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Original article

The skull vibration-induced nystagmus test: A useful vestibular screening test in children with hearing loss

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Skull-Vibration-Induced-Nystagmus Test (SVINT), a non-invasive first line examination test, stimulates both otolith and canal structures and shows instantaneously a vestibular asymmetry. This study aimed to analyze the SVINT results observed in children with hearing loss (HL) amplified with hearing aids (HA) or unilateral cochlear implant (uCI) and healthy children.
Material and methods: This case-control study compared the results of SVINT, caloric test (CaT) and video head-impulse-test (VHIT) in 120 controls to 30 children with HA and 30 with uCI, aged 5-18 years old. SVINT was recorded with videonystagmography after very high frequency (VHF) stimulation of mastoids and vertex.
Results: SVINT results were non-pathological in 98% of the control group but modified in the HL group (*P*-value = 0.04). In uCI participants, 13.3% had a bilateral weakness (BW) and 16.7% had a unilateral weakness (UW). In the HA group, 26.7% had BW, 10% had UW. SVINT was efficient to show a UW (6 out of 7 confirmed cases) but not efficient to show BW (1/12 confirmed cases).
Conclusion: SVINT can detect unilateral vestibular deficit in the VHF with a sensitivity of 86% and specificity of 96%. The positive predictive value is 75% and negative predictive value is 98%. In the case of bilateral deficit, the SVINT is inoperant. In amplified participants, a UW was equally detected whether using SVINT, CaT or VHIT. SVINT is a well-tolerated and useful test to screen vestibular asymmetry in children with HL when combined with other vestibular tests and shows its complementary at very high frequencies.

1. Introduction

Clinicians interested in diagnosing peripheral and central vestibular pathologies typically use one or more available vestibular tests (e.g., videonystagmography (VNG), vestibular-evoked myogenic potentials (VEMP), and video head-impulse test (VHIT)). Each structure of the vestibular system can be tested by different devices and techniques at different frequencies of stimulation.

The caloric test (CaT) assesses at low frequencies (LF) the vestibulo-ocular reflex (VOR) of the horizontal canal function by irrigating cold and warm water or air in the external ear canal. As part of the VNG test battery, it diagnoses possible damage to the superior vestibular nerve or lateral semicircular canal by identifying bilateral vestibular lesion (BVL) or unilateral peripheral vestibular lesion (UVL) [1]. CaT has been considered as the gold standard because it analyzes separately the degree of responsiveness of each ear at frequencies around 0.003 Hz [1]. The VEMP tests evaluate the utricle and saccule vestibular functions and explore the otolith organs. Myogenic potentials from the ocular or sternocleidomastoid muscles are recorded in response to air-conducted stimulations (AC) or bone-conducted vibration (BCV); hence providing information about the functionality of the otoliths and afferent system [2]. The VHIT is a recent technology that uses a high-speed digital video camera mounted on a goggle to measure the velocity of the eyes and records abnormalities in patients with a VOR dysfunction. It also provides information regarding the vestibular function of all 6 semi-circular canals (SCC) at high frequencies (HF) of 4 -7 Hz [3].

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Unfortunately, these procedures are cumbersome in young children, limited in cases of tympanic membrane perforation (CaT) or conductive hearing loss (VEMP), costly, time-consuming, and often not well-tolerated by young patients [4].

Recently, the Skull Vibration-Induced Nystagmus Test (SVINT) has retained attention because of its simplicity and efficiency: it was described as a "vestibular Weber test" [5]. SVINT, a non-invasive test, stimulates both otoliths and SCC [6]. Physicians have used it to screen a vestibular asymmetry and uncover a vestibular dysfunction. At the consensus meeting of the International Otoneurological Society (*Société Internationale d'Otoneurologie-SIO*) in Briançon, France, in 2006, SVINT was described as a test using BCV at 60 or 100 Hz applied to the skull (two mastoids and vertex) during a short period (5-10 seconds) [7]. In UVL patients, eye movements recordings revealed a nystagmus induced by vibration (SVIN) with a quick phase usually beating away from the affected side [5]. No nystagmus is typically observed in healthy subjects. The test has been used in adults and children with hearing loss and vestibular dysfunction [8], however normative data are not available in children. Literature has shown that children respond differently to vestibular tests when compared to adults (i.e. CaT), possibly due to maturation and plasticity of the central nervous system [9].

The first aim of this study is to measure the sensitivity and specificity of SVINT test through a comparison of cases (children with hearing loss) to control (healthy children) which has not been performed so far to our knowledge. Second aim was to study the possible modifications of vestibular tests exploring different vestibular frequencies in children amplified with hearing aids (HA) or unilateral cochlear implant (uCI). Third aim was to discuss the usefulness of this non-intrusive, simple, robust, rapid test and its capability to evaluate a possible vestibular asymmetry and help the surgeon to take a decision when determining the ear to implant in case of preoperative symmetrical hearing loss, or to evaluate a possible vestibular damage after unilateral cochlear implantation before proposing a contralateral surgery.

2. Material and methods

This case-control study was conducted over a period of 24 months after approval from the Institutional Review Board at the American University of Beirut, Lebanon (OTO.KA.05 and 07). All tests were performed in the Audiology and Balance Center at the American University of Beirut Medical Center (AUBMC) and were performed by the same examiner (SS). Written consents were obtained from the parents/guardians and children, respectively.

2.1. Participants

Two groups were included in this case-control study: a control group of 120 healthy children and 60 children with hearing loss (HL) and amplified (30 with HA and 30 with a uCI). All children were between 5-17 years old and the average age of hearing children was 11.33 ± 3.57 years, children with hearing aid 12.23 ± 3.58 years and children with cochlear implants 9.17 ± 3.01 years. Table 1 summarizes the subjects' descriptives. The first control group was constituted of normal hearing children (threshold lower than 15 dB) with normal middle ear function (normal tympanometry and ipsilateral and contralateral acoustic reflexes responses). In addition, the children did not have any history of otological (recurrent otitis), otoneurological (dizziness) or neurological complaints, nor any speech, language or mental delays. Children with ocular or ophthalmological pathology were not included in the study. Similarly, children with abnormal oculomotor results, abnormal caloric responses or spontaneous nystagmus were excluded. The second group, constituted by children with amplifications, had a hearing level between moderate-severe (56-70 dB) and severe (71-90 dB) hearing loss. The group of unilaterally implanted children (uCI) was the only group with a profound hearing loss (> 90 dB). Children with other syndromic pathologies, neurological or mental maturation delays (retardation) were excluded from the study.

2.2. Material and procedure

Both the control and cases group underwent a partial VNG and VHIT. The eye movements were recorded using VNG Ulmer device (Synapsys, Marseille, France). The child was seated on his/her parent's lap or by him/herself. The goggles, equipped with an infrared camera, was placed on his/her eyes. First, calibration was performed, followed by saccades test (without moving the head, the child follows a white square that appears randomly on the screen) and smooth pursuit test (the child fixates with his/her eyes, a target moving in a regular sinusoidal movement from left to right). Next, the gaze test explores the gaze right, left, up, and downwards for 30 seconds in each direction, and checks for possible nystagmus. To perform the SVINT, the examiner started by applying the vibrator VVIB 100 (Synapsys, Marseille, France) on the child's hand for a few seconds (to ensure the child the test is harmless). Then the child was asked to maintain his/her head straight, keep his/her eyes open (midline gaze) and avoid blinking during the test [5]. Next, the vibrator is applied firmly and perpendicularly on 3 positions successively: on the vertex, the right and the left mastoid processes at the level of the external auditory canal. Application on the tip of the mastoids should be avoided, in order not to stimulate cervical muscles [5,7,10]. Dumas et al. have suggested a stimulation during 5 to 10 seconds on each location, using 100 Hz which stimulates all the labyrinthine structures and produces optimal responses [6,10]. This has been also recommended by Zamora et al. [11]. However, in children (considering the numerous blinking events) a larger window of analysis of 20 seconds have been preferred to ensure more accurate analysis and observe more cleanly (or easily) the occurrence of a possible SVIN. Results were then categorized (normal or abnormal) based on the criteria mentioned in Fig. 1.

Next, the nystagmus Slow-Phase Velocity (SPV) was analyzed. In most of the kids aged 5-8 years old, SPV was calculated using a manual selection of 10-15 beats. An SPV higher than 2 degrees per second was considered significant. In the case of spontaneous nystagmus, a minimum of 50% enhancement of SPV is required to be considered abnormal [7]. A positive SVINT result was defined when horizontal/rotary nystagmus was observed (more than 10 beats and SPV $> 2^\circ$/s) in two or more locations, beating toward the same direction and reproducible in at least 2 locations (Criteria in Fig. 1). The child was also asked how uncomfortable was the SVINT (not at all, mildly, moderately, severe and cannot tolerate).

Next, caloric testing was performed following the British Society of Audiology's recommendation [1]. The test was performed by irrigating for 60 seconds cool air in the ears of normal children (24 °C), and in case of asymmetry the child was excluded. For children with HL, warm and cool air (24-50 °C) was irrigated in the ears. Meanwhile, a mental task was given to the child to ensure a maximum intensity and regularity of the nystagmus response. An interval of 5 minutes was given between two irrigations allowing the child to rest and insuring the absence of influence on the following contra lateral caloric test. The results of the CaT were analyzed in the categorical format: a UW was defined for a caloric asymmetric hypofunction > 15% and a BW for a total bilateral reflectivity < 12°/s (Fig. 1).

Finally, the child underwent a VHIT. This objective test measures the VOR gain across various head velocities [3,12]. ICS Impulse (GN Otometrics, Denmark) goggles were tightly placed on the child's head with the camera on the right eye. The subject was instructed

Table 1
Descriptive demographics of the groups of children by age, gender and hearing status.

	Children with normal hearing (control)			Children with hearing loss (cases)					
				With HA			With uCI		
	Female	Male	Total	Female(HA)	Male(HA)	Total	Female(uCI)	Male(uCI)	Total
5- 8 years	15	15	30	2	3	5	7	6	13
9-11 years	15	15	30	4	1	5	5	5	10
12-14 years	15	15	30	5	5	10	3	2	5
15-17 years	15	15	30	5	5	10	1	1	2
Total	60	60	120	16	14	30	16	14	60

HA: hearing aids, uCI: unilateral cochlear implant.

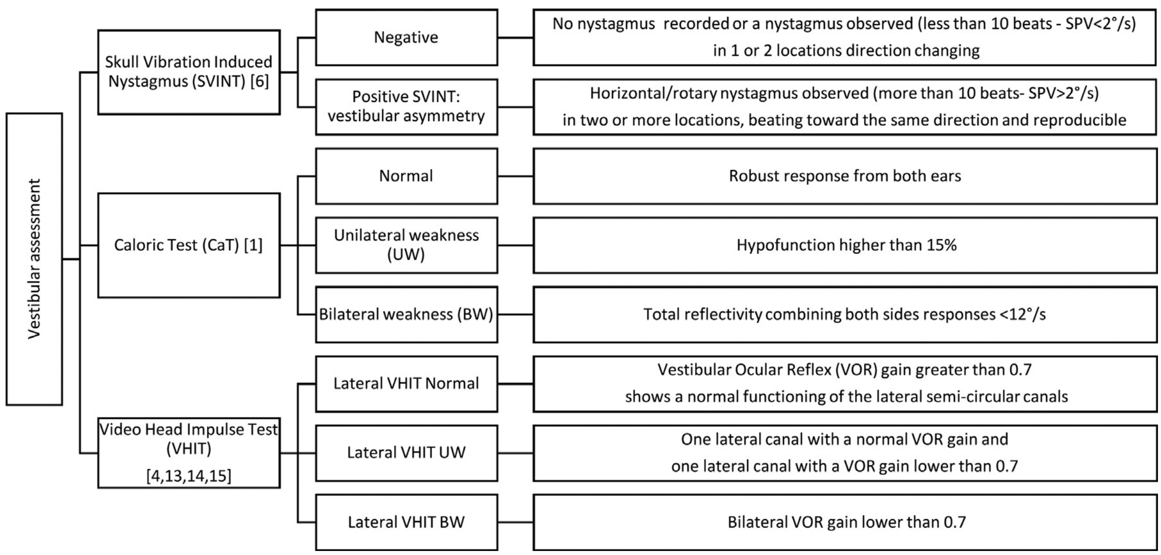

Fig. 1. Vestibular assessment normal criteria.

to fixate his/her eyes on a stationary dot located approximately 1.2 meters in front of the participant [13] while sitting on a regular chair. During the test, the examiner moved the subject's head at high velocity (range recommended by manufacturer 100-250°/s) in the horizontal plane to activate the lateral canals and the VOR [12]. A calibration before testing and a minimum of 10 head impulses were performed, as per the manufacturer's recommendation [13]. Results were then segregated as per Fig. 1.

Computerized dynamic posturography test and oculomotor tests were also performed for other case-control papers.

2.3. Statistics

The results of the SVINT, CaT and lateral VHIT (L-VHIT) were transformed to categorical data (Fig. 1). Weakness was also categorized as low frequency (when CaT showed weakness), high frequency (when L-VHIT showed weakness) and very high frequency (when SVINT showed weakness). Chi^2 tests (X2) and Fisher exact test (F) were used to compare results across groups. The level of significance was set at $P < 0.05$. For data analysis, the Software Statistical Package for Social Sciences (SPSS) version 25.0 was used.

To calculate the characteristic of the test the formulas reported below were used:

- sensitivity = True positive or TP/(TP + False negative or FN);
- specificity = True negative or TN/(TN + False positive or FP);
- positive predictive value (PPV) = TP/(TP + FP);
- negative predictive value (NPV) = TN/(TN + FN).

3. Results

3.1. Participants

As per the study design, the control group required children with normal CaT and VHIT results. As for the 60 children with HL, CaT responses were similar across age group and were not affected by gender. The type of amplification (uCI or HA) showed no statistical difference in the caloric result. Ten children or 16.66% showed a bilateral weakness (BW) 10% had a unilateral weakness (UW) ($n = 6$) and 73.33% ($n = 44$) had normal caloric responses. A tendency for decreased responses during a caloric test in the implanted ear was noted but was not statistically significant (P-value = 0.08). Some L-VHIT results from children under the age of 6 years were excluded from the study because of the slippage of the goggles on the children's heads which could induce possible false positive [13,15]. Hence, only the data from 58 children with hearing loss were analyzed. Sixteen children (27.5%) with hearing loss showed abnormal L-VHIT gain. Out of these 16 children, 8 had BW and 8 had UW. Although their L-VHIT was abnormal, 3 participants (1 UW and 2 BW) had a completely normal CaT. This correlation is statistically significant (F = 30.62, P-value = 0.000). Conversely, 3 children with a hypofunction at the calorics had limit normal value at the L-VHIT gain (gain = 0.7).

3.2. SVINT: Cases-Control

All participants were able to perform the SVINT test, the majority of the healthy children found the SVINT not disturbing at all ($n = 89$, 74%), mildly disturbing was found by the rest.

In normal children, clinically significant nystagmus was recorded in only 2.50% of the cases ($n=3$), a negative SVINT result was observed in the rest (97.50%) in accordance with the criteria defined in Fig. 1 ($n=94$ no nystagmus and $n=23$ had non-clinically significant nystagmus).

In comparison children with HL, SVINT results were different from the results in normal hearing children ($F=9.219$, P-value = 0.042). Table 2 represents these data. Eight children (13.33%) with HL had a positive test and the rest of the children had a normal SVINT. (86.77%, $n=42$). There was no significant difference in the distribution of positive SVINT upon age group and gender (P-value > 0.05).

A significant statistical association between the CaT results and SVINT results was found ($F=17.71$, P-value= 0.00). Eighty-three percent of the cases of UW in CaT had a positive SVINT test and 90% of the children with BW had a normal SVINT but one presented a positive test (UW at VHF). The results of L-VHIT and SVINT were inadequate agreement as well ($F=16.29$, P-value = 0.01). Forty-four percent of children with abnormal L-VHIT results had nystagmus recorded during SVINT and only one child had a normal VHIT and abnormal SVINT.

Among the 5 participants with uCI and positive SVINT, 3 had UW (all 3 tests show UW at LF, HF, and VHF), 1 had a BW (this case underlines CaT and L-VHIT results indicative of BW at LF and HF and differ from SVINT results which show a difference between both sides at VHF) and 1 had all other tests normal. This last patient result confirms that SVINT not only explores the horizontal semicircular canal but also the utricle at VHF. Two out of the three HA participants with positive SVINT had a UW finding across frequencies and 1 participant had UW confirmed by L-VHIT as well but a normal calorics suggesting a UW at only VHF.

The distribution of weakness type (i.e. BW, UW) and frequency (LF, HF, VHF) was the same across subgroups of cases (respectively $f=1.90$, $P=0.43$, $f=6.80$, $P=0.65$). Overall, seventy percent of children with uCI ($n=21$) had normal results, 13.33% had bilateral weakness and 16.64% had UW, in comparison to 63.33% of HA children had no vestibular findings, 26.67% had BW and 10% had UW (Table 3). In our population of uCI and HA combined, 10% of the children with hearing loss presented a global (across the frequency) unilateral vestibular deficit and 3% a high frequency unilateral vestibular deficit, 11.66% had a global bilateral deficit, and 8.33% a selective bilateral deficit (low 5% and 3.33% high frequencies).

Computation regarding the characteristics of the SVINT showed a sensitivity of 86% and a specificity of 96%. The positive predictive value is 75% and negative predictive value is 98%. In case of bilateral deficit, the SVINT is inoperant (Table 4) if the deafferentation is total bilateral symmetrical and concerns also very high frequencies.

4. Discussion

Results in control vs. cases provided evidence to confirm that SVINT can be trustworthy and useful as a vestibular screening test in children to show a vestibular asymmetry. Moreover, SVINT was positive for UW in 16% of uCI cases and 10% in HA cases; these percentages were similar to those obtained with CaT and VHIT to reveal a unilateral vestibular loss or hypofunction. This correlation allows to further discuss the possibility of using SVINT as a screening tool to reveal UVL.

4.1. SVINT: a vestibular screening test in children

Children with unilateral or bilateral sensorineural hearing loss have an increased risk for vestibular disorders and the risk increases with the degree of hearing loss [16–18]. This fact is attributed to the anatomical vicinity and the phylogenetical relation between cochlea and vestibule. Vestibular dysfunction is mentioned in the literature at a range between 30% to 70% of children with hearing impairment [17]. Tribukait et al. found that out of the 33 deaf children tested, 45% of the results were completely normal, 30% had bilateral hypo or areflexia, and 24% had a caloric asymmetry [18]. In our study in children with HL, 20% had a BW diagnosed by CaT and VHIT and 13.3% had UW confirmed by CaT and/or VHIT and SVINT. SVINT is a rapid, first line examination test that can be included as part of a vestibular screening performed by physicians in children with higher risk of vestibular dysfunction. It is simple and fast, well tolerated and easy to perform in both paediatric and adult population with a UVL [8].

When a 100 Hz BCV is applied to the cranium, this activates both otolith receptors (mainly the utricle) and the canal neurons of the SCC of each labyrinth on both sides [19]. In normal subjects, the stimulations of the 6 SCC cancel each other similarly to what happens in a simultaneous bilateral caloric stimulation. In UVL patients it has been speculated that for the vertical SVIN component the ipsilateral anterior and posterior canal inputs cancel each other, leaving the sole contra-lateral horizontal canal activation (unopposed by the other side) provoke an SVIN horizontal component. The cancellation does not occur in individuals with UW since the response issuing from the healthy receptor is stronger and unopposed generating a primarily horizontal unidirectional nystagmus [6]. It is usually negative, and no nystagmus is observed in subjects with no vestibular disorders or bilateral symmetrical lesions. In the adult, false positive results (patients with no clinically relevant nystagmus following criteria of Fig. 1) have been reported in 10% of cases when mastoids are vibrated at 60 Hz [6]. In our population of normal children (aged from 5 to 18 years old) with no history of otological or vestibular complaints reported, 19% had nystagmus of no clinical significance.

SVINT sensitivity (86%) and specificity (98%) were compared to the gold standards CaT and VHIT. A positive SVINT is highly correlated with a caloric unilateral hypofunction [20], although it can reveal peripheral vestibular asymmetry for higher frequencies than the CaT [6]. It acts as a vestibular Weber Test [6] and is less unpleasant and less time consuming in children than calorics [4]. The association VHIT and SVINT was more significant than CaT (probably due to the fact that these 2 tests explore higher frequencies than CaT). But VHIT is a relatively more expensive (and possibly more invasive) for most clinicians and there is still controversy about specificity and sensitivity of this test [20]. The comparison between the different vestibular tests, confirms that SVINT can detect a vestibular asymmetry and completes the battery of common vestibular tests in the multifrequency analysis of the vestibular system [6,11].

SVINT is a simple test in its setting and performance, it does not require expensive material: a 100 Hz vibrator and Frenzel goggles or infrared goggles are sufficient to reveal a vestibular asymmetry. It is better tolerated by children than CaT which requires water/air infusion in the child's ear and order them to keep their eyes open while they experience vertigo. SVINT is easy to perform and has no restraints due to calibration or quick head movements. This test requires a minimal collaboration of the child because of its short duration (1 minute) and can be easily repeated without habituation [6].

4.2. Vestibular impairment and cochlear implants

Researches have shown that cochlear implant surgery will not only improve sound detection and auditory perception skills but also the quality of life [21]. However, some authors have demonstrated that this improvement may cause imbalance and induce vestibular deficit [25]. During cochlear implantation, electrode insertion into the inner ear may produce possible permanent dam-

Table 2
Skull vibration-induced nystagmus test (SVINT) results in cases and controls.

SVINT results	Cases (uCI)		Cases (HA)		Total Cases (uCI + HA)		Control (normal)	
	n	%	*n*	%	*n*	%	*n*	%
Positive SVINT	5	16.70%	3	10.00%	8	13.33%	3	2.50%
Negative SVINT	25	83.30%	27	90.00%	52	86.67%	117	97.50%
Total	30	100%	30	100%	60	100%	120	100%

uCI: unilateral cochlear implant, HA: hearing aids.

Table 3
Vestibular results of skull vibration-induced nystagmus test (SVINT), caloric test (CaT) and lateral video head impulse test (L-VHIT) in children with unilateral cochlear implant (uCI) and hearing aids (HA). The frequency of the test exploring the vestibular weakness is indicated as follows (LF= low frequency, HF= high frequency and VHF= very high frequency).

		Cases (uCI)		Cases (HA)		Total	
		n	%	*n*	%	*n*	%
Bilateral weakness	CaT only (LF)	1	3.33	2	6.67	12	20.00
	L-VHIT only (HF)	0	0.00	2	6.67		
	CaT + L-VHIT (LF + HF)	2	6.67	4	13.33		
	CaT + L-VHIT + SVINT (LF + HF + VHF)	1	3.33	0	0.00		
	TOTAL	4	13.3	8	26.7		
Unilateral weakness	SVINT only (VHF)	1	3.33	0	0.00	8	13.33
	CaT + L-VHIT (LF + HF)	1	3.33	0	0.00		
	L-VHIT + SVINT (HF + VHF)	0	0.00	1	3.33		
	CaT + L-VHIT + SVINT (LF + HF + VHF)	3	10.00	2	6.67		
	TOTAL	5	16.7	3	10		
Normal	All 3 tests	21	70.00	19	63.33	40	66.67
	TOTAL	30	100	30	100	60	100

Table 4
SVINT sensitivity, specificity and predictive values.

		Positive SVINT			Negative SVINT			Total
		uCI	HA	Total	uCI	HA	Total	
Positive cases (unilateral weakness)	L-VHIT	0	1	6	0	0	1	7
	CaT + L-VHIT	3	2		1	0		
Negative cases (normal + bilateral weakness)	CaT + L-VHIT (normal)	1	0	2	21	19	51	53
	CaT + L-VHIT (BW)	1	0		2	4		
	BW calorics only	0	0		1	2		
	BW LVHIT only	0	0		0	2		
Total		8			52			60

True Positive = 6; False Positive = 2; False negative = 1, True negative = 49. Sensitivity: 6/7 = 86%; Specificity: 51/53 = 96%. Positive predictive value = 6/8 = 75. 71%; Negative predictive value = 49/50 = 98%

age to the different sensory structures of the vestibule and lateral canal [22].

Jacot et al. found that in 224 tested children before receiving implants 50% had abnormal vestibular results (20% had complete bilateral areflexia and 22.5% unilateral hypoexcitability) [16]. Out of the 89 who underwent CI, 71% had changes in vestibular function and 10% acquired post-surgery ipsilateral areflexia [16]. Cushing et al. reported that 50% of their 32 CI patients had an abnormal caloric response among which 38% had a mild to moderate unilateral abnormalities [17]. Moreover, Licameli et al. investigated the prevalence and severity of vestibular impairment in children with CI through a cohort study by analyzing the results of the vestibular test in 42 patients pre and post-cochlear implantation. They reported vestibular impairment in 60% of patients with CI and concluded that there was a potential negative impact on vestibular function caused by CI, especially in children who received bilateral implantation [23]. Dagkiran et al. explored all 5-vestibular end-organs functions prior to CI and at postoperative day 3 and month 3 in 42 patients. They observed a significant impairment of vestibular function on the implanted side in 28.5% of the patients when comparing pre and postoperative results at day 3 and at postoperative month 3 [24]. Our results resemble those described in the literature, in the uCI group 16.7% of children had a positive SVINT (showing a hypofunction on the implanted side), 13.3% had a unilateral CaT and 18% a unilateral horizontal VHIT weakness. BW was observed in 13.3% of the children with uCI. Since pre-implant assessment was not performed, it is not possible to establish direct association of UW or BW induced by the surgical implantation.

The future of implants is oriented toward bilateral cochlear implantation, increasing the potential vestibular risk of dysfunction after the implant surgery. This concern needs to be checked by at least vestibular assessment pre and post-implantation. Posturography and VEMP are essential tests to provide overall information of the child vestibular system, however, SVINT and VHIT constitute quick and reliable evaluation tests to help the surgeon to take a decision between unilateral or bilateral implant. Fig. 2 represents a decision tree prior to implant or post first implant (modified from recommendations by Wiener-Vacher et al. [25]). It is important, as seen in our data, to test children for UW and BW at different frequencies.

In summary, all kids with Usher or meningitis even with a bilateral loss are to receive bilateral CI at once. The rest of the children will require to be tested by SVINT, head impulse test, CaT and VEMP. Accordingly, and following the status of the residual ves-

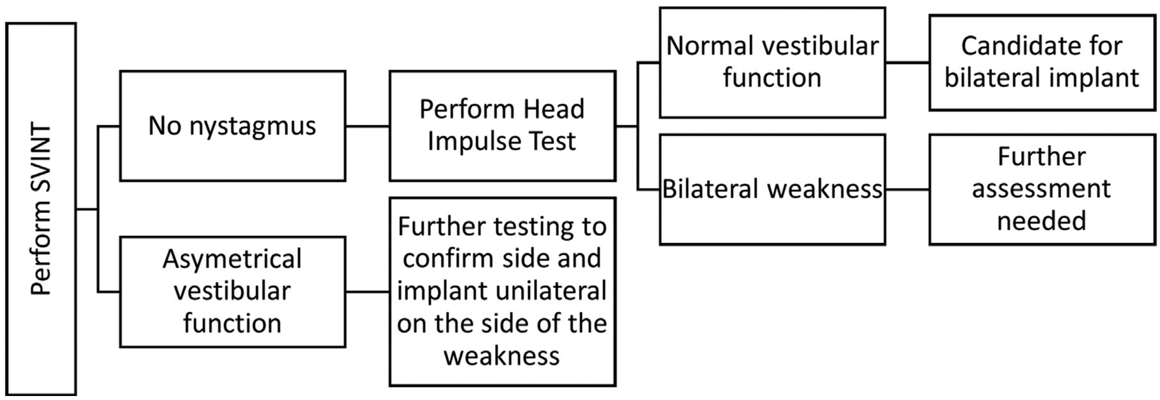

Fig. 2. Decision tree pre and post cochlear implant (recommendations by Wiener-Vacher et al. [25,26]), modified.

tibular function, the implant is to be placed on the side of the less functional vestibule. After first side implantation, the authors recommend a second vestibular evaluation: in case of no vestibular change, second implantation may be recommended on the other side. In the case of partial vestibular loss, it is wiser to discuss the benefit of the second implant and in case of complete unilateral vestibular loss, a second CI should not be scheduled (Fig. 2).

4.3. Challenges and future studies

In our current study, performing VHIT was very challenging in young children because of lack of cooperation, or failure of calibration, and inadequate goggles fit. Such challenges have already been reported [14], however, it is worth mentioning that other studies were able to test children as young as 3 months when a different setting/equipment with no goggle was used [26]. Moreover, this current paper is part of a larger project that collected normative data aiming to assess post-implant results via oculomotor testing and computerized dynamic posturography in addition to CaT, L-VHIT, and SVINT. The reason why these two tests were included is because the neuroimaging literature indicates that CI patients rely partly on visual cues [27] and that in normal children vestibular and oculomotor systems are functional but continue maturation until adolescence [28]. Finally, to better assess the specificity and sensitivity of SVINT pre-implant, it would be recommended that a larger case-control study comparing normal children to their peer candidate of implants between the age of 18-24 months with a larger battery test (CaT, VEMP, SVINT, all 3 planes of VHIT) be conducted. Such a study will not only explore the type and frequency of weakness but also establish a normative data of SVINT-SPV for even younger population.

5. Conclusion

The importance of early identification of hearing loss and intervention is well known for a better speech and language acquisition. Similarly, we should devote more time examining the integrity of the vestibular function. SVINT is a simple test which may allow early identification of vestibular asymmetry or dysfunction and a good indicator to start rehabilitation. This test is a robust, rapid not invasive test with a good specificity and is well tolerated in children. In uCI participants, it is as sensitive as CaT and VHIT to indicate a unilateral vestibular loss or asymmetry, post implant. It is less sensitive than CaT to show bilateral alterations. SVINT can alarm of a possible unilateral pretherapeutic vestibular lesion or of a post-surgical injury in uCI and suggests to the surgeon a more prudent attitude for the other side. It informs about a vestibular high-frequency unilateral hypo-function and may help the surgeon in his choice of first side implantation in bilaterally profound HL children. It is a useful tool when associated with other vestibular tests and complements them to explore very high frequencies.

Disclosure of interest

The authors declare that they have no competing interest.

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