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Sebastián Rivera Retamal[1,2]
Patricia Oyarzún Díaz[1]
Anthony Marcotti Fernández[3,4]
Camila Gallardo Muñoz[1]
Melissa Richard Espinoza[1]
Valeria Sepúlveda Araya[1]
Javiera Tapia Rivera[1]

Assessment protocol and reference values of vestibulo-ocular reflex (VOR) gain in the horizontal plane recorded with video-Head Impulse Test (vHIT) in a pediatric population

Protocolo de evaluación y valores de referencia de la ganancia del reflejo vestíbulo-ocular (RVO) en el plano horizontal registrado mediante el video-Head Impulse Test (v-HIT) en población pediátrica

Keywords

Head Impulse Test
Vestibular Function Tests
Semicircular Ducts
Child Health
Education Primary and Secondary

ABSTRACT

Purpose: To develop an assessment protocol and establish reference values of vestibulo-ocular reflex gain of the horizontal semicircular canal obtained with vHIT in a pediatric population without vestibular changes. **Methods:** Quantitative, non-experimental, analytical study with a non-probabilistic convenience sample. A total of 39 subjects aged 5 to 17 years were selected based on the inclusion and exclusion criteria. **Results:** The mean gain obtained of the horizontal right semicircular canal was 0.93 and of the left one, 1.08, with statistically significant differences between the ears. There were no statistically significant differences between the 5-to-10-year and 11-to-17-year subgroups. **Conclusion:** The vestibulo-ocular reflex gain in children neared the values found in the international scientific literature and the adult population. The protocol developed can guide beginning professionals in the otoneurological evaluation of children.

Prueba de Impulso Cefálico
Pruebas de Función Vestibular
Conductos Semicirculares
Salud del Niño
Educación Primaria y Secundaria

RESUMEN

Objetivo: Elaborar un protocolo de evaluación y establecer valores de referencia de las ganancias del reflejo vestíbulo-ocular del canal semicircular horizontal obtenidas con el v-HIT en población pediátrica sin alteraciones vestibulares. **Método:** Estudio cuantitativo, analítico, no experimental con muestreo no probabilístico por conveniencia. Se seleccionaron 39 sujetos entre 5 a 17 años, los cuales cumplieron los criterios de inclusión y exclusión. **Resultados:** El promedio de la ganancia obtenida para el conducto semicircular horizontal derecho fue de 0,93 y para el conducto semicircular izquierdo fue de 1,08. Existen diferencias estadísticamente significativas entre oídos. No existen diferencias estadísticamente significativas entre los subgrupos de 5 a 10 años y 11 a 17 años. **Conclusión:** La ganancia del reflejo vestíbulo-ocular en población pediátrica se acerca a los valores encontrados en la literatura científica internacional y de la población adulta. El protocolo confeccionado puede orientar a profesionales que están comenzando en la evaluación otoneurológica de esta población. Descriptores

Correspondence address:
Sebastián Rivera Retamal
Escuela de Fonoaudiología, Facultad de Salud, Universidad Santo Tomás
Avenida Uno Norte, 3041, Viña del Mar, Chile, Zip-Code: 2520000.
E-mail: srivera@santotomas.cl

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[1] Escuela de Fonoaudiología, Facultad de Salud, Universidad Santo Tomás - Viña del Mar, Chile.
[2] Unidad de Otorrinolaringología, Hospital Dr. Gustavo Fricke - Viña del Mar, Chile.
[3] Carrera de Fonoaudiología, Departamento de Ciencias de la Salud, Facultad de Medicina, Pontificia Universidad Católica de Chile - Santiago, Chile.
[4] Escuela de Fonoaudiología, Facultad de Ciencias de la Salud, Universidad de las Américas - Santiago, Chile.

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INTRODUCTION

Vestibular symptomatology is an important health problem in the general population, with a reported 4.9 to 59.2% incidence and a 29.5% prevalence throughout life[1,2]. In the case of children, a study based on the National Health Interview Survey Child Balance Supplement in the USA with a sample of 10,954 children aged 3 to 17 years found a 5.3% prevalence of dizziness and balance problems[3].

Balance is maintained with the integration of three systems: visual, proprioceptive, and vestibular. The vestibular system is related to the inner ear structures that register the linear and angular acceleration. One of its fundamental functions is to contribute to ocular stability with the vestibulo-ocular reflex (VOR). In 1988, Halmagyi and Curthoys first described the Head Impulse Test (HIT)[4], which detects vestibular changes by assessing the VOR. The HIT is performed with passive and unpredictable small-amplitude (10-20º), high-speed (200-400º/sec), and high-acceleration (3000-4000º/sec) head movements. Thus, it assesses the angular function of the labyrinth – i.e., the semicircular canals (SCC)[5]. When the VOR function is insufficient, an ocular deviation results from the head movements, causing an unstable retinal image that may, for instance, be reported as blurred or delayed vision[6]. This occurs because the eyes move in the same direction of the head rotation and, to keep them fixed on an object, compensatory saccades are made in the opposite direction of the head rotation. Such saccades, when made after finishing the head movement, are called overt saccades and are clinical signs of paresis of the stimulated SCC. Hence, with the naked eye, the HIT has a 55% to 72% sensitivity and a 78% to 83% specificity[7].

In 2005, Ulmer and Chays reported using a camera placed in front of the patient to record and register the eye movements during the HIT to quantify the function of each SCC[8]. Later, in 2009, McDougall, Weber, McGarvie, Halmagyi, and Curthoys described in detail the currently most used procedure[9]. The video-Head Impulse Test (vHIT) is based on eye movements recorded with high-speed cameras that can record compensatory movements during head impulse. Conventional cameras, much less the naked eye, cannot record them with higher acceleration, higher speed, and lower latency. This test has proved to effectively record compensatory eye movements with sensitivity and specificity close to 100%[9,10]. The relationship between the two speeds is referred to as VOR gain. Gain values close to 1 represent an efficient reflex[5,11], indicating that the response speed of the eye is almost identical to the head movement. In contrast, lower values indicate a pathological reflex, in which case, corrective saccades are expected – i.e., a compensatory phase after a brief head acceleration[12]. The literature recognizes vHIT as the present-day gold standard test to assess VOR in patients with suspicion of vestibular disorders. It is quickly applied, innocuous, and repeatable, and provides objective quantitative data of each SCC separately and, therefore, of both vestibular nerve branches[13].

Few studies have been conducted in children when compared with those in adults, which may be due to the great difficulty in reaching a precise diagnosis in that population. Therefore, there is an incipient need for making otoneurological assessments more objective and pleasant, particularly in the child and youth population, as they oftentimes cannot describe their vestibular symptomatology[14], and some procedures are not well tolerated. Moreover, due to the great number of changes in the vestibular system found in primary health care and their likely underreporting in children, it is essential to investigate more in-depth the assessments and the associated difficulties.

OBJECTIVE

The objectives of this paper are to develop an assessment protocol with the necessary procedures and recommendations to perform vHIT in children and establish reference values for VOR gain of the horizontal SCC obtained with vHIT in children without vestibular changes.

METHODS

This quantitative, non-experimental, analytical study was approved by the Research Ethics Committee of the *Universidad Santo Tomás*, Chile (code 05.19). Each participant's parents/guardians signed the informed consent form, and the minors signed the informed assent form, which emphasized their volunteer participation and explained in simple terms the objectives, tests, and each step in the study. The sample size was calculated with G*Power 3.1.9.4, considering two-tailed test parameters, 0.6 effect size, 0.05 error, and 0.95 power – which resulted in a total of 39 subjects. The subjects comprised a non-probabilistic convenience sample.

The study was carried out at the UNESCO educational institution of the city of Viña del Mar, in the Valparaíso Region, Chile, with students aged 5 to 17 years, having received due authorization and informed consent and assent forms signed. The following equipment was used: otoscope manufactured by Riester, model E-Scope, acoustic-immittance and otoacoustic emission device manufactured by Interacoustics, model Titan, and vHIT manufactured by Interacoustics, model EyeSeeCam. These were provided by the Speech-Language-Hearing School at the *Universidad Santo Tomás*, campus Viña del Mar.

The following inclusion criteria were considered: being 5 years to 17 years, 11 months, and 30 days old; living in the Valparaíso Region; having a normal balance, with performance equal or superior to 8 seconds in the tandem test[15]; presenting distortion-product otoacoustic emissions in at least three of the four frequencies assessed. The exclusion criteria were as follows: having a history of ototoxic exposure, ear surgery, vestibular suppuration and/or symptoms (such as dizziness, vertigo, and instability, verified in anamnesis), changes in the tympano-ossicular system (verified with acoustic immittance), and presence of cerumen impaction or other impairment in the external ear canal or tympanic membrane (verified with otoscopy).

At first, 77 subjects were assessed, considering the abovementioned criteria, of whom 38 were excluded for the following reasons: history of suppuration and/or ear surgery (nine subjects), presence of cerumen impaction (11 subjects), presence of ear eczema (two subjects), tympanic retraction (one subject), absence of two or more frequencies in otoacoustic emissions (six subjects), flat-curved tympanometry (four subjects), poor performance in the tandem test (two subjects). Moreover, three of them were excluded from the analysis due to VOR gain atypical values with vHIT, according to the distribution of results. Hence, the final sample comprised 39 subjects. A single 30-minute session was estimated for each participant to perform all the tests. Also, for logistical reasons, two examiners were present during vHIT data collection, considering the high inter-examiner reliability verified in a study carried out at the *Universidad de Valparaíso*[16].

To ensure the quality of the vHIT recordings, two stages were conducted before collecting the samples: training/piloting and defining an assessment protocol. In the first stage, the training consisted of the examiners' daily practicing 20 head impulses to each side (HIT) at home. Then, 35 volunteers were recruited for piloting and refining the head impulse technique with vHIT. Altogether, 2 months were dedicated to the first stage. In the second stage, having the experience from the first one, a protocol was developed with the necessary procedures and recommendations to assess children with vHIT (Annex 1).

The results were analyzed with the statistical program SPSS v24. The Shapiro-Wilk test was used to corroborate data distribution. Mean and standard deviation (SD) values were calculated, as well as their respective 95% confidence intervals (95% CI). The Levene's test was used for comparisons between ears and age groups, to corroborate equality of variance and Student's t-test. In the cases with significant differences, the effect size was also calculated with Cohen's d. Some analyses were conducted with age stratification into two subgroups: from 5 years to 10 years, 11 months, and 30 days (age group I), and from 11 years to 17 years, 11 months, and 30 days (age group II). The purpose was to consider the different development between childhood and adolescence. The demographic data and test results underwent descriptive analysis.

RESULTS

Considering the total sample, the mean in the right ear was 0.93 (SD 0.17, 95% CI 0.87-0.98), whereas in the left ear it was 1.08 (SD 0.17, 95% CI 1.03-1.14). There were statistically significant differences in gain between the right and left ears of the total sample ($t=-3.755$, $p=0.000$, $d=0.854$), as seen in Figure 1. Moreover, there was normal sample data distribution in all the variables analyzed ($p>0.05$). Thus, Levene's test confirmed the equality of variance in all the analyses ($p>0.05$).

As seen in Table 1, the mean gain in the age group I was 0.96 in the right ear (SD 0.21, 95% CI 0.86-1.06) and 1.11 in the left ear (SD 0.17, 95% CI 1.02-1.19). In age group II, the mean was 0.90 in the right ear (SD 0.13, 95% CI 0.84-0.97) and 1.06 (SD 0.17, 95% CI 0.98-1.14) in the left ear. No statistically significant differences were found between the 5-to-10-year and the 11-to-17-year age groups, either for the right ($t=0.958$, $p=0.344$) or left ear ($t=0.842$, $p=0.405$).

Asymmetry analysis was conducted for each participant with Jongkees, Maas, and Philipszoon's formula to compare the results between the age groups. In age group I, the mean asymmetry was 9.51% (SD 8.22, 95% CI 5.55-13.47%), whereas in age group II the mean was 8.73% (SD 7.11, 95% CI 5.40-12.06%). No statistically significant differences were found in this analysis ($t=0.319$, $p=0.751$).

Considering the likely presence of motion sickness in the population studied, they were asked: "Do you have motion sickness when you ride in a car or bus?". Hence, those who had motion sickness in such situations were compared with those who did not (see Table 2). The motion sickness group had 14 subjects, and the non-motion sickness group had 25 subjects.

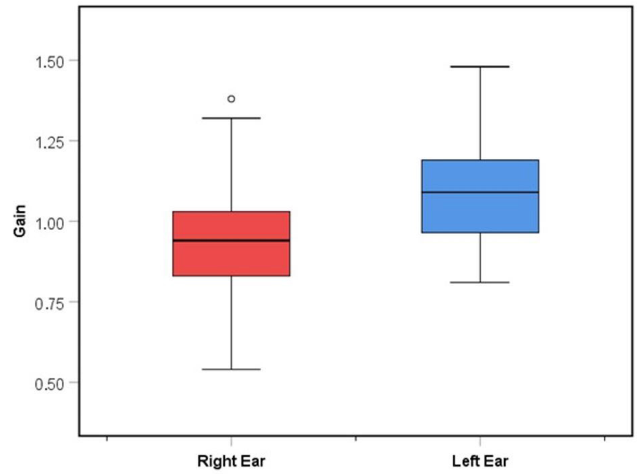

Figure 1. Horizontal vestibulo-ocular reflex gain in the right and left ear in 5- to 17-year-old children. A significant difference was verified between the ears ($t=-3.755$, $p=0.000$, $d=0.854$)

Table 1. Descriptive statistics of the vestibulo-ocular reflex gain in the horizontal plane per ear in both age groups. No statistically significant differences were identified in either ear

	Group	Shapiro-Wilk	Mean	SD	Min.	Max.	t-test
RE	I	p=0.547	0.96	0.21	0.54	1.38	p=0.344
	II	p=0.387	0.90	0.13	0.67	1.12	
LE	I	p=0.842	1.11	0.17	0.83	1.48	p=0.405
	II	p=0.350	1.06	0.18	0.81	1.43	

Caption: RE = right ear; LE = left ear; Group I = 5-to-10-year age group; Group II = 11-to-17-year age group; SD = standard deviation; Min. = minimum value obtained; Max. = maximum value obtained

Table 2. Descriptive statistics of the vestibulo-ocular reflex gain in the horizontal plane per ear in the groups with and without motion sickness. No statistically significant differences were identified in either ear

	Group	Shapiro-Wilk	Mean	SD	Min.	Max.	t-test
RE	With MS	p=0.965	0.91	0.21	0.54	1.38	p=0.672
	Without MS	p=0.424	0.94	0.15	0.67	1.32	
LE	With MS	p=0.145	1.06	0.20	0.83	1.48	p=0.607
	Without MS	p=0.287	1.09	0.16	0.81	1.36	

Caption: RE = right ear; LE = left ear; MS = motion sickness; SD = standard deviation; Min. = minimum value obtained; Max. = maximum value obtained

Table 3. Descriptive statistics of the vestibulo-ocular reflex gain in the horizontal plane per ear in the groups with and without vision problems. No statistically significant differences were identified in either ear

	Group	Shapiro-Wilk	Mean	SD	Min.	Max.	t-test
RE	With VP	p=0.988	0.93	0.23	0.54	1.38	p=0.925
	Without VP	p=0.398	0.93	0.15	0.67	1.32	
LE	With VP	p=0.148	1.08	0.23	0.84	1.48	p=0.985
	Without VP	p=0.465	1.08	0.15	0.81	1.36	

Caption: RE = right ear; LE = left ear; VP = vision problems; SD = standard deviation; Min. = minimum value obtained; Max. = maximum value obtained

The participants with motion sickness had a mean of 0.91 in the right ear (SD 0.21, 95% CI 0.79-1.04) and 1.06 in the left ear (SD 0.20, 95% CI 0.94-1.18). As for the non-motion sickness group, the mean in the right ear was 0.94 (SD 0.15, 95% CI 0.87-1.01) and in the left ear, 1.09 (SD 0.16, 95% CI 1.03-1.16). There were no statistically significant differences between the groups with and without motion sickness in either the right or left ears (respectively, t=-0.426, p=0.672, and t=-0.518 p=0.607).

According to data collected in the anamnesis, 11 participants had vision problems, while 28 did not. Considering its frequency, these two groups were compared (see Table 3). The group with vision problems had a mean of 0.93 in the right ear (SD 0.23, 95% CI 0.76-1.09) and 1.08 in the left ear (SD 0.23, 95% CI 0.93-1.24). As for those without vision problems, the mean in the right ear was 0.93 (SD 0.15, 95% CI 0.87-0.99) and in the left ear, 1.08 (SD 0.15, 95% CI 1.02-1.15). No statistically significant differences were found between the groups per ear (right ear: t=-0.095, p=0.925, and left ear: t=-0.018, p=0.985).

DISCUSSION

Few vestibular studies have been conducted in children in comparison with those in adults. This can be related to difficulties both in obtaining a detailed clinical history from the patient and applying certain tests, which are not well-tolerated. Only international studies approaching vHIT assessment in this population were found.

Comparing with the procedure normally conducted in adults, there were some difficulties in assessing this population – although such difficulties were heterogeneous within the encompassed age range, diminishing as the children were older. The difficulties included following instructions, having a short attention span, not recognizing or confusing the right and left sides to calibrate the eye movements, adjusting the head strap to the limit on smaller heads, and little tolerance of the vHIT glasses. One of the main objectives of developing an assessment protocol was to diminish these and other difficulties that may take place when evaluating children. It was also intended for clinicians to have various recommendations available regarding each step of the assessment (Annex 1).

Concerning horizontal VOR gain in children, a study conducted in Spain by Melgarejo-Moreno et al.[17] in 5- to 12-year-old children found a mean gain of 0.91 (SD=0.08) in the right ear and 0.90 (SD=0.09) in the left ear, with no statistically significant difference between the ears. Bachmann et al. [18] found a mean 0.96 (SD=0.09) for horizontal right SCC and 1.04 (SD=0.09) for horizontal left SCC in 4- to 12-year-old children. Furthermore, they found no statistically significant difference between the 4-to-6, 7-to-9, and 10-to-12-year-old age groups, which are also comparable to the results found in adults. In Iran, a study with 6- to 12-year-old children aiming to establish VOR normative data found a mean VOR gain of 0.99 (SD=0.05) in the right ear and 1.00 (SD=0.04) in the left ear[19].

The values found in the present study – mean gain of 0.93 in the right ear and 1.08 in the left ear – were similar to those of the said studies, except that we found statistically significant differences between the ears. A study conducted by McGarvie et al.[20] reported the same interaural finding in subjects without vestibular changes. This was attributed to the camera, hypothesizing that placing it in front of the right eye would generate more gain in the impulses made to that side. On the other hand, in the present study, the camera was likewise placed on the right side, but the greatest gains were obtained for the left side. This phenomenon should be further investigated with additional variables, such as the brand of the equipment used.

A commonly used clinical datum, related to the previous one, is vestibular asymmetry. The study conducted in Chile by Gómez et al.[21] with 18- to 25-year-old subjects described this value with a 10% mean (SD=7.45). This agrees with what was evidenced in the present study, as the first age group had a mean of 9.5% (SD=8.22), and the second one had a mean of 8.7% (SD=7.11).

Considering that 36% of the sample had motion sickness, it was also compared with those who did not have it. The study conducted by Neupane et al.[22] compared subjects with and without motion sickness in an adult population, reporting in the first group a mean of 0.98 in the left ear and 1.02 in the right ear. As for the gains in the group without motion sickness, they reported a mean of 0.97 in the left ear and 1.02 in the right ear, with no significant differences between the two groups. In the present investigation, the mean in the left ear was 1.06 and in the right ear, 0.91, while the subjects without motion sickness had a gain of 1.09 in the left ear and 0.94 in the right ear. Therefore, even though Neupane et al. [22] investigated adults, whereas the present study approached the child and youth population, the gain values are similar in subjects with and without motion sickness.

Regarding subjects with and without vision problems, a study carried out in the United States with 18- to 80-year-old subjects found no statistically significant differences in the VOR gain obtained with vHIT. Hence, they suggest that no corrective measures are necessary when performing the test[23]. These reports agree with the values found in the present investigation, in that there are no statistically significant differences in subjects with vision changes. Future studies can analyze it more in-depth considering the type and degree of the vision problems.

CONCLUSION

The values obtained with vHIT in children are similar to those reported in the international literature, which are close to 1. Also, no statistically significant differences were found between the different age groups in the child and youth population. The v-HIT is a quick, simple, noninvasive examination that helps diagnose vestibular changes in a population oftentimes difficult to evaluate. The protocol proposed, with some steps and considerations, can guide beginning professionals in the otoneurological evaluation of children.

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Author contributions

SRR participated in conceptualizing the study, analyzing and interpreting the results, and writing the manuscript; POD participated in conceptualizing the study and writing the manuscript; AMF participated in analyzing and interpreting the results, and writing the manuscript; CGM, MRE, VSA, and JTR participated in collecting data and writing the manuscript.

Annex 1. Assessment protocol of vHIT in pediatric population

STEP	PROCEDURE	RECOMMENDATIONS
Explaining the purpose of the evaluation.	· Explain the purpose of the evaluation to the parents/ guardians and the patient.	Explain with simple words – e.g., "The reflex enables us to gaze steadily at a given point when our head moves".
	· Explain roughly and in simple words the vestibulo-ocular reflex and its function.	
Building rapport with the patient.	· Talk and interact with the patient to develop greater confidence and ease before beginning the test.	Ask simple questions, such as the patient's name, what they enjoy doing, and so forth, and then explain in simple words, as if it were a game, the procedures and elements that will be used.
	· Show the parts of the equipment and explain in simple words how they work.	
Choosing a target point.	· Show the patient a variety of stickers. Ask them to choose the one they like the most, which will be used as the target point.	Set apart at least 6 different stickers (1 for each canal) and switch them to ensure maximum attention throughout the test.
Placing the seat.	· The seat must be placed 1 meter away from the wall where the target point will be.	Indicate on the floor the exact position of the seat as a reference, so it can be put back in place in case the patient moves it.
	· The seat must be appropriate to the patient's stature. It must be steady and comfortable.	Provide different types of seats (e.g., for preschoolers).
Instructing the patient about the examination	· Using simple words, instruct the patient to gaze at the target point, regardless of the head movements.	"I'm putting these special glasses on you and you have to keep your eyes on the sticker you picked out. I'm going to move your head, but you must look only at the sticker. Pay close attention so you won't miss it!"
Giving a practical example	· Make some training impulses to ensure the patient understood the instructions. If there are any difficulties, go back to the previous step.	Use friendly language and short sentences, such as: "Let's try it once to check if you understood how it works".
		Some head impulse techniques in the horizontal plane (with outstretched arms):
		· Thumbs on the posterior part of the head and the index and middle fingers on the zygomatic bone.
		· Fingers and hands on the superior part of the head.
Adjusting the glasses	· Verify that the glasses are properly adjusted. Put the glasses in front of the eyes first. Then, pass the head strap over the head and make sure it is well-adjusted.	Inform: "We're going to use the glasses I told you about, the ones with a camera. They're a little tight, but it won't take long. You're not supposed to touch them. If you need, call me and I take them off". To verify the proper fit of the lenses, trying to pass the little finger between the head and the tape, it should pass with difficulty.
		If they do not tolerate the glasses, loose the head strap, rest, and adjust them again.
Calibrating	· Verify whether they can tell their right from their left. If they cannot, the examiner should point the direction they are supposed to look at.	Tell the patient while holding their head: "See these red spots? I'm going to tell you which one you must look at, whether the one at the top, the bottom, on the right or the left (showing them each one). Move only your eyes, not the head".
	· Steady the head with the hands.	If they cannot tell their right from their left, point them out: "I'm showing you with my finger what spot you must look at. Move only your eyes, not the head".
Carrying out the examination	· Help the patient be as attentive as possible throughout the examination, keeping up a conversation and giving positive feedbacks.	Be patients and rest for a few seconds in between impulses. The frequency depends on the patients' tolerance.
	· Take breaks often for the patient to rest and blink and to give positive reinforcements.	Constantly restate the instructions.
		Pay attention to the screen and make the impulses only when the patient is not blinking.
Explaining the results	· Invite the parent/guardian and the patient to look at the screen and explain to them the results of the examination.	It is important to use simple words, indicating in the graph what corresponds to the eye movement and the head movement.