**Title:** The Effect of a Structured and Progressive Rhythmic-Cognitive Dual-Task Exercise Program on Impulsivity in Children with ADHD

**Running Title**: Dual-Task Exercise Program on Impulsivity in ADHD

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## Abstract

**Background:** Impulsivity is a core diagnostic feature of Attention deficit and hyperactive disorder (ADHD) in children. Deficits in inhibitory control can lead to behavioral issues and difficulties in interpersonal communication. Due to the limited use of medication at early ages and the broad impact of impulsivity on developmental domains, there is an increasing need for effective interventional approaches.

**Objectives:** This study aimed to evaluate the effectiveness of a structured dual-task exercise program that incorporates rhythmic movements preferred by children, along with visual and auditory cues, in reducing impulsivity and its related symptoms.

**Methods:**This randomized clinical trial was conducted on 60 children aged 6 to 12 years diagnosed with ADHD. Participants were allocated equally into intervention (dual-task) and control groups using Covariate Adaptive Randomization. Both groups received 18 intervention sessions of 45 minutes during 6 weeks. Evaluations were performed at baseline, post-intervention, and one-month post-intervention to assess the sustainability of outcomes using the Integrated Visual and Auditory Continuous Performance Test (IVA-2) and Cambridge Neuropsychological Test Automated Battery (CANTAB) assessments.

**Results:** Significant improvements were found between the two groups in all response control and prudence measures, including auditory and visual subdomains ($P < 0.001$). Reaction time indicators also demonstrated significant between-group differences ($P < 0.001$). At the one-month follow-up, response control and auditory response control measures showed no significant difference; however, other outcomes maintained significant improvements.

**Conclusion:** The findings suggest that a rhythmic-cognitive dual-task training program can positively impact impulsivity symptoms and enhance inhibitory control in children with ADHD.


**Keywords:** ADHD, Impulsivity, Inhibition, Dual-task, Rhythmic movement, Attention

## Introduction

Impulsivity, as a multidimensional personality trait, encompasses a wide range of immature and inappropriate behaviors that often result in undesirable consequences (Bezdjian et al., 2011; Meda et al., 2009). It holds particular significance during childhood and adolescence (Chamorro et al., 2012), a developmental period during which impulsivity manifests in various clinical diagnoses, including ADHD, autism spectrum disorder, anxiety disorders, and obsessive-compulsive disorder (Amini et al., 2016; Bezdjian et al., 2011; Goya-Maldonado et al., 2010; Hamilton et al., 2015; Sebastian et al., 2013; Sebastian et al., 2014; Stahl, 2020).

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), impulsivity is one of the core diagnostic features of attention-deficit/hyperactivity disorder (ADHD), particularly evident in preschool-aged children and those with the hyperactive-impulsive (ADHD-HI) subtype. Impulsivity often leads to behavioral difficulties in social contexts, such as an inability to wait one's turn, frequent interruptions during conversations, or answering before a question is completed. In addition to impulsive decision-making, children and adolescents with ADHD often exhibit impaired motor coordination and increased postural sway (Newton-Howes, 2004). Research shows that children and adolescents with ADHD tend to make more impulsive decisions than their neurotypical peers (Patros et al., 2016), and disturbances in motor coordination and postural control have been linked to deficits in self-regulation and inhibitory control (Amini et al., 2018; Jahani et al., 2016).

According to Barkley's theory, the hyperactive-impulsive subtype of ADHD is more prevalent in early childhood and is closely associated with attentional deficits. In his model, the primary underlying deficit in ADHD is a failure of response inhibition, which in turn disrupts four core executive functions: (a) working memory, (b) self-regulation of emotion, motivation, and arousal, (c) internalization of speech, and (d) reconstitution (i.e., behavioral analysis and synthesis). These impairments compromise the integration of the motor and perceptual systems necessary for goal-directed behavior (Barkley, 1997; Barkley et al., 1990). In this framework, executive dysfunction is posited as the primary cause of maladaptive behaviors, and response inhibition deficits are responsible for both distractibility and impulsivity in children with ADHD. Thus, inattention is considered a secondary consequence, whereas impulsivity represents a primary symptom (Barkley, 1997; Barkley et al., 1990).

Given the high prevalence of motor control impairments (approximately 50%) and postural instability (ranging from 47% to 69%) among children and adolescents with ADHD (Fliers et al., 2008; Piek et al., 2004; Williams et al., 2006), along with significant deficits in behavioral inhibition, working memory, and emotional regulation (Barkley, 1997; Barkley et al., 1990) motor-control-based physical interventions have been increasingly used as a therapeutic strategy for this population (Archer & Kostrzewa, 2011; Donnelly et al., 2016).

One fundamental cause of motor control and coordination difficulties in children with ADHD is attributed to deficits in rhythm and timing. These children often struggle to process environmental rhythms particularly auditory ones which are essential for achieving motor coordination in goal-directed activities (Shin et al., 2023). Notably, research suggests that humans synchronize more effectively to auditory rhythms than to visual or multimodal cues Rhythm-based physical training has demonstrated promising effects on motor development and emotional regulation, which, in turn, enhance executive functioning and social engagement in children (Sakai et al., 2004). Accordingly, a growing body of literature has investigated the role of physical activity in this context.

Since 2014, systematic reviews have shown that most interventions rely on aerobic exercises such as treadmill running, cycling, yoga, and mixed physical activity programs. While these interventions generally enhance executive function in the short term, they typically involve 30-minute sessions focused solely on physical exertion elevating heart rate (HRR), respiratory output ($VO_2$max), and neurotransmitter levels in children with ADHD. The observed effect sizes often increase with session duration, ranging from 10 to 30 minutes (Grassmann et al., 2017). However, these studies rarely incorporate dual-task designs that combine physical and cognitive training to address impulsivity. Furthermore, such interventions frequently lack individualization, variety, or opportunities for home-based continuation. Rhythmic movement based on auditory cues has also been underexplored, and overall, the integration of auditory-motor synchronization has not been prioritized (Donnelly et al., 2016; Grassmann et al., 2017).

Impulsivity is closely associated with self-regulation deficits (Barkley, 1997) and executive dysfunction (Bjørkly, 2013), which, from a neuroanatomical perspective, are linked to dysfunction in fronto-striatal circuits involving the basal ganglia, anterior cingulate cortex, and orbitofrontal cortex regions responsible for regulating goal-directed behaviors.

Successful dual-tasking requires divided attention and the simultaneous processing of multiple internal and external stimuli (Garon et al., 2008). Neuroimaging studies highlight the role of the prefrontal cortex (PFC) in such multitasking, and underscore the basal ganglia's importance in aligning motor behavior with auditory rhythms(Arvaniti, 2009; Thaut & Abiru, 2010).

Building on these findings, the present study employs a dual-task paradigm that involves the simultaneous performance of two independent tasks with distinct objectives (Lee et al., 2013; Pashler, 1994; Watanabe & Funahashi, 2015). This approach combines bodily movement with synchronized auditory and visual rhythms.

Recognizing the importance of fostering executive function development in children with ADHD—particularly within educational settings to promote adaptive learning behaviors (Cepeda et al., 2000) and considering the normative developmental pattern of subcortical brain circuit maturation, the dual-task format was selected as an intervention strategy. Additionally, the program was designed based on evidence showing that auditory rhythms can improve inhibitory control (Slater & Tate, 2018), and that sequential and timed motor activities enhance working memory and attentional capacity (Petrides, 1994; Smith & Jonides, 1999). Gross motor exercises have also been shown to benefit spatial awareness and response inhibition (van Der Fels et al., 2019). Accordingly, the training package developed for this study integrates these evidence-based components.

To ensure engagement and efficacy, the program incorporates principles such as task grading from simple to complex (Tomporowski & Pesce, 2019), diversity in exercise formats, and elements that promote enjoyment, empowerment, and intrinsic motivation in children (Brand & Ekkekakis, 2018; Cox et al., 2008; Diamond, 2015; Nasuti & Rhodes, 2013; Ryan & Deci, 2000). A preliminary feasibility study assessing the program's acceptability among children has been conducted, and its findings have been published (Amini et al., 2024).

The aim of this study was to investigate the effect of a structured training package consisting of dual-task rhythmic physical and cognitive exercises on impulsivity, caution, alertness, and reaction time in children with ADHD. Additionally, the study examined the persistence of the effects one month after the intervention.

## Methods

### Study Design and Ethics

This study was a single-blind, randomized clinical trial and represented the final intervention phase of a doctoral dissertation conducted in the Department of Occupational Therapy at the University of Rehabilitation and Social Health Sciences, Tehran. The study was approved by the university's Ethics Committee (Ethics Code: IR.USWR.REC.1400.207) and was registered in the Iranian Registry of Clinical Trials (IRCT Code: IRCT20220212054004N1).



### Participants

The sample size was calculated to achieve sufficient statistical power to detect differences between the groups. Assuming a 5% significance level ($p < 0.05$) and a power of 0.80, a total of 60 participants (30 per group) were required. Sixty children with ADHD, aged between 6 and 12 years, were therefore recruited and randomly assigned to either the intervention or control group.

Participants were recruited from public and private clinical centers affiliated with Tehran universities and the Tehran Medical System Organization. Inclusion criteria were: a confirmed diagnosis of ADHD (combined type or hyperactive-impulsive type) by a psychiatrist and documented in the child's medical records; chronological age between 6 and 12 years; absence of obvious physical disabilities based on therapist evaluation; elevated impulsivity scores on the short-form Connors Parent Questionnaire; no prior participation in rhythmic motor training programs; normal cognitive functioning as evidenced by enrollment in mainstream education; responsiveness and cooperation from the child; parental literacy; and absence of neurological, rheumatic, or orthopedic conditions that would interfere with participation in the intervention.

Covariate adaptive randomization was used to assign participants to groups, ensuring balance across key variables.

Before enrollment, informed written consent was obtained from all parents or legal guardians. After the intervention period, the results were shared with families. For ethical considerations, the intervention program was offered free of charge to families in the control group upon completion of the study. Exclusion criteria included a lack of family cooperation during the intervention, withdrawal from the study, or any change in the child's medication dosage during the trial period.

**Equipment**

The intervention consisted of a graded dual-task training package combining rhythmic physical activities with age-appropriate cognitive tasks. The program was developed based on expert feedback and approved in multiple review stages.

This dual-task program integrates rhythmic bodily movements with cognitive challenges using a three-level difficulty scale (from easy to hard) based on a structured dual-task paradigm (see Appendix 1; the original Persian protocol is translated into English for the appendix). The feasibility and high engagement level of the program for children were previously evaluated and confirmed in a pilot study (see published article(Amini et al., 2024)).

Each phase of the program consisted of six 45-minute sessions, divided into three components: warm-up, intervention, and cool-down. The cool-down phase included motivational elements to encourage children's participation. Exercises were tailored to the child's performance and developmental level, offering a set of motor-cognitive-rhythmic tasks from which the child could choose.

**Assessment Tools**

The following assessment tools were used:

- IVA-2 (Integrated Visual and Auditory Continuous Performance Test): This CPT assesses five types of attention—focused, sustained, selective, divided, and shifting—across both visual and auditory modalities. IVA-2 is a specialized tool for diagnosing ADHD and measuring attention-related indices, and is currently the only CPT validated through fMRI and QEEG studies.

- CANTAB (Cambridge Neuropsychological Test Automated Battery): A highly reliable and widely used neuropsychological assessment tool, independent of language and culture. The CANTAB battery includes 25 tests in domains such as visual memory, executive functioning, attention, verbal/semantic memory, decision-making and response inhibition, and social cognition. For this study, the RTI (Reaction Time) test from the CANTAB battery was used.

- Connors Parent Rating Scale – Short Form: This questionnaire was used to evaluate ADHD symptoms and impulsivity from the perspective of the caregiver.

- Demographic Information Questionnaire: This form collected general information about participants.



**Procedure**

Participants were selected based on the inclusion criteria, and after receiving appropriate coordination with parents (completion of the consent form and demographic questionnaire), they were randomly assigned to one of two groups using Covariate Adaptive Randomization: an intervention group (which received a graded exercise package consisting of dual physical, rhythmic, and cognitive tasks) and a control group (which received standard occupational therapy exercises). Each group consisted of 30 participants.

The IVA-2 and CANTAB assessments were administered by four trained evaluators. These evaluators were senior psychometric experts and experienced occupational therapists. In the intervention phase, the occupational therapists had received training on the specific implementation of each exercise set, with the procedures practiced and refined across three preliminary sessions.

Both groups participated in 45-minute weekly sessions for a duration of 6 weeks. In the intervention group, each 45-minute session was divided into three phases: warm-up, intervention, and cool-down. Each phase included a combination of physical, rhythmic, and cognitive exercises, progressively increasing in difficulty. During the intervention, participants received verbal guidance, encouragement, and corrective feedback to optimize their performance. In the cool-down phase, motivational strategies, rewards, and incentives were implemented to enhance engagement and participation.

Participants in the control group continued their regular occupational therapy program, which followed the standard treatment protocol. Therapists and family members observed and recorded each child's progress during sessions, and detailed records were maintained in individual files under a specific code to ensure confidentiality.

All children attended the 18 planned sessions. In cases where a participant missed a session, a makeup session was scheduled. Two days after completing the final training session, the post-intervention tests (IVA-2 and CANTAB) were re-administered by the evaluators. Additionally, to assess the persistence of any potential effects, the tests were re-administered one month after the conclusion of the intervention.

Following the final evaluations, the data were analyzed to examine the impact of the intervention on impulsivity and related cognitive outcomes.

## Intervention Fidelity

To ensure intervention fidelity, all sessions were implemented by trained occupational therapists who had received specific instruction on the intervention protocol. Prior to the intervention phase, therapists participated in a structured training program, during which the goals, procedures, and content of each exercise set were reviewed. The therapists practiced all intervention components through hands-on implementation to ensure procedural accuracy and consistency. A standardized checklist outlining the key steps of each training set was used throughout the sessions to guide implementation and maintain adherence to the protocol. Supervisory oversight and regular review of session records further supported fidelity assurance. All participants in the intervention group completed the full 18-session protocol (45 minutes per session), and missed sessions were rescheduled to ensure completeness of exposure.

## Statistical Analysis

Data were analyzed using both descriptive and inferential statistics with SPSS software version 26. Descriptive statistics (means and standard deviations) were used to summarize demographic characteristics and baseline scores. The normality of the data distribution was assessed using the Shapiro–Wilk test. Given the research design, which included one within-subject factor (time: pre-test and post-test) and one between-subject factor (group: intervention vs. control), appropriate statistical tests were applied to evaluate intervention effects. Analysis of covariance (ANCOVA) was used to compare post-test scores between groups while controlling for baseline scores. Within-group changes were analyzed using paired t-tests for normally distributed data or Wilcoxon signed-rank tests for non-normal data.

One-way ANOVA was used to assess the retention effects within the intervention group one month after the intervention. Eta-squared ($\eta^2$) was calculated to estimate the effect size of the intervention on each outcome variable. A significance level of $p < 0.05$ was considered statistically significant.

**Result**

Participants in this study were categorized into two age groups (6–9 years and 9–12 years) and assigned to either the intervention or control group. The assessments employed included IVA and CANTAB, targeting impulsivity-related variables such as Response Control, Audio Response Control, Visual Response Control, and Reaction Time.

The majority of participants in both groups were aged 6 to 9 years—76.7% (n = 23) in the intervention group and 73.3% (n = 22) in the control group. Conversely, the 9 to 12 age group comprised a smaller proportion: 23.3% (n = 7) in the intervention group and 26.7% (n = 8) in the control group.

In both groups, the majority of participants were boys. Specifically, 83.3% (n = 25) in the intervention group and 76.7% (n = 23) in the control group were male, while the intervention and control groups included 5 and 7 girls, respectively (Table 1).

**Table 1** - Description of the age and gender of participants in each group

| Personal Information | Intervention | | Control | |
|---|---|---|---|---|
| Age | 6 to 9 years | 9 to 12 years | 6 to 9 years | 9 to 12 years |
| | (76.7%) 23 | (23.3%) 7 | (73.3%) 22 | (26.7%) 8 |
| Gender | Boy | Girl | Boy | Girl |
| | (83.3%) 25 | (16.7%) 5 | (76.7%) 23 | (23.3%) 7 |

The results for the Response Control variable revealed a statistically significant difference before and after the intervention in both the intervention and control groups ($P < 0.001$). Furthermore, the between-group difference was also significant ($P < 0.001$). The effect size for this variable was $\eta^2 = 0.638$.

Similarly, a significant pre-post intervention difference was observed in the Audio Response Control variable for both groups ($P < 0.001$), and the between-group comparison also yielded a statistically significant result ($P < 0.001$). The corresponding effect size was $\eta^2 = 0.671$.

For the Visual Response Control variable, there was a statistically significant change from pre- to post-intervention ($P < 0.001$) in both groups. The between-group difference was also significant ($P < 0.001$), with an effect size of $\eta^2 = 0.620$ (Table 2).

**Table 2 -** Results of response control variables

| Variable | Group | Number | Before Intervention | | After Intervention | | Clinically Significant Difference | Probability Value** | Probability Value* | Eta Square |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Standard Deviation | Mean | Standard Deviation | | | | |
| Response Control | Intervention | 30 | 75.1 | 6.01 | 84.13 | 6.01 | -9.033 | <0.001 | <0.001 | 0.63 |
| | Control | 29 | 74.97 | 6.19 | 77.31 | 6.78 | -2.344 | <0.001 | | |
| Audio Response Control | Intervention | 30 | 75.06 | 5.35 | 83.96 | 5.42 | -8.9 | <0.001 | <0.001 | 0.67 |
| | Control | 29 | 76.28 | 5.9 | 78.14 | 6.55 | -1.862 | <0.001 | | |
| Visual Response Control | Intervention | 30 | 74.26 | 6.36 | 82.36 | 6.41 | -8.1 | <0.001 | <0.001 | 0.62 |
| | Control | 29 | 74.65 | 7.34 | 76.83 | 7.06 | -2.172 | <0.001 | | |

The Response Control Audio Prudence variable showed a statistically significant pre-post intervention difference in both the intervention and control groups (P < 0.001). The between-group difference was also significant (P < 0.001), with an effect size of $\eta^2 = 0.673$.

Similarly, the Response Control Visual Prudence variable demonstrated a significant change from pre- to post-intervention across both groups (P < 0.001). The difference between the two groups was also statistically significant (P < 0.001), with an effect size of $\eta^2 = 0.605$ (Table 3).



**Table 3**- Results of prudence variables

| Variable | Group | Number | Before Intervention | | After Intervention | | Clinically Significant Difference | Probability Value** | Probability Value* | Eta Square |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Standard Deviation | Mean | Standard Deviation | | | | |
| Prudence audio | Intervention | 30 | 74.56 | 5.53 | 84.03 | 5.20 | -۷.۵۶۶ | <0.001 | <0.001 | 0.67 |
| | Control | 29 | 76.83 | 5.81 | 78.83 | 6.08 | -۲<۰.۰۰۱ | <0.001 | | |
| Prudence visual | Intervention | 30 | 76.06 | 5.14 | 83.46 | 4.76 | -۷.۴۰۰ | <0.001 | <0.001 | 0.60 |
| | Control | 29 | 77.07 | 6.84 | 79.07 | 6.29 | -۲<۰.۰۰۱ | <0.001 | | |

The Mean Simple Reaction Time variable revealed significant changes before and after the intervention in both the intervention ($P < 0.001$) and control groups ($P = 0.008$). A significant between-group difference was also observed ($P < 0.001$).

Regarding the Mean Five Choice Reaction Time variable, the intervention group exhibited a significant improvement post-intervention ($P < 0.001$), whereas the control group did not show a significant change ($P = 0.107$). The between-group difference remained significant ($P < 0.001$).

For the Five Choice Accuracy variable, a statistically significant difference was observed before and after the intervention in both groups ($P < 0.001$). The difference between the intervention and control groups was also significant ($P < 0.001$) (Table 4).

**Table 4 -** Results of reaction time variables

| Variable | Group | Number | Before Intervention | | After Intervention | | Clinically Significant Difference | Probability Value** | Probability Value* | Eta Square |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Standard Deviation | Mean | Standard Deviation | | | | |
| Mean simple Reaction Time | Intervention | 30 | 471.79 | 57.76 | 439.14 | 57.33 | 32.64 | <0.001 | <0.001 | 0.565 |
| | Control | 29 | 478.07 | 50.07 | 470.64 | 51.07 | 7.43 | 0.008 | | |
| Five Choice Accuracy | Intervention | 30 | 25.20 | 1.15 | 28.73 | 1.65 | -3.53 | <0.001 | <0.001 | 0.178 |
| | Control | 29 | 24.65 | 1.67 | 27.10 | 1.68 | -2.44 | <0.001 | | |
| Mean Five choice Reaction Time | Intervention | 30 | 418.45 | 30.63 | 384.87 | 30.22 | 33.66 | <0.001 | <0.001 | 0.728 |
| | Control | 29 | 417.19 | 23.40 | 414.43 | 25.52 | 2.75 | 0.107 | | |

No statistically significant differences were found one month after the intervention in the indicators of Response Control (P = 0.379) and Audio Response Control (P = 0.4983), indicating the persistence of improvements in these variables (Table 5).

**Table 5** - Results of variables with persistence after follow-up

| variable | After the intervention | | One month after the intervention | | Probability Value |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | |
| Response Control | 84.28 | 6.38 | 84.10 | 6.02 | 0.37 |
| Audio Response Control | 84.21 | 5.33 | 84.42 | 4.90 | 0.48 |



Conversely, a significant decline in performance was observed one month after the intervention in the following variables: Visual Response Control (P < 0.001), Prudence Audio Response Control (P < 0.001), Prudence Visual Response Control (P = 0.003), Mean Simple Reaction Time (P < 0.001), and Mean Five Choice Reaction Time (P < 0.001) (Table 6).

**Table 6** - Results of non-persistent variables after follow-up

| variable | After the intervention | | One month after the intervention | | Probability Value |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | |
| Visual Response Control | 82.57 | 6.42 | 81.14 | 5.96 | <0.001 |
| Prudence Audio Response Control | 83.85 | 5.20 | 82.64 | 4.64 | <0.001 |
| Prudence Visual Response Control | 83.35 | 4.80 | 82.50 | 5.06 | 0.003 |
| Mean simple reaction time | 439.92 | 53.74 | 446.06 | 54.08 | <0.001 |
| Mean Five choice Reaction time | 384.39 | 30.06 | 391.21 | 30.95 | <0.001 |



**Discussion**

Although the occurrence of visible and noticeable differences in these variables between the intervention and control groups was consistent with the results of previous studies, mentioning the possible reasons for the occurrence of these behaviors can be effective in clarifying the underlying causes and applying them in clinical settings.

Attention deficit hyperactivity disorder is known as a disorder characterized by weakness in the functions of the frontal lobe of the brain, especially in executive functions, as well as a defect in the connection of the specialized circuit of this part with subcortical structures such as the basal ganglia.

The basal ganglia are known as one of the main processing centers of the brain, which is effective in producing and presenting the final output of motor behavior and causes the convergence and integration of received environmental information.

The importance of paying attention to these two components in modern perspectives has become so strong that Gabriel (1997) refers to the basal ganglia as “cognitive pattern generators” and emphasizes the role of this structure in the scaffolding of cognitive performance.

It seems that basal ganglia play a key role in explaining the results of this study because, considering the five main circuits of basal ganglia (Pesce et al., 2019) and their role in both verbal functions and auditory processing in terms of sound sequences and rhythms (Ben-Soussan et al., 2015; Koziol et al., 2014) and the production and continuity of rhythm production(Thaut et al., 2009) , it also plays a role in nonverbal functions such as memory and attention (Bhide et al., 2013) or the perception of timing (Repp & Su, 2013; Thaut & Abiru, 2010), especially in the perception of motor rhythms and the regulation of motor sequences (Vogt, 2019) and the fragmentation of skillful motor functions and their segmentation (Dahan & Reiner, 2017) and the construction of meaningful and purposeful behavioral sequences (Ferguson et al., 2024).

Of course, in the meantime, it is necessary to consider the function Over Arching (Pesce et al., 2019) also considered the integration of all circuits and networks related to the basal ganglia and providing an integrated and unified function, on the other hand, it overlooked the importance of the fifth basal ganglia circuit (the hyperdirect pathway) in the rapid functions of inhibiting and controlling impulsive behaviors (Pesce et al., 2019).

The selection of variables related to response control (Response Control, Audio Response Control, Visual Response Control) and also regarding response selection time (Five Choice Accuracy, Mean Five choice reaction time, choice movement time Mean Five) has been observed in the accepted definition and acceptance of impulsivity, which refers to the occurrence of a behavior (motor and automatic dimension) without thinking about the consequences (cognitive dimension and behavior selection). Today, it has been determined that each of the motor qualities and components can have the greatest impact on which aspect of the aforementioned cases (Chamorro et al., 2012; Deslandes et al., 2009), for example, gross skillful movements are related to working memory, spatial perception and response inhibition (Kramer & Erickson, 2007). The role of rhythmic movements in facilitating social relationships has been mentioned. Also, sequential and timing exercises affect working memory and attention (Buchanan et al., 1997; McAuley et al., 2005), while rhythmic movements and movements related to rhythmic hearing have a special effect on inhibitory functions (Ohgi et al., 2008). Perhaps the overall outcome of these cases can be considered as one of the reasons that the Audio Response Control variable in this study had a much larger effect size than the Visual Response Control variable, because in this proposed set of exercises, the role of auditory stimulation and corresponding and proportionate body rhythm has been particularly emphasized.

Other studies have also shown that if an auditory or motor rhythmic sequence is maintained, the complementary premotor areas of the frontal cortex can compensate for the dysfunction of the basal ganglia (Jamey et al., 2024), and this two-way interaction can play a more significant role in rehabilitation models (Myers et al., 2019).

Considering the age range of the participants, it is also crucial to acknowledge the role of neural maturation in this process. Given that the age of the participants in this study was over six years old, it can be expected that after the second year, connections between the limbic circuit and the anterior cingulate in addition to the prefrontal region have been established (Mathias et al., 2020), and the self-regulatory circuit is maturing and developing, and these connections can cause a connection between cognition and emotion (Deforche & De Bourdeaudhuij, 2015; Laffere et al., 2021), and this age after five years of age (Janmohammadi et al., 2020; Koziol et al., 2014)can be very valuable in ensuring the completion of the self-regulatory circuit, which seems to have been useful in achieving improvements related to response inhibition and laying the groundwork for controlling impulsivity (Mathias et al., 2020).

Some researchers have also pointed out the importance of a step-by-step and progressive level of difficulty in exercises in the form of homework as a requirement to facilitate executive functions (Amrani & Golumbic, 2019). Some have also emphasized the importance of this in such a way that if physical exercises do not have this feature, they cannot affect executive function (Deslandes et al., 2009). On the other hand, some researchers have also emphasized the diversity of exercise combinations and their ability to attract and interest the child and instill a sense of empowerment (Ahmed & Mohamed, 2011; Burnham, 2012; Chamorro et al., 2012) and pleasure (Bustamante, 2013; Chen et al., 2012), and have considered these issues as characteristics of a motor exercise package (Chamorro et al., 2012; Cornelius et al., 2017; Hoza et al., 2016; Kang et al., 2011) that can affect the child's self-regulatory functions.

Research has also focused on the use of various rhythms in the form of rhythmic movements or auditory rhythms from the surrounding environment (Chamorro et al., 2012; Lufi & Parish-Plass, 2011; Medina et al., 2010; Piepmeier et al., 2015) and their effects through body-centered cognitive theories (Donnelly et al., 2016; Tse et al., 2021), as well as the theory of the influence of the musician (Diamond, 2015; Ohgi et al., 2008) on the child's learning, cognitive (van Der Fels et al., 2019) and self-regulation functions, and examples of these have been presented in the form of a combination of rhythm and movement.

ADHD has been closely associated with deficits in core executive functions, such as inhibitory control, cognitive flexibility, and working memory).Barkley, (١٩٩٧ Specific deficits related to inhibition include impairments in working memory, inner speech, self-regulation, emotional modulation, motivation, and arousal. In the proposed training package, the cognitive demands and ultimately working memory capacity within the dual-task paradigm are progressively increased in a structured and hierarchical manner, and external rhythm-based self-regulation is emphasized throughout all major training components (Myers et al., 2019) .

In general, it can be stated that in the field of impulse control, all parts were tried to be considered in the exercises, and the results are also in line with this effort and goal setting. The first topic is presented in new perspectives that refer to the sensory-motor paradigm and the role of the continuity of sensory functions in decision-making and problem solving. These perspectives also emphasize the interaction of subcortical parts and cortical areas (Pesce et al., 2019). The signs and traces of this neural cooperation are seen in all types of mammals and it is considered the most specialized sensory and motor information processing system, which plays an important role in cooperation with subcortical areas such as the basal ganglia and the cerebellum with the prefrontal. In some sources, this collaboration has been referred to as the "dual-tiered model," emphasizing the importance of these regions collaborating with higher cortical regions in complex behavioral outcomes such as problem solving and decision making. This model of collaboration explains both the monitoring and regulation of automatic behaviors and higher-level cognitive behaviors that require inhibitory patterns (Heyder et al., 2004; Rae et al., 2015).

It should be kept in mind that more than ninety-five percent of human behavior is performed automatically, and paying attention to this issue highlights the importance of the unconscious and involuntary subcortical parts of the central nervous system. The self-regulation circuit and neural network, which plays a central role in controlling impulses, making decisions, and resolving conflicts and tensions(Sylvester et al., 2018) , is also composed of two cortical parts (prefrontal and anterior cingulate regions (Deforche & De Bourdeaudhuij, 2015) and subcortical parts (basal nuclei and cerebellum).

From a pathological and pathophysiological perspective, structural and functional damage in these regions also has the greatest burden and contribution in children with attention deficit hyperactivity disorder (Jaschke et al., 2018; Vazou et al., 2019; Wilson, 2002).

It seems that considering the two aspects of motor activity (Boes et al., 2009) and interest and attractiveness (Ahmed & Mohamed, 2011; Chamorro et al., 2012; Rothbart et al., 2011) for participants, the role of the neurotransmitter “dopamine” should also be mentioned, because these are considered part of the proven functions of this neurochemical carrier, and the secretion and increased presence of this substance in synaptic spaces can play a role in the construction and formation of neural circuits, their stabilization, and the strengthening of these currents (Aylward et al., 1996).

The “musician’s advantage” perspective (Ohgi et al., 2008) is also one of the modern psychological perspectives that, by emphasizing body-centered cognition (Tse et al., 2021) and the function of the cerebellum in the self-regulation and control network of motor behaviors (Diamond & Lee, 2011; Donnelly et al., 2016), refers to the clinical use of motor rhythm and the harmony of physical movement patterns with the emergence of observable behaviors and the generalization of these rhythmic and coordinated patterns to the entire motor and physical behaviors of the individual, and its effects on behavioral inhibition in different individuals and clinical groups And considering the use of balance exercises and their combination with movement rhythms in this training package, a portion of the changes and improvements achieved can be attributed to this.

Another aspect of the improvements achieved could be related to the mediating role of working memory in this regard (Buchanan et al., 1997; Krain & Castellanos, 2006; McAuley et al., 2005), because it has been shown that generalization and organization of information in the working memory section improves the attentional control system as well as emotional control and improves the individual's self-regulation. Another aspect is the use of ball exercises in combination with the proposed exercise package, which in another study (Hoza et al., 2016) has also been pointed out for the effect of such exercises on the development of restraint, self-control and monitoring of one's own behaviors.

Additionally, in the motivation section, an incentive was provided to the child at the final stage of each phase and after completing the main activity. This approach not only reinforced motivation throughout the exercises but also served to teach reward delay.

## Conclusion

In this study, the effectiveness of a package of rhythmic physical dual-task exercises combined with cognitive activities on impulsivity and self-regulation in children with ADHD was investigated. Given the diversity of treatment approaches and the common parental concerns about the side effects of pharmacological interventions, the implementation of a structured, leveled program of rhythmic physical-cognitive dual tasks appears to offer a promising alternative. Such an approach, which is both comprehensive and feasible, may enhance family engagement and increase the child's intrinsic motivation due to its inherent attractiveness. Overall, this intervention could contribute to effective symptom management, particularly in reducing impulsivity, in children with ADHD.

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**Author Contributions**

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**Conflict of Interest**

There were no conflicts of interest during the implementation of the study.

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**Ethics Statement**

The Human Studies Ethics Committee of the University of Rehabilitation Sciences and Social Health has received the Code of Ethics (IR.USWR.REC.1400.207). The clinical trial code of this study (IRCT20220212054004N1) was also approved in the IRCT system. The studies were conducted in accordance with local laws and institutional requirements. Written informed consent to participate in this study was provided by the legal guardians/close relatives of the participants.

**Data Availability Statement**

The raw data supporting the conclusions of this article will be made available by the authors without undue restriction.

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**Appendix1**:

| | | | | |
|---|---|---|---|---|
| | | Warm-up<br>5 min | Intervention-main<br>20-25 min | Relaxation(motivation)<br>15 min |
| **Stage 1**<br>**(1-6 sessions)**<br>**45min** | M | Run on a treadmill (speed:2km/h)<br>Hopping<br>(Three times, 10 jumps in a straight line.) | Butterfly movement with a step Butterfly movement with a step between the legs(Sets with 10 movements)<br>Forward Butterfly with step in front (Sets with 10 movements)<br>Butterfly with two steps on the sides of the legs (Sets with 10 movements)<br>Asymmetric propeller with two steps on the sides (Sets with 10 movements) | Basketball<br>Soccer<br>Handball<br>Walking Backwards |
| | C | Color naming<br>(From 4 colors)<br>Counting<br>Collection naming | Working memory relation<br>Cue coding color- fruit<br>(2 color)<br>Reverse counting<br>Visual perception (Usual familiar)<br>Memorize an audio story | Start / stop (inhibition) |
| | R | -Pace of treadmill<br>-Synchronization slow- moderate | Beat synchronization to familiar song<br>singing familiar song<br>Mirroring- Imitation | -Rhythmic sound of kicks on the floor<br>-Relaxation music |

| | | Warm-up<br>5 min | Intervention-main<br>20-25 min | Relaxation(motivation)<br>15 min |
|---|---|---|---|---|
| **Stage 2**<br>**(6-12 sessions)**<br>**45min** | M | Run on a treadmill (speed:3km/h)<br>Hopping<br>(Three times, 10 jumps in a straight line.) | Butterfly movement with a step Butterfly movement with a step between the legs(Sets with 15 movements)<br>Forward Butterfly with step in front (Sets with 15 movements)<br>Butterfly with two steps on the sides of the legs (Sets with 15 movements)<br>Asymmetric propeller with two steps on the sides (Sets with 15 movements) | Basketball<br>Soccer<br>Handball<br>Walking Backwards |
| | C | Color naming<br>(From 6 colors)<br>Counting<br>Collection naming | Working memory relation<br>Cue coding color-fruit (3 color)<br>Reverse counting<br>Visual perception(familiar)<br>Memorize an audio story | Start / stop (inhibition) |
| | R | -Pace of treadmill<br>-<br>Synchronization slow- moderate | Beat synchronization to familiar song<br>singing familiar song<br>Mirroring-Imitation | -Rhythmic sound of kicks on the floor.<br>-Relaxation music |

| | | | | |
|---|---|---|---|---|
| **Stage 3**<br>**(12-18 sessions)**<br>**45min** | | Warm-up<br>5 min | Intervention-main<br>30 min | Relaxation(motivation)<br>10 min |
| | M | Run on a treadmill<br>(speed:3.5km/h)<br>Hopping<br>(Three times, 10 jumps in a straight line.) | Butterfly movement with a step Butterfly movement with a step between the legs(Sets with 20 movements)<br>Forward Butterfly with step in front (Sets with 20 movements)<br>Butterfly with two steps on the sides of the legs (Sets with 20 movements)<br>Asymmetric propeller with two steps on the sides (Sets with 20 movements) | Basketball<br>Soccer<br>Handball<br>Walking Backwards |
| | C | Color naming<br>(From 10 colors)<br>Counting<br>Collection naming | Working memory relation<br>Cue coding color- fruit (4 color)<br>Reverse counting<br>Visual perception (Unusual)<br>Memorize an audio story | Start / stop (inhibition) |
| | R | -Pace of treadmill<br>-Synchronization slow- moderate | Beat synchronization to familiar song<br>singing familiar song<br>Mirroring- Imitation | -Rhythmic sound of kicks on the floor<br>-Relaxation music |



Abbreviations: M: Motor; C: Cognitive; R: Rhythmic.

Notes: In the cognitive section (C) of warm-up, color naming means knowing the color from the card. In the cognitive part (C) of

warming up, collection naming means naming a group of fruits, animals and so on. In the cognitive section (C) of the intervention, cue coding color-fruit means naming a fruit of the same color as the color presented to the child. In the cognitive part (C) of the intervention, visual perception means recognition of images from visual education cards such as fruits and animals, etc. The cognitive section (C) of intervention means memorizing an audio story for retrieving parts of a short story that has been played audio for the child, such as the names of fruits, animals and so on. In the rhythmic sections, the rhythm is created as a single sound.