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ATTENTION DEMAND AND POSTURAL CONTROL IN CHILDREN WITH HEARING DEFICIT

Małgorzata Derlich [a], Krzysztof Kręcisz [b,*], Michał Kuczyński [b,a]

[a]Faculty of Physiotherapy, Academy of Physical Education in Wrocław, Poland
[b]Department of Biomechanics, Opole University of Technology, Poland
[*]Corresponding author at: Department of Biomechanics, Opole University of Technology, ul. Prószkowska 76, 45-758, Opole, Poland. Tel.: +48 77 400423; fax: +48 77 4556089. E-mail address: k.krecisz@po.opole.pl (K.Kręcisz).

Abstract

To elucidate the mechanisms responsible for deteriorated postural control in children with hearing deficit (CwHD), we measured center-of-pressure (COP) variability, mean velocity and entropy in bipedal quiet stance (feet together) with or without the concurrent cognitive task (reaction to visual stimulus) on hard or foam surface in 29 CwHD and a control group of 29 typically developing children (CON). The CwHD displayed an overall decreased postural performance as compared to the CON in the medial-lateral plane ($p < 0.05$). Standing on foam pad revealed slower simple reaction time in the CwHD ($p < 0.05$) while the results on hard surface were not different. The CwHD decreased ($p < 0.05$) the amount of attention invested in posture during dual task which accounted for the need of more cognitive resources to handle two tasks simultaneously than controls. It was unmistakable that the intergroup differences emerged when the tasks performed were relatively novel and untrained: feet together, foam pad, and reaction time. All these tasks, while being very easy for the CON, made the CwHD deteriorate postural or cognitive performance. These results unravel the difficulty in reaching the consecutive developmental stages in the CwHD and call for specific therapeutic modalities that might facilitate this development.

Keywords: postural sway; stability; motor development; adolescent; dual task; entropy

1. Introduction

It is known that the absence of sense of hearing puts impact on human development (Siegel, Marchetti, & Tecklin, 1991; Rine et al., 2000). Children with hearing deficit (CwHD) differ from their normal hearing peers, among other things, in the level of maturity of postural control (An, Yi, Jeon, & Park, 2009; Suarez et al., 2007). Probably it is caused by vestibular deficits that very often accompany deafness (Angeli, 2003; Selz, Girardi, Konrad, & Hughes, 1996). Rine et al., (2004) explained it by close anatomical location, the same neural pathway and interaction of these systems. Furthermore, these authors indicated the possibility of sensory integration deficits in CwHD.

Due to the above-mentioned disorders the CwHD may need a targeted therapy to support their function. Postural control deficit requires special care, in particular in CwHD with abnormal vestibular responses (Suarez et al., 2007). The purpose of postural control is to ensure an optimal position of the center of mass against the base of support to provide adequate body stability in varying situations. As the optimal position heavily depends on the task condition and environmental constraints, postural control system must be robust and flexible, and must effectively explore and integrate visual, vestibular and proprioceptive inputs. The exploration of sensory inputs is manifested by spontaneous excursions of the body's center of mass (sway). Basically, better postural performance is usually associated with lesser sway.

In everyday life postural stability very often interacts with simultaneously performed cognitive tasks like communication, counting, and just simple conscious thinking. The balance and cognitive systems do not function entirely independently (Hanes & McCollum, 2006; Smith, Zhenga, Horiib, & Darlingtona, 2005; Redfern, Talkowski, Jennings, & Furman, 2004). Mental activities demand attention as does postural control (Woollacott & Shumway-Cook, 2002) and the role of attention increases with the difficulty of postural task (Dault, Geurts, Mulder, & Duysens, 2001). Hence, because of limited sensory information due to vestibular deficit, the CwHD may need more cognitive resources for postural control. Although there are some reports on balance, vestibular, and cognitive dysfunction of CwHD, the interaction of cognitive performance and postural control in these children has been insufficiently explored and is not fully understood. Further, being aware alone of deteriorated postural control in CwHD is not enough to help these children. To elaborate effective targeted therapy, the mechanisms responsible for stability deficit need to be established.

The assessment of reciprocal interactions between balance and cognition is possible in a dual-task paradigm. Using this experimental modification helps assess the amount of attention invested in postural task (Roerdink, Hlavackova, & Vuillerme, 2010). Moreover, besides the linear parameters of sway, its sample entropy as a measure of sway regularity may supplement the traditional posturographical variables. Reduced entropy reflects the increase in the amount of attention invested in maintenance of posture, which under normal circumstances takes place in a nearly automatic fashion (Stins, Michielsen, Roerdink, & Beek, 2009). Due to sensory input deficit related to vestibular disorders in CwHD, the natural development of automatic postural control may differentiate the CwHD from normally developing children.

The aim of this study was to compare postural performance and control in children with hearing deficit with normal healthy control group. Our experiment was intended to include quiet standing in a set-up slightly differing from the common circumstances. In particular, we included compliance of the support surface and a single vs. dual task into experimental conditions. The former condition was expected to differentiate between the two investigated groups in terms of their reliance on proprioception which was supposed to be larger in CwHD due to limited vestibular input. The latter condition was expected to show intergroup differences regarding the interaction between postural control and attention. We hypothesized that (1) CwHD would present larger balance deterioration than controls in challenging situations, and (2) postural control in CwHD would be different from that in controls because of insufficient cognitive resources to cope with the increased postural challenge in the CwHD.

2. Methods

2.1 Subjects

The study involved 29 children with hearing deficit and a control group of 29 typically developing children (CON). The children were recruited from two Lower Silesian Schools from Wroclaw, Poland (Table 1). A questionnaire was developed to record the following characteristics: date of birth, medical conditions, and the cause of deafness. Level of hearing was determined based on the previous auditory testing made not earlier than one year before the present experiment. Inclusion criteria for CwHD included any hearing loss above 20dB. Exclusion criteria for all children included lack of neurological deficits and balance disorders. The study was approved by the local bioethics committee and all subjects provided informed consent signed by their parents.

		CwHD children	CON children
Number of subjects		29	29
Sex	Male	19	11
	Female	10	18
Age		12.2(1.7)	12.5(0.8)
Height (cm)		148.9(11.4)	158.2(7.6) *
Weight (kg)		44.6(13.1)	51.7(12.8) *
Hearing loss	Mild (20-40dB)	3	
	Moderate (40-70dB)	4	
	Severe (70-90dB)	11	
	Profound (pow.90dB)	11	
Etiology	Unknown	19	
	Congenital	3	
	Genetic	4	
	Prematurity	3	
Cochlear implant		5	

* - unpaired t-test significant statistical difference, $p<0.05$

Table 1. Characteristics of the subjects.

2.2 Procedure

Postural stability was assessed in four experimental conditions which included quiet stance on hard (force platform) or compliant surface (a 50 kg/m^3 foam pad placed on the platform) with or without a concurrent cognitive task (simple reaction time, RT). The condition with the concurrent cognitive task is referred to as dual task in contrast to single task which requires only maintaining body equilibrium. During dual tasking, the children were instructed to respond as fast as possible to visual stimulus (light-emitting diode) located adjacent to the response switch on a modified computer mouse. The mouse was held with both hands at the waist level during all trials. The subjects were asked to stand barefoot with their feet together and as motionless as possible. A practice run was allowed prior to the test to ensure that the subjects felt comfortable in the laboratory area. Each recording started 10 s after the subject was ready for testing to eliminate possible transients in the COP data.

2.3 Data analysis

Data were recorded on a force plate (Kistler 9286AA) at sampling frequency 100Hz and filtered using a second-order zero-phase Butterworth low-pass digital filter with a cut-off frequency of 10 Hz. The COP signal was calculated from the recorded ground reaction forces in the medial-lateral (ML) and anterior-posterior (AP) plane separately.

Postural balance was evaluated by three parameters based on the COP: standard deviation (SD), mean speed (MV) (Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996) and sample entropy (SE) (Richman & Moorman, 2000). Measures of COP variability and mean speed determine performance with lower values of these indices indicating better performance. Sample entropy indexes the regularity or predictability of the COP. Increased values of sample entropy, which indicate larger irregularity of the COP, has been attributed to a reduced amount of attention invested in posture (Roerdink et al., 2010). Input parameters for estimating the sample entropy were based on the median value of the relative error (Lake, Richman, Griffin, & Moorman, 2002) resulting in the selection of pattern length $m = 3$ and error tolerance $r = 0.02$ as optimal parameters for both ML and AP planes (normalized to unit variance) of all subjects and tasks.

All COP dependent variables were subjected to 2 groups (CwHD and CON) x 2 surfaces (hard and compliant) x 2 tasks (single and dual task) x 2 planes (AP and ML) ANOVA (Statistica 8.0) with repeated measures on the last three factors. The reaction time data were submitted 2 groups (CwHD and CON) x 2 surfaces (hard and compliant) ANOVA with repeated measures on the latter factor. Selected pairwise comparisons were explored using follow-up analyses (Tukey test). The level of significance was set at $p < 0.05$.

3. Results

The means and their standard deviations of the dependent variables are showed in Table 2.

		Platform		Foam pad	
	Group	**single task**	**dual task**	**single task**	**dual task**
AP					
SD (mm)	CON	5.7 ± 1.5	5.7 ± 1.9	9.3 ± 1.7	9.2 ± 1.9
	CwHD	6.4 ± 3.2	5.7 ± 2.4	10.2 ± 4.1	9.6 ± 2.8
MV (mm/s)	CON	11.1 ± 2.9	11.7 ± 3.8	20.7 ± 4.6	21.0 ± 4.6
	CwHD	12.1 ± 6.2	12.4 ± 4.6	25.8 ± 11.6	26.3 ± 9.8
SE	CON	0.48 ± 0.07	0.50 ± 0.08	0.50 ± 0.05	0.51 ± 0.06
	CwHD	0.46 ± 0.08	0.51 ± 0.07	0.51 ± 0.07	0.52 ± 0.06
ML					
SD (mm)	CON	6.4 ± 2.0	6.3 ± 1.8	8.7 ± 2.0	8.8 ± 2.5
	CwHD	6.9 ± 2.2	6.9 ± 2.5	11.1 ± 3.0	11.7 ± 4.4
MV (mm/s)	CON	11.3 ± 2.8	11.8 ± 3.4	23.1 ± 5.1	23.3 ± 6.7
	CwHD	12.5 ± 6.6	13.2 ± 4.8	28.3 ± 10.8	31.0 ± 12.2
SE	CON	0.45 ± 0.07	0.44 ± 0.06	0.51 ± 0.06	0.52 ± 0.05
	CwHD	0.40 ± 0.10	0.43 ± 0.07	0.47 ± 0.07	0.49 ± 0.06
RT (ms)	CON		257 ± 88		242 ± 65
	CwHD		262 ± 82		268 ± 77

Table 2. The group means and standard deviations of all dependent variables. ML - medial-lateral plane, AP - anterior-posterior plane, SD - standard deviation, MV - mean speed, SE - sample entropy, RT - reaction time, CON - control group, CwHD - children with hearing deficit.

Group, surface and plane significantly affected COP standard deviation, $F(1, 56) = 5.02$, $p < 0.05$; $F(1, 56)= 210.15$, $p < 0.05$; and $F(1, 56) = 9.91$, $p < 0.05$, respectively as did the group x surface $F(1, 56) = 6.28$, $p < 0.05$, the group x plane, $F(1, 56) = 8.28$, $p < 0.05$ and group x surface x plane $F(1, 56) = 6.51$, $p < 0.05$ interactions. Post-hoc analysis showed significant increase SD on foam pad for both groups, both $p < 0.05$ and SD was significantly greater for CwHD on foam pad, $p < 0.05$. No difference was significant between groups on platform. CwHD showed greater SD in ML plane ($p < 0.05$) and significant difference between the planes, greater in ML, $p < 0.05$. No effect of dual task versus quiet standing in both groups was significant.

Group, surface and plane significantly affected COP mean speed, $F(1, 56) = 5.92$, $p < 0.05$; $F(1, 56) = 261.97$, $p < 0.05$ and $F(1, 56) = 25.91$, $p < 0.05$, respectively as did the group x surface, $F(1, 56) = 8.99$, $p < 0.05$ and the surface x plane, $F(1, 56) = 17.68$, $p < 0.05$. Again there was a statistically significant increase on the foam pad in both groups, $p < 0.05$ and CwHD on the foam pad showed a greater MV then CON, $p < 0.05$. No effect of dual task versus quiet standing in both groups was significant.

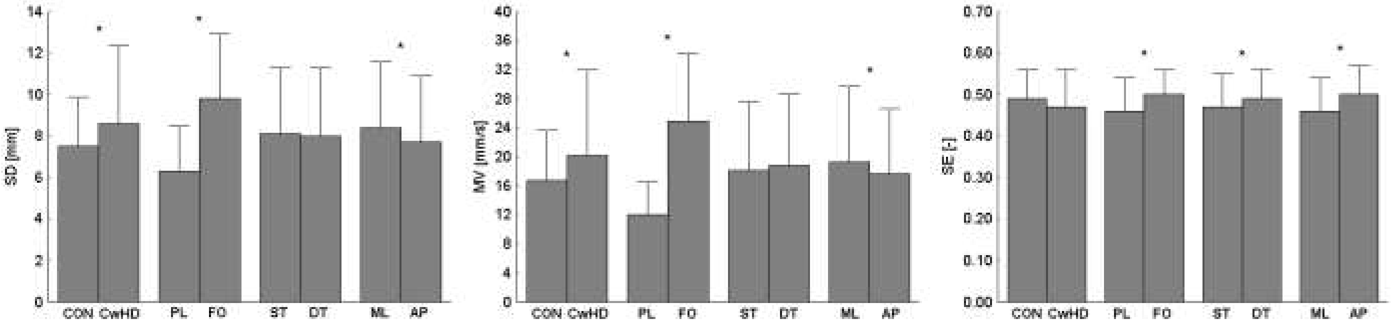

Figure 1. Mean ± standard deviations values of the three dependent posturographic measures (SD - standard deviation, MV - mean speed, SE - sample entropy), collapsed over group, surface, cognitive task and plane. Asterisks indicate a significant ($p < 0.05$) difference evaluated using post-hoc Tukey test. CON - control group; CwHD - children with hearing deficit; PL - platform; FO - foam pad; ST - single task; DT - dual task; ML - medial-lateral plane; AP - anterior-posterior plane.

Surface, task and plane significantly affected sample entropy, $F(1, 56) = 44.22$, $p < 0.05$; $F(1, 56) = 11.26$, $p < 0.05$ and plane, $F(1, 56) = 39.51$, $p < 0.05$, respectively as did group x task, $F(1, 56) = 4.38$, $p < 0.05$ (Fig. 2), group x plane, $F(1, 56) = 7.61$, $p < 0.05$ and surface x plane, $F(1, 56) = 24.64$, $p < 0.05$. Post-hoc analysis revealed that sample entropy was greater in dual task condition for CwHD, $p < 0.05$ in the absence of such differences in the control group or between groups. CwHD group also showed a greater value of sample entropy in the AP plane compared to ML plane, $p < 0.05$.

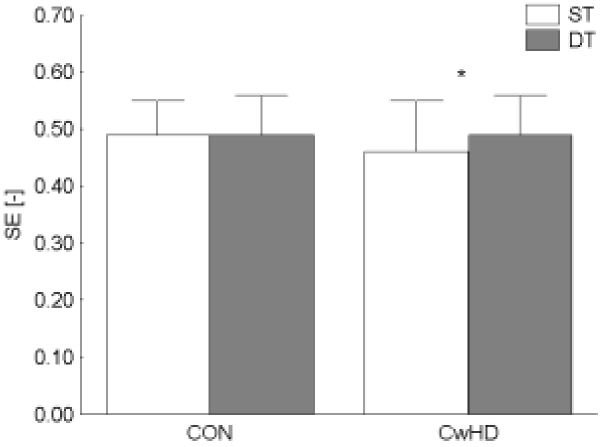

Figure 2. Group x Task interaction on sample entropy. Asterisks indicate a significant ($p < 0.05$) difference evaluated using post-hoc Tukey test. CON - control group; CwHD - children with hearing deficit; ST - single task; DT - dual task.

Group significantly affected reaction times, $F(1, 378) = 6.02$, $p < 0.05$ revealing longer reaction time in CwHD. The group x surface interaction, $F(1, 378) = 4.20$, $p < 0.05$ showed the opposite effect of foam pad on our groups: CON tended to decrease while CwHD to increase the reaction time. Post-hoc analysis showed significantly higher, $p < 0.05$ reaction times on foam pad for CwHD group (268 ± 77 ms vs. 242 ±

65) and no differences on the platform (262 ± 82 ms vs. 257 ± 88). No differences within groups were significant.

4. Discussion

The purpose of this study was to compare postural performance and control in children with hearing deficit (CwHD) and age-matched normal healthy control group (CON). We hypothesized that the dual task paradigm and the entropy as a measure of sway regularity might shed some light on the mechanisms responsible for different postural behavior in these two groups. In short, three findings seem of interest. First, the CwHD displayed an overall decreased postural performance as compared to the CON in the M/L plane. Second, standing on foam pad increased the simple reaction time in the CwHD having no effects on CON. Third, only the CwHD decreased the amount of attention invested in posture during dual task. It is unmistakable that the intergroup differences emerged when the tasks performed were relatively novel and untrained: feet together, foam pad, and reaction time. All these tasks, while being very easy for the CON, made the CwHD deteriorate postural or cognitive performance.

Although we did not make vestibular evaluation of the CwHD group, previous studies concerning epidemiology and balance testing of children with hearing deficit have been rather unanimous in indicating vestibular dysfunction as the main causative factor responsible for poor balance proficiency in CwHD. It has been reported that over 50% of children with hearing loss suffer from vestibular dysfunction (An et al. 2009) and this prevalence increases with the level of deafness (Selz et al., 1996). Suarez et al. (2007) showed that deaf children with normal vestibular rotary responses did not differ in posturographic tests from their healthy age-matched peers. They found deteriorated postural stability only in deaf children with vestibular deficit while standing on foam pad with eyes closed in contrast to no differences on hard surface with eyes open (Suarez et al., 2007). Despite some differences between experimental protocols, the sway performance measures in our study concur with the latter works and thus provide additional evidence on the role of vestibular dysfunction in the CwHD balance deficit. Further, our results based on the sway entropy measure and on dual tasking seem to add more specificity to this role, i.e. they help elucidate the compensatory mechanisms that were initiated in CwHD due to their vestibular dysfunction.

The secondary RT task did not affect the baseline performance: COP variability and mean velocity remained unchanged in both groups in dual task as compared to standing alone. This finding concurs with no effect of a simple RT secondary task on postural responses (Teasdale, Bard, LaRue, & Fleury, 1993; Vuillerme & Nougier, 2004) and on gait (Lajoie, Teasdale, Bard, & Fleury, 1996). The ability to perform a primary task with little or no interference by a demanding secondary task is a defining characteristic of automaticity (Logan, 1988), so the participants may have exhibited just an appropriate level of automatic postural control. On the other hand, if the RT task was perceived by our subjects as an easy one (Huxhold, Li, Schmiedek, & Lindenberger, 2006), the attention demand of the RT task was too low to interfere with postural control. Based on the COP performance measures only, it is impossible to say what was the actual postural control adopted by either group.

In contrast to the lack of effect of the RT on posture, there was an effect in the opposite direction, i.e. more difficult stance conditioned the RT results. Group x Surface interaction indicated differences between our subjects. During foam pad stances the CwHD and CON tended to increase and to decrease their RTs, respectively. The deteriorated cognitive performance in the CwHD was reminiscent of the results from Teasdale et al. (1993) who compared young and elderly adults and found that as the sensory information decreased the postural task became increasingly difficult and required more of the attentional capacity in the older group, i.e. the group with sensorimotor and/or central integration deficit. In view of this data the CwHD, who had deteriorated balance, were the ones to be more challenged than CON by the performance on foam pad which might account for the need to shift more attention to postural task. However, the observed change in the COP entropy did not confirm this shift of attention. Quite to the contrary, the CwHD increased COP entropy while standing on foam pad as compared to the firm surface indicating diminished attentional involvement in postural control. If we tried to balance these shifts of attention in the CwHD, we would wind up with a debit. Removing attention from the RT task did not aid posture, nor did removing attention from posture speed up the cognitive task. These attention resources that were taken away from both tasks must have been transferred to another activity that was needed by CwHD to accomplish the dual task in a satisfactory way.

As compared to the CwHD, CON presented entirely different results, having shown no changes in RT and no signs of attention shifts. In short, the general performance of CON in dual task, including postural sway, RT, and attention capacities, did not differ from a single postural task which accounted for high adaptation abilities of postural control system in healthy children who had no problems with sharing attentional capacities between the two tasks. It was probably these adaptation abilities that differentiated both groups in the most significant way. In particular, the insufficient adaptation abilities in CwHD very likely resulted from the excessive attention demands that were necessary for the coordination and overall handling of an unfamiliar dual task. The last notion seems to find support in Redfern et al. (2004) who suggested that adult patients with vestibular loss may have an information processing deficit which extends beyond postural control. This attention deficit is thought to be due to shifts of attention required to maintain compensation for chronic loss of vestibular function (Talkowski, Redfern, Jennings, & Furman, 2005). We can speculate that similar cognitive cost was paid by our CwHD and the limited unexpended resources were insufficient for the optimal dual task performance.

Our experiment revealed that the demand for excessive attention in CwHD, that underpinned their vestibular problem, was the main agent leading to deteriorated postural control. This finding derived from a relatively easy experimental protocol raises a question on how difficult the motor learning in these children might be. It is known that deaf children with vestibular loss are eventually very well compensated for by other sensory systems, the pyramidal and extrapyramidal motor system, and by intellectual development, and they practically catch up with healthy children in late adolescence (Kaga, 1999). However, the reports on how they actually progress through the consecutive milestones are lacking. One can only speculate that they are having a really hard time at each stage of motor development due to the need to accumulate extraordinary cognitive resources to advance in this process. It has been argued that loss of vestibular function impairs the development of functional effectiveness of sensory modalities in behaviors in which the modalities typically interact (Rine et al., 2004). This typical area of interaction is gross motor learning and performance that have an adequate postural control as a prerequisite.

The results of our study show that it is necessary to develop therapeutic approaches that will support children with hearing deficit in their motor progress rather than leaving them alone in this developmental struggle. Although hearing impairment per se is not a developmental disability, its existence along with relationships between cognitive resources and motor control may exacerbate problems associated with other diseases of this type.

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