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The Effect of Sustained Attention Tasks on Gait Pattern Variations in Children with Attention Deficit-Hyperactivity Disorder: A Clinical Trial

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Original Article

Abstract

Introduction: The current gait profile of ADHD children is incomplete and mainly based on a short time walking without the involvement of different senses. The aim of this study was to investigate the dual-task gait of ADHD and typically developed (TD) children while receiving sustained visual-vestibular stimulus.

Materials and Methods: 21 children with ADHD and 12 typical children (7-10 years) participated in the study. Participants walked on the treadmill in three, at self-selected speed in three-minute trials in single-task (without visual instructions) and dual-task (simultaneously following visual-vestibular saccade and smooth pursuit stimuli) conditions. Stride length, global angle of the dominant foot, step width, and the variability of these parameters were assessed using a factor analysis of variance at significant level of 0.05.

Results: The effect of group×stimulus interaction on stride length was not significant ($P = 0.860$), but its variability was significant (less variability for typical children compared to children with ADHD ($P = 0.0001$). The interactive effects on the global angle were significant ($P = 0.0001$), but its variability was not significant ($P = 0.72$). In without instruction and in smooth pursuit conditions, significant ankle rotation was observed in children with ADHD ($P = 0.0001$) compared to that of typical children. Step width ($P = 0.0001$) and its variability ($P = 0.003$) were significantly affected and typical children had wider walking with less variability than the other groups ($P = 0.0001$).

Conclusion: Different visual-vestibular instructions can affect the gait of children with ADHD children in various ways. These results can be considered as a basis for the integration of dualistic and synergy models and guidance for educators of ADHD children.

Keywords: Attention deficit-hyperactivity disorder; Gait; Saccade; Smooth pursuit; Vestibulo-ocular reflex

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Introduction

Attention deficit-hyperactivity disorder (ADHD) is the most common childhood neurological syndrome. Children with ADHD show the main symptoms of inattention, hyperactivity, and poor response inhibition (1). In addition, a significant number of these children experience impairment in fine and gross movement skills, including static (2) and dynamic (3) instability, impaired coordination and speed, and lack of movement rhythm (Dysrhythmias) (4). Motor skill dysfunctions related to ADHD, especially in gait patterns, have a significant effect on a person's performance (5); because children with ADHD have less desire for physical activity or organized sports that increases obesity and depression risk (6). Also, a higher rate of injury and increased health costs have been reported in these children (7). So that efforts to improve movement function related to ADHD can only be achieved by, rehabilitation interventions focused on specific movement abnormalities (5).

Safe gait simultaneously with posture control requires the ability to integrate inputs from different senses, which is impaired in ADHD children (8).

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Disturbance in gait Pattern due to unusual neural structure has also been confirmed in children with ADHD (3). However, the few studies that examined the gait Pattern in ADHD children compared to normal children have provided contradictory results (5, 9-16). Moreover, in general, the variability of spatio-temporal parameters is a factor to better determine the differences (13, 17). The reasons for the inconsistencies in research can be considered in the sample of ADHD children. According to studies, there is a different correlation between spatio-temporal indicators of gait and cognitive symptoms of different sub-types of ADHD children, such as dominant attention deficit (ADHD-I) or Combined ADHD (ADHD-C) (14). In addition, variances in the ankle joint in children with ADHD is different during gait with different sub-types (18). However, most of the studies that examined the gait Pattern of children with ADHD (5, 11, 13, 16, 19, 20), except for one case (15) has not separated ADHD sub-types. On the other hand, during examining research contradictions, it should pay attention that gait is not a simple reflexive task and higher cognitive processes play an important role in maintaining postural control while walking (21).

A common method to evaluate the effect of these cognitive processes on the gait pattern is to use dual-task paradigms (22). In such a model, people are asked to walk while performing a cognitively challenging task. In dual-task conditions, depending on the type of simultaneous task, it is possible that cognitive or motor performance may be damaged due to the limitation of cognitive resources (23).

Considering the impairment of executive functions in children with ADHD (24), it can be expected that dual-task situations affect gait pattern in children with ADHD to a greater extent than normal children. Researches that investigated the effect of dual-task on gait pattern in children with ADHD are limited and have shown different findings so far (11, 13, 16). In several studies, eye movements have been mentioned as one of the most important sources of attention affecting the postural control of children with ADHD (19, 20, 25). These findings showed that despite the poor postural control in children with ADHD, the improvement of postural instability during the execution of Saccadic eye movements compared to Smooth pursuit and Fixation has been observed (19, 20). Meanwhile, another study showed that in different conditions of the dual-task of postural-eye movement control, both groups of typical children and children with ADHD have poor postural control (25). These results can be seen as consistent with the U-shaped non-linear model. This model is one of the dualistic cognitive models in relation to explaining the changes in the simultaneous execution of postural-supra postural tasks that emphasize on the competition of attention resources (26).

According to the U-shaped dual model, cognitively easy dual-tasks may improve postural control and difficult dual-tasks may worsen it (26). A cognitively easy eye movement can also divert attention away from postural control and lead to better automatic postural performance (20). An overlooked fact in relation to dual cognitive models is that in real life, people are able to perform accurate vision tasks while standing without falling (27). Therefore, the functional synergistic model states that the central nervous system (CNS) may need to unify both cognitive processes involved in controlling posture and visual tasks. Also, visual and posture intersystem in people with disorders such as Children with ADHD should have functional communication with less efficiency than typical people (28).

Two notable cases can be seen in the studies related to different models which justify the facilitation or destruction of people's performance in the dual-task paradigm. (20, 26-29). The first case is limiting the visual tasks in the central vision and fixing the head. In a natural eye-tracking situation, head movements are added to eye movements to obtain a wide range of motion (30). In this situation, the suppression of vestibulo-ocular reflex (VOR) is responsible for guiding the eyes in the direction of head movement (31). This issue becomes important while children with ADHD have shown VOR suppression impairment compared to typical children (32, 33). However, the effect of VOR suppression impairment on gait Pattern changes has not been investigated. The second issue is the execution of vision and gait tasks simultaneously in a very limited time and the number of gait cycles is very small (20). Impaired motor performance of children with ADHD is evident when tasks require Sustained attention; even in this condition, the serious injury rate of these children increases (34). Therefore, the more dual-tasks are performed in an ecological situation, a more comprehensive and complete understanding of the attention processes involved in the gait pattern of children with ADHD (25). Based on the ecological approach of cognitive-motor dual-tasks (35), the dual-task cost trade-offs considering all individual, environmental and task factors occur and limiting people's performance in cognitive or motor tasks leads to distancing from the natural conditions of performance and creating different adaptations (36).

In most of the previous studies regarding the gait of children with ADHD, Spatio-temporal indicators have been examined (5, 9, 11, 13, 15, 16); Because the normality of these indicators requires certain neural connections, including the cerebellum (37), frontal cortex (38), basal ganglia, corpus callosum, and motor cortex (39), which may be altered in children with ADHD. In addition, as the vital signs of gait, these indices are sensitive to gait abnormalities caused by developmental-neurological abnormalities such as developmental coordination disorder (40). In addition, since the variability of Spatio-temporal indices obviously shows the differences in gait between children with ADHD and children with typical development (13, 17), it is possible to identify the difference of these children in the conditions of the dual-task considered in the current research. Based on the results of previous studies related to the gait Pattern of children with ADHD (5, 9, 16) and current understanding of the role of neural substrates in controlling gait, it is hypothesized that compared to peers with normal development, children with ADHD show different functional synergies in dual-task conditions of visual-vestibular gait. On this basis, due to the insufficiency of the existing research to define the current characteristics of gait in ADHD children, especially with the separation of the sub-types of this disorder in the anatomical condition, it seems that identifying the gait disorder of children with ADHD in the ecological situation is very important to inform the physicians and rehabilitation specialists in the appropriate formulation of motor exercises to improve the gait pattern. In turn, it addresses the negative long-term psychosocial and public health consequences of ADHD. For this reason, Spatio-temporal indicators of gait and their variability were used to evaluate the gait Pattern of children with ADHD (ADHD-C and ADHD-I) and typical children in gait continuously and simultaneously with the secondary task.

Materials and Methods

This study was semi-experimental and clinical trial, and the target population was 7-10 year old children with ADHD in Tehran. Sampling was done by the method available in psychiatric clinics in Tehran. ADHD children diagnosed with the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (41, 42) were separated by the clinic psychiatrist. In order to be more sure of the definitive diagnosis and to specify the sub-types of the disorder, the second edition of the Integrated Visual and Auditory Attention-2nd Edition (IVA-2) (43, 44) and the Revised Conners' Parent Rating Scale (CPRS-R) (45, 46) was used. In order to check, whether these children are pure in terms of motor disorders, the second edition of the Movement Assessment Battery for Children Test (MABC-2) (47, 48) was also implemented. The criteria for entering the research included obtaining a score above 34 from the CPRS-R questionnaire, diagnosis of ADHD with IVA-2, a percentage score above 0.16 from MABC-2, and an IQ above 70 based on children's medical records. The final experimental group included 21 children with ADHD, 11 children with ADHD-C (8 boys and 3 girls) and 10 children with ADHD-I (8 boys and 2 girls). A group of 12 children with typical development (TD) matched in terms of age with children with ADHD (9 boys and 3 girls) were included in the study as a control group. Exclusion criteria for all children included gait abnormalities or disorders, other neurodevelopment disorders diagnosis (excluding ADHD diagnosis for the experimental groups), or any affecting medical problems such as hearing or vision impairments based on the opinion of the specialist physician of each center. Four people in the ADHD-C group and three people in the ADHD-I group used Methylphenidate (MPH). On average, the children had been taking methylphenidate for 6 to 8 months. To eliminate the effects of drug on the Test day, these children stopped their drug 24 hours before the evaluation session with the coordination of their physician and then started the drug again. This protocol was based on studies in this field (11, 12, 15). Organizational Committee of Ethics in Biomedical Research of Tehran University approved the current research with code IR.UT.PSYEDU.REC.1399.011. Moreover, the parents signed the written informed consent approved by the ethics committee. Evaluations were carried out in two screening stages (by the research team) and the main evaluation (by the expert operator of the laboratory, without knowledge of the groupings) in the movement analysis laboratory at Javad Mofaffian Neurorehabilitation Center in Tehran. In the screening stage, in addition to the initial evaluations, gait training on a treadmill (model Spirit xt-685, USA) was also done. In order to fit the treadmill handle to the children's height, a walker at the height of the children's waist was replaced by the treadmill handle. This ensured that all children were able to walk at their preferred speed safely and without fear. The average preferred speed of people was 3.20 ± 0.55 km/h. Motion data collection was done through a VICON motion capture device (VICON motion capture, England) with ten infrared cameras. The data was recorded through the Nexus software (Vicon Corp. Released 2018. Nexus, Version 2/12. England) connected to the device. Marking was based on the Plug-in gait pattern with 39 markers (49). In the present study, only the toe, heel and ankle markers were investigated.

Subjects were given a control test (without visual instructions) and two tests with visual instructions (smooth pursuit and Saccade) while walking on a treadmill as dual-tasks. The stimulus presentation tool is a researcher-made tool (Figure 1) was adapted from similar studies (31). The instruction of 1/3 vision conditions was presented to the participant before a three-minute test. Between each 3-minute gait test, there was a 5-minute break without any feedback or verbal instructions. In a laboratory room with natural light, the stimuli were displayed at the child's eye level on a white semicircular screen in front of the person.

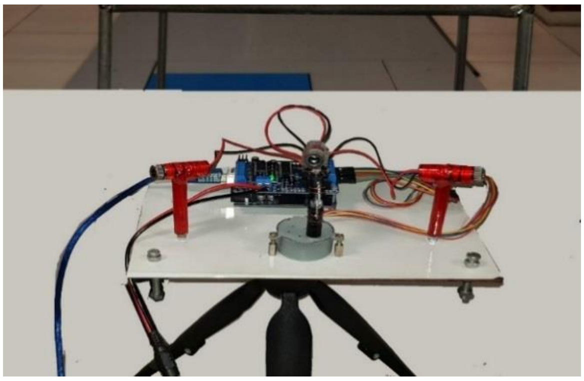

Figure 1. Researcher-made device for presenting visual stimuli

The distance between the center of the stimulus and the child's eyes was 1.1 m (31) and the child's head moved 70 to 90 degrees to the right or left in response to the stimulus.

Visual-vestibular conditions are listed below:

Visual Saccadic instructions: Saccade trials consisted of a target (laser) located in the center of the screen (zero degree visual angle) with a variable delay between 2000 and 3500 ms. After this fixation period, the central target was off and a target appeared 200 ms later (gap interval) randomly for 1000 ms on the right or left side of the semicircular screen (left and right lasers). After that, the central fixation target reappeared and the next trial began (Figure 2) (20, 31, 50). Subjects were encouraged to follow the stimulus as it appeared while walking on a treadmill.

Visual smooth pursuit instructions: Smooth pursuit trials consisted of a target (laser) placed in the center of the screen (zero degree visual angle). In addition, the target moved to the right or left side (randomly) of the semicircular screen at a speed of 0.2 Hz.

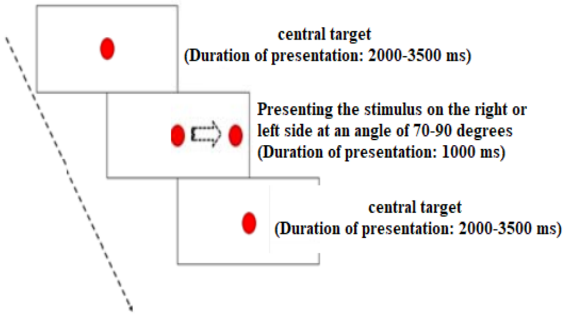

Figure 2. Saccadic movement pattern

Then, it moved towards the center of the screen in the same direction and with the same speed as the target. This pattern was repeated again (Figure 3) (20, 31). People were encouraged to follow the stimulus while walking on the treadmill. Stride length (longitudinal distance between successive contact points of the heel of one leg in centimeters), global angle of the dominant foot (the angle of the dominant foot with respect to the line of the direction of travel in degrees) and step width (transverse distance between the center of one foot and the center of the opposite foot in centimeters) was calculated as the gait performance index. The variability of each gait index was presented with the coefficient of variation [CV = (standard deviation/mean) × 100] and expressed as a percentage (5).

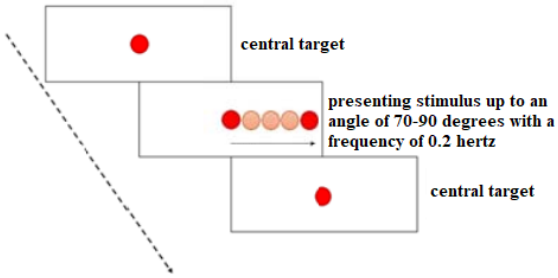

Figure 3. Smooth pursuit movement pattern

ANOVA test was used to evaluate the difference in average preferred speed, age, height, and IQ of different groups. A 3 (group) × 3 (visual task) design with a significance level of 0.05 was used to evaluate intra-group and inter-group differences in the form of factor analysis of variance. Levene's test was used to check the assumption of homogeneity of variance. One-way

ANOVA test was used to investigate significant interactions between two or more variables and Bonferroni test was used for post hoc comparisons. Finally, data were analyzed in SPSS software version 24 (version 24, IBM Corporation, Armonk, NY). The sample volume was calculated using G.Power software (G.power 3.1.9.2, University of Düsseldorf, Düsseldorf, Germany). Examining the sample size in order to compare the main and interactive effects at the significance level of 0.05 and the power of the test 80% (β = 0.2) was considered based on similar research in children with ADHD (51). Based on statistical analysis method, degrees of freedom and effect size of the f of was considered 4 and 0.7, respectively (52). On this Basis, the total number of samples in three groups was determined to be 30 people, and then, the number of people collected after screening was sufficient for the statistical analysis.

Results

Demographic Characteristics of children in different groups is presented in table 1. According to Levene's Test, the equality of variances was confirmed at all investigated variables (P > 0.050). The results of the ANOVA Test showed that there was no significant difference between the age, IQ, height and weight of the children in the three groups (P > 0.050). The Spatio-temporal Characteristics of the participants' gait in the three groups under the investigated conditions is shown in table 2.

The results of ANOVA Test showed that the interaction effect of group and visual conditions (Table 2) on children's stride length ($F_{(4,90)} = 0.27$, $\eta^2 = 0.01$, P = 0.890) was not statistically significant. However, this interaction was reported to be significant in relation to stride length variability ($F_{(4,90)} = 66.65$, $\eta^2 = 0.74$, P = 0.001,) (Table 3). By examining the interaction effect, the variability between the couple of groups with ADHD was not statistically significant in the conditions without visual instructions (P = 0.270) and Saccade (P > 0.999), but the variability of both groups with ADHD was significantly higher than typical children (P = 0.001). In the Smooth pursuit condition, children with ADHD-C showed significantly less variability in stride length than children with ADHD-I, but still significantly more variability than the control group (P = 0.001) (ADHD-I > ADHD-C > TD). By examining the intragroup effects, the highest and lowest significant variability was assigned to the ADHD-C (P = 0.001) and ADHD-I (P = 0.001) groups in the Smooth pursuit condition and the Saccade condition, respectively. Nevertheless, in different visual conditions, Children in the control group did not show a significant difference in the variability of their stride length (P = 0.080) (Table 3).

The interactive effect of group and different visual conditions on the global angle of the dominant foot ($F_{(4,90)} = 54.69$, $\eta^2 = 0.71$, P = 0.001) was reported statistically significant, but this interaction was not significant in relation to its variability ($F_{(4,90)} = 0.10$, $\eta^2 = 0.005$, P = 0.980). In the conditions without visual instructions and smooth pursuit, the internal rotation of the ankle in the ADHD-C group was significantly higher than the ADHD-I and control groups (P = 0.001). Moreover, both the control and ADHD-I groups showed ankle rotation outward, but the difference in the global angle of the dominant leg in the ADHD-I group was significantly higher than the control group in the condition without visual instructions (P = 0.006) and smooth pursuit (P = 0.007). In the saccade condition, there was no significant difference between the ADHD groups (P > 0.999), ADHD-C and the control group (P = 0.450), and the ADHD-I group and the control group (P > 0.999), and all three groups had a dominant ankle external rotation. By examining the intragroup effects, in the conditions without instructions and smooth pursuit, ADHD-C children reported internal rotation of the ankle and there was no significant difference between these two conditions (P = 0.020). Whereas, in the condition of saccade, the ankle rotation was came close to natural condition and was significantly different from both other conditions (P = 0.001). ADHD-I children showed external rotation of the ankle in the condition without instruction and smooth pursuit, and there was no significant difference between these two conditions (P = 0.450), but in the saccade condition, the ankle rotation was close to the normal and the difference was significant with both other conditions (P = 0.001).

Typical children reported little external rotation of the ankle in the condition without instructions and Smooth pursuit, and there was no significant difference between these two conditions (P = 0.530), but in the Saccade condition, the external rotation of the ankle decreased and there was a significant difference with both condition (P = 0.001).

Table 1. Demographic Characteristics of children in different groups

Demographic Characteristics	ADHD-C	ADHD-I	TD	P value (Intergroup comparison)
Age (year)	8.42 ± 1.07	7.95 ± 0.76	7.78 ± 0.79	0.25
IQ	91.90 ± 4.65	91.36 ± 7.94	97.57 ± 7.74	0.09
Height (cm)	135.30 ± 18.90	127.33 ± 6.78	128.31 ± 8.07	0.32
Weight (kg)	31.40 ± 10.76	28.95 ± 9.14	29.67 ± 7.06	0.83

ADHD: Attention deficit-hyperactivity disorder; ADHD-I: ADHD with dominant attention deficit; ADHD-C: Combined ADHD; TD: Typical development

Data are reported as mean ± standard deviation

Table 2. Spatio-temporal Characteristics of gait participants of different groups in three studied conditions

Spatio-temporal Characteristics	Test Conditions	ADHD-C	ADHD-I	TD	P value (Intergroup comparison)
Stride length (cm)	Without visual instructions	36.92 ± 5.19	35.94 ± 3.87	36.30 ± 2.58	0.840
	Smooth pursuit	9.95 ± 1.92	9.63 ± 1.59	9.19 ± 1.66	0.690
	Saccade	37.99 ± 4.20	38.91 ± 3.98	37.38 ± 2.99	0.630
	P value (intragroup comparison)	0.001	0.001	0.001	
Global angle of the dominant foot (degree)	Without visual instructions	-5.24 ± 1.51	6.17 ± 1.56	3.17 ± 1.22	0.001
	Smooth pursuit	-8.38 ± 1.03	7.86 ± 1.78	3.87 ± 0.54	0.001
	Saccade	0.83 ± 0.51	1.08 ± 0.60	1.34 ± 0.52	0.280
	P value (intragroup comparison)	0.001	0.001	0.001	
Step width (cm)	Without visual instructions	8.25 ± 1.76	8.55 ± 1.66	7.96 ± 1.19	0.680
	Smooth pursuit	4.30 ± 0.68	8.62 ± 2.36	7.74 ± 1.29	0.001
	Saccade	10.17 ± 1.98	7.14 ± 2.78	7.28 ± 1.83	0.004
	P value (intragroup comparison)	0.001	0.280	0.510	

ADHD: Attention deficit-hyperactivity disorder; ADHD-I: ADHD with dominant attention deficit; ADHD-C: Combined ADHD; TD: Typical development
Data are reported as mean ± standard deviation.

The interactive effect of group and different visual conditions on step width ($F_{(4.90)}$=13.88, η^2 = 0.38, P = 0.0001), and variability of step width ($F_{(4.90)}$ = 4.01, η^2 = 0.15, P = 0.005) was significant. Step width between different groups in conditions without visual instructions (P < 0.999) and in Saccade conditions between children of control groups and ADHD-I (P = 0.390), control groups and ADHD-C (P = 0.050) and there was no significant difference between ADHD-I and ADHD-C groups (P > 0.999). On the other hand, in the Smooth Pursuit condition, the step width of children in the control group was significantly greater than that of children with ADHD-C (P = 0.001) and ADHD-I (P = 0.010), but between the two groups with ADHD (P = 0.720) no significant difference was observed.

The variability of step width in the condition without visual instructions was significantly lower in control group children than ADHD-I (P = 0.003) and ADHD-C (P = 0.001), but there was a difference between the two groups with ADHD. There was no significance (P > 0.999). These conditions were also observed in Smooth pursuit and Saccade mode, and both groups with ADHD showed higher variability than the children in the control group with no significant difference from each other (P > 0.999). By examining intragroup differences, the highest significant gait width in Saccade conditions and the lowest significant gait width in Smooth pursuit were in ADHD-C (P = 0.001) and ADHD-I (P = 0.007) groups, respectively.

Table 3. Variability of spatio-temporal Characteristics of gait in participants of different groups in the three studied conditions

Spatio-temporal Characteristics	Test Condition	ADHD-C	ADHD-I	TD	P value (Intergroup comparison)
Stride length variability (percentage)	Without visual instructions	15.25 ± 2.38	17.14 ± 2.07	5.81 ± 2.24	0.001
	Smooth Pursuit	19.63 ± 0.34	29.02 ± 2.01	4.38 ± 1.10	0.001
	Saccade	9.51 ± 1.18	8.97 ± 1.61	5.84 ± 1.05	0.001
	P value (Intragroup comparison)	0.001	0.001	0.080	
Variability of the global angle of the dominant foot (percentage)	Without visual instructions	57.20 ± 7.94	57.90 ± 9.22	44.63 ± 8.79	0.005
	Smooth Pursuit	55.91 ± 9.75	56.80 ± 10.00	42.35 ± 9.03	0.003
	Saccade	56.90 ±10.28	54.58 ± 9.06	41.44 ± 9.34	0.001
	P value (Intragroup comparison	0.950	0.740	0.690	
Step width Variability (percentage)	Without visual instructions	51.06 ± 7.83	46.07 ± 9.56	21.24 ± 4.11	0.001
	Smooth Pursuit	20.26 ± 3.44	19.69 ± 2.49	9.09 ± 1.08	0.001
	Saccade	62.00 ± 15.19	66.42 ± 10.85	25.84 ± 8.92	0.001
	P value (Intragroup comparison	0.001	0.001	0.010	

ADHD: Attention deficit-hyperactivity disorder; ADHD-I: ADHD with dominant attention deficit; ADHD-C: Combined ADHD; TD: Typical development
Data are reported as mean ± standard deviation.

However, there was no significant difference in different visual conditions in children of the control group. Regarding the variability of gait width, all three groups experienced the least significant variability (P = 0.001) in the Saccade condition compared to the other couple of conditions.

Based on the continuum introduced by Cohen (52), the effect size of the Stride length of the group interaction was small and non-significant in the visual conditions (η^2 = 0.01). The observed power of this interactive effect (1- β = 0.10) also confirmed the absence of any significant difference. In relation to stride length variability, a large effect size of 0.74 was obtained and confirmed by the observed power; Because the observed power of the significance of the interaction effect of the group in visual conditions on the stride length variability (1-β = 1.00) was complete and without any statistical error was significant. The effect size of the group interaction in visual conditions was 0.71 and the observed power of this interaction was statistically (1-β = 1.00) on the global angle of the dominant foot similar to the stride length variability. On the other hand, the variability of the global angle of the dominant foot with a non-significant effect size (η^2 = 0.005) and a negligible observed power (1-β = 0.07) was not affected by the considered interaction. The step width was significantly affected by the group interaction in the visual conditions with a medium effect size (η^2 = 0.37), but the statistically observed power showed a definite significant effect (1-β = 1.00). In relation to the variability of step width, despite the significance of the interaction with a small effect size (η^2 = 0.15), the observed statistical power (1-β = 0.90) showed the certainty of significance.

Discussion

The present study investigated the effects of dual-tasks of sustained attention accompanied with the Visual-vestibular sense on gait pattern in children with Attention Deficit-Hyperactivity Disorder (ADHD). In addition, a sample population of children with ADHD with two subtypes of ADHD-C and ADHD-I were compared with a matched sample of TD children. The findings provided evidence regarding significant effects of dual-tasks, as before mentioned, on gait pattern in children with ADHD. Moreover, gait pattern variations in children in dual-task situations were significantly different compared to the control group. Therefore, according to research hypotheses, children with ADHD showed higher gait variability in situations, which required high attention; In other words, in situations that required optimal sharing of cognitive resources, gait variability in children with ADHD was more rather than the typical children.

Results showed that gait pattern in all three groups was affected by dual-task situations. In both groups of children with ADHD showed more irregularity in gait pattern with increasing stride length variability in the smooth pursuit situation. However, this variability reached the lowest level in the saccade task. Results obviously showed that the variability of children with ADHD was higher than typical children. Different impressibility of two groups with ADHD towards different visual tasks was also significant: The smooth pursuit situation caused more performance disorders in children with ADHD-I than children with ADHD-C. Regarding the debilitating of gait performance in some tasks, the findings support previous claims based on that gait is not an automatic behavior, but requires higher cognitive functions (21). Present findings in line with Mohring et al. (13) represented that Children with ADHD are more affected by dual-task situations rather than normal children. Finding was expected, whereas children with ADHD have impaired executive functions (24). In return, some studies reported no significant importance in gait pattern in children with ADHD and typical children (11, 16). Since, it has been shown that the task type simultaneously affects dual-task performance, (23, 53), a justifying reason for the contradictions is the tasks type; In the researches where receptive cognitive tasks used as an auditory stimulus (11, 16), results are different from when more active production tasks is used like as an expression of a specific classification (13). Therefore, it is possible that more active tasks may affect the gait pattern, especially in children with ADHD with different cognitive functions (13). Another reason is the sustained attention task in this research; If the gait cycles in this research is reduced to a limited number, similar to previous research, it is possible to observe different results; But it should be noted that in such conditions, children's performance is measured separated from their daily life.

According to the present results, dual variant tasks can lead to variant affects on gait pattern, and also Saccadic eye movements can improve gait pattern and especially movement rhythm. Results can be discussed with the dual U-shaped model (26) and synergy (28). It worth to mention that the variability of the stride length in the Saccade dual-task was reduced, compared to the conditions without visual instructions, in all three groups of children with

ADHD and the control group which indicated a better control of gait during this dual-task (54). Result is in accordance with the hypothesis that a secondary task can divert the attention from gait and posture control and lead to better automatic gait and posture (26). Bucci et al., by the results in line with the present research, stated that the improvement of posture in some eye tasks and its disorders in others, is accordance with the dual U-shaped model (20). On the contrary, regarding two variables including global angle of dominant foot and step width in gait, disaffirms the obtained results. As stride length variability during the saccade task reduced, step width in gait variability was reduced during the smooth pursuit situation. However, the reduction of step width variability was at the cost of reducing step width during the smooth pursuit situation. These results can be explained by the fact that ADHD children reduce the step width in gait, in order to maintain the regularity and rhythm during walking. Therefore, in different visual situations, a functional synergy occurs so that children create an optimal gait pattern. These results are in line with the functional synergy model (28) between precise eye tasks such as smooth pursuit and maintaining posture control. The present research focus was not on controlling posture and maintaining balance, but with the tangible variations in step width in gait during situations without visual instructions and two other situations, it can be assumed that the variabilities in spatio-temporal factors of gait such as step width in gait and its variability causes instability in children with ADHD. In the smooth pursuit situation, children with ADHD showed significantly less step width in gait and less variability while in saccade situations, these results was reversed. So that, ankle angle approaches the natural gait conditions. This issue is consistent with the results of previous studies (20, 50) and improves posture control in saccade situations in the control group and ADHD children group. One issue can be mentioned here; In ecological conditions, only variant cognitive and attention load does not affect gait control, and especially in children with ADHD, the effect of disordered integration of senses (8) and suppression disorder of VOR (32, 33) is important. Considering the head rotation in dual-tasks in the present study, VOR suppression can be effective in control and regularity of gait (31).

In Smooth pursuit situations, where the highest variability and departure from the normal gait mode is observed in children with ADHD, based on the frequency of head rotation, slow VOR suppression should occur (31). Meanwhile, the high variability and variations in step width in gait and ankle angle in the Smooth pursuit situation can come from this disorder. On the other hand, in Saccade situations, in addition to lower cognitive load, rapid VOR suppression occurs (31) and it can be hypothesized that in conditions of lower cognitive load such as Saccade (19, 20, 50) the possibility of integration Sensation and suppression of the VOR occurs optimally. By expressing sensory motor and cognitive coordination and its effect on gait performance, the functional synergy model (28) could be referred in this regard. According to the synergy model, the CNS may need integrate both cognitive processes involved in precise visual tasks and gait to succeed in precise visual tasks (28). On the other hand, paying attention to functional synergy between body posture and vision, structural-sensory integration, especially in children with ADHD and sensory integration problems (8) should not be ignored. Children with ADHD have impairments in vestibular function and VOR suppression. Therefore, the difference between the findings of the present study and the former findings can be due to the task type that is performed simultaneously with walking. In the present study, ADHD children needed to integrate both visual and vestibular senses. In previous studies, by limiting the range of vision and fixing the head, involvement and manifestation of possible impairments in the vestibular sense were prevented.

Limitations

Due to the need for simultaneous visual-vestibular tasks and walking continuously and for a long time, walking on the treadmill was done. According to the differences in the coordination of the lower limbs in the two conditions of walking on the ground and on the treadmill (55), the evaluated task in parts such as changes in gait speed, especially with regard to the effect of visual-vestibular stimulation, was somewhat far from the natural conditions. Although, in the current study, the effect of drugs was controlled under the supervision of a physician and within the framework of ethics in the research. However, since the children had used the drugs for a long time, it is possible that the long-term effects of these drugs on the gait Pattern of the children affected the results of the study.

Recommendations

It is suggested to investigate the simultaneous effect of drug use [regarding the difference in postural control of children with ADHD (13, 20) and Visual-vestibular intervention on the cognitive and movement components of children with ADHD in a long period of time. In addition, it would be desirable to conduct research in the conditions of gait on the ground as the usual conditions of gait in children with ADHD. Other researches in order to compare the gait of children with ADHD who are required to use medication with children who do not use medication will also be valuable.

Conclusion

Results of the present study showed that children with ADHD have impaired gait control, high variability, and low step width, which especially affects posture. The reason for these differences compared to typical children is probably cerebellum insufficiency, vestibular disorders and low attention capacity in the long term. Furthermore, when children with ADHD performed Saccadic eye movements, they approached the normal gait pattern. Therefore, the present study provides a context for therapists and educators to focus on Visual-vestibular interventions to improve basic movement skills in ADHD children.

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Authors' Contribution

Study design and ideation: Sana Soltani
Getting financial resources for the study: Abbas Bahram and Farhad Ghadiri
Scientific and executive support of the study: Alireza Farsi & Sana Soltani
Data collection: Sana Soltani
Analysis and interpretation of results: Sana Soltani and Farhad Ghadiri
Specialized statistics services: Sana Soltani, Abbas Bahram, Farhad Ghadiri, Alireza Farsi
Manuscript preparation: Sana Soltani, Abbas Bahram, Farhad Ghadiri, Alireza Farsi
specialized scientific evaluation of the manuscript: Sana Soltani, Abbas Bahram, Farhad Ghadiri, Alireza Farsi
Confirm the final manuscript to be submitted to the journal: Sana Soltani, Abbas Bahram, Farhad Ghadiri, Alireza Farsi
maintaining the integrity of the study process: Sana Soltani, Farhad Ghadiri

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Conflict of Interest

The authors did not have a conflict of interest. Dr. Abbas Bahram gets the funding for the present work from Kharazmi University and has been working as a professor at the Department of motor behavior since 2012. Dr. Farhad Ghadiri has been working as an associate professor at Kharazmi University in the Department of motor behavior since 2012. Dr. Alireza Farsi has been working as a professor at Shahid Beheshti University in the Department of motor behavior since 2017. Sana Soltani gets the second part of the funding for the present work from the Cognitive Sciences and Technologies Council with confirmation from Kharazmi University and has been studying at Kharazmi University since 2018 as a PhD student in motor behavior.

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