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The Influence of a Vestibular Dysfunction on the Motor Development of Hearing-Impaired Children

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Objectives/Hypothesis: To identify the predictive ability of vestibular function test results on motor performance among hearing-impaired children.

Study Design: Cross-sectional study.

Methods: Fifty-one typically developing children and 48 children with a unilateral (n = 9) or bilateral hearing impairment (n = 39) of more than 40 dB HL between 3 and 12 years were tested by the Movement Assessment Battery for Children–Second Edition (M ABC-2), clinical balance tests, posturography, rotatory chair testing, and vestibular evoked myogenic potential (VEMP). From the group of hearing-impaired children, 23 had cochlear implants.

Results: Balance performance on M ABC-2, clinical balance tests, as well as the sway velocity assessed by posturography in bipedal stance on a cushion with eyes closed and in unilateral stance differed significantly between both groups. Presence of a VEMP response is an important clinical parameter because comparison of the motor performance among hearing-impaired children between those with present and absent VEMPs showed significant differences in balance performance. The three most important predictor variables on motor performance by bivariate regression analyses are the vestibular-ocular reflex (VOR) gain value of the rotatory chair test at 0.01 and 0.05 Hz frequency, as well as the VEMP asymmetry ratio. Multivariate regression analyses suggest that the VOR asymmetry value of the rotatory chair test at 0.05 Hz and the etiology of the hearing loss seem to have additional predictive value.

Conclusions: Hearing-impaired children are at risk for balance deficits. A combination of rotatory chair testing and VEMP testing can predict the balance performance.

Key Words: Balance performance, vestibular function testing, hearing-impaired children.

Level of Evidence: 2c.

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INTRODUCTION

Several studies have shown that hearing-impaired (HI) children display motor deficits and more specifically balance deficits.[1–5] Because adequate postural stability requires integration and evaluation of the visual, vestibular, and somatosensory information by the central nervous system to generate motor responses that keep the body in balance, the stability problems of HI children are not surprising.[2,6] The vestibular system and the inner ear are in close anatomic relationship and may be susceptible to the same noxious or developmental factors; therefore, it is reasonable to presume that many HI children have concomitant vestibular loss.[7–9] Published reports found vestibular dysfunction in approximately 30% to 70% of HI children.[8–13] It is known that the prevalence of vestibular test abnormalities is higher in profound sensorineural hearing loss,[9,11] acquired deafness (meningitis),[9,10,14] and in some syndromes associated with deafness (Usher, Waardenburg, and Pendred syndrome).[15] Even deafness associated with mutations in the *GJB2* gene, which encodes connexine 26 in the gap junction, has an increased risk for vestibular dysfunction.[7] Additionally, a cochlear implant (CI), an accepted rehabilitation device for HI children, entails a potential risk for additional vestibular damage.[16–21]

The mature vestibular system generates 3 motor reflexes: the vestibular-ocular reflex (VOR) responsible for visual stabilization, the vestibular-collic reflex (VCR) responsible for neck stabilization, and the vestibular-spinal reflex (VSR), which maintains the orientation of the body in space and contributes to the postural tone necessary for the acquisition of motor developmental milestones.[9,22] To evaluate the VOR, traditional techniques like caloric and rotatory chair testing can examine horizontal semicircular canal and superior vestibular nerve function. The VCR can be evaluated by the vestibular evoked myogenic potential (VEMP) test, in which a loud auditory stimulus induces an ipsilateral inhibition of the tonic neck muscle activity recorded on

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electromyography (EMG). VEMP testing is a child-friendly option to investigate saccular and inferior vestibular nerve function. Finally, for evaluating the VSR, posturography and balance tests enable evaluating the result of the complex interaction between cortical control of lower motor centers through pyramidal and extrapyramidal tracts, vestibular influences through the medial and lateral vestibular-spinal tracts, and the reticulospinal tract.[22]

A few studies have evaluated the relationship between motor performance and vestibular function tests in HI children. Kaga et al. (1981)[23] and Rapin (1974)[24] showed that HI children with hypoactive caloric responses reached specific motor developmental milestones like head control, sitting, and independent walking later than typically developing children. Horak et al. (1988)[2] established that reduced or absent vestibular responses, assessed by rotatory chair testing, were associated with balance performance but not with the general motor proficiency evaluated by the Bruininks-Oseretsky Test in HI children. More recently, Shall (2009)[25] and Jafari and Asad (2011)[26] found a significant association between static balance performance and the absence versus presence of the VEMP. Cushing et al. (2008)[4] showed that rotatory chair testing correlated better with the balance performance on Bruininks-Oseretsky Test–Second Edition than with VEMP and caloric testing.

The aim of the current study was to identify the predictive ability of vestibular function tests by rotatory chair and VEMP testing, as well as other factors such as the degree of the hearing loss, the etiology of the hearing loss, the hearing aid, and additional disabilities on motor performance among a heterogeneous group of HI children.

MATERIALS AND METHODS

Participants

Forty-eight HI children between 3 and 12 years old (23 females, 25 males; mean age 7 years, 6 months; standard deviation [SD] 2 years, 5 months) were recruited by a mainstream education program, a special school for HI children, and the Ear-Nose-Throat Department of the Ghent University Hospital. In the HI group, nine presented with a unilateral sensorineural hearing impairment of more than 40 dB hearing level (HL) and 38 with a bilateral sensorineural hearing impairment of more than 40 dB HL in the better ear. Fifty-one typically developing (TD) children (22 females, 29 males; mean age 8 years, 0 months; SD 2 years, 3 months) were recruited by a regular school. Exclusion criteria were neuromotor disorders such as cerebral palsy, orthopedic dysfunctions and vision problems that cannot be corrected. All HI children had a nonverbal intelligence quotient (IQ) higher than 80 based on a standardized IQ test in the last year. All TD children were in mainstream education in their appropriate grade.

The characteristics of the group of HI children are described in Table I. Twenty-three children had CIs, of which 15 were unilateral and eight bilateral. The etiology of the hearing impairment was genetic nonsyndromal (connexine 26), genetic syndromal (Pendred, Waardenburg, enlarged vestibular aqueductus, and deafness, onychodystrophy, osteodystrophy, and retardation syndrome), acquired (ototoxic drugs, cytomegalovirus, meningitis, and Ménière disease), and unknown. Among HI children, 17 children had additional disabilities: six had attention deficit hyperactivity disorder, three an autism spectrum disorder, five a learning disorder, and six had other disorders such as an atrial septum defect, a thyroid dysfunction, or a metabolic disorder.

TABLE I.
Characteristics of the Group of Hearing-Impaired Children.

	Total Group HI Children (N = 48)	Bilateral HI Children (N = 39)	Unilateral HI Children (N = 9)
Hearing loss (PTA), mean (SD)	87.6 dB (29.5 dB)	88.1 dB (29.0 dB)	85.5 dB (33.7 dB)
Hearing level (N)			
Moderate (40–60 dB HL)	14	11	3
Severe (61–80 dB HL)	6	4	2
Profound (>81 dB HL)	28	24	4
Cochlear implant (N)			
CI	23	23	0
No CI	25	16	9
Etiology (N)			
Genetic nonsyndromal	14	13	1
Genetic syndromal	11	8	3
Acquired	11	8	3
Unknown	12	10	2
Additional disabilities (N)			
No	31	26	5
Yes	17	13	4
School type (N)			
Mainstream education	32	24	8
School for special needs	16	15	1

HI = hearing impaired; PTA = pure-tone average; SD = standard deviation; CI = cochlear implant.

The study was approved by the ethical committee of the Ghent University Hospital and informed consent forms were obtained from the children's parents.

Methods

The Movement Assessment Battery for Children–Second Edition (M ABC-2)[27] is a test to identify motor impairments in 3- to 16-year-old children. The test contains eight items that are divided in three domains: manual dexterity, ball skills abilities, and balance. Standardized (SS) and percentile scores are calculated based on a Dutch standardization sample.[28] M ABC-2 is proven to be reliable and valid.[27]

Balance beam walking and one-leg hopping are items from the Koperkoördinationstest für Kinder.[29] For balance beam walking, the child had to walk backward three times on three different balance beams with a decreasing width. For one-leg hopping, the child had to hop on one leg over an increasing number of foam plates. Excellent test-retest reliability is reported.[30]

One-leg stance (OLS) was performed by a standardized protocol.[31] The child had to stand as long as possible with a maximum of 20 seconds for each trial on one leg. The scores of three trials were summed for both legs with eyes open (OLS EO) and with eyes closed (OLS EC).[31] Reliability of this protocol is excellent.[30]

Posturography was evaluated by an AccuGait force platform (Advanced Medical Technology, Inc., Watertown, MA). The

mean sway velocity of the center of pressure was chosen as response parameter because of its high reliability.[30] Each subject completed the modified Clinical Test of Sensory Interaction for Balance (mCTSIB), unilateral stance (US) (on each foot), and tandem stance (heel-to-toe stance with each foot in front). The mCTSIB consists of four standing conditions in their preferred side-by-side foot position: eyes open on a firm surface (EO), eyes closed on a firm surface (EC), eyes open on a foam cushion (CEO), and eyes closed on a foam cushion (CEC). Each condition had three trials of 10 seconds. The subjects were barefoot and were instructed to stand as steady as possible with the arms by their sides. A more detailed description of this protocol is available.[30,32]

Rotatory chair testing, (version 1.70; Toennis Nystagliner, Höchberg, Germany) was evaluated in a completely darkened room. Horizontal eye movements were registered during three sinusoidal harmonic acceleration tests at frequencies 0.01, 0.05, and 0.1 Hz. Response parameters gain, phase, and asymmetry were calculated. The gain parameter describes the ratio of the peak slow phase eye velocity to the peak head velocity and is expressed as a percentage. The phase parameter expresses the temporal relationship between peak eye and peak head velocity, expressed in degrees and calculated by subtracting the inverted eye velocity from the head velocity. The asymmetry parameter describes the percentage difference between the peak slow component eye velocities to the right and to the left.[33] A more detailed description of this protocol is available.[33]

For VEMP testing, the child was lying supine on a comfortable chair with an inclination angle of 30° from the horizontal plane. EMG activity of the sternocleidomastoid (SCM) muscle was recorded (Bio-Logic Navigator-Pro platform; Bio-logic Systems Corp., Mundelein, IL) while the child lifted the head 30° from the chair, thereby bilaterally tensing the SCM muscle. Meanwhile, air-conducted tone bursts were presented through insert earphones at an intensity of 95 dB HL. Response parameters: P1 and N1 latencies (ms), interpeak amplitude (μV), and asymmetry ratio (%) were calculated. The absolute latencies of P1 and N1 were determined as the time in ms between 0 ms and the maximal peak of P1 and N1, respectively. Interpeak amplitude covered the amplitude span between P1 and N1, where both peaks are expressed in μV relative to the baseline. The asymmetry ratio was determined by calculating the interaural interpeak amplitude difference divided by the sum of the interpeak amplitude of both ears.[34] A detailed description of the protocol is available.[35] Prior to the VEMP test, otoscopy and tympanometry were performed to rule out any conductive component.

Data Analysis

The Kolmogorov-Smirnov test was used to check normality assumptions. Group differences were evaluated using Pearson χ^2 (for categorical variables), analysis of covariance (ANCOVA) with the age as covariate (for raw scores), and independent t tests (for standardized scores). If the sample sizes of the groups were extremely different, nonparametric Mann-Whitney U tests were used. Because of the large number of comparisons to be performed, a Bonferroni adjustment for between-group comparisons of the motor test results was carried out to reduce the risk of type I error. The significance was set at $P \leq .10/14 = .007$, two-tailed. Additionally, significance at $P \leq .05$, two-tailed, was cautiously taken into consideration as a trend. Effect sizes indicated by partial η^2 were computed for between-group comparisons. By convention, small, medium, and large effect sizes were defined as values of 0.01, 0.06, and 0.14, respectively.[36]

For the regression analyses, the most discriminating balance parameters were the criterion variables. Among HI children, bivariate regression analyses were performed to determine the predictive nature of each vestibular parameter and the hearing level. In addition, among HI children, between-group comparisons of the criterion variables were analyzed by ANCOVA with categorical variables as CI, etiology, and additional disabilities. After checking for multicollinearity, significant and borderline significant variables ($P < .2$) on those bivariate regression analyses and ANCOVAs were included in multivariate regression analysis (enter method).

RESULTS

Comparison of both groups showed no differences for age ($t(97) = -1.078$, $P = .284$), and gender ($\chi^2(1) = 0.228$, $P = .689$). Table II presents the comparison of motor performance between both groups. The total and balance SS on M ABC-2 showed significantly different results, whereas the SSs on manual dexterity and ball skills showed a trend to significance. All clinical balance tests differed significantly. From all posturography conditions, only CEC and US showed a significant difference, whereas CEO showed a trend to significance.

Among HI children, a 2 ×2 ANCOVA with factor hearing level classification (<80 dB HL vs. ≥81 dB HL) and factor localization of the hearing impairment (unilateral vs. bilateral) showed no effect for each factor as for the interaction on all motor parameters.

The clinical interpretation of VEMP responses primarily depends on the presence or the absence of the VEMP waveform.[35] Seven HI children had a unilateral or bilateral absent VEMP (absent VEMPs in 11 out of 76 HI ears) despite normal findings on otoscopy and tympanometry. In contrast, all TD children had bilateral present VEMPs. All seven HI children with an absent VEMP had a bilateral profound hearing loss and a CI (four bilateral and three unilateral). Because the children with absent VEMPs were excluded for all regression analyses with VEMP parameters, we compared the motor performance among HI children between those with bilateral present VEMP responses and those with a unilateral or bilateral absent VEMP by the use of Mann-Whitney U tests. Table III shows significant differences for the balance SS of M ABC-2 and OLS EC, whereby the HI children with absent VEMPs performed weaker, as well as for the mean sway velocity in CEC, whereby the HI children with absent VEMPs showed a larger postural instability.

The following criterion variables were selected for the regression analyses: balance SS of M ABC-2, clinical balance tests, and CEC of posturography. Because age is a significant predictor of the scores on clinical balance tests and sway velocity in CEC, the age is always included as a covariate in the bivariate regression analyses with those criterion variables. The three most important predictor variables on motor performance seem to be the rotatory test gain values at 0.05 and 0.01 Hz as well as the VEMP asymmetry ratio. The gain value at 0.05 Hz is a significant predictor variable of balance SS of M ABC-2 ($R^2_{adjusted} = 0.088$; $P = .025$), balance beam walking ($R^2_{adjusted} = 0.500$; $P = .011$), one-leg hopping ($R^2_{adjusted} = 0.770$; $P = .038$), and OLS EC ($R^2_{adjusted} = 0.393$; $P = .009$), whereas the 0.01 Hz gain value is a

TABLE II.
Comparison of Motor Test Results Between Hearing-Impaired and Typically Developing Children.

	Group HI Children, Mean (SD)	N	Group TD Children, Mean (SD)	N	*P*	Effect Size, Partial η^2
Movement ABC-2						
Manual dexterity (SS)	8.1 (2.3)	48	9.3 (2.1)	51	.01*†	0.067
Ball skills (SS)	9.2 (2.9)	48	10.3 (2.6)	51	.033*†	0.046
Balance (SS)	7.2 (3.4)	48	10.9 (2.3)	51	<.001*†‡	0.287
Total (SS)	7.3 (2.7)	48	10.3 (2.1)	51	<.001*,†,‡	0.285
Clinical balance tests						
Balance beam (RS)	17.0 (15.3)	48	33.2 (14.8)	51	<.001†,‡,§	0.284
One-leg hopping (RS)	23.6 (20.5)	48	39.3 (21.7)	51	<.001†,‡,§	0.223
OLS EO (RS)	61.7 (42.0)	48	92.7 (33.6)	51	<.001†,‡,§	0.221
OLS EC (RS)	16.6 (16.4)	48	43.5 (27.5)	51	<.001†,‡,‖	0.262
Posturography						
EO (cm/s)	2.4 (1.2)	48	2.0 (0.8)	51	.106§	0.027
EC (cm/s)	3.6 (2.2)	48	2.8 (1.3)	51	.061§	0.036
CEO (cm/s)	4.0 (2.3)	48	3.1 (1.5)	51	.047†,§	0.041
CEC (cm/s)	8.7 (4.6)	48	5.6 (1.9)	51	<.001†,‡,‖	0.173
TS (cm/s)	5.0 (1.9)	24	4.5 (1.4)	41	.101§	0.043
US (cm/s)	6.4 (2.5)	22	5.1 (1.8)	37	.003†,‡,§	0.143

*t test for equal variances.
†$P < .05$.
‡Bonferroni correction: $0.10/14 = 0.007 \geq P < .007$.
§Analysis of covariance with age as covariate.
‖t test for unequal variances.
HI = hearing impaired; SD = standard deviation; TD = typically developing; Movement ABC-2 = Movement Assessment Battery for Children–Second Edition; SS = standardized score; RS = raw score; OLS EO = one-leg stance with eyes open; OLS EC = one-leg stance with eyes closed; EO = bipodal stance with eyes open; EC = bipodal stance with eyes closed; CEO = bipodal stance on the cushion with eyes open; CEC = bipodal stance on the cushion with eyes closed; TS = tandem stance; US = unipodal stance.

significant predictor variable of balance SS of M ABC-2 ($R^2_{adjusted}$= 0.083; P = .032), balance beam walking ($R^2_{adjusted}$= 0.486; P = .009), OLS EC ($R^2_{adjusted}$= 0.428; P = .001), and CEC ($R^2_{adjusted}$= 0.177; P = .005). VEMP asymmetry ratio is a significant predictor variable of balance SS of M ABC-2 ($R^2_{adjusted}$= 0.112; P = .040) and balance beam walking ($R^2_{adjusted}$= 0.574; P = .046). Furthermore, the gain value at 0.1 Hz is a significant predictor variable of balance beam walking ($R^2_{adjusted}$= 0.531; P = .009), the hearing level of OLS EC ($R^2_{adjusted}$= 0.379; P = .025), and the asymmetry parameter at 0.01 Hz of CEC ($R^2_{adjusted}$= 0.190; P = .045).

Among HI children, between-group comparisons of all criterion variables were analyzed by ANCOVA with categorical variables CI, etiology, and additional disabilities (α = .05). Only OLS EC showed a significant difference for the factor additional disabilities ($F(2,45)$ = 4.590; P = .038) and for the factor CI ($F(2,45)$ =5.123; P = .028).

Table IV presents six final multivariate prediction models for all criterion variables. The model that explained the largest percent of the variance, expressed by the adjusted R^2, is the model to predict one-leg hopping. This model explains 88.4% of the variance ($F(8,20)$ = 27.653; $P < .001$; $R^2_{adjusted}$= 0.884) based on the age of the child, the asymmetry and the gain value at 0.05 Hz rotation, VEMP asymmetry ratio and N1 latency, and etiology. Two other models are able to explain more than 70% of the variance: balance beam walking ($F(7,21)$ = 12.199; $P < .001$; $R^2_{adjusted}$= 0.737) and OLS EO ($F(8,21)$

TABLE III.
Comparison of Motor Parameters Among Hearing-Impaired Children Between Those With Bilateral Present VEMPs and Those With a Unilateral or Bilateral Absent VEMP.

	VEMP Present (n = 35), Mean (SD)	VEMP Absent (n = 7), Mean (SD)	Mann-Whitney *U* (*P* Value)
Age, yr	7.4 (2.2)	7.7 (3.1)	0.869
Movement ABC-2			
Manual dexterity (SS)	8.0 (2.4)	8.3 (2.0)	0.792
Ball skills (SS)	9.3 (2.8)	8.6 (4.5)	0.692
Balance (SS)	7.6 (3.2)	3.6 (2.5)	0.003*
Total (SS)	7.5 (2.8)	5.4 (2.8)	0.122
Clinical balance tests			
Balance beam (RS)	17.5 (15.4)	8.0 (10.2)	0.099
One-leg hopping (RS)	24.0 (21.4)	18.7 (20.9)	0.597
OLS EO (RS)	63.1 (41.3)	52.0 (53.0)	0.426
OLS EC (RS)	18.7 (17.4)	4.6 (6.2)	0.013*
Posturography			
EO (cm/s)	2.4 (1.0)	2.6 (2.2)	0.644
EC (cm/s)	3.6 (1.8)	4.9 (3.8)	0.692
CEO (cm/s)	4.0 (2.2)	3.7 (2.8)	0.671
CEC (cm/s)	7.8 (3.4)	13.6 (5.5)	0.008*

*$P < .05$.
VEMP = vestibular evoked myogenic potential; SD = standard deviation; Movement ABC-2 = Movement Assessment Battery for Children–Second Edition; SS = standardized score; RS = raw score; OLS EO = one-leg stance with eyes open; OLS EC = one-leg stance with eyes closed; EO = bipodal stance with eyes open; EC = bipodal stance with eyes closed; CEO = bipodal stance on the cushion with eyes open; CEC = bipodal stance on the cushion with eyes closed.

TABLE IV.
Final Multivariate Regression Models of the Six Criterion Variables.

	df	*F* Value	Adjusted R^2	Slope (B)	Standard Error	*P* Value
M ABC-2 balance SS	(3,26)	6.708	0.371			.002*
F 0.05 asymmetry				−0.161	0.063	.017*
F 0.05 gain				0.086	0.036	.025*
VEMP AR				−0.055	0.023	.025*
Balance beam RS	(7,21)	12.199	0.737			<.001*
Age				0.363	0.058	<.001*
F 0.05 asymmetry				−0.569	0.207	.012*
F 0.1 gain				0.180	0.117	.140
VEMP AR				−0.237	0.073	.004*
Etiology						.050*
Genetic nonsyndromal vs. unknown				−7.939	4.262	.048*
Genetic syndromal vs. unknown				−8.992	4.583	.006*
Acquired vs. unknown				−10.160	4.682	.115
One-leg hopping RS	(8,20)	27.653	0.884			<.001*
Age				0.784	0.074	<.001*
F 0.05 asymmetry				−0.586	0.205	.010*
F 0.05 gain				0.133	0.116	.265
VEMP AR				−0.203	0.071	.037*
VEMP latency N1				−2.227	0.996	.010*
Etiology						.152
Genetic nonsyndromal vs. unknown				−7.939	4.276	.078
Genetic syndromal vs. unknown				−8.992	4.687	.069
Acquired vs. unknown				−10.160	4.881	.050*
OLS EO	(8,21)	9.869	0.710			<.001*
Age				1.085	1.085	<.001*
F 0.05 asymmetry				−1.461	−1.461	.019*
F 0.1 gain				0.590	0.590	.108
VEMP AR				−0.304	−0.304	.199
VEMP latency P1				−8.226	3.765	.040*
Etiology						.058
Genetic nonsyndromal vs. unknown				−24.031	13.594	.092
Genetic syndromal vs. unknown				−35.524	13.892	.018*
Acquired vs. unknown				−35.992	13.896	.017*
OLS EC	(8,21)	7.834	0.670			<.001*
Age				0.380	0.076	<.001*
F 0.05 asymmetry				−0.846	0.245	.002*
VEMP AR				−0.170	0.092	.078
VEMP Latency P1				−4.704	1.605	.008*
Etiology						.012*
Genetic nonsyndromal vs. unknown				−20.618	5.620	.001*
Genetic syndromal vs. unknown				−15.158	6.032	.020*
Acquired vs. unknown				−16.939	5.997	.010*
Additional disabilities (no vs. yes)				8.742	4.362	.058
CEC	(7.32)	3.833	0.343			.004*
Age				−0.043	0.018	.014*
F 0.05 gain				0.044	0.024	.074
F 0.01 phase				0.083	0.029	.007*
F 0.01 asymmetry				−0.088	0.045	.061
Etiology						.193
Genetic nonsyndromal vs. unknown				−1.773	1.273	.173
Genetic syndromal vs. unknown				0.489	1.421	.733
Acquired vs. unknown				−2.321	1.474	.125

*$P < .05$.

M ABC-2 = Movement Assessment Battery for Children–Second Edition; SS = standardized score; F 0.05 = frequency 0.05 Hz; VEMP AR = vestibular evoked myogenic potential asymmetry ratio; RS = raw score; F 0.1 = frequency 0.1 Hz; OLS EO = one-leg stance with eyes open; OLS EC = one-leg stance with eyes closed; CEC = bipodal stance on the cushion with eyes closed; F 0.01 = frequency 0.01 Hz.

= 9.869; $P < .001$; $R^2_{adjusted} = 0.710$). The remaining prediction models of OLS EC, balance SS on M ABC-2, and CEC are able to explain respectively 67.0%, 37.1%, and 34.3% based on vestibular parameters in addition to etiology and/or additional disabilities.

DISCUSSION

The main problems facing HI children are communication and language deficits. However, HI children have also a higher risk for motor and more specifically balance deficits, which may often be overlooked. This study confirmed early reports[1–4] that many HI children have clear balance deficits. Moreover, HI children showed a trend to perform weaker also on manual dexterity and ball skills abilities of M ABC-2. Those findings can be explained by the fact that adequate postural control is a necessary condition for adequate motor development. Additionally, children with a genetic syndromal or acquired hearing impairment could have a mild motor disorder linked to neurological damage.

Previous studies on vestibular dysfunction[8,9,26,37] and balance performance[1,5,38,39] in HI children were mostly conducted in bilateral, profound HI children. This study also included children with unilateral or a moderate hearing loss and found that they all performed equally on motor and balance tests. This means that the group of children with a moderate or a unilateral hearing impairment with lower risks for communication and language deficits has similar risks for motor and balance deficits as profound HI children and therefore may not be neglected.

The present study showed that rotatory chair and VEMP testing had predictive abilities for the balance performance of HI children.

A first important vestibular clinical parameter is the absence of a VEMP response. All children with an absent VEMP performed significantly weaker on static balance measures whereby visual and/or somatosensory information is unreliable. This finding confirms that the saccule has an important role in the development of static balance. Our results are in accordance with Jafari and Asad (2011)[26] and Shall (2009)[25] but in contrast to Cushing et al. (2008)[4] who found no association. This difference could be related to the fact that the current study registered VEMPs in 86.6% of HI ears. Those percentages are much higher than those of Cushing et al. (2008),[4] Shall (2009),[25] and Jafari and Asad (2011)[26] but similar to Shinjo et al. (2007).[8] Factors such as etiology, degree of hearing loss, and CI, but also stimulus type, stimulus presentation, and unilateral or bilateral activation of the SCM muscle, could probably explain the reasons for the differences in the incidence of VEMP responses among HI children.[4,8,25,26] All children with an absent VEMP in this study had a bilateral profound hearing loss and a CI. This finding suggests that the absence of a VEMP response could be related to the degree of the hearing loss or could be a consequence of injury to the inner ear during the implantation process. However, longitudinal investigations with pre- and postimplant data are necessary to rule out the impact of a CI on vestibular function. Because VEMP testing is already possible in very young infants, screening of young HI infants by VEMP could contribute in the decision to start early motor interventions.

Based on bivariate regression analyses, the three most important predictor variables on balance performance seem to be the rotatory test gain value at 0.05 and 0.01 Hz as well as the VEMP asymmetry ratio. In addition, multivariate regression analyses suggested that the asymmetry value at 0.05 Hz frequency and the etiology had an additional relationship with the balance performance.

Of all rotatory chair parameters, the gain parameter seems to be the most important predictive value probably because gain is ideal to specify the extent of a bilateral vestibular dysfunction or a marked unilateral vestibular reduction.[35] If the VEMP is present, the VEMP asymmetry ratio is an important parameter. This parameter reflects an asymmetry in saccular function between both ears and therefore declares its important relationship with balance performance.

Although, ANCOVA showed no significant effect for the etiology of the hearing loss on the motor performance, the etiology had an important additional value in predicting motor performance by multivariate regression analyses. HI children with acquired deafness and genetic syndromal deafness performed somewhat weaker than those with genetic nonsyndromal deafness.

Although this study paradigm was not aimed at assessing the impact of a CI on balance performance, it could show a significant effect of CI on OLS EC. However, the CI had no predictive value in any multivariate regression model.

Notwithstanding the limitation of the small sample size and the necessity of consequent validation, the reported results are of clinical value for everyone working with HI children. This study suggests that identification of vestibular function by rotatory chair and VEMP testing is important and can give additional information to physiotherapists in formulating a motor intervention plan. Children with vestibular loss must learn to use substitutive sensory and motor strategies. Children with a vestibular dysfunction need to be taught to recognize and handle dangerous situations in which visual and somatosensory systems are rendered unreliable. Although the consequences of CI on balance performance are still not clear, we advocate the evaluation of the vestibular function and balance performance in all CI, and especially in bilateral CI candidates, to study the effects of a CI on balance performance in the future.

CONCLUSION

HI children are at risk for balance deficits. Rotatory chair testing and VEMP testing can be used to predict balance performance. The presence of a VEMP response is a first important clinical parameter with a significant effect on static balance performance. Three important predictor variables are the gain value at 0.01 and 0.05 Hz rotation and the VEMP asymmetry ratio.

Additionally, the asymmetry value at 0.05 Hz and the etiology of the hearing loss seem important characteristics with an influence on the balance performance.

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