effects of Augmented Reality Cognitive–Motor Training on Social Skills, Attention, and Motor Coordination in Children with Autism: A Randomized Controlled Trial

Valiollah Shahedi \*

Assistant Professor, Department of Physical Education and Sports Sciences, Pa.C., Islamic Azad University, Parand, Iran.

\*Corresponding Author: Valiollah Shahedi, Assistant Professor, Department of Physical Education and Sports Sciences, Pa.C., Islamic Azad University, Parand, Iran. Email: [dr.shahedi@iau.ac.ir](mailto:dr.shahedi@iau.ac.ir)

Received: 10 AOctober, 2025; Revised: 07 December, 2025; Accepted: 17 December, 2025; Published: 26 December, 2025.

## Abstract

**Introduction:** Augmented reality (AR) interventions offer an innovative approach to engage children with autism while fostering their motor and social skill development. By leveraging technology-driven methods, such as AR and game-based cognitive-motor training (CMT), these interventions aim to enhance skill acquisition and increase participant engagement.

**Objective:** This study sought to evaluate the effectiveness of an AR game-based CMT program on various aspects of functioning in children with autism, with a particular emphasis on social skills, attention, and motor coordination.

**Methods:** This study employed a semi-experimental design that included a practical application, utilizing a pre-test and post-test framework alongside a control group. Following a comprehensive screening process, 60 children with autism were selected as participants and randomly divided into intervention and control groups, ensuring equal representation. The intervention group engaged in AR game-based CMT sessions twice a week for eight weeks. Standardized assessment tools were used to measure the research variables, and data analysis was conducted using MANCOVA.

**Results:** The findings indicated that the AR intervention significantly enhanced social skills ( $p < 0.001$ ,  $F = 23.31$ ), attention ( $p < 0.001$ ,  $F = 18.47$ ), and motor coordination ( $p < 0.001$ ,  $F = 17.55$ ) in children with autism.

**Conclusion:** The findings of this study indicate that AR game-based CMT serves as an effective intervention for improving social skills, attention, and motor coordination in children diagnosed with autism. This study is practically and clinically important as it offers an engaging, evidence-based intervention to enhance social skills, attention, and motor coordination in children with autism, providing a useful tool for clinicians and educators.

**Keywords:** Augmented Reality, Autism, Social Skills, Motor Behavior, Attention

**How to Cite:** Shahedi V. Effects of Augmented Reality Cognitive–Motor Training on Social Skills, Attention, and Motor Coordination in Children with Autism: A Randomized Controlled Trial. *Phys. Act. Child.* 2025;2(2):41-49. doi:10.22034/pach.2025.552406.1073

## 1. Introduction

Autism, also known as Autism Spectrum Disorder (ASD), is a multifaceted neurodevelopmental disorder that manifests through a range of difficulties in social communication and interaction, as well as through distinct patterns of restricted and repetitive behaviors, interests, or activities (1,2). Notable characteristics of autism include differences in social communication, where individuals may struggle to interpret social cues, maintain eye contact, or participate in conventional conversational exchanges (3). Additionally, many autistic individuals exhibit repetitive behaviors, which can manifest as specific routines, rituals, or repetitive physical movements. Sensory sensitivities are also common, with some individuals displaying heightened or diminished reactions to sensory stimuli such as sounds, lights, textures, or odors (4). Furthermore, it is important to recognize that many individuals on the autism spectrum possess unique strengths, often demonstrating exceptional abilities in areas such as memory, pattern recognition, or analytical thinking,

which can lead to remarkable achievements in their areas of interest (5).

Attention difficulties are prevalent among individuals with autism, with research indicating that approximately 30-50% of individuals on the autism spectrum also exhibit substantial attention deficits or hyperactivity (6,7). Neurologically, autism is associated with atypical functioning in brain regions responsible for executive functions, particularly the prefrontal cortex, which plays a crucial role in regulating attention, controlling impulses, and managing working memory (8). The implications of these attentional difficulties are profound, as they can significantly hinder learning, social interactions, and everyday functioning for autistic individuals. For instance, a child with autism may find it particularly challenging to remain engaged during classroom activities or to follow complex, multi-step instructions, ultimately impacting their educational experience and social development (9).

Motor coordination difficulties are also prevalent among individuals with autism, drawing increasing



attention from researchers in the field (10). Many autistic children encounter challenges with both gross motor skills, such as running, jumping, and maintaining balance, as well as fine motor skills, which include tasks like writing, buttoning clothing, and using utensils (11). Research indicates that as many as 80% of children on the autism spectrum may exhibit some form of motor coordination impairment (11,12). These issues can manifest in various ways, including poor coordination and balance, delayed achievement of motor milestones during early childhood—such as late crawling or walking—dyspraxia or developmental coordination disorder (DCD), which involves difficulties in planning and executing movements, and fine motor challenges that hinder activities like handwriting or manipulating small objects (12). Additionally, gait abnormalities and atypical movement patterns are often observed (13). The neurological basis for these motor coordination deficits is believed to involve atypical functioning in brain regions such as the cerebellum, basal ganglia, and motor cortex, all of which play critical roles in movement planning and control (14). It has been proposed that irregular neural connectivity may interfere with the smooth execution of motor tasks (13,14). The implications of these motor difficulties extend beyond physical capabilities, impacting daily activities, independence, and social engagement. For instance, motor skills are essential for participation in playground activities and sports, which are vital for social interaction among peers. Furthermore, the challenges associated with motor coordination often intersect with sensory processing differences and attentional issues, exacerbating the overall difficulties faced by individuals with autism (15).

Recent studies have identified a range of effective interventions designed to improve social skills, attention, and motor coordination in children with autism (16,17). Notable, among these are cognitive-motor training (CMT), behavioral therapy, and, in some cases, pharmacological treatments, all of which have shown promise in enhancing attention (18,19). Additionally, mindfulness and attention training programs have emerged as valuable tools, promoting sustained attention, emotional regulation, and social responsiveness, particularly when integrated with movement practices like yoga or Tai chi to bolster motor coordination (20). Moreover, sensory-motor integration and sports-based training have demonstrated significant benefits (21). Lastly, a combined approach utilizing a music-therapy robotic platform has also shown promise, as a pilot study indicated improvements in motor control and turn-taking behaviors among children with autism, highlighting the potential of integrating robotics with therapeutic interventions (22).

Augmented Reality (AR) interventions offer innovative approach to engage children with autism while simultaneously enhancing their motor and social skills (23,24). These interventions increasingly leverage technology-driven methodologies, such as AR and game-based CMT to promote skill development and increase participant engagement (25,26). For instance, a study involving 24 children diagnosed with autism revealed that AR-based CMT led to significant improvements in executive functioning, attention, and reaction times, although it had minimal impact on restricted and repetitive behaviors (27). Additionally, another investigation explored the feasibility of

multiplayer AR games integrated with dual-task exercises, yielding notable advancements in social skills and cognitive abilities, thereby underscoring the potential efficacy of such interventions (28). Furthermore, a mobile AR neurofeedback game named "Eggly" was created to bolster social and attentional skills in children with ADHD (29). Field studies conducted with this game indicated promising outcomes, suggesting its viability as a scalable intervention for enhancing the developmental trajectories of children on the autism spectrum.

This research was designed to further examine the effectiveness of an AR game-based CMT on various aspects of children with autism including social skills, attention, and motor coordination. This research introduces several innovative aspects that set it apart from existing studies in the field of autism. Firstly, it adopts an integrated approach by simultaneously addressing social skills, attention, and motor coordination, which are often examined in isolation in previous research. This holistic intervention represents a significant advancement, as it combines these core deficits into a single, cohesive program. Secondly, the study leverages AR technology in a novel way by incorporating it into game-based CMT. While AR has been utilized in autism research, its application as a structured therapeutic tool that merges physical movement with cognitive challenges is relatively unexplored. Lastly, the focus on CMT within an AR gaming context is particularly innovative, as this area remains underrepresented in the literature concerning autism. The potential for scalability and engagement is another noteworthy aspect; traditional interventions often necessitate trained professionals and clinical settings, whereas AR-based interventions can be more accessible and engaging, making them suitable for implementation in schools or home environments. In total, the aim of this study was to explore the effects of AR game-based cognitive-motor training on social skills, attention, and motor coordination in children with autism.

## 2. Methods

### 2.1. Participants

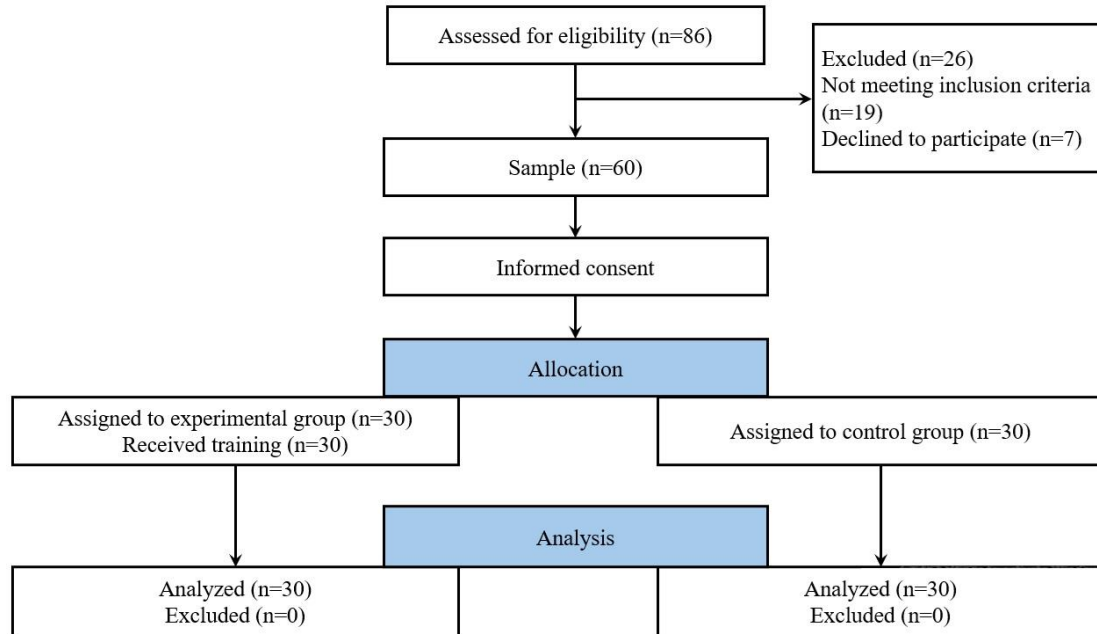
This research was conducted in compliance with the principles outlined in the Declaration of Helsinki. Prior to their children's involvement in the study, parents were provided with comprehensive information regarding the research objectives, methodologies, and potential risks. They were then required to provide written consent, ensuring that the participation of their children was both informed and voluntary.

A cohort of 60 children, aged between 6 and 12 years, was selected for this study based on their diagnosis of ASD in accordance with the criteria outlined in the DSM-5. An a priori power analysis conducted using G\*Power indicated that a minimum sample size of participants was required to detect a medium effect size with 80% power ( $\alpha = .05$ ); the study's final sample of 60 participants met this requirement. The recruitment process involved collaboration with special education institutions, ensuring a diverse representation of participants. To qualify for inclusion, children were required to exhibit mild to moderate levels of ASD severity, as determined by the Autism

Diagnostic Observation Schedule (ADOS), and to demonstrate the capacity to comprehend and follow simple instructions. Conversely, individuals were excluded from participation if they presented with severe intellectual disabilities, uncontrolled epilepsy, or significant sensory impairments, thereby ensuring that the study focused on a population that could effectively engage with the research protocols.

This research utilized a randomized controlled trial methodology, in which participants were

systematically assigned to either the intervention group or the control group (each consisted of 60 participants) through a computer-generated randomization process, ensuring allocation concealment to maintain the integrity of the trial. This design not only enhances the reliability of the findings but also allows for a rigorous comparison between the effects of the AR training and the no training experienced by the control group. Figure 1 shows the CONSORT flow diagram of the study.



**Figure 1.** CONSORT Flow Diagram of the Study

## 2.2. Measurements

### 2.2.1. Social Skills

Social skills were evaluated using the Social Responsiveness Scale, Second Edition (SRS-2) (30). The SRS-2 comprises 65 items rated on a four-point Likert scale from 0 (Not true) to 3 (Almost always true). The assessment covers five key domains: Social Awareness, Social Cognition, Social Communication, Social Motivation, Restricted Interests and Repetitive Behavior. To derive a total score, raw scores from each subscale are summed and subsequently converted into T-scores that are standardized by age and gender, facilitating comparisons with normative data. T-scores of 60 or above indicate mild to moderate social impairment, while scores of 75 or higher suggest severe social impairment, with higher scores correlating with increased severity of social deficits. In this study, eight experts yielded the reliability of this scale where Content Validity Index (CVI) and Content Validity Ratio (CVR) were 0.92 and 0.94, respectively. In addition, the reliability of the SRS-2 was assessed, yielding a Cronbach's alpha of  $\alpha=0.90$ .

### 2.2.2. Attention

Attention was evaluated using the Conners' Continuous Performance Test (CPT) (31). The CPT consists of a 14-minute task where participants engage with visual stimuli displayed on a screen, responding by pressing a key when specific target letters or images appear while refraining from responding to non-target stimuli. The CPT produces an in-depth report that

reflects the participant's answers throughout the assessment, incorporating both raw scores and standardized scores, specifically T-scores, which are benchmarked against normative data that is age- and gender-specific. This report includes several key scoring metrics that provide insight into the participant's cognitive functioning. Omissions, are indicative of challenges with sustained attention; a higher frequency of these errors suggests potential inattention. Conversely, commissions may reveal issues related to impulsivity or inadequate inhibitory control, with increased errors pointing to these concerns. The Hit Reaction Time (Hit RT) measures the average time taken (in milliseconds) to accurately identify target stimuli, where prolonged reaction times may signify slower cognitive processing or indecisiveness. Additionally, the variability in Hit RT across the test can indicate inconsistent attention or fluctuating levels of alertness, with greater variability suggesting a lack of focus. Detectability, represented by the measure  $d'$ , assesses the participant's ability to differentiate between target and non-target stimuli; lower scores in this area may reflect difficulties in recognizing relevant information. Lastly, perseverations, characterized by exceedingly rapid responses (often less than 200 milliseconds), can indicate impulsive behavior or anticipatory responses, with elevated scores suggesting a tendency to over-respond. The raw scores obtained from the CPT are subsequently transformed into T-scores, which are standardized with a mean of 50 and a standard deviation of 10. Scores exceeding 60 are generally interpreted as indicative of clinically significant

impairments in the assessed domains, and these results are contextualized against normative data that is matched by age and gender, facilitating comparisons across different individuals and groups. In this study, the reliability of the CPT was assessed, yielding a Cronbach's alpha of  $\alpha=0.88$ .

### 2.2.3. Motor Coordination

Motor coordination was evaluated using the Movement Assessment Battery for Children-2 (MABC-2) (32). The MABC-2 serves as a standardized evaluation tool aimed at identifying motor coordination challenges in children aged 3 to 16 years. The test is structured around three primary domains that evaluate distinct facets of motor skills: Manual Dexterity, Aiming and Catching, and Balance. The administration of the MABC-2 typically requires 20 to 40 minutes, depending on the child's age, and is conducted individually by trained professionals using standardized materials provided in the MABC-2 kit. Scoring involves evaluating each task based on performance metrics such as time, accuracy, or success rate, with raw scores subsequently converted into standard scores and percentile ranks derived from normative data. A Total Standard Score is computed by aggregating scores from the three domains, with percentile cut-offs indicating varying levels of motor performance: scores below the 5th percentile suggest significant motor impairment; scores between the 6th and 15th percentiles signal a risk for motor difficulties; and scores above the 16th percentile reflect typical motor performance. In this study, the reliability of the SRS-2 was assessed, yielding a Cronbach's alpha of  $\alpha=0.91$ .

### 2.3. Procedure

The research initiative began with crucial collaboration from the Special Education Department, which played a pivotal role in securing the necessary permissions to advance the study. This foundational step was followed by a comprehensive briefing session aimed at educating both students and their parents about the objectives of the research, the methodologies employed, and the specifics of the intervention's implementation. During this session, participants and their parents were provided with detailed information to ensure a clear understanding of the study's framework and anticipated outcomes. Once written consent was obtained from the parents, those in the intervention group were formally invited to engage in the AR game-based CMT program, designed to enhance their cognitive and motor skills through interactive and immersive experiences.

The intervention was specifically designed to improve social skills, attention, and motor coordination in children diagnosed with ASD (27). This innovative program immerses children in interactive AR games that seamlessly integrate cognitive challenges with physical activities, thereby fostering both mental and physical growth. The training sessions are meticulously organized to encompass various components, including cognitive tasks aimed at enhancing executive functions such as attention, memory, and problem-solving abilities. Additionally, motor tasks are incorporated to promote physical movements that refine motor coordination and control. To further enrich the training experience, dual-task activities are introduced, requiring

participants to engage in simultaneous cognitive and motor responses, which cultivates multitasking skills and enhances overall functional performance. Each training session is designed to last approximately 30 minutes and is conducted twice a week over an eight-week period, culminating in a total of sixteen sessions. In contrast, the control group received standard care, which consisted of their regular educational and therapeutic activities without the inclusion of the AR training component.

### 2.4. Statistical Analysis

To provide a comprehensive overview of the participant demographics, descriptive statistics were employed to summarize key characteristics. To assess the differences in post-intervention outcomes between the groups, while controlling for baseline measurements, Multivariate Analysis of Covariance (MANCOVA) was utilized. This statistical technique allows for the adjustment of initial scores, thereby providing a clearer understanding of the intervention's impact. Additionally, effect sizes were computed using Cohen's *d* to quantify the magnitude of the differences observed. A level for statistical significance was established at  $p < 0.05$ . SPSS version 27 was used for statistical analysis.

## 3. Results

The demographic assessment indicated that the participants had an average age of 8.67 years, accompanied by a standard deviation of 1.29 years, suggesting a relatively homogeneous age group with slight variability. In terms of physical measurements, the mean height of the participants was found to be 128.64 cm, with a standard deviation of 3.94 cm, indicating a consistent stature among the children. Furthermore, the average weight was recorded at 25.69 kg, with a standard deviation of 2.47 kg, which provides insight into the weight distribution within this cohort. These measurements culminated in a calculated body mass index (BMI) of 15.53, with a standard deviation of 0.93, reflecting the overall body composition and health status of the participants.

The results of the Kolmogorov-Smirnov test indicated that the distributions of social skills, attention, and motor coordination across different levels of the independent variable adhered to a normal distribution, as evidenced by a *p*-value greater than 0.05. Complementing this finding, the Levine test confirmed that the assumption of homogeneity of variances was upheld, also with a *p*-value exceeding 0.05. Further examination through scatter plots illustrated a linear relationship between the covariance and the posttest variables, suggesting a consistent pattern in the data. Additionally, the regression slope homogeneity test revealed that the slopes of the regression lines for both research groups were statistically similar, with a *p*-value greater than 0.05. Finally, the Box test produced non-significant results, again with a *p*-value above 0.05, which supported the assumption of equality within the variance-covariance matrix. As a result of these findings, multivariate analysis of covariance was utilized to conduct a comprehensive analysis of the data.

Table 1 displays the mean and standard deviation for social skills, attention scores, and motor

coordination across the intervention control groups during both the pre-test and post-test phases. In addition, the findings from the multivariate analysis of covariance, as detailed in Table 2, reveal that the intervention had a significant positive impact on the social skills, attention, and motor coordination of children diagnosed with autism. The analysis yielded an effect size of 0.75, with statistical significance

indicated by  $p < 0.001$  and an F-value of 59.63. This substantial effect size implies that a remarkable 75% of the variations observed in the children's social skills, attention, and motor coordination can be directly linked to the implemented intervention, underscoring its effectiveness in enhancing these critical developmental areas.

**Table 1.** The Mean Values and SD for the Research Variables Observed in both the Intervention and Control Groups.

Variable	Test	Intervention		Control	
		Mean	SD	Mean	SD
<b>Social skills</b>					
Social Awareness	Pre-test	58.64	5.22	57.96	5.95
	Post-test	52.37	4.19	57.54	5.14
Social Cognition	Pre-test	63.13	8.73	64.02	7.43
	Post-test	55.27	7.37	63.85	7.42
Social Communication	Pre-test	58.49	6.42	58.24	5.83
	Post-test	53.08	5.76	58.36	5.27
Social Motivation	Pre-test	54.28	7.11	55.21	8.42
	Post-test	49.88	6.35	54.80	7.43
Restricted Interests and Repetitive Behaviors	Pre-test	62.55	9.58	63.25	8.58
	Post-test	55.69	7.47	64.28	8.90
Total Score	Pre-test	59.41	7.59	59.73	6.93
	Post-test	52.45	6.94	59.84	7.42
<b>Attention</b>					
Omission	Pre-test	14.25	13.72	14.12	12.76
	Post-test	16.86	12.41	14.18	11.83
Commission	Pre-test	27.44	6.35	27.93	7.22
	Post-test	24.11	5.27	27.55	7.01
Hit RT	Pre-test	356.27	95.68	352.44	90.35
	Post-test	327.44	88.95	355.27	88.96
Overall index	Pre-test	7.8	6.5	7.7	5.9
	Post-test	7.1	5.8	7.8	5.7
<b>Motor Coordination</b>					
Manual Dexterity	Pre-test	4.82	1.86	4.79	1.74
	Post-test	6.57	2.23	4.75	1.66
Aiming and Catching	Pre-test	5.17	2.63	5.14	2.20
	Post-test	6.97	2.84	5.16	1.91
Balance	Pre-test	5.73	3.42	5.69	2.41
	Post-test	7.84	3.95	5.60	2.32
Total Score	Pre-test	4.25	2.47	4.21	2.27
	Post-test	6.21	3.13	4.24	2.82

**Table 2.** Results of MANCOVA Based on the Wilks' Lambda Report.

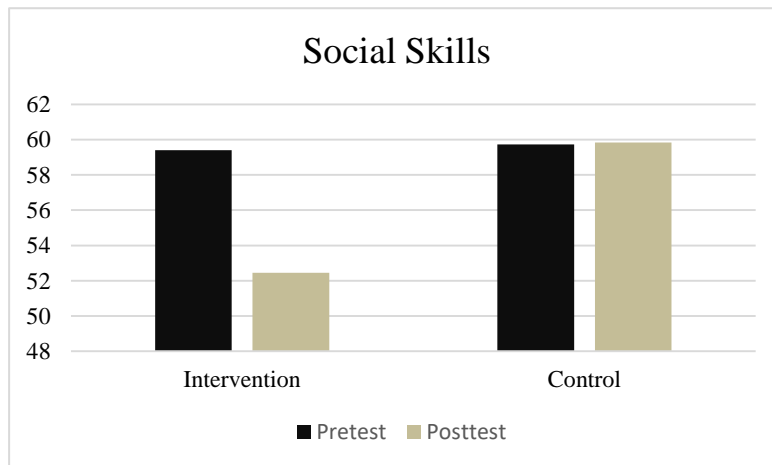
Effect	Statistical Value	F-Value	Hypothesis df	Error df	Sig.	Effect Size
Group	0.125	59.63	3	55	<0.001	0.75

The results of the multivariate MANCOVA, as shown in Table 3, reveal a significant difference in the adjusted mean total score for social skills between the intervention group and the control group, with scores of 52.45 and 59.84, respectively. This difference is statistically significant, evidenced by a partial eta squared value of 0.17 ( $p < 0.001$ ,  $F = 23.31$ ), indicating that the intervention had a significant positive impact on enhancing social skills in children with autism (Figure 2). Furthermore, the analysis highlighted a significant difference in the adjusted mean overall index for attention, where the intervention group achieved a score of 7.1, in contrast to the control group's score of 7.8. This finding, supported by a partial  $\eta^2$  of 0.13 ( $p < 0.001$ ,  $F = 18.47$ ), reinforces the effectiveness of the intervention in improving attention among the same

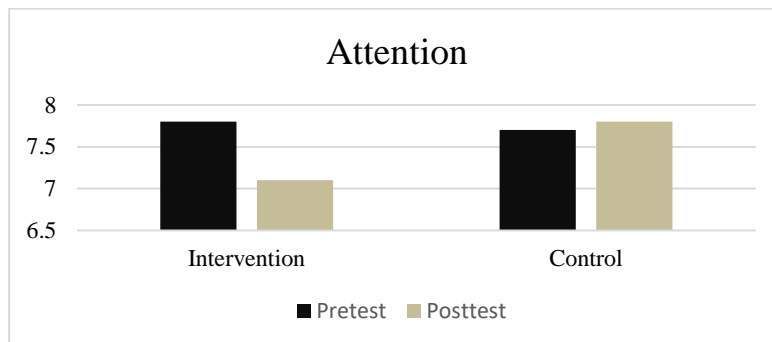
demographic (Figure 3). Lastly, the analysis also identified a significant difference in the total score for motor coordination, with the intervention group averaging 6.21 compared to 4.24 for the control group. This result, with a partial  $\eta^2$  of 0.13 ( $p < 0.001$ ,  $F = 17.55$ ), further underscores the intervention's efficacy in fostering significant improvements in motor coordination skills among children with autism (Figure 4).

**Table 3.** Results of MANCOVA.

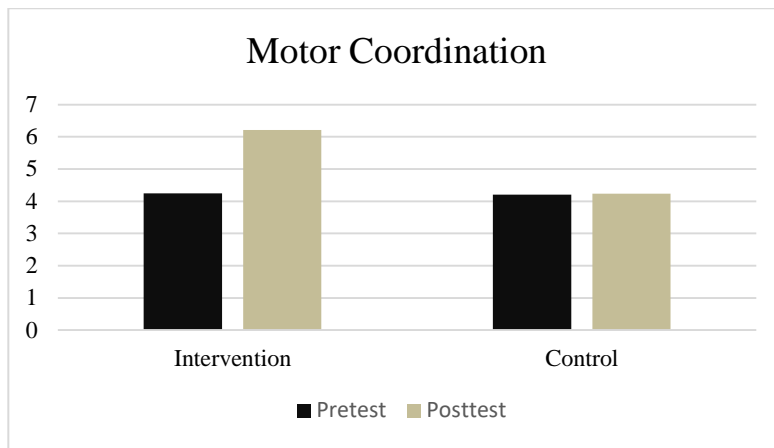
Variable	Effect	SS	df	MS	F-Value	Sig.	Effect Size
<b>Social skills</b>							
Social Awareness	Group	39.71	1	39.71	15.47	<0.001	0.11
	Error	80.41	57	9.64			
Social Cognition	Group	14.25	1	14.25	22.64	<0.001	0.15
	Error	17.54	57	3.85			
Social Communication	Group	33.64	1	33.64	18.94	<0.001	0.13
	Error	75.48	57	4.74			
Social motivation	Group	25.64	1	25.64	25.41	<0.001	0.19
	Error	56.94	57	7.44			
Restricted Interests and Repetitive Behaviors	Group	27.41	1	27.41	16.94	<0.001	0.12
	Error	66.39	57	5.31			
Total Score	Group	29.68	1	29.68	23.31	<0.001	0.17
	Error	70.14	57	6.41			
<b>Attention</b>							
Omission	Group	25.41	1	25.41	15.96	<0.001	0.11
	Error	69.84	57	3.42			
Commission	Group	20.13	1	20.13	26.74	<0.001	0.20
	Error	54.28	57	5.61			
Hit RT	Group	33.64	1	33.64	20.31	<0.001	0.16
	Error	92.42	57	4.88			
Overall index	Group	25.69	1	25.69	18.47	<0.001	0.13
	Error	69.48	57	6.94			
<b>Motor Coordination</b>							
Manual Dexterity	Group	20.33	1	20.33	15.74	<0.001	0.11
	Error	71.41	57	5.74			
Aiming and Catching	Group	18.43	1	18.43	23.96	<0.001	0.19
	Error	59.67	57	4.39			
Balance	Group	23.64	1	23.64	18.74	<0.001	0.13
	Error	66.54	57	7.94			
Total Score	Group	20.41	1	20.41	17.55	<0.001	0.13
	Error	72.47	57	5.83			



**Figure 2.** The Pretest-Posttest Scores of Social Skills in the Intervention and Control Groups.



**Figure 3.** The Pretest-Posttest Scores of Attention in the Intervention and Control Groups.



**Figure 4.** The Pretest-Posttest Scores of Motor Coordination in the Intervention and Control Groups.

#### 4. Discussion

AR interventions present a novel strategy for engaging children with autism, while also promoting the development of their motor and social skills. These interventions increasingly utilize technology-based approaches, such as AR and game-oriented motor training, to facilitate skill acquisition and enhance participant involvement. This study aimed to investigate the effectiveness of an AR game-based CMT program on various dimensions of functioning in children with autism, specifically focusing on social skills, attention, and motor coordination. The findings indicated a statistically significant improvement in the overall social skills scores of the intervention group compared to the control group, suggesting that the AR intervention effectively bolstered social capabilities among children with autism. Additionally, the analysis revealed a notable enhancement in attention, further affirming the intervention's role in improving attentional capacities within this population. Furthermore, the results demonstrated a significant increase in motor coordination scores, highlighting the intervention's success in fostering substantial advancements in motor skills among children with autism. These outcomes align with existing literature (27-29) that underscores the multifaceted benefits of AR game-based CMT in enhancing social skills, attention, and motor coordination in children on the autism spectrum.

The findings indicated a statistically significant improvement in the overall social skills scores of the intervention group compared to the control group, suggesting that the AR intervention effectively bolstered social capabilities among children with autism. To interpret these findings, it can be stated that one of the key features of AR is its ability to create immersive and interactive social scenarios that simulate real-life interactions. These virtual environments provide a safe and controlled space for children to practice essential social behaviors, such as taking turns, recognizing facial expressions, and interpreting social cues (22). By engaging in these scenarios, children can develop their social skills without the anxiety often associated with real-world interactions, allowing for a more relaxed learning experience. Furthermore, AR's multi-sensory learning approach, which combines visual, auditory, and sometimes tactile feedback, plays a crucial role in helping children with ASD process and respond to

social information more effectively (23,24). This multi-faceted stimulation not only enhances their understanding of social dynamics but also strengthens the neural pathways associated with social cognition, ultimately fostering improved social interactions and relationships.

In addition, the findings indicated a statistically significant improvement in the overall attention scores of the intervention group compared to the control group, suggesting that the AR intervention effectively bolstered attentional capabilities among children with autism. To interpret these findings, it can be stated that one of the primary advantages of AR games is their ability to foster sustained engagement via interactive gameplay. Unlike traditional educational methods, AR games create immersive experiences that captivate children's interest for extended periods (26,28). The vibrant and dynamic environments inherent in these games effectively mitigate feelings of boredom and distraction, thereby promoting prolonged attention spans. Furthermore, many AR interventions are designed with incremental difficulty levels that adapt to the child's performance, allowing for a gradual increase in challenges. This tailored approach not only enhances attention control mechanisms but also bolsters cognitive endurance without overwhelming the child (23,24). Additionally, the multi-sensory stimulation provided by AR-integrating visual, auditory, and sometimes tactile elements—activates various sensory pathways, which can be particularly beneficial for children with atypical sensory processing. The immediate feedback and reinforcement mechanisms embedded in these games, such as points, sounds, and visual effects, serve to validate correct responses and encourage sustained focus, thereby motivating children to remain engaged with the tasks at hand (22,25). Moreover, the dual-task training aspect of AR, which simultaneously engages cognitive and motor systems, necessitates heightened attentional control, ultimately strengthening the neural networks responsible for attention. This practice of divided or selective attention within a game context can lead to improved attentional skills in everyday life. Lastly, AR environments can be meticulously designed to minimize external distractions, creating a controlled setting that allows children to concentrate more effectively on relevant tasks, thereby reducing the likelihood of attentional lapses (26,27).

Finally, the findings indicated a statistically significant improvement in the overall motor coordination scores of the intervention group compared to the control group, suggesting that the AR intervention effectively bolstered motor coordination capabilities among children with autism. To interpret these findings, it can be stated that AR-CMT significantly enhances motor coordination in children with autism by engaging them in goal-directed movements. Through AR games, children are prompted to execute specific physical tasks such as reaching, grasping, balancing, or stepping in response to visual stimuli. These targeted actions foster purposeful and controlled motor responses, which are essential for improving overall coordination (27,28). Furthermore, the AR system offers real-time visual and auditory feedback regarding the accuracy, timing, and force of their movements. This immediate feedback allows children to make necessary adjustments to their motor output, thereby facilitating motor learning and the fine-tuning of their movements. The design of these tasks encompasses both gross motor skills - such as balance, walking, and jumping - and fine motor skills, including hand-eye coordination and finger dexterity (25,27). By providing a fun and interactive environment for repeated practice, AR training promotes the development of motor skills across these various domains. Additionally, the multi-sensory integration offered by AR environments, which includes visual, auditory, and sometimes tactile cues, aids children in processing sensory information crucial for executing smooth and coordinated movements. Enhanced sensory processing contributes to improved motor planning and execution (23,24). The progressive nature of task difficulty in AR training allows for a gradual increase in complexity, which challenges motor control while encouraging continuous improvement without overwhelming the child. This structured progression is instrumental in building strength, balance, coordination, and motor planning skills over time (22,26). Moreover, the gamified and interactive aspects of AR significantly boost motivation, encouraging children to engage in motor activities that they might otherwise perceive as repetitive or challenging. Increased engagement leads to more practice opportunities, ultimately resulting in better motor outcomes (27). Lastly, many AR tasks necessitate the use of both sides of the body or require maintaining balance during movement, thereby enhancing bilateral coordination and core stability, which are critical components of overall motor function (27,28).

This study has several strengths and limitations. Among its strengths, it employed a randomized controlled trial design and included a clearly defined intervention, which enhances the internal validity and allows for a more rigorous examination of the effects of augmented reality game-based cognitive-motor training. The study also addressed multiple outcomes - social skills, attention, and motor coordination - providing a comprehensive view of its impact. However, limitations include the relatively small sample size ( $n = 60$ ), which may limit the generalizability of the findings, and the short duration of the intervention, which prevents conclusions about long-term effects. Additionally, reliance on standardized assessments and observational measures may introduce measurement bias. Despite these limitations, the study provides valuable preliminary

evidence supporting the practical use of augmented reality interventions for children with autism.

#### 4.1. Conclusion

The findings of this study indicate that AR game-based CMT serves as an effective intervention for improving social skills, attention, and motor coordination in children diagnosed with autism. This method is not only easy to implement but also necessitates only minor modifications to current educational frameworks. To build on these promising results, future research should investigate strategies for seamlessly integrating game-based cognitive-motor activities into educational environments specifically designed for students with special needs, including those on the autism spectrum. One promising direction for this integration is the miniaturization of these exercises, which could enhance their adaptability within the classroom setting while simultaneously maximizing their positive impact on the developmental outcomes of these children.

Based on the findings, it is recommended that clinicians, educators, and therapists consider incorporating augmented reality game-based cognitive-motor training into intervention programs for children with autism. Such interventions can be used to enhance social skills, attention, and motor coordination in an engaging and motivating way. Schools and therapy centers should provide appropriate training and resources to ensure effective implementation, and future programs could integrate these tools alongside traditional therapies to maximize functional outcomes in daily activities.

#### Acknowledgments

The author is grateful to all participants who took part in this research.

#### Footnotes

**Authors' Contribution:** This study was carried out solely by the corresponding author.

#### Conflicts of Interest

Non to declare.

**Data Availability:** The data that support the findings of this study are openly available upon request from the corresponding author.

**Ethical Approval:** This study was conducted in accordance with the ethical guidelines outlined in the Declaration of Helsinki and received approval from the University Ethics Committee (Code: IR.IAU.PIAU.REC.1403.010). Informed consent was secured from all participants as well as their guardians.

#### Funding Support

This study received no grant.

**Informed Consent:** Informed written consent was obtained from all participants

**Supplementary information** accompanies this paper at doi: 10.22034/pach.2025.552406.1073

#### ORCID iD

Valiollah Shahedi  <https://orcid.org/0000-0001-9046-8341>

## References

- Hodges H, Fealko C, Soares N. Autism spectrum disorder: definition, epidemiology, causes, and clinical evaluation. *Transl Pediatr.* 2020;**9**(1):55-65. [PubMed ID: 32206584]. [PubMed Central ID: PMC7082249] <https://doi.org/10.21037/tp.2019.09.09>
- Dana A, Rezaei R, Shams A. The effects of active game intervention and Exergames on the executive function of high-functioning Autistic children. *Shenakht.* 2021;**8**(5):113-125. <http://dx.doi.org/10.32598/shenakht.8.5.113>
- Rafiee S. Effect of an Intervention Based on the Picture Exchange Communication System in Physical Education on Physical Activity and Social Skills of Children with Autism. *Phys Act Child.* 2025;**2**(1):20-25. <https://doi.org/10.61882/pach.2025.514405.1046>
- Baniasadi T, Ranjbari S, Khajaeaflootoon Mofrad S, Ghorbani S. Exploring the Associations Between Physical Activity and Happiness in Children with Autism: The Mediating Role of Mental Health. *Int J Sch Health.* 2023;**10**(4):181-188. <https://doi.org/10.30476/intjsh.2023.98615.1305>
- Halder S, Bruyere SM, Gower WS. Understanding strengths and challenges of people with autism: insights from parents and practitioners. *Int J Dev Disabil.* 2022;**70**(1):74-88. [PubMed ID: 38456143]. [PubMed Central ID: PMC10916907] <https://doi.org/10.1080/20473869.2022.2058781>
- Al Ghamdi K, AlMusailhi J. Attention-deficit Hyperactivity Disorder and Autism Spectrum Disorder: Towards Better Diagnosis and Management. *Med Arch.* 2024;**78**(2):159-163. [PubMed ID: 38566879]. [PubMed Central ID: PMC10983102] <https://doi.org/10.5455/medarch.2024.78.159-163>
- Leitner Y. The co-occurrence of autism and attention deficit hyperactivity disorder in children - what do we know? *Front Hum Neurosci.* 2014;**8**:268. [PubMed ID: 24808851]. [PubMed Central ID: PMC4010758] <https://doi.org/10.3389/fnhum.2014.00268>
- Cundari M, Vestberg S, Gustafsson P, Gorcenco S, Rasmussen A. Neurocognitive and cerebellar function in ADHD, autism and spinocerebellar ataxia. *Front Syst Neurosci.* 2023 Jun 21;17:1168666. [PubMed ID: 37415926]. [PubMed Central ID: PMC10321758] <https://doi.org/10.3389/fnsys.2023.1168666> Erratum in: *Front Syst Neurosci.* 2024;**18**:1462062. <https://doi.org/10.3389/fnsys.2024.1462062>
- Hours C, Recasens C, Baleyte JM. ASD and ADHD Comorbidity: What Are We Talking About? *Front Psychiatry.* 2022;**13**:837424. [PubMed ID: 35295773]. [PubMed Central ID: PMC8918663] <https://doi.org/10.3389/fpsy.2022.837424>
- Miller HL, Licari MK, Bhat A, Aziz-Zadeh LS, Van Damme T, Fears NE, Cermak SA, Tamplain PM. Motor problems in autism: Co-occurrence or feature? *Dev Med Child Neurol.* 2024;**66**(1):16-22. [PubMed ID: 37332143]. [PubMed Central ID: PMC10725993] <https://doi.org/10.1111/dmcn.15674>
- Bhat AN. Motor Impairment Increases in Children With Autism Spectrum Disorder as a Function of Social Communication, Cognitive and Functional Impairment, Repetitive Behavior Severity, and Comorbid Diagnoses: A SPARK Study Report. *Autism Res.* 2021;**14**(1):202-219. [PubMed ID: 33300285]. [PubMed Central ID: PMC8176850] <https://doi.org/10.1002/aur.2453>
- Wang LAL, Petrulla V, Zampella CJ, Waller R, Schultz RT. Gross motor impairment and its relation to social skills in autism spectrum disorder: A systematic review and two meta-analyses. *Psychol Bull.* 2022;**148**(3-4):273-300. [PubMed ID: 35511567]. [PubMed Central ID: PMC9894569] <https://doi.org/10.1037/bul0000358>
- Karadaş C, Bakkaloglu H, Demir Ş. Exploring the effect of motor coordination on repetitive behaviours in children with autism spectrum disorder. *Int J Dev Disabil.* 2021;**69**(2):238-247. [PubMed ID: 37025329]. [PubMed Central ID: PMC10071942] <https://doi.org/10.1080/20473869.2021.1948318>
- Yoshida J, Onate M, Khatami L, Vera J, Nadim F, Khodakhah K. Cerebellar Contributions to the Basal Ganglia Influence Motor Coordination, Reward Processing, and Movement Vigor. *J Neurosci.* 2022;**42**(45):8406-8415. [PubMed ID: 36351826]. [PubMed Central ID: PMC9665921] <https://doi.org/10.1523/jneurosci.1535-22.2022>
- Wen L, Wu Z. The impact of sensory integration based sports training on motor and social skill development in children with autism spectrum disorder. *Sci Rep.* 2025;**15**(1):19974. [PubMed ID: 40481216]. [PubMed Central ID: PMC12144193] <https://doi.org/10.1038/s41598-025-05393-3>
- Alahmari FS, Alhabbad AA, Alshamrani HA, Almuqbil MA. Effectiveness of social skills training interventions for children with autism spectrum disorder: A systematic review and meta-analysis. *Saudi Med J.* 2025;**46**(3):226-237. [PubMed ID: 40096975]. [PubMed Central ID: PMC11918677] <https://doi.org/10.15537/smj.2025.46.3.20240788>
- Xing Y, Wu X. Effects of Motor Skills and Physical Activity Interventions on Motor Development in Children with Autism Spectrum Disorder: A Systematic Review. *Healthcare (Basel).* 2025;**13**(5):489. [PubMed ID: 40077051]. [PubMed Central ID: PMC11899540] <https://doi.org/10.3390/healthcare13050489>
- Chung KM, Chung E, Lee H. Behavioral Interventions for Autism Spectrum Disorder: A Brief Review and Guidelines With a Specific Focus on Applied Behavior Analysis. *J Korean Acad Child Adolesc Psychiatry.* 2024;**35**(1):29-38. [PubMed ID: 38204739]. [PubMed Central ID: PMC10774556] <https://doi.org/10.5765/jkacap.230019>
- Busti Ceccarelli S, Ferrante C, Gazzola E, Marzocchi GM, Nobile M, Molteni M, Crippa A. Fundamental Motor Skills Intervention for Children with Autism Spectrum Disorder: A 10-Year Narrative Review. *Children (Basel).* 2020;**7**(11):250. [PubMed ID: 33238562]. [PubMed Central ID: PMC7700578] <https://doi.org/10.3390/children7110250>
- Simione L, Frolli A, Sciatella F, Chiarella SG. Mindfulness-Based Interventions for People with Autism Spectrum Disorder: A Systematic Literature Review. *Brain Sci.* 2024;**14**(10):1001. [PubMed ID: 39452015]. [PubMed Central ID: PMC11506216] <https://doi.org/10.3390/brainsci14101001>
- Homayounnia Firouzjah M, Majidi Yaeichi N, Hematnia R. The Effectiveness of Sensory-Motor Integration Exercises on Social Skills and Motor Performance in Children with Autism. *J Autism Dev Disord.* 2025;**55**(5):1902-1909. [PubMed ID: 38565778]. <https://doi.org/10.1007/s10803-024-06325-2>
- Feng H, Mahoor MH, Dino F. A Music-Therapy Robotic Platform for Children With Autism: A Pilot Study. *Front Robot AI.* 2022 May 23;9:855819. doi:10.3389/frobt.2022.855819. Erratum in: *Front Robot AI.* 2022;**9**:965369. [PubMed ID: 35677082]. [PubMed Central ID: PMC9169087] <https://doi.org/10.3389/frobt.2022.855819>
- Fuentes C, Gómez S, De Stasio S, Berenguer C. Augmented Reality and Learning-Cognitive Outcomes in Autism Spectrum Disorder: A Systematic Review. *Children (Basel).* 2025;**12**(4):493. [PubMed ID: 40310103]. [PubMed Central ID: PMC12026450] <https://doi.org/10.3390/children12040493>
- Dechsling A, Orm S, Kalandadze T, Sütterlin S, Øien RA, Shic F, Nordahl-Hansen A. Virtual and Augmented Reality in Social Skills Interventions for Individuals with Autism Spectrum Disorder: A Scoping Review. *J Autism Dev Disord.* 2022;**52**(11):4692-4707. [PubMed ID: 34783991]. [PubMed Central ID: PMC9556391] <https://doi.org/10.1007/s10803-021-05338-5>
- Cheng Y, Bololia L. The Effects of Augmented Reality on Social Skills in Children with an Autism Diagnosis: A Preliminary Systematic Review. *J Autism Dev Disord.* 2024;**54**(4):1317-1331. [PubMed ID: 36633722]. <https://doi.org/10.1007/s10803-022-05878-4>
- Denizli-Gulboy H, Genc-Tosun D, Gulboy E. Evaluating augmented reality as evidence-based practice for individuals with autism spectrum disorder: a meta-analysis of single-case design studies. *Int J Dev Disabil.* 2021;**69**(4):472-486. [PubMed ID: 37346255]. [PubMed Central ID: PMC10281417] <https://doi.org/10.1080/20473869.2021.1972741>
- Nekar DM, Lee DY, Hong JH, Kim JS, Kim SG, Seo YG, Yu JH. Effects of Augmented Reality Game-Based Cognitive-Motor Training on Restricted and Repetitive Behaviors and Executive Function in Patients with Autism Spectrum Disorder. *Healthcare (Basel).* 2022;**10**(10):1981. [PubMed ID: 36292426]. [PubMed Central ID: PMC9602056] <https://doi.org/10.3390/healthcare10101981>
- Nekar DM, Kang H, Alao H, Yu J. Feasibility of Using Multiplayer Game-Based Dual-Task Training with Augmented Reality and Personal Health Record on Social Skills and Cognitive Function in Children with Autism. *Children (Basel).* 2022;**9**(9):1398. [PubMed ID: 36138707]. [PubMed Central ID: PMC9497827] <https://doi.org/10.3390/children9091398>
- Kwon SY, Seo G, Jang M, Shin H, Choi W, Lim YB, Shin MS, Kim BN. The Effect of Mobile Neurofeedback Training in Children with Attention Deficit Hyperactivity Disorder: A Randomized Controlled Trial. *Clin Psychopharmacol Neurosci.* 2024;**22**(1):67-78. [PubMed ID: 38247413]. [PubMed Central ID: PMC10811401] <https://doi.org/10.9758/cpn.23.1054>
- Carty A, Green R, Goodman CV, McLaughlin JR, Hu H, Lanphear B, Muckle G, Till C. Performance of the Social Responsiveness Scale-2 for the Assessment of Autistic Behaviors in a Sample of Canadian Preschool-Aged Children. *J Autism Dev Disord.* 2024;**10**.1007/s10803-024-06487-z. [PubMed ID: 39102070]. [PubMed Central ID: PMC11794590] <https://doi.org/10.1007/s10803-024-06487-z>
- Tullo D, Levy B, Faubert J, Bertone A. Characterizing Attention Resource Capacity in Autism: A Multiple Object Tracking Study. *J Autism Dev Disord.* 2024;**54**(8):2802-2815. [PubMed ID: 37344729]. [PubMed Central ID: PMC11300490] <https://doi.org/10.1007/s10803-023-05974-z>
- Higashionna T, Iwanaga R, Tokunaga A, Nakai A, Tanaka K, Tanaka G. The Relationship between Motor Coordination Ability, Cognitive Ability, and Academic Achievement in Japanese Children with Autism Spectrum Disorder and Attention Deficit/Hyperactivity Disorder. *Brain Sci.* 2022;**12**(5):674. [PubMed ID: 35625060]. [PubMed Central ID: PMC9140156] <https://doi.org/10.3390/brainsci12050674>