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Original Article

The Effect of Different Degrees of Sensorineural Hearing Loss on Vestibular Function in Children

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ABSTRACT

Background: Sensorineural hearing loss (SNHL) is expected to negatively affect vestibular functions since the cochlea and the vestibular system are interconnected anatomically and physiologically. This study aimed to (1) assess the vestibular functions in hearing-impaired (HI) children who have no symptoms of vestibular dysfunction (VD), (2) investigate a possible association between the severity of SNHL and the presence of VD.

Methods: Sixty-sex children aged 6-18 years old and free of VD were included. Participants were divided into two groups (Control group: 33 normal-hearing children, Study group: 33 HI children). HI children were divided into three subgroups (mild, moderate, and severe-profound SNHL) for the purpose of the study. All children underwent a set of audiological and vestibular assessments including pure tone audiometry, vedionystagmography (VNG), cervical and ocular evoked myogenic potential (cVEMP, oVEMP), and video head impulse tests (vHIT).

Results: In terms of the results of the VNG, no statistically significant difference was found between the control and study groups. However, a statistically significant difference was found between the two groups in cVEMP and oVEMP latencies, amplitudes, and asymmetry ratio and in the gain of vHIT. Moreover, a statistically significant difference was found between the 3 subgroups in cVEMP, oVEMP, and vHIT revealing that the more the severity of HL, the more VD was identified.

Conclusions: VD is prevalent in HI children. An association was found between the severity of SNHL and the presence of VD in children regardless of the absence of vestibular symptoms.

Key words: vestibular function; hearing loss; hearing impaired; children

INTRODUCTION

The auditory and vestibular systems are interconnected to each other because the cochlea and the vestibular end organs are closely related anatomically and developmentally. Therefore, strong potential exists for a related vestibular dysfunction (VD) when the hearing mechanism is impaired [1, 2]. Considerable etiologies for VD associated with hearing loss (HL) could be any of the following: otitis media, large vestibular aqueduct syndrome, idiopathic congenital hearing loss, common syndromes associated with HL such as Usher, Waardenburg, Pendred, and Alport, Cytomegalovirus, HL caused by meningitis, congenital malformation of the vestibular labyrinth, and acquired post-surgery such as in cochlear implantation [3-6].

O'Reilly et al. [7] and Li et al. [8] reported a prevalence of VD in children of 0.5 - 5%, however, the prevalence is much higher in hearing impaired (HI) children (20% to 85%) [9-13]. The considerable variability in the reported prevalence could be due to methodological differences across studies. Nonetheless, regardless the reported high prevalence only 29.9% of children with VD received treatment [8]. This suggests that pediatric VD may be an under-recognized clinical condition particularly for HI children.

VD could negatively impact the quality of life of the affected children. It could cause delayed motor development such as delayed head control, delayed sitting independently, and late onset of walking. Additionally, children may become clumsy, unsteady, uncoordinated, and complain of

frequent falls. Moreover, they could have difficulty walking on uneven surfaces and in low-light areas and difficulty riding bikes, furthermore, they may have blurred vision and difficulty reading [4-6, 14-15].

Most children with VD do not complain of vertigo, which could be due to their inability to describe its complex symptoms. In addition, parents may not understand their children's complaints and thus ignore them or explain them with different thoughts such as the unwillingness of their children to cooperate [13]. Hence, it is expected that the prevalence of VD in children is higher than reported in the literature. Therefore, screening for vestibular function in HI children is crucial as it could assess in identifying children with VD earlier and engaging them in suitable rehabilitation programs to avoid any hazardous impacts [16].

Based on the above considerations, the first aim of the present study was to assess the vestibular function in HI children who do not complain of vertigo and are medically free except for SNHL and compare their performance to children with normal hearing (NH). The second aim was to look at the effect of the severity of HL on the function of the vestibular system.

METHODS

Ethical approval was obtained from the Institutional Review Board of Zagazig University (IRB# 10332/22-1-2023). Informed consents were obtained from the parents and verbal assents were obtained from the children before starting data collection.

The sample calculation was based on an assumed frequency of profound degrees of SNHL of 20% in normal versus 56% in bilateral cases. With a power of 80% and a confidence level of 95%, the estimated sample size required for the study was 66 cases (reference [17]).

A comparative study was conducted, including 66 participants (132 ears) who were selected randomly. The study was conducted in the Audio-vestibular Unit, at Zagazig University Hospitals. Participants were divided into two groups: the study group and the control group. Each group consisted of 33 participants. The control and study groups were matched in terms of age and sex.

Control group*:* 33 NH children with an age range between 5-18 years old. The inclusion criteria were as follows: all participants had hearing sensitivity within 25 dB HL for frequencies ranging from 250 to 8000 Hz, type A tympanogram, and preserved acoustic reflexes at 500, 1000, 2000, and 4000 Hz. Additionally, participants had no recent history or presence of any otological pathologies, such as ear discharge, earache, or ear surgery. Furthermore, they were free of any systemic disease or neurological symptoms.

Study group: 33 HI children aged between 5-18 years old were included in the study. The inclusion criteria were as follows: participants were previously diagnosed with SNHL of any degree (mild to profound), and exhibited type A tympanogram with acoustic reflexes coinciding with hearing thresholds at 500, 1000, 2000, and 4000 Hz. Additionally, participants had no recent history or presence of any otological pathologies such as ear discharge, earache, or ear surgery. Furthermore, they were free of any systemic disease or neurological symptoms.

The study group was divided into 3 subgroups according to the severity of HL in order to look at the effect of the degree of HL on the function of the vestibular system. Each group consisted of 11 participants (Subgroup I: mild SNHL, Subgroup II: moderate SNHL, Subgroup III: severe to profound SNHL). Full case history was obtained from all participants and basic audiological assessments were carried out. Pure tone audiometry, using Interacoustics AD 629, encompassed air conduction and bone conduction testing for both ears, with thresholds exceeding 25 dB considered abnormal. Speech reception threshold and speech discrimination testing employed Arabic spondee words [18] and Arabic phonetically balanced words [19]. Immittance testing, conducted with the Interacoustics AT 235, included tympanogram and acoustic reflex threshold measurements at 500, 1000, 2000, and 4000 Hz. Additionally, vestibular evaluations were performed including the following procedures.

Videonystagmography (VNG) using Micro Medical Visual Eyes 525 by Interacoustics.

Saccade testing: Participants were asked to fixate on a randomly appearing dot and refrain from moving their heads during this task. The software measured the latency, velocity, conjugacy, accuracy, and asymmetry.

Smooth Pursuit testing: Participants were instructed to follow a target (green dot) on a screen in front of them with their eyes only without moving their heads. The target moved from one side of the screen to the other in a smooth and predictable motion at a low frequency (0.2-0.7 Hz). The software calculated the gain of the smooth pursuit.

Optokinetic Nystagmus: In this test, jerk nystagmus was measured at low frequency by showing a horizontally moving field to the participant at a speed of 30, 40, or 60/s for one

minute. This was preceded by a one-minute break reversing the pattern in the opposite direction.

Positional test: The test was performed for different positions. The eye movements were monitored for 30 seconds for each position.

Positioning test (Dix-Hallpike test): Participants wore Frenzel lenses and were asked to sit with their legs stretched out and turn their heads 45 degrees to one side. Next, the participants were rapidly lowered with their heads supported and placed 30° below the horizontal plane. Participants stayed for at least 30 sec and were carefully observed for nystagmus or vertigo in this position. As soon as the participant was upright, the maneuver was repeated with the head turned 45 degrees to the opposite side.

Vestibular-evoked myogenic potential (VEMP)

Cervical VEMP (cVEMP)

Subjects: The participant turned his head to the contralateral side against resistance in the sitting position and the responses from the ipsilateral sternocleidomastoid muscle (SCM) were recorded.

Electrode montage: The active electrode was placed on the middle part of the SCM muscle, while the reference and the ground electrodes were placed over the upper sternum and the forehead, respectively.

Stimulus parameters: 500 Hz tone burst stimulus was delivered to the tested ear at an intensity of 100 dB nHL. The analysis time for each response was 50 msec with an average of 100 sweeps per run. Band-pass filtered between 30 and 1500 Hz.

Ocular VEMP (oVEMP)

Subjects: the participant was instructed to lay supine and keep upward gazing at a fixed mark in the ceiling.

Electrode montage: The active electrode was placed just inferior to the center of the lower eyelid. The reference electrode was positioned on the cheek 1–2 cm below the positive electrode, while the ground electrode was positioned over the forehead.

Stimulus parameters: Utilizing similar stimulus parameters of cVEMP, the stimulus was delivered to the tested ear (the contralateral ear to the measured eye).

Video head impulse tests (vHIT)

The vHIT was performed using an Otometrics ICS impulse system. Recordings were obtained for each of the six semicircular canals in all participants (horizontal, LARP, RALP). The participant wore a pair of lightweight, tightly fitting goggles on which a small video camera and a half-silvered mirror that reflects the image of the patient's right eye into the camera are mounted. Calibration of the eye position signal was carried out with the subject successively fixating on two projected laser dots separated by a known horizontal angle. The patient was asked to stare at an earth-fixed target not less than one meter in front. The head movement speed was measured by the sensor in the goggles, and the image of the eye was captured by a high-speed camera (250 Hz) and processed to yield eye velocity. In a full test, 20 impulses were delivered randomly in each direction. At the end of the full test, all the head velocity stimuli and eye velocity responses were displayed on the computer screen, together with a graph of the calculated vestibulo-ocular reflex (VOR) gain (ratio of eye velocity to head velocity) for every head rotation. The VOR mean gain and the appearance of saccades after head impulse to the right and the left were evaluated.

Statistical Analysis

The Statistical Package of Social Science (SPSS) version 24.0 was used to analyze the data. When presenting continuous variables, the mean and standard deviation (SD) were used. The comparison of the quantitative variable between the control and study groups was performed using the independent t-test. One-way ANOVA was performed to compare the three subgroups of HI children (mild, moderate, and severe to profound SNHL) with the Bonferroni post hoc test. A significant difference was considered when $p \leq 0.05$.

RESULTS

The age of participants ranged from 6 to 18 years old with a mean age of 11.4 ±3.0 and 11 ±2.6 for the control group and the study group respectively. There were 15 males (45.5%) and 18 (54.5) females in the control group whereas in the study group, there were 17 (51.5%) males and 16 (48.5%) females. No statistically significant difference was there between the two groups in terms of the age (t= 0.52, p=0.06) and the sex of the participants (X^2= 0.24, p=0.6). The pure tone thresholds in the study group ranged from mild to profound SNHL (>25 to >90 dB HL). On the other hand, all participants in the control group had an average hearing threshold not exceeding 15 dB HL in both ears.

Concerning the results of the oculomotor testing (saccade, smooth pursuit, optokinetic), no statistically significant difference was there between the two groups (Table 1). Besides, participants of both groups showed no nystagmus in the gaze test, no spontaneous nystagmus, and no nystagmus in positional and positioning tests. Table 2 shows the response rate in cVEMP and oVEMP for both groups and Table 3 shows that a

statistically significant difference was found between the two groups in cVEMP and oVEMP latencies, amplitudes, and asymmetry ratio. Moreover, a statistically significant difference was found between the two groups regarding the gain of vHIT (Table 4). As mentioned previously, the study group was classified into 3 subgroups based on the degree of HL. One-way ANOVA test results show a statistically significant difference between the 3 subgroups in cVEMP, oVEMP, and vHIT testing (Table 5). The Bonferroni post hoc test showed that subgroup III is the most affected group. In order to look for the effect of age and gender on the performance of children in cVEMP, oVEMP, and vHIT testing, the Pearson Correlation test and independent t-test were performed. No effect of age and gender on the performance of children was found (Tables 6 and 7).

Table 1: Oculomotor testing results for the study and control groups

Test	variable		*Mean ±SD*		*t**	*p-value*
			Study group (n=33)	**Control group (n=33)**		
Saccadic test	**Latency**	**Rt. Ear**	234.7 ±52.2	240.8 ±27.0	0.604	0.548
		Lt. Ear	236.8 ±37.3	245.1 ±24.2	1.07	0.287
	Accuracy	**Rt. Ear**	375.9 ±86.5	391.6 ±74.1	0.79	0.431
		Lt. Ear	369.4 ±53.0	352.1 ±52.7	1.33	0.185
	Velocity	**Rt. Ear**	230.6 ±16.4	236.3 ±22.5	1.16	0.24
		Lt. Ear	234.7 ±52.2	240.8 ±27.0	0.604	0.548
smooth pursuit	**0.3 Hz**	**Rt. Ear**	0.76±0.12	0.80±0.08	1.58	0.119
		Lt. Ear	0.77±0.08	0.80±0.09	1.43	0.157
	0.6 Hz	**Rt. Ear**	0.79±0.13	0.81±0.07	0.564	0.575
		Lt. Ear	0.81±0.21	0.81±0.08	0.038	0.970
Optokinetic	**gain**	**Rt. Ear**	0.90±0.21	1.37±1.9	1.38	0.170
		Lt. Ear	0.92±0.19	1.14±1.3	0.928	0.357

*t-test

Table 2: Response rate of cVEMP and oVEMP in the study group

Side	cVEMP N (%)		oVEMP N (%)	
	Study group	Control group	Study group	Control group
Present bilaterally	22 (66.7)	33 (100)	23 (69.7)	33 (100)
Absent unilaterally	8 (24.3)	0	7 (21.2)	0
Absent bilaterally	3 (9)	0	3 (9.1)	0
Side	cVEMP N (%)		oVEMP N (%)	
	Study group	Control group	Study group	Control group
Present bilaterally	22 (66.7)	33 (100)	23 (69.7)	33 (100)
Absent unilaterally	8 (24.3)	0	7 (21.2)	0
Absent bilaterally	3 (9)	0	3 (9.1)	0

Table 3: The results of cVEMP and oVEMP of the two groups

		Study group *mean ± SD*	Control group *mean ± SD*	*t**	*p-value*
cVEMP	P13 latency (msec.)	15.7 ± 2.0	14.8 ± 1.7	2.78	0.006**
	N23 latency (msec.)	22.9 ± 1.5	22.4 ±0.9	2.32	0.021**
	P13-N23 amplitude (µV)	35.1 ± 15.6	42.5 ± 16.3	2.66	0.008**
	Asymmetry ratio (%)	48.5 ± 40.6	15.5 ± 8.4	6.46	0.000**
oVEMP	N1 latency (msec.)	11.6 ± 2.8	10.7 ± 1.1	2.43	0.016**
	P2 latency (msec.)	15.8 ± 4.1	14.6 ± 1.9	2.15	0.032**
	N1-P1 amplitude (µV)	15.5 ± 4.2	17.3 ± 5.2	2.18	0.03**
	Asymmetry ratio (%)	59.8 ± 45.4	25.8 ± 10	4.6	0.000**

* t-test

**Statistical significance difference as $p \leq 0.05$

Table 4: The results of vHIT in the two groups

vHIT results (gain)	Study group Mean ±SD	Control group Mean ±SD	*t**	*p-value*
Lateral	0.6 ±0.3	1.0 ± 0.4	6.49	0.000**
Anterior	0.7 ± 0.2	1.1 ± 0.1	14.5	0.000**
Posterior	0.8 ± 0.2	1.1 ± 0.3	6.75	0.000**

* t-test

**Statistical significance difference as $p \leq 0.05$

Table 5: Comparison between the three subgroups with regards to the cVEMP, oVEMP, and vHIT

variables		subgroup I Mean ±SD	subgroup II Mean ±SD	subgroup III Mean ±SD	*F**	*p- value*
cVEMP	*P13 latency*	14.3 ±0.9	15.8 ±2.1	18.6 ±1.8	35.1	0.000**
	N23 latency	21.2 ±1.1	24.3 ±1.9	26 ±1.2	56.5	0.000**
	amplitude	27.3 ±7.7	23.5 ±12.2	16.7 ±2.9	8.6	0.000**
oVEMP	*N1latency*	10.2 ±1.3	11.9 ±2.4	13.3 ±2.6	11.0	0.001**
	P1latency	15.1 ±2.3	16.5 ±2.1	18.4 ±2.3	11.3	0.001**
	amplitude	17.7 ±4	15.3 ±1.5	14.2 ±2.4	8.2	0.001**
vHIT	*lateral*	1.2 ±0.4	0.8 ±0.17	0.6 ±0.12	33.7	0.000**
	anterior	1.2 ±0.3	0.9 ±0.13	0.7 ±0.14	30.9	0.000**
	posterior	1.2 ±0.3	0.9 ±0.2	0.6 ±0.13	30.8	0.000**

* One-way ANOVA
** Statistical significance difference as $p \leq 0.05$

Table 6: Correlation between age and each of cVEMP, oVEMP, and vHIT

		Age	
		*r**	*p-value*
cVEMP	**P13 latency (msec.)**	0.04	0.74
	N23 latency (msec.)	0.10	0.41
	P13-N23 amplitude (µV)	0.14	0.24
oVEMP	**N1 latency (msec.)**	0.08	0.47
	P2 latency (msec.)	0.11	0.36
	N1-P1 amplitude (µV)	0.15	0.22
vHIT	**Lateral**	0.17	0.16
	Anterior	0.17	0.16
	posterior	0.16	0.18

*r: Correlation coefficient

Table 7: Correlation between gender and each of cVEMP, oVEMP, and vHIT

		Male (mean ±SD)	**Female (mean ±SD)**	***t****	**P value**
cVEMP	**P13 latency (msec.)**	14.6 ±1.7	15.1 ±1.4	0.91	0.36
	N23 latency (msec.)	22.5 ±1.7	23.1 ±2.1	0.90	0.37
	P13-N23 amplitude (µV)	26.3 ±8.3	25.7 ±10.9	0.17	0.85
oVEMP	**N1 latency (msec.)**	10.3 ±1.7	11.5 ±2.4	1.6	0.10
	P2 latency (msec.)	15.9 ±2.5	16.7 ±1.8	1.0	0.30
	N1-P1 amplitude (µV)	16.7 ±4	17 ±3.3	0.23	0.81
vHIT	**Lateral**	1.2 ±0.4	1.0 ±0.3	1.6	0.11
	Anterior	1.2 ±0.3	1.1 ±0.25	1.0	0.30
	Posterior	1.3 ±0.4	1.2 ±0.27	0.8	0.40

* t-test

DISCUSSION

It is reported in the literature that VD is related to SNHL since the cochlea and the vestibular systems are related anatomically and physiologically. Therefore, it is expected for HI individuals including children to experience VD and thus balance disturbance [20, 21]. That said, it seems that running complete vestibular function testing on HI children is necessary in order to identify the affected children as early as possible,

particularly young children who might not articulate their suffering. Early identification and intervention through appropriate vestibular rehabilitation is crucial to improve the quality of life of the identified children as it has been found to reduce the consequences of VD in terms of motor development [22] and visual acuity [5], which are more likely to be impaired in the affected children [23-26].

The first aim of the current study was to look at the vestibular function in HI children who do not complain of vestibular symptoms and are medically free except for SNHL. For that purpose, participants were examined using the VNG, VEMP, and vHIT. Results of the VEMP and vHIT showed a substantial difference between children with SNHL and those with normal hearing. Singh et al. [9] conducted a study to examine the VEMP in children with SNHL and vestibular malformation. The study revealed that individuals with SNHL were extremely prone to otolith dysfunction, regardless of the existence of accompanying vestibular malformations. In line with this, Jin et al. [27] assessed the VEMP results of 12 children before cochlear implant surgery and reported decreased amplitude in one child while the absence of VEMP response in 5 children. In the present study, HI children showed impaired VEMP responses which correlate with the findings of the aforementioned studies.

Prevalence of VD

Previous studies reported a moderate to high prevalence of VD in HI children [2, 9, 27-29]. O'Reilly et al. [7] reported that the prevalence of vestibular disorders in children is low (0.45%), however, they found that the presence of SNHL was one of the factors that was significantly associated with the diagnosis of VD. This indicates that HI children are more vulnerable to VD than NH children. In line with this, a systematic review that aimed to investigate the prevalence of VD in HI children reported that all the included studies found a significant difference (p <0.05) between NH children and HI children in terms of the functionality of the vestibular system [11]. These findings support the results of the current study where 100% of the NH children were found to have no VD whereas 33% of the HI children showed some degree of VD (Table 2).

The prevalence of VD among HI children varies in the literature between 30% [30] and 85% [31]. This could be explained by the use of different diagnostic tools in different studies and the variation in the sample size [11]. The prevalence reported in the current study is comparable with the prevalence of the studies that reported moderate prevalence [29, 30, 32] but much lower than other studies that reported high prevalence [27, 28, 31]. The higher prevalence might be explained by the fact that those studies included only children who received cochlear implants, which is reported to increase the vulnerability to experiencing progressive VD [33]. Besides, children who receive cochlear implants are usually the ones who have severe to profound HL. This leads us to the second aim of the current study which was investigating the association between the degree of the HL and the presence of VD.

Association between severity of HL and VD

Most studies that investigated the association between VD and the severity of HL included only children with severe to profound degrees of HL [2, 10, 11, 27, 28, 33]. Few studies were found to include children with moderate HL in their study sample [1, 23, 32]. However, for the purpose of the current study, HI children with all degrees of HL from mild to profound SNHL were included. Our results affirm the findings of previous studies [1, 11, 24] by finding that the worse the degree of HL, the more likely the child to have VD. In contrast, Raj and Gupta [34] and Pajor et al. [35] reported no effect of the severity of HL on VD. The disagreement could be explained by the following. First, the latter two studies included only children with severe to profound HL, thus the effect of the severity of HL might not appear since there is no big difference between these two degrees of HL in terms of the threshold of HL, while in the current study, the degree of HL ranged from mild to profound HL. Second, the use of different assessment tools, for instance, Raj and Gupta [34] used only caloric testing to assess the vestibular system whereas this test was not used in the current study, but rather other vestibular assessments as mentioned in the methods. Third, it was reported in the literature that the cause of HL is associated with increasing the risk of VD; while acquired HL such as meningitis could cause VD, congenital HL is less likely to be associated with VD [36, 37]. Raj and Gupta [34], for instance, included only children with congenital non-syndromic SNHL, hence their risk of having VD is lower and this was shown by the low prevalence of VD (18.75%). However, the cause of HL was not investigated in the current study. Thus, we are unable to determine whether it influences the difference in the results between our study and those studies that reported no association between the severity of HL and VD.

An important finding of the present study is that it added to the knowledge that even a minimum degree of HL increases the risk of children to have VD. This finding contrasts with

the recommendation reported by Jankey et al. [12] who suggested vestibular evaluation for children whose hearing threshold is ≥ 66 dB. Based on the findings of the current study, it is recommended to assess the functionality of the vestibular system in HI children regardless of the severity of their HL and regardless of the presence of vestibular symptoms. This is because children might experience vestibular symptoms but are unable to express themselves. On the other hand, some children might not have any vestibular symptoms because of the high elasticity of the brain which might compensate for the VD by any compensation process such as habituation, adaptation, and/or substitution [38]. Additionally, because of their sensory deficit, children with SNHL and VD might not rely on the input from the vestibular system but rather rely on the input from the visual and somatosensory systems [32]. Thus, regardless of the absence of vestibular and balance symptoms, those children might have an underlying VD. It is worth mentioning that this compensation process could be altered by any change to sensory input and hence cause the symptoms to appear [39] such as in cases of cochlear implants. Therefore, running full vestibular examination on children who are illegible for cochlear implants is crucial in order to appropriately set their rehabilitation plan to avoid further complications.

Association between the age and gender and the VD

It is controversial in the literature whether VD is more common in HI females than in HI male children and whether the prevalence is proportional to age. A systematic review conducted by Fancello et al. [40] supported that VD is more prevalent in HI females and older children, however, other researchers such as Raj and Gupta [34] did not. The present study did not show a significant difference either between the results of the two genders or the different ages (Tables 6 and 7).

CONCLUSIONS

VD is prevalent in HI children even the ones who do not complain of vestibular symptoms and are medically free, except for SNHL. An association was found between the severity of the HL and the presence of VD in children. It is recommended to assess the vestibular system functionality in children with SNHL regardless of the degree of the HL as this study found that even children with a mild degree of HL would also have VD.

An important strength of the current study is that it included HI children who have no complaints of vestibular symptoms. Additionally, all degrees of HL, even mild degrees of SNHL, were included in the study sample.

One limitation of the study is that young children less than 6 years old were not included. However, young children were not intentionally excluded but no children at younger ages were available and/or gave consent to participate (parental consent) at the time of data collection. Another limitation is that the causes of HL were unknown, and it is known that different causes have different effects on the vestibular system.

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