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Sensory Integration in Attention Deficit Hyperactivity Disorder: Implications to Postural Control

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1. Introduction

A major task of the central nervous system is to configure the way in which sensory information becomes linked to adaptive responses and meaningful experiences. The neural systems that bridge the gap between sensation and action provide the substrates for 'intermediary' or 'integrative' processing (Miller et al., 2009). Sensory integration disorder 'SID' is a neurological disorder that results from the brain's inability to integrate certain information received from the body's five basic sensory systems (vision, auditory, touch, olfaction, and taste), the sense of movement (vestibular), and/or the positional sense (proprioception). Sensory information is sensed normally, but perceived abnormally affecting participation in functional daily life routines and activities (Bundy et al., 2002).

Around 16 percent of the general population has symptoms of SID. In attention deficit hyperactivity disorder 'ADHD', the frequency of SID rises to 40 - 84% as reported in different studies (Mulligan, 1996; Dunn & Bennett, 2002; Ben-Sasson et al., 2009). One of the categories proposed within SID included sensory-based motor disorder. Sensory-based motor disorder comprises postural disorder (which reflects problems in balance and core stability) and dyspraxia (which encompasses difficulties in motor planning and sequencing movements) (Miller et al., 2007, 2009; Buderath et al., 2009).

Static postural control (stability) is the ability to maintain center of mass (center of gravity) within the base of support (Horak, 1987). The integration of the sensory information from somatosensory, visual, and vestibular origins by the central nervous system, followed by coordinated automatic outputs involving the muscles of postural control is crucial to maintain stability and orientation of the body to the environment (Hunter & Hoffman, 2001). With children, postural stability is gradually acquired as various systems mature, greater experiences accumulate and sensory integration takes place. They begin to approximate adult levels of performance by the age of seven years (Palmeri et al., 2002; Shepard & Janky, 2008).

What is not understood is the developmental profile of children with ADHD. Children with ADHD have been found to have an increased velocity of postural sway than normal

children (Zang et al., 2002; Shum & Pang, 2009). In daily activities, they manifest problems performing certain athletic sports, were frequently and involuntarily bumping into things, lacking bounce when walking and running, and became more easily tired and exhausted than peers (Stray et al., 2009).

Computerized Dynamic Posturography 'CDP' assesses the functional capacity of the balance system in an objective and quantifiable manner. By systematically manipulating support surface and visual surround, the sensory organization test (SOT) is an important tool which helps quantify the sensory contributions that aid in sensory integration and the development of postural control (Shepard & Talian, 1996). It evaluates the ability to use in combination or individually the three sensory inputs during maintenance of stance. Information about the automatic patients' reactions to unexpected external disturbances in their centre of mass position is obtained from the motor control (MCT). Furthermore, the adaptation (ADT) test illustrates the response adaptation to irregular/varying support surface conditions. Both MCT and ADT evaluate the postural control long loop pathway (Allum & Shepard, 1999).

Balance deficits are usually not addressed with ADHD children because awkwardness and clumsiness are likely attributed to lack of "attention or concentration". This study was designed to compare the static postural control function in a group of ADHD/C children and typically developing (TD) children using CDP. This might be considered as a step to investigate one of SID subtypes in the studied children.

2. Methodology

2.1 Patients

Twenty children with ADHD of the combined subtype (ADHD/C) were included in the present study. They were diagnosed according to the diagnostic and statistical manual 'DSM-IV' criteria for ADHD (American Psychiatric Association, 1994). Selection of children was randomly obtained from the clinic records of the psychiatry outpatient clinic, Institute of Psychiatry, Ain Shams University Hospitals during the period from January 2010 to July 2010. Informed consent was taken from the parents with explanation of the test procedures, benefits, and risks according to the ethical rules.

Selection of children considered an age range between eight and ten years. Intelligent Quotient (IQ) should be more than 85 using Wechsler Intelligence Test for Children 'Arabic version'. A minimum score of 70 (markedly atypical) on at least 2 subscales of the Conner's Parent Rating scale was an important inclusion criterion. Children should be free from neurological, sensory, and orthopaedic problems and not on psychotropic medications.

Twenty age, sex and height matched typically developing (TD) children were used as a control group. They had no history suggestive of behavioral, attention problems, medical, hearing, balance, orthopaedic, visual or neurological disorders.

2.2 Procedures

Careful history taking and neuro-psychiatric assessment was performed by a child psychiatrist. The Arabic version of the Mini-International Neuro-psychiatric Interview for Children and Adolescents (M.I.N.I-Kid) was applied to confirm the ADHD diagnosis,

subtype and exclude other co-morbid conditions. MINI-Kid is a short, structured interview designed to assess symptoms of several Axis I disorders as listed in the DSM-IV and the International Statistical Classification of Diseases and Related Health Problems (Ismail & Melika, 1961). Assessment of IQ was done using Wechsler intelligence scale for children (Sheehan et al., 1998) by a clinical psychologist.

To assess the degree of ADHD severity, the Conner's parent rating scale revised, long version (CPRS-R-L) was used (Conner, 1997). It represented an 80 items questionnaire with an average administration time of 25-30 minutes. It scored the parents report of their child's behavior during the past month on a 4-point response scoring.

In the vestibular clinic, Ain Shams university hospitals, the postural control system was tested for all children by an audiologist. It was done using Computerized Dynamic Posturography 'CDP' SMART EquiTest system. The CDP sub-tests used were: sensory organization test 'SOT', motor control test 'MCT', and adaptation test 'ADT'. The test procedure, instructions, and analysis followed the SMART EquiTest system manual version 8 specifications.

The SOT measured the ability to perform volitional quiet stance during manipulation of the different sensory inputs available for use. During the SOT, the somato-sensory and visual environments were altered systematically through movement of forceplate, visual surround, or both. Six conditions of the SOT assessment were applied as illustrated in (Figure 1). The system recorded data for a maximum of three trials for each of the six conditions. Each trial lasted 20 seconds. Prior to each trial the child was given the proper instructions.

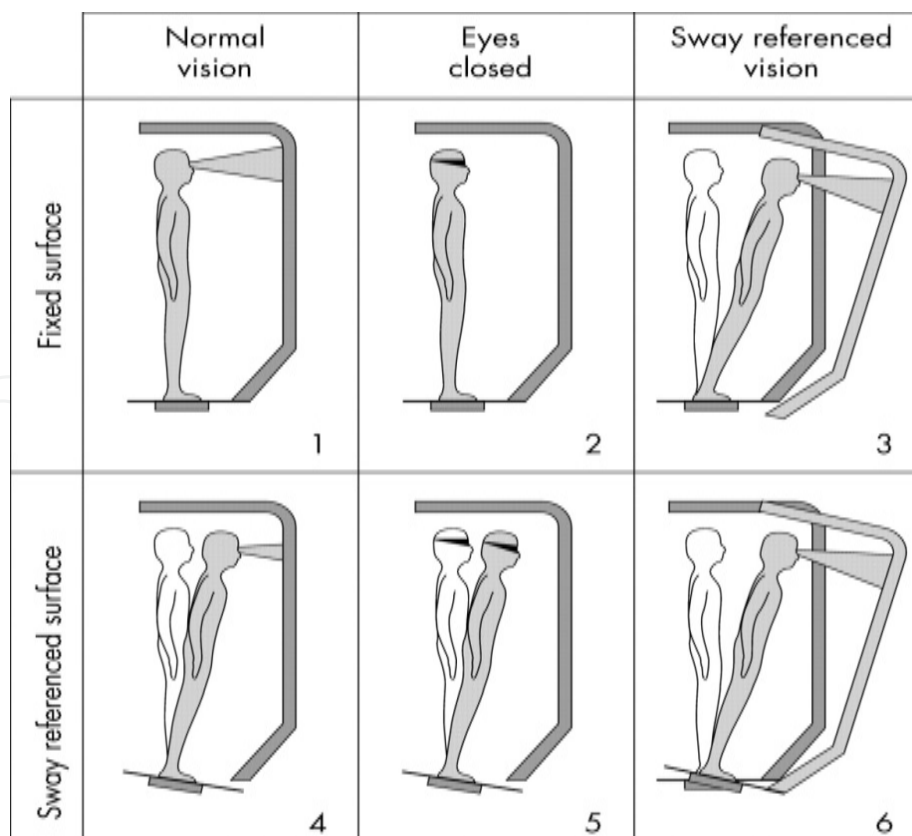


Fig. 1. Sensory Organization Test conditions (SOT 1- 6).

The data obtained from SOT analysis were:

- **Equilibrium Score:** It is a percentage score reflecting the magnitude of sway of centre of mass in the sagittal plane for each trial of the 6 sensory conditions. The normal value of patient's sway limit should be within 12.5 degrees of sway in the antero/posterior direction, 8 and 4.5 degrees in forward and backwards directions, respectively. A patient swaying to these limits will receive a very low score. The highest possible score was 100, which indicates that the patient did not sway at all. The composite equilibrium score was also recorded.
- **Sensory Analysis:** It included the sensory ratios computed from the average equilibrium scores obtained on specific pairs of sensory test conditions as described in table 1.

Sensory ratio	SOT conditions	Significance
Somatosensory 'SOM'	Condition 2/condition 1	Patient's ability to use input from the Somatosensory system to maintain balance
Visual 'VIS'	Condition 4/condition 1	Patient's ability to use input from the visual system to maintain balance
Vestibular 'VEST'	Condition 5/condition 1	Patient's ability to use input from the vestibular system to maintain balance
Visual preference 'PREF'	Condition 3+6 /condition 2+5	Degree to which patient relies on visual information to maintain balance, even when the information is incorrect

Table 1. Computation of the sensory analysis ratios

- **Strategy Analysis:** It showed the relative amounts of movement about the ankles (ankle strategy) and about the hips (hip strategy) that the patient used to maintain balance during each procedure. Exclusive use of ankle strategy to maintain equilibrium resulted in a score of 100. Exclusive use of hip strategy would give a score near 0. Scores between these two extremes represented a combination of the two strategies.

The *MCT* assessed the ability of the automatic motor system to quickly recover following an unexpected external disturbance. This demonstrated the patient's ability to coordinate automatic movement responses to maintain standing posture. Three sequences of platform translations of varied sizes (Small, medium and large) were administered in forward and backward directions lasting less than one second. The sizes of the translations were scaled to the patient's height to produce sway disturbances of equal size. A random delay of 1.5 to 2.5 seconds was between the trials. For the child to perform the test, weight-bearing symmetry was ensured to be within the normal limits.

The Measurements collected from the *MCT* were the speed of reaction (latency), and the relative response strength. The *Latency* was defined as the time in milliseconds (ms) between the onset of a translation and the onset of the patient's active response to the support surface movement. The *relative response strength* was calculated as the amplitudes of the patient's active response to each size and direction of translation in degrees/sec. Values for each leg in the small, medium and large movements and in the forward and backward direction were also obtained.

The ADT demonstrated the ability of the automatic postural control to adapt to recurrent surface movements. A series of rotary platform movements, making the patient's toes to go up or down, were used. Rotations lasted 0.4 seconds and with uniform amplitude for all trials (8°). There were five trials for each type of rotation with a random delay of 3.0 to 5.0 seconds. The reaction force generated by the patient to minimize AP sway was measured.

Initially, the TD children group was tested to obtain norms for the 8-10 years age group. These normative data were subsequently used for comparison with the results obtained from ADHD/C children. To maximize subject familiarity with the tests, subjects practiced each assessment exercise before data collection. Subjects performed without shoes and socks. A harness was loosely fastened around the participant to prevent the participant from falling.

Statistical analysis: Statistical analyses were performed using (SPSS) 10.1. The Student's t test was used to analyze differences between the study groups. For comparing the variables in each group, the paired t test was applied. A level of $p < 0.05$ was considered significant while $p < 0.01$ was highly significant. A statistician was used for guidance in the study.

3. Results

Both ADHD/C and TD children were age and sex matched. They had mean age 8.9 (Standard Deviation 'SD' 0.9) and 9.2 (± 0.8) years, respectively. The ADHD/C group included 16 males and 4 females while the TD had 15 males and 5 females. The Conner's parent rating scale revised showed mean ADHD index scores = 73, mean clinical global impression for restless and impulsive = 79, mean total clinical global impression = 81. All these values reflected the severity of the ADHD condition. According to the parents' reports, four of the ADHD/C children frequently fall during running and three children had difficulty to engage in the gym class at school.

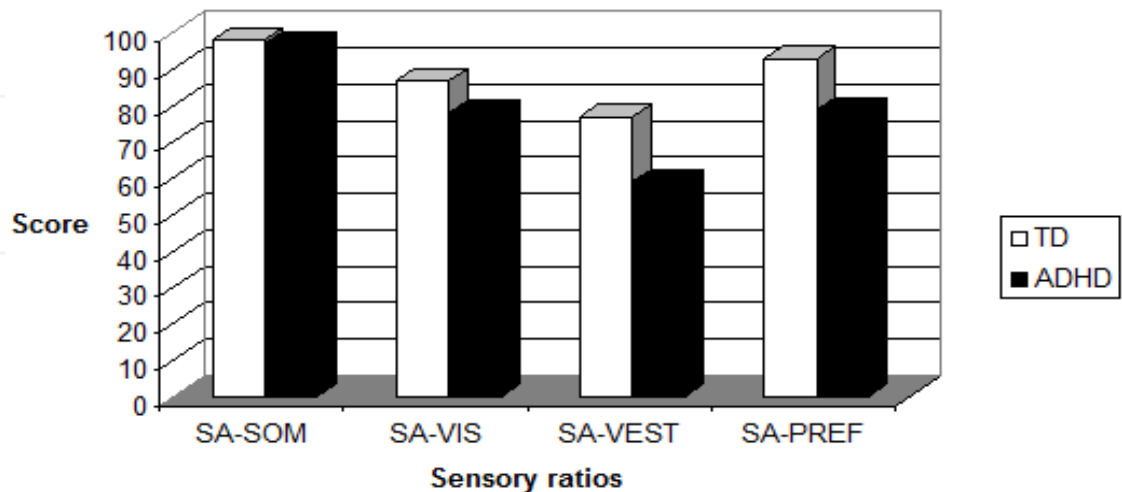
Looking to the CDP test results, the TD children group had mean values that approached the adult values (in the age range 20-59 years) in nearly all tests. On the other hand, children with ADHD had statistically significant lower mean SOT equilibrium scores in the six tested conditions and lower mean equilibrium composite score ($p < 0.05$). More difficulty was encountered in SOT conditions 5 and 6. The lowest scores and the greater difference in scores between the two groups were obtained in these two challenging conditions (Table 2). The SOT test was interrupted in five ADHD/C children as they tended to fall (three children in condition 6 and two children in condition 5 & 6).

Group	SOT1		SOT2		SOT3		SOT4		SOT5		SOT6		Comp	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
ADHD	89	4	85	4	84	5	71	9	55	11	31	21	58	22
TD	93	3	90	3	88	5	81	6	70	12	61	9	73	7
t value	-2.8		-4		-1.9		-3.9		-3.7		-5		-2.5	
p value	0.01*		0.001*		0.04*		0.001*		0.001*		0.001*		0.02*	

$p < 0.05$ = statistically significant. Comp = composite equilibrium score.

Table 2. The equilibrium scores (%) obtained in the different SOT conditions in both study groups.

The sensory analysis showed that ADHD/C had lower somatosensory, visual, vestibular ratios by 1%, 9%, and 18%, respectively compared to the TD children (Figure2). This difference was statistically significant for the visual and vestibular inputs ($p < 0.05$).



SOM: Somatosensory, VIS: Visual, VEST: Vestibular, PREF: Preference

Fig. 2. Sensory analysis (SA) ratios in both study groups.

Both groups used predominantly the ankle strategy during all SOT conditions to maintain equilibrium with no statistical significant difference detected. The strategy score in SOT conditions 1 - 6 was $98 (\pm 0.6)$, $98 (\pm 1.2)$, $97.5 (\pm 2)$, $87 (\pm 5.2)$, $80 (\pm 6)$, and $71 (\pm 8)$ respectively in ADHD children. In the TD children, it was $99 (\pm 1.7)$, $98 (\pm 1.6)$, $97 (\pm 2)$, $89 (\pm 5)$, $88 (\pm 7)$, and $74 (\pm 9)$ respectively.

In the MCT, prolonged latencies were observed in ADHD/C children relative to the TD group. The difference between the two groups reached statistical significance in more than one test condition ($p < 0.05$) (Table 3a, 3b). Both groups demonstrated comparable relative response strength. The right / left leg responses in each group did not show statistical significant difference in all test conditions.

The ADT scores were higher in the ADHD/C children in the two test situations (toes up & down) when compared to the TD children. This difference was statistically significant. The TD children had values approaching the adult values that decreased with increase the trial number. In ADHD/C children, the scores did not differ among the five conditions (Fig. 3a,b).

Movement Group	Small L		Medium L		Large L		Small R		Medium R		Large R	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
ADHD	120	11	123	17	123	11	122	10	123	7	129	25
TD	113	31	122	9	117	11	109	42	123	9	117	9
t value	-0.8		0.2		1.5		-1.2		-0.1		1.7	
p value	0.2		0.4		0.05		0.1		0.4		0.04*	

L = left leg, R = right leg, $p < 0.05$ = statistically significant.

Table 3a. The MCT latency in both groups in each leg during backward movements.

Movement Group	Small L		Medium L		Large L		Small R		Medium R		Large R	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
ADHD	143	31	139	26	140	27	148	32	134	22	142	29
TD	129	13	125	9	126	13	135	31	125	10	126	17
t value	1.6		2		1.8		1.2		1.4		2	
p value	0.06		0.02*		0.03*		0.1		0.08		0.03*	

L = left leg, R = right leg, $p < 0.05$ = statistically significant.

Table 3b. The MCT latency in both groups in each leg during forward movements.

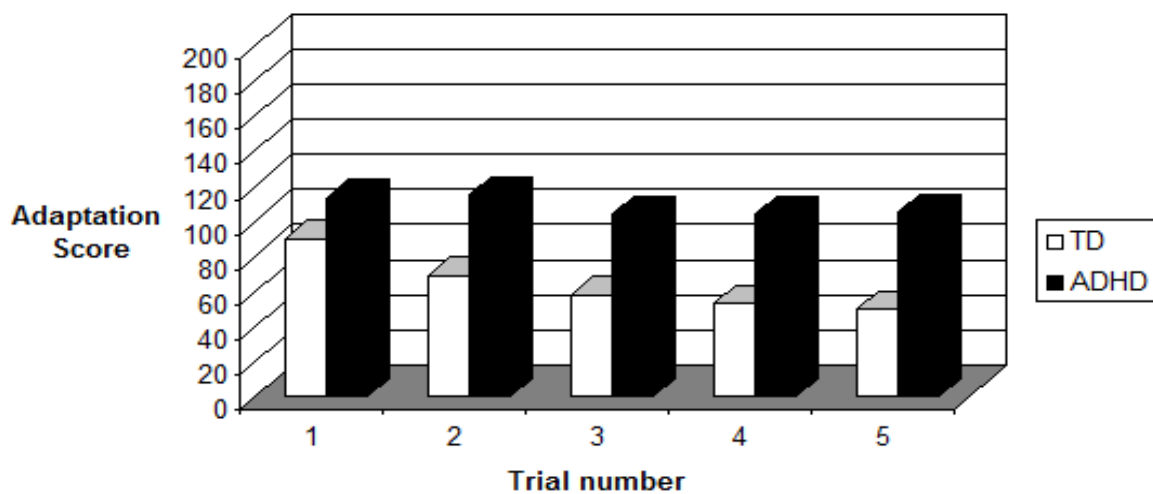


Fig. 3a. Adaptation test results toes up condition in both study groups.

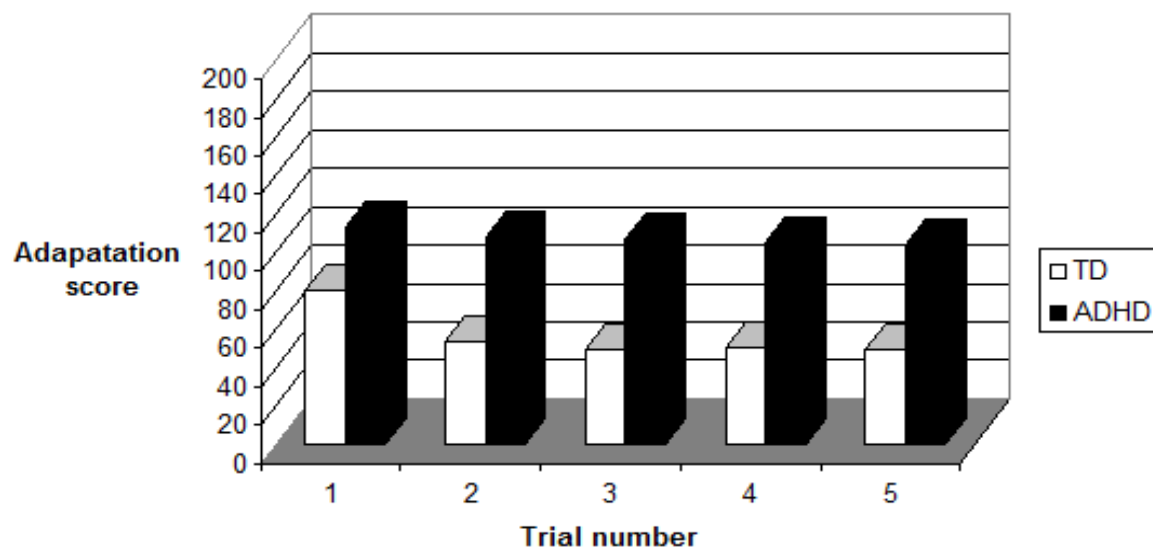


Fig. 3b. Adaptation test results toes down condition in both study groups

4. Discussion

In the present study, children with ADHD/C could not maintain quiet stance and showed more sway while performing all SOT conditions. The composite equilibrium score was 15% lower than the TD children (table 1). This could be the result of a lack of adequate interaction among the three sensory inputs that provide orientation information to the postural control system (Guskiewicz & Perrin, 1996). Higher equilibrium scores in the TD children indicated better coping mechanisms to balance perturbations (Bauer et al., 2001).

Poor stability with significant deficits in SOT was reported in ADHD/C by Shum & Pang (2009) and Cherng et al (2001). As the individual matures and develops, sensory integration mechanisms are developed to suppress or inhibit irrelevant information and keep an excess of central nervous system arousal in check (Wang et al., 2003). This particular feature of development appears to be absent in individuals with ADHD. A lack of inhibition and sensory-motor homeostasis is linked to a lazy frontal lobe with the ADHD population and inadequate vestibular and somato-sensory feedback (Ayers, 1972; Mulligan, 1996; Zang et al., 2002).

Notably in this work, difficulties in postural control in ADHD/C showed up more clearly in the greater task constraints, evidenced by lower equilibrium scores in SOT conditions 5 and 6 with a tendency to fall in five children (25%). From SOT and sensory analysis, the vestibular system appeared to be less than fully developed sensory system relative to the somatosensory and visual systems. ADHD/C could not depend solely on the vestibular system information, resulting in poor scores in SOT conditions 5 & 6. In these conditions, the vestibular system is the only accurate system contributing to posture control (Shepard & Telian, 1996).

The vestibular system is known to be less than adequate in individuals diagnosed with ADHD as reported by Zang et al (2002). They found that ADHD children were more dependent on visual feedback during the execution of the movement. It is well known that of the three sensory systems, the vestibular apparatus is the one lagging behind in development (Cherng et al., 2001). This phenomenon was more pronounced in the studied ADHD/C when compared to the TD children suggesting a delay in the maturation process that involves the vestibular system. An intact vestibular system is crucial to normal levels of arousal, attention and motor planning (Mulligan, 1996).

Furthermore, children with ADHD/C needed more time to recover from the unexpected disturbances in the support surface compared to the TD children. Prolonged latencies are strong evidence of musculoskeletal/biomechanical problems and/or pathology within the long loop pathways including the peripheral nerves, ascending and descending spinal pathways, and brain structures involving brainstem, basal ganglion, cerebellum and motor cortex (Shepard & Telian, 1996).

Although exposed to destabilizing rotary stimuli in the ADT, the TD children showed an appropriate corrective response to prevent fall after the first trial. Sway responses to the first rotation were typically larger than those of subsequent rotation, because patients usually reduce the resistance of their ankle joints to subsequent rotations. A normal postural control system is able to modify its response as an adaptive learning system (Shepard & Janky,

2008). On the other hand, the ADHD/C children generated more force than the normal children to minimize the antero-posterior sway ($p < 0.05$). They could not adapt to the randomly presented familiar destabilizing rotations on repeated trials (Figure 3a, 3b). Hence, a difficulty in motor learning and adaptation to change was suspected in those children.

Altered brain activity in children with ADHD could explain the sensori-motor deficits seen in the MCT and ADT in this study. The possible involved brain areas are the right inferior frontal cortex, left sensorimotor cortex, basal ganglia, and bilateral cerebellum and the vermis as well as in the right anterior cingulate cortex, and bilateral brainstem (Niedermeyer & Naidu, 1997). Numerous MRI studies observed smaller cerebellar volume with a particular reduction in the posterior inferior vermis in ADHD children (Bledsoe et al., 2009).

Dysfunction in the above mentioned areas would result in poor postural control (moderate hypotonia or hypertonia, poor distal control, static and dynamic balance), difficulty in motor learning (learning new skills, planning of movement, adaptation to change, automatization), and poor sensorimotor coordination (coordination within/between limbs, sequencing of movement, use of feedback, timing, anticipation, strategic planning) (Zang et al., 2007).

Balance deficit in children with ADHD/C is either a separate, co-morbid conditions or side effects of dysfunctional attention or impulsiveness. The cooperation of the ADHD children and their ability to attend & understand the task needed represented an important limitation in our study. Geuze (2005) and Fliers et al. (2009) argued a shared etiology for ADHD with co-occurring balance / motor problems that might be attributed to genetic and/or shared environment effects. The postural function has been closely associated not only with gross motor movements, such as sitting, standing, walking and fine motor movements, but also with human behaviors (Shum & Pang, 2009).

5. Conclusion

From this work, it is obvious that the static postural control is one of the domains of perceptual motor performance in which a group of children with ADHD/C can be impaired. The studied ADHD/C group was homogenous in terms of severity of symptoms. They showed poor static postural control, especially in extremely difficult situations. The authors assumed that the studied ADHD/C exhibited a form of sensory integration disorder reflected on their postural control.

In light of the current study, it is recommended to follow up the progress of the postural control in the studied children with ADHD/C. History of postural control problems should be included as routine in evaluation of ADHD/C children and referral for postural testing could be done whenever possible. The effects of CNS stimulants in balance improvement in this population warrant to be investigated. Retraining for Balance may be a functional technique for training children and youth with sensorimotor difficulties and might constitute a complement to regular treatment of ADHD, but controlled studies are necessary before more decisive conclusions can be drawn.

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7. References

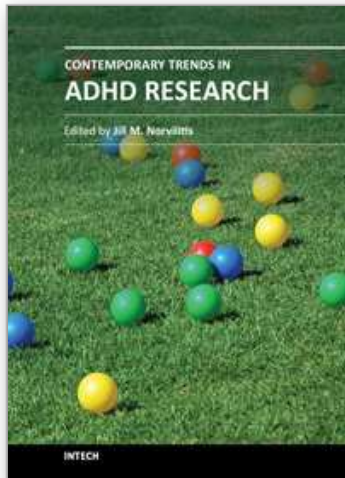
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With many children and adults affected by Attention Deficit Hyperactivity Disorder, researchers strive to understand the underpinnings of ADHD and associated factors on both a basic and applied level. The goal of this volume is to explore some of the broad array of research in the field of ADHD. The 12 chapters cover a variety of topics as varied as postural control, endocrine dysfunction, juvenile justice, and academic outcomes. These chapters will provide valuable insights for students reading about ADHD for the first time, researchers wishing to learn about the latest advances, and practitioners seeking new insight in the field.

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