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Original Article

Circuit-based coordinative approach and cognitive-motor performance in children with level 1 autism spectrum disorder: an observational pilot study

Abordagem coordenativa em circuito e desempenho cognitivo-motor de crianças com Transtorno do Espectro Autista nível 1: estudo piloto observacional

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Abstract

Introduction: Innovative interventions are important to support functional improvements in children with autism spectrum disorder (ASD). **Objective:** To investigate the effects of 12 weeks of a circuit-based coordinative approach (CCA) on cognitive–motor performance in children with level 1 ASD. **Method:** Seven male children aged 7 to 12 years participated. The CCA was delivered twice weekly in 70-minute sessions. For diagnostic, attentional, and behavioral assessments, the Autism Treatment Evaluation Checklist (ATEC), the Swanson, Nolan and Pelham Rating Scale–IV (SNAP-IV), and the Childhood Autism Rating Scale (CARS) were administered, respectively. Postural control was measured using a force platform under eyes-open (EO) and eyes-closed (EC) conditions. A model motor circuit (MMC) was used to assess motor coordination. Paired *t*-tests and generalized estimating equations were used for statistical analysis ($p < 0.05$). **Results:** The children were confirmed as level 1 ASD. After the intervention, improvements were observed in cognitive-behavioral scores (ATEC) ($p = 0.022$) and inattentiveness scores (SNAP-IV) ($p = 0.036$), whereas hyperactivity showed no significant change ($p = 0.078$). Regarding balance, center-of-pressure sway area decreased under EC ($p = 0.026$), and mean velocity decreased under EO and EC ($p < 0.001$). Errors and completion time decreased on the MMC (from 3:14 min to 1:18 min). **Conclusion:** The CCA significantly improved cognitive and attentional performance, postural stability, and motor coordination in children with level 1 ASD, and it may represent a feasible, low-cost, nonpharmacological strategy to promote functional development in this population.

Keywords: Autism Spectrum Disorder, Cognition, Psychomotor Performance, Postural Balance.

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Resumo

Introdução: Intervenções inovadoras são importantes para apoiar melhorias funcionais em crianças com Transtorno do Espectro Autista (TEA). **Objetivo:** Investigar os efeitos de 12 semanas de uma Abordagem Coordenativa em Circuito (ACC) no desempenho cognitivo-motor de crianças com TEA nível 1. **Método:** Participaram do estudo sete crianças do sexo masculino, com idades de 7 a 12 anos. A ACC foi realizada duas vezes por semana, com sessões de 70 minutos. Para as avaliações diagnóstica, atencional e comportamental foram aplicadas, respectivamente, a Escala de Avaliação do Tratamento do Autismo (ATEC), a Escala de Avaliação Swanson, Nolan e Pelham – versão IV (SNAP-IV) e a Escala de Avaliação do Autismo Infantil (CARS). O controle postural foi mensurado por meio de uma plataforma de força, sob condições de olhos abertos (OA) e olhos fechados (OF). Um Circuito Motor Modelo (CMM) foi utilizado para avaliar a coordenação motora. Testes *t* pareados e equações de estimativa generalizadas foram utilizadas para análise estatística ($p < 0,05$). **Resultados:** As crianças foram confirmadas dentro do espectro nível 1. Após a intervenção, houve melhora nos escores cognitivo-comportamentais (ATEC) ($p = 0,022$) e nos escores de desatenção (SNAP-IV) ($p = 0,036$), enquanto a hiperatividade não apresentou alteração significativa ($p = 0,078$). Em relação ao equilíbrio, houve redução na área de oscilação do centro de pressão com OF ($p = 0,026$) e na velocidade média com OA e OF ($p < 0,001$). Observou-se redução dos erros e do tempo de conclusão (de 3:14 min para 1:18 min) no CMM. **Conclusão:** A intervenção ACC melhorou significativamente o desempenho cognitivo e atencional, a estabilidade postural e a coordenação motora em crianças com TEA nível 1, podendo ser uma estratégia não farmacológica viável e de baixo custo para promover o desenvolvimento funcional nessa população.

Palavras-chave: Transtorno do Espectro do Autismo, Cognição, Desempenho Psicomotor, Equilíbrio Postural.

Introduction

Autism spectrum disorder (ASD) is characterized by persistent deficits in social communication, repetitive behaviors, and motor difficulties, which substantially affect everyday functioning and quality of life (Ben Hassen et al., 2023). In addition to cognitive and social differences, children with ASD often present deficits in motor coordination, postural control, and attentional regulation, which directly influence their participation in everyday activities and occupational performance (Matsukura, 1998; Stins & Emck, 2018; Bhat, 2020).

The relationship between motor function and cognitive-behavioral performance has been widely discussed, suggesting that motor difficulties in children with ASD are not isolated but rather part of a broader neurofunctional profile in which postural instability, inattention, and difficulties in motor planning may coexist (Iuculano et al., 2020; Leisman et al., 2023; Gao et al., 2024). These difficulties have been associated with dysfunctions in brain areas responsible for sensorimotor integration and attentional control, such as the prefrontal cortex, basal ganglia, and cerebellum (Subramanian et al., 2017).

With respect to postural control, children with ASD tend to show greater variability in postural stability, reflecting less efficient sensory integration and deficits in motor adjustment (Abdel Ghafar et al., 2022; Ferreiro-Pérez et al., 2024). This impairment may directly affect these children's safety and autonomy during basic activities and social interactions, making it essential to incorporate interventions that promote motor development and postural control.

A circuit-based coordinative approach (CCA) may be a way to stimulate motor and functional skills by improving coordination, postural control, and self-regulation. A previous study indicated that this approach can modulate variability in neuromotor function in older adults (Gonçalves et al., 2020), but its impact in children with ASD has not yet been investigated. By structuring progressively challenging activities in a predictable format, this approach facilitates motor adaptation, reduces sensory overload, and promotes functional engagement, which are essential for children with ASD (Shi & Feng, 2022; Marcilla-Jordá et al., 2025). Moreover, there is evidence that interventions that improve movement precision and organization can positively affect behavioral regulation and the ability to sustain attention in these children (Hou et al., 2024; Tan et al., 2016).

Another relevant aspect of this approach is the structuring of the motor environment, which allows children to adjust their movements in response to spatial and temporal stimuli. This process may contribute to the development of emotional and behavioral self-regulation, because predictability and improved coordination help reduce impulsiveness and promote greater organization of motor and cognitive responses (Vasilopoulos & Ellefson, 2021; Nicholson et al., 2021).

In this context, this study aims to investigate the effects of a 12-week circuit-based coordinative program delivered twice weekly on motor, attentional, and behavioral performance in children with level 1 ASD. According to the Diagnostic and Statistical Manual of Mental Disorders, 5th edition (DSM-5; American Psychiatric Association, 2022), ASD is classified into three severity levels based on the need for support in social communication and restricted and repetitive behaviors. Level 1 represents the mildest level of the spectrum and is characterized by individuals who require support but generally have functional language, autonomy in everyday activities, and the ability to learn at school with specialized support.

The present study is based on the progression of coordinative activities and aims not only to improve postural stability and coordination but also to yield potential benefits in attention and functional engagement, which are essential for autonomy and social participation in this population.

Materials and Method

Study design

This study is part of a randomized clinical trial registered in the Brazilian Registry of Clinical Trials (ReBEC: RBR-54k8gnf) titled "Effect of virtual reality education and coordinative exercise on cognitive, motor, and psychosocial parameters in children with mild autism spectrum disorder (ASD)". The main trial included two intervention types: virtual reality education and coordinative exercises. This study presents a subanalysis focused on the coordinative arm and aims to investigate the effects of 12 weeks of coordinative activities on the participating children's motor, attentional, and behavioral performance.

A single-group quasi-experimental design was used, with pre- and post-intervention assessments, constituting a pilot, exploratory study derived from the main trial and focused on feasibility and effect trends. The study was conducted between March and August 2018, approved by the Ethics Committee of the Federal University of São Francisco Valley (UNIVASF) (opinion No. 2.496.875), and conducted following the STROBE guidelines and the CONSORT extension for pilot and feasibility trials (Eldridge et al., 2016).

Participant recruitment

The CCA-based education program was advertised in public and private educational institutions in Petrolina, Pernambuco; in associations of mothers of children with autism in the Vale do São Francisco; in private clinics; through flyers, personal invitations, and social media platforms such as Facebook and WhatsApp; and through radio and television. A total of 48 families expressed interest in the study. After an explanation of the program's potential benefits, 11 families agreed to participate. Of the remaining families, 26 did not have a complete diagnosis, eight had scheduling conflicts, and three chose not to participate. The intervention lasted 12 weeks, was delivered twice weekly, and was conducted in collaboration with the Physical Education Department of UNIVASF in Petrolina, Pernambuco.

Inclusion criteria

To be eligible, participants had to be male, aged 7 to 12 years, have an ASD diagnosis confirmed by a pediatric neurologist or psychiatrist, have written informed consent signed by a legal guardian, and provide verbal assent. In addition, participants had to be classified as having mild ASD, currently corresponding to level 1, according to the DSM-5-TR (American Psychiatric Association, 2022).

Non-inclusion criteria

Non-inclusion criteria were comorbidities such as attention-deficit/hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), epilepsy, or intellectual disability, as well as any condition that prevented participation in physical exercise. Participants also had to be free of physical limitations that could hinder performance of the activities, have verbal communication skills, and not be using medications that could interfere with test performance, such as beta-blockers.

Exclusion criteria

Participants were excluded if they missed three consecutive sessions or more than 20% of sessions, arrived late frequently enough to compromise the progression of the program, or showed difficulty understanding the procedures. Figure 1 presents the study flow diagram.

In this study, assessments were performed to measure cognitive, behavioral, motor, and postural variables in children with level 1 ASD. The selected instruments were designed to capture changes in key domains related to the intervention, such as postural control, attention, behavior, motor functioning, and task engagement.

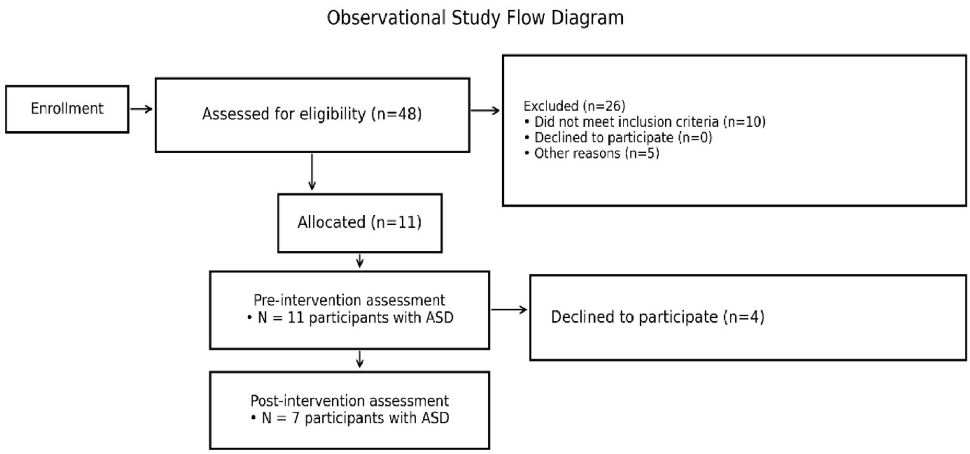

Figure 1. Flow diagram of the observational study.
Source: Prepared by the authors based on the study data. Pernambuco, 2025.

The following instruments were used in this study: The Childhood Autism Rating Scale (CARS) was used for diagnostic assessment of ASD and to monitor symptom severity, according to the version translated and validated for the Brazilian context by Pereira et al. (2008). The Swanson, Nolan, and Pelham Rating Scale–IV (SNAP-IV) was administered to caregivers to assess levels of inattention and hyperactivity/impulsiveness according to DSM-IV criteria, using the Brazilian version validated by Mattos et al. (2006) and later corroborated by Costa et al. (2019) regarding internal consistency and clinical accuracy. The Autism Treatment Evaluation Checklist (ATEC) was used to assess functioning in the domains of communication, sociability, cognition, and physical behavior, according to the original instrument by Rimland & Edelson (1999). The quasi-static postural control assessment (QSPCA) was used to evaluate postural stability using a force platform by comparing center-of-pressure sway under eyes-open and eyes-closed conditions, following standardized stabilometric protocols described by Ruhe et al. (2010). Finally, the model motor circuit (MMC) was used to analyze motor coordination and task performance based on completion time and number of errors. The design of this protocol is grounded in principles of the coordinative approach and structured motor circuits proposed by Gonçalves et al. (2020), who reported beneficial effects of a circuit-based coordinative intervention on autonomic parameters in older adults.

SNAP-IV, ATEC, postural control, and MMC assessments were repeated after 12 weeks of intervention. The circuit-based coordinative approach (CCA) was structured as a sequence of progressively challenging motor activities designed to optimize the children's cognitive-motor performance.

Assessments

Assessments were conducted over three consecutive mornings. The first instrument administered was CARS, which assesses behavior in 14 domains potentially affected by ASD, along with a general category reflecting the overall impression of autism (Schopler et al., 1980). The 15 assessed items include interpersonal relationships, imitation, emotional response, body use, object use, adaptation to change, visual and auditory responses, taste, smell, and touch responses, fear or nervousness, verbal and nonverbal communication, activity level, consistency of intellectual response, and general impressions. Each domain is scored on a scale from 1 (within normal limits) to 4 (severe symptoms). Total scores range from 15 to 60, with a cutoff score of 30 for an ASD diagnosis (Schopler et al., 1980). Scores from 30 to 36.5 indicate mild to moderate symptoms. This scale is widely used because of its internal consistency and sensitivity and can be effectively combined with other tools to support diagnostic confirmation.

The second instrument was the SNAP-IV questionnaire, a parent- or caregiver-completed scale used to assess symptoms of inattention, hyperactivity, and impulsiveness in children and adolescents (Swanson, 2001). Although it is widely used as an ADHD screening tool, SNAP-IV is also sensitive for measuring inattention in children with ASD, even in the absence of a formal ADHD diagnosis. Accordingly, it was used in this study to examine changes in attention and behavioral regulation after the intervention. The version used includes 18 items: the first nine address inattention, and the remaining nine address hyperactivity and impulsiveness. The total score is obtained by summing the scores for all items, reflecting symptom severity. Higher scores indicate greater symptom severity, whereas lower scores reflect reductions in the assessed symptoms.

The third instrument was the ATEC, a questionnaire completed by the primary caregiver to measure individual changes after interventions (Rimland & Edelson, 1999). Comprising 77 items organized into four subscales, ATEC yields a total score from 0 to 180, with lower scores indicating greater independence (Freire et al., 2018). The first subscale assesses speech, language, and communication (14 items; score range: 0–28); the second subscale measures sociability (20 items; score range: 0–40); the third subscale assesses sensory and cognitive awareness (18 items; score range: 0–36); the fourth subscale evaluates health, physical performance, and behavior (25 items).

For the quasi-static postural control assessment, an AMTI 3.05 force platform was used. Upon arriving at the laboratory, the children underwent an adaptation period to become familiar with the environment and test procedures. They were then instructed to stand still on the platform for 60 seconds with eyes open (EO) and then for 60 seconds with eyes closed (EC). Each 60-second trial was repeated three times, with 40-second intervals between them. Total assessment time ranged from 20 to 25 minutes per participant. The following variables were assessed: (1) total sway area, which measures the extent of center-of-pressure displacement over time and reflects overall postural stability; (2) anteroposterior sway area, which represents the amplitude of center-of-pressure (COP) displacement along the sagittal axis and indicates forward and backward sway; (3) mediolateral sway area, which assesses the amplitude of COP displacement along the frontal axis and reflects lateral sway; (4) total mean velocity, which indicates the mean speed of COP displacement in all directions and serves as a marker of postural control efficiency; (5) anteroposterior mean velocity, which measures the speed of sway along the sagittal axis and is associated with the ability to stabilize the body forward and backward; (6) mediolateral mean velocity, which quantifies the speed of lateral sway and is relevant for maintaining balance during dynamic tasks; (7) anteroposterior and mediolateral root mean square values, which represent statistical measures of postural variability and provide a more refined analysis of dynamic stability along the respective axes (Li et al., 2021).

To assess the degree of motor progression across activities, a model motor circuit (MMC) was used and organized into progressively challenging tasks adapted to the motor demands of each activity. The MMC consisted of eight activities: (1) walking or running forward and backward between two ropes on the floor, stimulating spatial organization and anteroposterior control; (2) running in a zigzag pattern between three cones, targeting lateral deceleration and acceleration and proprioceptive organization; (3) walking in a zigzag pattern along a rope arranged in three sinusoidal wave shapes, promoting dynamic balance and anticipatory postural adjustments; (4) simulating running over four foam mats, improving dynamic balance and intersegmental coordination; (5) running along a semicircular rope, improving dynamic balance and postural adjustments; (6) climbing two steps, rotating around the body axis, and descending backward, developing working memory and complex motor control; (7) running to the cones, positioning backward, and running in a zigzag pattern, practicing forward movement projection and balance control; (8) making five throws of a ball into a basket, integrating spatial-temporal coordination, force modulation, and accuracy (Gonçalves et al., 2020). The MMC was recorded to document the time required to complete each station and the number of errors committed. A detailed description of the stations and error calculation methods is provided in the study supplements (Figure 2).

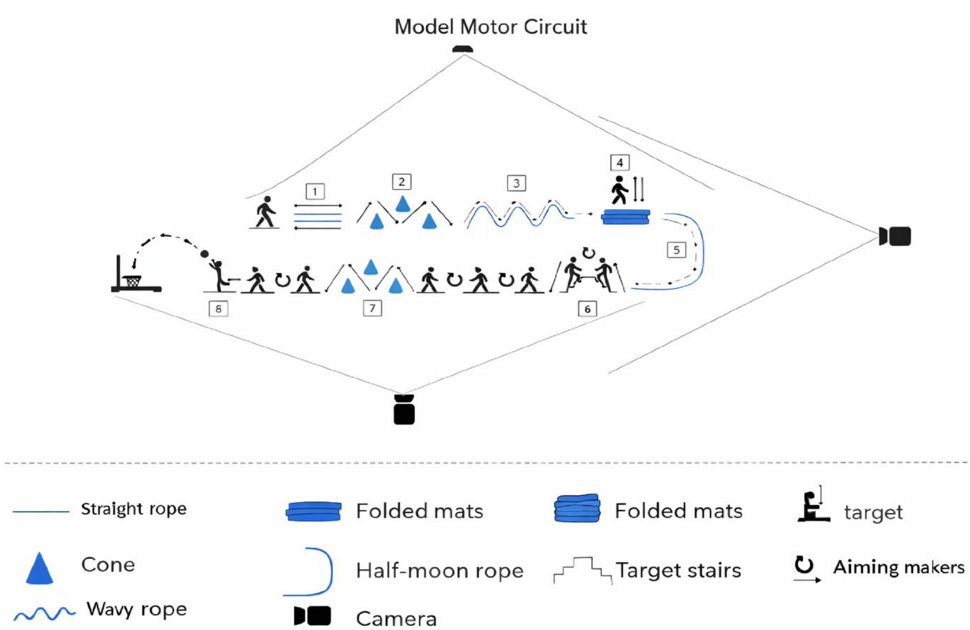

Figure 2. Model Moter Circuit (MMC).
Source: Prepared by the authors based on the study data. Pernambuco, 2025.

Intervention protocol

The CCA education program was delivered over 12 weeks, with 70-minute sessions twice weekly. Before the intervention, a 1-week familiarization period was implemented, during which the children were introduced to the activities in the coordinative circuit.

A total of 30 activities were distributed across six circuits, each containing five required activities, performed consecutively three times per session. Circuit organization followed Winnick's (2004) criteria to facilitate the participation of children with ASD in sport settings, including: (1) the presence of a trained assistant; (2) the use of peer tutors or a partner system; (3) clear transitions between activities; and (4) visual cues to guide task sequences.

Activities were performed in groups of three children, selected based on affinities observed during the familiarization phase, with the aim of promoting cooperation and social engagement. The instructor demonstrated every step of each task and used visual and temporal cues to ensure predictability and reduce sustained-attention demands. Verbal instructions were brief, specific, and repeated as needed.

Each coordinative circuit comprised a progressive motor sequence, structured into blocks with a gradual increase in complexity (A → AB → ABC → BC), which promoted consolidation of motor patterns and improved attentional control. Tasks combined components of balance, coordination, spatial orientation, temporal organization, and speed-accuracy demands, represented in different motor arrangements.

For example, during the first weeks, children performed jumps over cables and aligned hoops, walked along ropes arranged in a straight line or half-moon shape, and threw objects at fixed targets, emphasizing postural control and spatial-temporal organization. In the intermediate circuits, tasks began to include single-leg hopping, zigzag locomotion, and ball manipulation during movement, requiring integration of bimanual coordination, dynamic balance, and divided attentional control. In the final phase, activities incorporated dual-task demands (movement + moving target), such as throwing balls into moving hoops, dribbling balls of different sizes between cones, and climbing steps while holding objects, which increased motor-planning demands and cognitive flexibility.

Each circuit was repeated for two weeks to allow progressive adaptation. Task complexity was quantified using the Task Difficulty Index (TDI) and the Circuit Difficulty Index (CDI), according to the model proposed by Gonçalves et al. (2020). These indices considered fine and gross motor demands, balance, body schema, spatial and temporal organization, complexity versus organization, and speed versus accuracy. A complete description of the activities, their difficulty scores, and the six circuits is provided in the Supplementary Material.

Calculation of the Task Difficulty Index (TDI)

The TDI was calculated based on motor-learning demands and considered four aspects: (1) motor components involved, with complexity increasing as the number of components increased, such as fine motor skills, gross motor skills, balance, and laterality; (2) required precision, especially in activities involving unstable objects or precision demands, scored from 0 (no requirement) to 3 (high requirement); (3) task complexity and organization, scored from 0 (no complexity) to 3 (high complexity with low organization); and (4) dual-task level, reflecting the attention required for simultaneous motor and cognitive demands, scored from 0 (full focus on a single task) to 2 (multitasking) (Gonçalves et al., 2020).

Circuit Difficulty Index (CDI)

Circuits were organized based on the TDIs of their tasks. The CDI was calculated as the sum of the TDIs within each circuit. Over the 12 weeks, gradual increases in TDI and CDI were encouraged to promote progressive development of participants' motor and cognitive skills (Gonçalves et al., 2020).

Data analysis

Descriptive analyses were used to summarize sample characteristics and variables using measures of central tendency and dispersion. The Shapiro–Wilk test was used to assess data distribution. Paired *t*-tests compared pre- and post-intervention means for CARS, ATEC, and SNAP-IV questionnaire scores.

For postural control data, a generalized estimating equation (GEE) was used to compare differences between EO and EC conditions before and after the intervention. Center-of-pressure data were adjusted for body mass, which differed significantly after the intervention. The Akaike Information Criterion (AIC) was applied to select the most appropriate model. A Gamma distribution was identified, and an identity link function was adopted for all analyses (Hardin & Hilbe, 2013; Liang & Zeger, 1986). Post-estimation contrast tests and Bonferroni-adjusted paired comparisons were conducted to identify the sources of main effects and significant interactions. An alpha significance level of 0.05 (type I error probability) and a target statistical power of 0.80 (1–β) were assumed. Statistical analyses were porcessed using JAMOVI software.

Results

A total of 11 children were initially selected; however, only seven completed the pre- and post-intervention assessments. Demographic data indicate that mean age increased from 8.22 ±1.72 years at baseline to 8.57 ±1.62 years post-intervention, with no statistically significant difference (p = 1.00). Mean body mass also increased slightly, from 29.61 ±6.15 kg to 30.77 ±6.23 kg (p = 0.064). Mean height increased from 131.22 ±9.25 cm to 134.00 ±10.07 cm (p = 0.057). Body mass index remained essentially unchanged, from 17.28 ±3.54 to 17.40 ±3.64, with no statistically significant difference (p = 0.937).

Mean values and standard deviations for CARS, ATEC-1, and SNAP-IV in the pre- and post-intervention periods were analyzed, along with their corresponding significance values. For CARS-1, which refers to ASD classification, the mean score before the intervention was 32.83 ±2.71; no post-intervention values were available. For ATEC-1, the domains yielded the following results: in Speech/Language, the mean score increased from 22.57 ±4.11 to 23.57± 4.11 (p = 0.393); in Sociability, mean values increased from 9.42 ± 7.41 to 12.14 ± 8.00 (p = 0.375); in Cognitive Behavior, there was a significant increase from 7.85 ±4.25 to 30.28 ±4.53 (p = 0.022); and in Health Behavior, the mean score increased from 15.00 ±6.85 to 19.57± 11.37 (p = 0.235). The total ATEC-1 score increased significantly, from 54.85 ±12.65 to 85.57± 19.24 (p = 0.016). For SNAP-IV, mean Inattention scores decreased significantly from 17.42 ±1.71 to 11.14 ±5.92 (p = 0.036), whereas Hyperactivity scores decreased from 14.42 ±7.18 to 10.28 ±6.44, without statistical significance (p = 0.207). The total SNAP-IV score decreased from 31.85 ±7.10 to 21.42 ±9.60, with no statistically significant difference (p = 0.150). Overall, the findings indicate positive effects for some variables, particularly ATEC-1 Cognitive Behavior and SNAP-IV Inattention.

Analysis of postural control variables indicated that, although education was effective under both visual conditions, the intervention appeared to have a more pronounced effect for certain variables under EC, especially for lateral stability. For other variables, such as postural adjustment velocity, the impact was more evident under EO, suggesting that visual feedback contributed to a faster and more efficient response. Notably, body mass did not significantly influence postural control variables ($p > 0.05$).

Interaction analyses between the EO and EC conditions and the pre- and post-intervention time points showed significant differences for several postural control variables. Total COP area (A95%) showed a significant interaction ($p = 0.026$), indicating that the intervention affected these conditions differently. Post hoc comparisons showed significant reductions in both conditions (EO: $p < 0.001$; EC: $p < 0.001$); however, the reduction was more pronounced under EC, suggesting a stronger impact on postural stability when visual feedback was absent.

Anteroposterior area showed no significant interaction ($p = 0.270$) but improved significantly under both EO ($p < 0.001$) and EC ($p = 0.005$). The improvement was greater under EO, suggesting that control along this axis was more sensitive to training when visual feedback was present. In contrast, mediolateral area showed a significant interaction ($p < 0.001$). Although both conditions improved, the difference was more pronounced under EC ($p < 0.001$) than under EO ($p = 0.249$), indicating that the intervention was particularly effective in improving lateral stability in the absence of visual feedback.

Total mean velocity showed a significant interaction ($p < 0.001$), with improvements under both conditions (EO and EC, both $p < 0.001$). The improvement was more pronounced under EO, suggesting that the intervention enhanced a more efficient response when visual feedback was available. Similarly, anteroposterior mean velocity showed a significant interaction ($p < 0.001$), with significant improvement under EO ($p < 0.001$) but no change under EC ($p = 0.709$). These findings indicate that postural adjustment along the anteroposterior axis was more strongly influenced by training with visual feedback.

In turn, mediolateral mean velocity showed a significant interaction ($p = 0.036$), with improvements under both conditions (EO: $p < 0.001$; EC: $p < 0.001$). The difference was slightly greater under EO, suggesting more consistent improvement in lateral adjustment when visual feedback was available.

Anteroposterior root mean square showed no significant interaction ($p = 0.106$); however, EC showed a significant change ($p = 0.019$), whereas EO remained stable ($p = 1.00$). By contrast, mediolateral root mean square showed a significant interaction ($p = 0.034$), with improvements under both conditions (EO: $p < 0.001$; EC: $p = 0.020$). The larger change occurred under EO, suggesting that the intervention promoted more consistent lateral movements when visual feedback was present (Table 1).

Regarding performance on the MMC, a reduction in errors was observed for tasks 2, 4, 6, 7, and 8 ($p < 0.005$); however, no significant differences were found for tasks 1, 3, and 5 ($p > 0.05$). In addition, mean MMC completion time decreased from 3 min 14 s at pre-intervention to 1 min 18 s at post-intervention. Figure 3 presents the mean and standard deviation of errors per station across the three MMC trials at pre- and post-intervention.

Table 1. Interaction values between visual conditions (EC–EO) and time points (Post–Pre) for COP variables.

Parameter	Effects	Estimate	SE	Inferior	Superior	Z	*p*
A95%	**CE-OE* POST-PRE**	-3.45	1.55	-6.50	-0.41	-2.225	**0.026***
A95%	OE Pre-POST	5.26	0.60	4.08	6.43	8.72	**<0.001***
A95%	CE Pre-POST	31.03	1.82	27.47	34.59	17.01	**<0.001***
APA	**CE-OE* POST-PRE**	0.44	0.40	-0.34	1.23	0.27	0.270
APA	OE Pre-POST	1.45	0.26	0.95	1.95	5.42	**<0.001***
APA	CE Pre-POST	1.00	0.30	0.42	0.58	3.33	**0.005***
MLA	**CE-OE* POST-PRE**	-4.20	0.68	-5.55	-2.85	-6.11	**<0.001***
MLA	OE Pre-POST	0.66	0.32	**0.04**	1.28	2.03	0.249
MLA	CE Pre-POST	4.87	0.60	3.70	6.04	8.05	<0.001
TMV	**CE-OE* POST-PRE**	3.50	0.94	1.64	5.36	3.68	**<0.001***
TMV	OE Pre-POST	7.35	0.61	6.16	8.54	12.04	<0.001
TMV	CE Pre-POST	3.85	0.72	2.44	5.26	5.30	<0.001
APV	**CE-OE* POST-PRE**	2.07	0.49	1.10	3.03	4.21	**<0.001***
APV	OE Pre-POST	2.59	0.35	1.91	3.27	7.24	<0.001
APV	CE Pre-POST	0.52	0.33	-0.12	1.16	1.56	0.709
MLV	**CE-OE* POST-PRE**	1.83	0.87	0.11	3.55	2.09	**0.036***
MLV	OE Pre-POST	5.02	0.53	3.99	6.05	9.37	<0.001
MLV	CE Pre-POST	3.19	0.69	1.84	4.54	4.61	<0.001
RMS-AP	**CE-OE* POST-PRE**	**-0.05**	**0.03**	-0.12	**0.01**	-1.61	0.106
RMS-AP	OE Pre-POST	**0.02**	**0.02**	**-0.01**	**0.05**	1.29	1.00
RMS-AP	CE Pre-POST	0.08	**0.02**	**0.05**	0.11	2.94	**0.019***
RMS-ML	**CE-OE* POST-PRE**	0.12	**0.05**	0.00	0.24	2.12	**0.034***
RMS-ML	OE Pre-POST	0.25	**0.03**	0.16	0.34	6.49	<0.001
RMS-ML	CE Pre-POST	0.12	**0.04**	**0.05**	0.19	2.94	**0.020**

APA: anteroposterior area; MLA: mediolateral area; TMV: total mean velocity; APV: anteroposterior velocity; MLV: mediolateral velocity; RMS-AP: anteroposterior root mean square; RMS-ML: mediolateral root mean square. No significant influence of body mass index (BMI) was observed for any of the data; * $p < 0.05$. Source: Prepared by the authors based on the study data. Pernambuco, 2025.

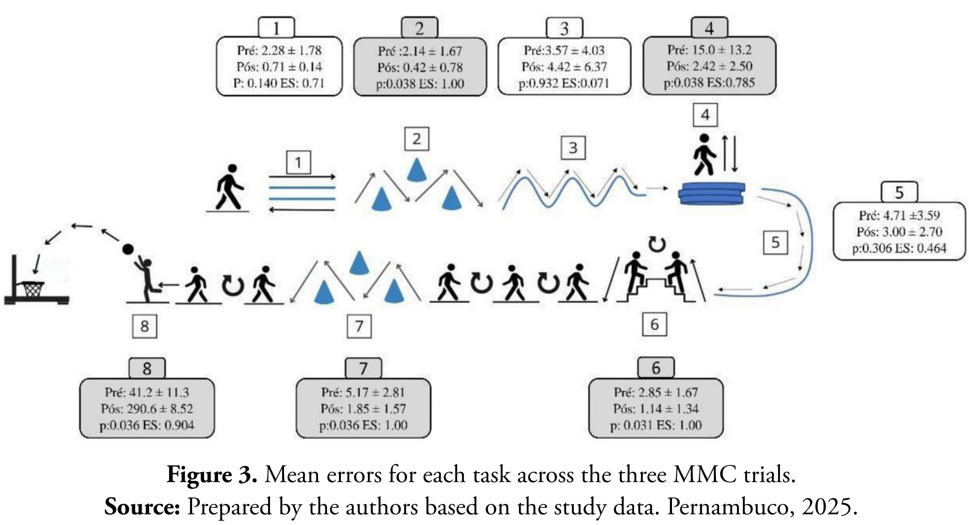

Figure 3. Mean errors for each task across the three MMC trials.
Source: Prepared by the authors based on the study data. Pernambuco, 2025.

Discussion

The findings of this study indicate that the CCA significantly improved motor performance, attention, and postural control in children with level 1 ASD. After 12 weeks of intervention, a significant reduction in inattention and an increase in behavioral scores were observed, along with improvements in COP metrics and MMC motor performance. However, not all behavioral domains showed marked changes, suggesting that some benefits may require longer or more targeted interventions.

The reduction in inattention, measured by SNAP-IV, and the increase in cognitive-behavioral scores assessed by ATEC suggest that structured motor activities may have positively influenced attentional processes. Prior studies report that active engagement in coordinative exercises can stimulate neural connectivity in sensorimotor and executive networks, promoting better attention and behavioral regulation (Nejati & Derakhshan, 2021).

The activities applied in this study followed the original CCA protocol developed by the Neuromotor Plasticity Research Group at UNIVASF and detailed in the Supplementary Material. Each circuit comprised five tasks organized in a progression of motor and cognitive complexity, based on the TDI and CDI empirically defined by the group (Gonçalves et al., 2020). Exercises included bipedal and single-leg jumps between hoops and ropes, walking along lines or narrow surfaces, dribbling and bouncing balls in different directions, throws at fixed and moving targets, sack races, and step climbing while carrying objects. This structure was designed to require continuous balance adjustments, postural control, and spatial-temporal organization, while also demanding sustained attention, anticipation, and inhibitory control.

The CCA was designed to promote a gradual and predictable progression of difficulty, allowing children to anticipate motor programs through observation of the environment and supporting temporal and spatial organization of action. This predictability reduces contextual uncertainty and facilitates anticipatory motor planning, which is frequently impaired in children with ASD. In addition, the CCA was developed based on coordinative motor-learning principles that emphasize variability, motor adaptation, and sensory-cognitive integration as mechanisms supporting neural efficiency and executive control (Lopes et al., 2011; Pesce, 2012).

One hallmark feature of ASD is difficulty with emotional control and cognitive rigidity in response to unexpected changes. The gradual and stable structure of the CCA can therefore act as a regulatory mediator, reducing contextual interference, anxiety, and stress during task performance. This predictable environment may support better adherence to the protocol, improved emotional adjustment, and fewer avoidance behaviors, creating conditions for positive motor experiences and increased perceived competence. Although the literature suggests that, over the long term, higher contextual interference can yield greater motor-learning gains (Magill & Hall, 1990; Shea & Morgan, 1979), this phase of CCA implementation prioritized adherence and engagement, which are critical for developing self-confidence and enjoyment of practice.

Furthermore, the method emphasizes movement quality, focus on bodily sensations, optimization of body schema, and the child's critical awareness of their motor performance. Because of its gradual and predictable structure, the CCA may allow children with ASD to dissociate emotional stress from cognitive and physical effort, reducing emotional overload and increasing task focus.

Overall, the observed benefits are not attributable to any single task, but rather to the integrated structure of the circuit, which expands motor repertoire, body awareness, environmental and temporal perception, and attentional and emotional self-regulation. Taken together, these factors may positively modulate cognitive-motor performance and support the theoretical and empirical rationale for the CCA.

Conversely, the lack of significant changes in hyperactivity suggests that the intervention was more effective for attentional processes than for impulsive motor control. This difference may be related to intervention duration or to the type of motor stimuli applied, as programs specifically focused on motor self-regulation and inhibitory control tend to produce more pronounced effects on hyperactivity when implemented for longer periods (Bedard et al., 2021).

The postural control findings reinforce the effectiveness of the CCA in stabilizing COP. Intervention effects varied by visual condition, with greater postural stability under EC conditions, suggesting that the intervention improved postural adaptation in the absence of visual feedback. This adaptation may reflect increased efficiency of the somatosensory and vestibular systems, which contribute to maintaining posture when visual input is removed (Horak, 2006; Peterka, 2002; Chisari et al., 2024).

Moreover, improvements in the speed and accuracy of postural adjustments under EO conditions indicate that visual feedback contributed to faster and more efficient motor responses, consistent with strengthened connections between visual, cerebellar, and parietal regions that integrate spatial and kinesthetic information (Assländer & Peterka, 2014; Paulus et al., 1984).

These findings align with evidence that coordinative and dynamic balance exercises can improve sensorimotor integration, increasing the ability to reorganize postural strategies under different sources of sensory information (Donath et al., 2016; Goble & Baweja, 2018). Accordingly, the pattern of improvement observed under both EO and EC conditions suggests that the CCA contributed to more flexible and efficient balance control, with relatively greater reliance on proprioceptive inputs under visually restricted conditions, which may indicate neural adaptation and more automated postural control.

The more pronounced reduction in lateral (mediolateral) sway under EC conditions suggests that the intervention improved stability under greater sensory challenges. This finding agrees with studies indicating that children with ASD often show sensory integration difficulties that affect postural stability, particularly when they need to compensate for the absence of visual cues (Abdel Ghafar et al., 2022).

The literature indicates that structured motor interventions can improve postural stability by promoting more efficient motor adjustments and reducing disorganized sway patterns in children with ASD (Ben Hassen et al., 2023; Frazão et al., 2023; Roșca et al., 2022). Although the anteroposterior area showed no significant interaction, an overall positive effect on balance was observed regardless of visual feedback. In contrast, the mediolateral area improved more strongly under EC conditions, supporting evidence that children with ASD present specific difficulties in lateral control that can be reduced with structured motor practice (Lim et al., 2017). Children with ASD may process visual feedback less efficiently, which can reduce the effectiveness of postural strategies and result in less adaptive motor patterns (Lim et al., 2020; Knight et al., 2023). By promoting ongoing postural adjustments under different visual conditions, the CCA may have supported improved sensorimotor integration and more efficient stability mechanisms.

For the MMC, a significant reduction in errors was observed in five of the eight tasks, along with a reduction in total completion time. These findings suggest gains in motor coordination, dynamic stability, and motor adaptation to environmental demands. Repetitive practice of motor activities supports automation of motor patterns and integration of bilateral coordination, both of which are critical domains for children with ASD (Ben Hassen et al., 2023; Chen et al., 2019).

Tasks requiring lateral and intersegmental control, such as zigzag running and balancing on unstable mats, showed the greatest improvement, indicating enhanced dynamic postural adjustment. Additionally, activities involving organized motor sequences, such as step climbing and rotating around the body axis, showed a positive effect on motor planning and motor working memory, which may have contributed to the children's cognitive performance (Li et al., 2023; Gentile et al., 2024).

Despite these promising findings, the small sample size (N = 7) may have limited statistical significance for some analyses. In addition, the exclusion of female participants limits generalizability, and the exclusive focus on children with level 1 ASD limits applicability to other levels within the spectrum. Future studies should include larger samples and extend the intervention period to investigate the sustainability of motor and attentional gains over time.

Conclusion

The findings of this study indicate that a 12-week circuit-based intervention consisting of coordinative activities was effective in improving attentional performance, postural stability, and motor coordination in children with level 1 ASD. Moreover, the CCA proved to be an accessible, low-cost strategy that can be implemented using simple, readily available materials. These results suggest that the intervention may be a viable alternative for fostering functional development in children with ASD across different settings, including educational and clinical environments. Future studies should examine the expansion of this approach to children at other ASD levels and investigate its effectiveness across different profiles.

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Karoliny Teixeira Santos: study organization, intervention delivery, data collection, and manuscript writing. Ana Cecília Pereira Gomes: data processing, statistical analysis, providing feedback to caregivers, and manuscript writing. Terezinha Abel Alves: study organization, intervention delivery, data collection, and manuscript writing. Queoma Silveira Lima: study organization, intervention delivery, data collection, and manuscript writing. Natália Goulart Lemos: study organization, intervention planning, data processing, and manuscript review. Fernando Aguiar Lemos: study organization, intervention planning and supervision, data processing, statistical analysis, and manuscript review. All authors approved the final version of the text.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Supplementary Material

Este artigo acompanha material suplementar.

Legenda S1. Circuit-Based Coordinative Approach / Coordinative Motor Circuits.

Este material está disponível como parte da versão online do artigo na página https://doi.org/10.1590/2526-8910.cto411740412