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A possible correlation between vestibular stimulation and auditory comprehension in children with attention-deficit/hyperactivity disorder

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Abstract

Twenty children, aged 10 to 12 years with attention-deficit/hyperactivity disorder (ADHD), were selected to study the effect of vestibular stimulation on auditory perception and sensitivity using the Integrated Visual and Auditory Continuous Performance Test (IVA CPT; a neuropsychological test that is applied in occupational therapy clinics). The present study examined children based on the criteria of the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition, text revision. After obtaining guardian and parental consent, the children were enrolled in the study and randomly matched according to age across intervention and control groups. The IVA CPT was applied as a pre-test. The children in the intervention group then received vestibular stimulation during therapy sessions twice per week for 10 weeks. The IVA CPT assessment (post-test) was then applied in both groups. The mean pre- and post-test scores were compared across groups. The statistical analyses revealed a significant difference in improvement in auditory comprehension. In conclusion, the present findings suggest that vestibular training is a reliable and powerful treatment option for ADHD, especially when combined with other training. Stimulating the sense of balance highlights the important interaction between inhibition and cognition.
Keywords: vestibular training, auditory comprehension, attention-deficit/hyperactivity disorder.

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Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurobehaviorial disorder that affects 3-7% of school-age children. Despite its high prevalence and growing clinical research, some symptoms might persist into adulthood (Carlotta, Borroni, Maffei, & Fossati, 2013). Rehabilitation strategies play a pivotal role in attenuating hyperactivity, impulsivity, and inattention and improving children's performance in school (Sadock, 2003). Symptoms of inattention have been reported to be usually ignored by parents before the children begin school, but these behaviors can lead to noticeable problems with learning in school (Glanzman & Blum, 2007; Lucangeli & Cabrele, 2006). Concentration and visual and auditory comprehension in children are crucial for effective learning and have drawn interest from both researchers and clinicians. Approximately 30-50% of children with ADHD have poor balance and a poor interplay between movement and actions (Sohlberg et al., 2003). Moreover, brain imaging studies of children with ADHD compared with normal children indicated that the cerebellum, prefrontal cortex, and striatum are smaller. Methylphenidate increases regional brain metabolism in the cerebellum and frontal and temporal lobes. Vestibular caloric stimulation of the labyrinth in the inner ear activates the limbic system and neocortex, supporting a connection between vestibular stimulation and dopaminergic modulation of the limbic system (Rappaport & Coffey, 2004).

The basal ganglia and cerebellum are involved in the regulation of motor control (Kornhuber, 1978) and cognitive and emotional function (Stoodley & Schmahmann, 2010). Differences in these brain structures between children with ADHD and normal children may explain many general performance deficits at the cognitive and motor levels (Qiu, Ye, Li, Liu, Xie, & Wang, 2011). Vestibular function deficits usually cause a high level of alertness and vigilance, problems maintaining focus, problems paying selective attention, and alterations in precision and attention to stimuli (Wang, Wang, & Ren, 2003). Therefore, the

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present study examined auditory comprehension in children with ADHD who were treated with vestibular stimulation using the IVA CPT.

Methods

Instruments

The IVA CPT is a continuous performance test that is commonly used by neuropsychologists to measure inattention, impairments in executive function, and impulsivity in children with ADHD. The IVA CPT has higher diagnostic accuracy than other CPTs (Tinius, 2003). A cue-target version (A-X; Sandford & Turner, 1995) with a reliability coefficient that ranged from .53 to .93 was used in this study to test auditory comprehension and sensitivity in children with ADHD before and after stimulating the vestibular system (intervention group) and clinical movement exercises (control group).

Vestibular stimulations

For semicircular canal stimulation, the child sat and then squatted in a swiveling chair that was rotated clockwise and then counterclockwise for 20 s (.5 Hz frequency). The child was then laid on his side and rolled forward and backward in a straight line (5 m) 10 times (Kelly, 1989; Niklasson, Niklasson, & Norlander, 2010). Otholite stimulation consisted of jumping on a trampoline 10 times, resting for 20 s, sitting on a swing that was moved forward, backward, and sideways 20 times, and walking on a balance beam.

The protocol for combined stimulation consisted of jumping 10 times on a trampoline while rotating the body 360° around the body's longitudinal axis, which was repeated another 10 times. The child was then placed on a large therapy ball in a prone position while reaching his/her arms above the head while ensuring that the feet were controlled. The hands were raised and lowered off the ground, and then the child was restored to his original position (McKeone, 1994; Rowan, 2013; Smith, 2010).

Clinical exercises

The cognitive activities used for the control group included playing a memory card game, massage, and proprioceptive practices, such as rolling the ball over the child while lying prone solving mazes (simple to complex, depending on the child's age), visual attention training with a flashlight in a dark room, reading books, finding a character specified by the therapist on a newspaper page, figure-ground discrimination (the ability to distinguish an object through its contrast against a background), and stringing beads to match a specific model (Anselmo, 1985; Barth, 2004; Furth & Wachs, 1974).

Experimental procedures

Twenty children were diagnosed with ADHD based on the criteria of the *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition, text revision (DSM-IV-TR; American Psychiatric Association, 2000) in a comprehensive psychiatric center in Atieh. All of the participants (13 boys and seven girls; mean age, 7.75 years; SD = 1.10 years; range, 6-9 years) had the combined ADHD type and were not undergoing additional treatments, including medication, speech, or occupational therapy (Table 1). The Wechsler Intelligence Scale for Children and IQ test were performed after the diagnosis of ADHD was made. Informed consent was obtained from the parents. We employed vestibular intervention (independent variable) to evaluate auditory comprehension (dependent variable) in the children with ADHD. The participants were randomly divided into the intervention and control groups. The IVA CPT was applied for all of the subjects by a psychiatrist. Errors of omission, errors of commission, and reaction times were used to evaluate comprehension characteristics. The children with ADHD were seated at a distance of approximately 60 cm from a 15-inch computer monitor. The target stimulus (number 2) was randomly presented on the computer screen among the untargeted stimulus (number 1). These stimuli were verbally presented through the headphones by the examiner. The participants were asked to listen during the presentation and then use the computer mouse to respond. The number of true and false responses, the number of missed targets, and response speed were recorded on the computer. After the pre-test, vestibular stimulation was given in the intervention group. The control group was given clinical exercises. Both groups spent 10 weeks (twice per week) attending therapy sessions. The IVA CPT was conducted following the therapy sessions (post-test).

Table 1. Demographic data for the study groups.

Group	Age (years)		Gender		Additional treatment
	M	SD	Female	Male	
Intervention	7.6	1.17	4	6	No
Control	7.5	1.08	3	7	No

Results

All of the children with ADHD completed the IVA CPT before and after the therapy sessions. The data were then checked for normality using the Kolmogorov-Smirnov test. The statistical analysis showed that all of the data had a normal distribution ($p > .05$). The mean scores were compared using a paired t-test within each group (pre- and post-test). Mean scores for auditory comprehension in the children with ADHD in the intervention and control groups on both tasks are summarized in Table 2. No significant differences were found between the groups that received clinical exercises or vestibular stimulation ($p > .05$). To compare the effect of vestibular intervention between the intervention and control groups, independent t-tests were used (Table 3). The mean differences between the pre- and post-test in the intervention group (in the presence of vestibular stimulation) were significantly higher than in the control group ($p < .05$).

Table 2. Comparison of auditory attention data within group (paired *t*-test).

Group	Pre-test	Post-test	*p*
Intervention	53.15 ± 5.44	70.67 ± 9.86	.07
Control	44.92 ± 3.02	47.30 ± 11.43	.42

Table 3. Comparison of mean difference in auditory attention between groups (independent *t*-test).

Variable	Control group	Intervention group	*p*
Auditory comprehension	2.4 ± 9.46	17.5 ± 3.59	.033

Discussion

The correlation between vestibular stimulation and auditory processing was studied by Phillips-Silver & Trainor (2008), but they included normal people as their subjects. In the present study, further efforts were made to investigate the effect of vestibular stimulation on auditory comprehension in children with ADHD. The instructions and practice protocol, which consisted of a regular and steady rhythm, were designed to improve balance control and vestibular rehabilitation in children with ADHD and were shown to be effective at the level of consciousness and subsequently attention (Health Success Rehab Center, 2013; Clark et al., 2008). Vestibular stimulation gradually calms children by provoking uniformity in the autonomic nervous system, leading to a significant impact on children's hyperactivity in therapy sessions (Kantner & Tocco, 1980). Vestibular connections with the cerebral cortex and subcortical brain structures, such as the thalamus, are involved in the role of the vestibular system in executive function. Anatomical connections between the vestibular and auditory systems raise the possibility that these two systems work together. Accordingly, based on multisensory integration (Parush, Sohmer, Steinberg, & Kaitz, 2007), stimulation of the vestibular system can activate the auditory system. This may explain the increased level of auditory comprehension in the intervention group compared with the control group in the present study. In fact, if repetitive intervention tasks are administered at a constant rate and in only one direction, then the vestibular system cannot detect motion, thus inhibiting vestibular-sensory interactions and subsequently multisensory integration (Brandt, Bartenstein, Janek, & Dieterich, 1998; Kelly, 1989).

Previous studies indicated that movement-based instructions facilitate the process of listening comprehension (McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Sueyoshi & Hardison, 2005). Interestingly, body movement affects the auditory rhythm processing of music, and the posterior parietal cortex integrates auditory information with balance information (Chen, Zatorre, & Penhune, 2006; Phillips-Silver & Trainor, 2008). Exercise protocols for vestibular stimulation are based on counting the number of practice repetitions with an auditory stimulus. Our results indicated that vestibular stimulation might protect vestibular-auditory interactions and improve auditory comprehension in children with ADHD.

In conclusion, vestibular stimulation, together with other common types of training, relieved the symptoms of ADHD.

Limitations

The main limitations of the present study were the small sample size and overrepresentation of males in the study groups. However, boys are more likely to have ADHD than girls. Furthermore, all of the individuals in this study were clinically referred children who received a diagnosis of both the inattentive and hyperactive types of ADHD (i.e., combined ADHD) and did not undergo any additional treatments. Therefore, our results confirm the possible correlation between vestibular stimulation and auditory comprehension.

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