Three Years of Vestibular Infant Screening in Infants With Sensorineural Hearing Loss

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abstract

OBJECTIVES: Although vestibular deficits are more prevalent in hearing-impaired children and can affect their development on many levels, a pediatric vestibular assessment is still uncommon in clinical practice. Since early detection may allow for timely intervention, this pioneer project has implemented a basic vestibular screening test for each six-month-old hearing-impaired infant in Flanders, Belgium. This study aims to report the vestibular screening results over a period of three years and to define the most important risk factors for abnormal vestibular screening results.

METHODS: Cervical Vestibular Evoked Myogenic Potentials with bone-conduction were used as a vestibular screening tool in all reference centers affiliated to the Universal Newborn Hearing Screening Program in Flanders. From June 2018 until June 2021, 254 infants (mean age: 7.4 months, standard deviation: 2.4 months) with sensorineural hearing loss were included.

RESULTS: Overall, abnormal vestibular screening results were found in 13.8% (35 of 254) of the infants. The most important group at risk for abnormal vestibular screening results were infants with unilateral or bilateral severe to profound sensorineural hearing loss (20.8%, 32 of 154) ($P < .001$, odds ratio = 9.16). Moreover, abnormal vestibular screening results were more prevalent in infants with hearing loss caused by meningitis (66.7%, 2 of 3), syndromes (28.6%, 8 of 28), congenital cytomegalovirus infection (20.0%, 8 of 40), and cochleovestibular anomalies (19.2%, 5 of 26).

CONCLUSIONS: The vestibular screening results in infants with sensorineural hearing loss indicate the highest risk for vestibular deficits in severe to profound hearing loss, and certain underlying etiologies of hearing loss, such as meningitis, syndromes, congenital cytomegalovirus, and cochleovestibular anomalies.

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WHAT'S KNOWN ON THIS SUBJECT Hearing-impaired children are at risk for vestibular deficits because of the close anatomical and embryological relationship between the auditory and vestibular systems. Although vestibular deficits can affect the child's development, pediatric vestibular assessment is not routinely implemented in clinical practice.

WHAT THIS STUDY ADDS The Vestibular Infants Screening – Flanders project was a pioneer to implement a vestibular screening for all hearing-impaired infants in Flanders, Belgium. This large-scale study reports results after three years of vestibular screening and identifies risk factors for abnormal screening results.

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In 1993, the National Institutes of Health[1] published a consensus statement recommending early identification of hearing impairment in infants. Subsequently, the Joint Committee on Infant Hearing initiated a Universal Newborn Hearing Screening Program (UNHSP), which allowed early detection (ie, within the first 2 months of life) and intervention (ie, before the age of 3 months) of infants with permanent hearing loss to maximize their linguistic competences, communicative skills, and literacy development.[2,3] In 1998, Flanders was a pioneer to implement this UNHSP by means of automated auditory brainstem responses (ABR), which was organized by the infant welfare agency of the Flemish government "Child and Family." This UNHSP has already proven its benefits, because an increasing number of children and adolescents with hearing aids or cochlear implants (CI) are enrolled in mainstream education.[4] Therefore, UNHSP can prevent hearing-impaired children to fall behind their hearing peers in language, cognition, and social-emotional development, which may improve the child's educational level and professional career in adulthood.[5]

The close anatomical and embryological relationship between the auditory and vestibular end organs suggests that the underlying etiology of hearing loss may also affect vestibular function.[6,7] Accordingly, a higher occurrence of vestibular deficits in children with sensorineural hearing loss in comparison with normal-hearing children was found in literature.[8] Similar to hearing loss, vestibular deficits can affect the child's development on many levels. Whereas a severe vestibular deficit can result in a reduced balance control and a delayed acquisition of gross motor milestones (eg, head control, independent sitting and walking) in young children,[6,9–17] this can also affect fine motor, writing, reading, and learning skills, as well as cognitive and socio-emotional development at a later age.[15,18–24] Nevertheless, a universal vestibular infant screening program does not exist and pediatric vestibular assessment in clinical practice often remains limited to specific groups such as CI-candidates or older children with vestibular complaints. In June 2018, 20 years after the start of the Flemish UNHSP, Flanders was the first region worldwide to implement a vestibular screening for all six-month-old infants with confirmed permanent hearing loss.[25,26] The Vestibular Infant Screening (VIS) – Flanders project selected cervical Vestibular Evoked Myogenic Potentials (cVEMP) as a vestibular screening tool, because it is a child-friendly, brief, and objective examination.[27,28] Moreover, it is feasible to introduce this test on a large scale since ABR devices generally also contain cVEMP modules. Several studies have also shown that the results of the cVEMP, which mainly assesses saccular function,[29–31] strongly correlate with the child's motor performance.[9,11,13] Similar to UNHSP, early vestibular screening will enable early detection of vestibular deficits, which can lead to prompt referral for motor assessment and therapy, if needed. However, it remains to be proven that early detection of vestibular deficits results in better functional outcomes.

The purpose of this paper is to report the results after 3 years of vestibular screening in Flanders, and to identify the most important risk factors for abnormal vestibular screening results in infants with sensorineural hearing loss.

METHODS

Participants

The vestibular screening was offered to all Flemish infants with permanent hearing loss around the age of 6 months in 1 of the 25 reference centers involved in the UNHSP. As the preliminary VIS-Flanders study showed normal screening results in infants with permanent conductive hearing loss, only infants with sensorineural hearing loss were included.[26] This multicenter crosssectional study was approved by the leading Ethical Committee of the Ghent University Hospital and the ethical committees of all participating centers (Belgian registration number: B670201835971, ClinicalTrials.gov registration number: NCT05061069). In accordance with the ethical standards of the Helsinki Declaration, written informed consents of parents were obtained.

Vestibular Screening Procedure

The vestibular screening protocol and its addition to the existing Flemish neonatal hearing screening protocol are reported by Martens et al.[25,26] The cVEMP test was performed with the commercial Neuro-Audio equipment (Neurosoft, version 2010, Ivanovo, Russia). Bone-conducted stimuli (RadioEar B71W, Middelfart, Denmark) (59 dB nHL, 129 dB FL) were presented at the ipsilateral mastoid. More details about the applied stimulus parameters, software algorithm, recording parameters, electrode configuration, and test setup can be consulted in Martens et al.[26] Electromyographic background activity was automatically quantified by the software (ie, accepted range of mean rectified voltage: 80–250 μV) and displayed on a screen.[26] At least 2 trials were recorded on each side to check waveform reproducibility. The averaged rectified interpeak amplitude was

calculated from the 2 trials with equivalent sternocleidomastoid muscle tension (ie, averaged electromyographic differences ≤30 μV). Only final screening results were used for further analyses. More specifically, if the child needed a retest (ie, within 3 months after the first screening, thus before the age of 10 months, prior to possible CI-surgery) to confirm the first screening results (eg, in case of inconclusive results, see Martens et al[26]), only the second screening results were included. Results were considered as normal if 2 reproducible biphasic P1-N1 waveforms were recorded with an averaged rectified interpeak amplitude ≥1.3 (ie, based on normative data of the Ghent University Hospital in 34 control subjects (mean age = 7.6 months; standard deviation [SD] = 1.5 months).[26] Abnormal screening results included inconclusive responses (ie, insufficient sternocleidomastoid muscle tension) during the retest, absent responses (ie, no reproducible waveforms), and decreased responses (ie, reproducible waveforms with an averaged rectified interpeak amplitude <1.3). Since presence and amplitude of cVEMP responses strongly correlate with the child's motor performance,[9,11] these criteria are clinically relevant to decide if referral for motor assessment is needed.

Possible Predisposing Factors for Abnormal Vestibular Screening Results

All centers collected results of transient evoked or distortion product otoacoustic emissions, high frequency tympanometry (1000 Hz), and click-evoked ABR. These results were used to determine possible predisposing factors for abnormal vestibular screening results (ie, further described as "risk factors"). The International Bureau of Audiophonology[32] criteria were considered to categorize the degree of hearing loss. Onset of hearing loss was grouped as congenital (ie, abnormal hearing screening after birth) or early-onset (ie, normal hearing screening after birth, but permanent hearing loss detected before 10 months of age as a cVEMP retest is advised before this age). Additionally, risk factors related to hearing loss etiology included congenital cytomegalovirus (cCMV)-status, results of *Connexin 26* (*Cx26* or *GJB2*, autosomal recessive deafness type 1 [DFNB1]) mutation analysis, and the presence of perinatal factors that are associated with an increased risk for hearing loss. Infants with sensorineural hearing loss were standardly tested for cCMV within 3 weeks after birth by performing virus isolation or polymerase chain reaction in urine or saliva, or after this period with polymerase chain reaction on neonatal dried blot spots (ie, Guthrie card). cCMV definitions were applied as described in the European Consensus Statement of 2017.[33] Perinatal factors were considered as present in case of prematurity (ie, gestational age < 36 weeks), low birth weight (ie, birth weight < 2500g),[34] or hospitalization longer than 5 days at a NICU. Other perinatal factors, such as hyperbilirubinemia and ototoxic medications, were not included as they are not provided by all centers. All aforementioned risk factors, including *Cx26*- and cCMV-status, were standardly known at the age of screening, whereas more advanced etiological work-up, such as imaging and genetic testing by means of next generation sequencing technology, was not always allowed by the parents or available at the moment of screening. Therefore, underlying etiology of hearing loss was reported descriptively to estimate the most important groups at risk for abnormal screening results.

Etiological work-up results were classified as genetic nonsyndromic; genetic syndromic; TORCHES infections (ie, toxoplasmosis, other infections such as syphilis, varicella-zoster, parvovirus B19, rubella, cytomegalovirus, and herpes); meningitis; cochleovestibular anomalies (ie, cochleovestibular nerve aplasia or inner ear malformations confirmed by MRI or CT that could not be classified into 1 of the first 4 categories); or an unknown etiology.

Statistical Analysis

Statistical analysis was completed with SPSS software (IBM, version 27.0, Armonk, NY). On subject level, abnormal screening results indicated abnormal responses in at least 1 ear, and the degree of hearing loss was categorized according to the worst ear in case of bilateral hearing loss. The two-tailed Fisher's Exact test was used to evaluate the association between screening results and possible predisposing factors. On ear level, data were analyzed more in-depth by means of generalized estimating equations, which takes the clustered data structure (ie, 2 ears within 1 child) into account and provides a robust estimator of the covariance matrix. Results of etiological work-up of hearing loss were not included as a predictor to avoid multicollinearity and because the underlying etiology was not known in all infants. Included predictors were on ear level (ie, degree and onset of hearing loss) or on subject level (ie, gender, laterality of hearing loss, cCMV-status, *Cx26*-status, and presence of perinatal factors). Odds ratios (OR) with 95% confidence intervals (95% CI) were reported. The significance level (ie, two-tailed) was set at $P < .01$ to correct for multiple testing.

RESULTS

Subjects

Overall, 301 hearing-impaired infants were screened, of which 47 infants were excluded (Fig 1). All 22 excluded infants with permanent conductive hearing loss showed normal vestibular screening results. In total, 254 infants (ie, 125 boys and 129 girls) with sensorineural hearing loss were included (ie, 508 ears). The mean age during the final screening test was 7.4 months (SD = 2.4 months). Table 1 displays the distribution of hearing loss characteristics and etiology. The majority showed unilateral or bilateral severe to profound hearing loss (60.6%, 154 of 254). Six infants had normal hearing at birth but developed early-onset hearing loss (2.4%, 6 of 254), in 3 children it was caused by meningitis, and in 3 children it was caused by cCMV (symptomatic: $n = 1$ and asymptomatic: $n = 2$). Genetic (ie, nonsyndromic and syndromic) hearing loss was found in 29.9% (76 of 254) of the infants, whereas 17.0% (43 of 254) had acquired hearing loss (ie, TORCHES and meningitis). Most TORCHES infections were caused by cCMV (97.5%, 39 of 40). DFNB1 (*Cx26*) was the leading cause for genetic nonsyndromic hearing loss (66.7%, 32 of 48), followed by DFNB3 (*MYO15A*) (6.3%, 3 of 48), DFNB16 (*STRC*) (6.3%, 3 of 48), and DFNB12 (*CDH23*) (4.1%, 2 of 48). The most common syndromic causes were Waardenburg syndrome (10.7%, 3 of 28), CHARGE syndrome (7.1%, 2 of 28), Usher type 1 syndrome (7.1%, 2 of 28), Usher type 2 syndrome (7.1%, 2 of 28), Down syndrome (7.1%, 2 of 28), and Pendred syndrome (7.1%, 2 of 28).

Vestibular Screening Results

At the subject level, abnormal results were found in 13.8% of the infants (35 of 254) (Table 5).

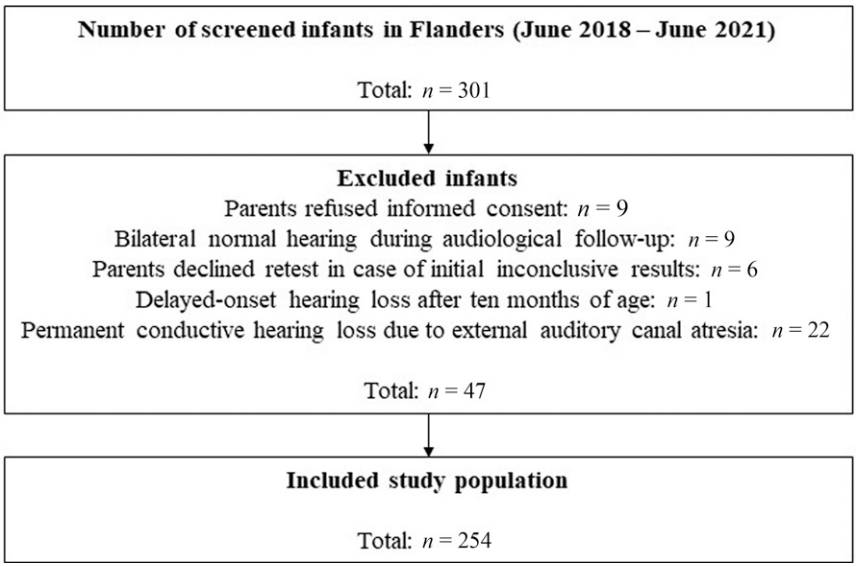

FIGURE 1
Number of screened infants, excluded infants, and included study population.

Unilateral abnormal results were found in 8.3% (21 of 254), whereas bilateral abnormal results were seen in 5.5% (14 of 254). The latter group contained 6 infants with bilateral inconclusive results, in which a bilateral vestibular deficit was confirmed in 5 infants during

TABLE 1 Characteristics and Etiology of Hearing Loss ($n = 254$ infants)

	(%)	(*n*/*N*)
Characteristics of hearing loss		
Degree and laterality		
Unilateral mild-moderate	11.8	(30/254)
Bilateral mild-moderate	27.6	(70/254)
Unilateral severe-profound	24.8	(63/254)
Bilateral severe-profound	35.8	(91/254)
Onset		
Congenital	97.6	(248/254)
Early-onset	2.4	(6/254)
Etiology of hearing loss		
cCMV[a]		
No	84.6	(215/254)
Yes	15.4	(39/254)
DFNB1 (*Cx26*)[a]		
No	87.4	(222/254)
Yes	12.6	(32/254)
Presence of perinatal factors[a]		
No	72.8	(185/254)
Yes	27.2	(69/254)
Advanced etiological work-up results		
Genetic nonsyndromic	18.9	(48/254)
Genetic syndromic	11.0	(28/254)
TORCHES	15.8	(40/254)
Meningitis	1.2	(3/254)
Cochleovestibular anomalies	10.2	(26/254)
Unknown (cCMV- and *Cx26*-negative)	42.9	(109/254)

cCMV, congenital cytomegalovirus; DFNB, autosomal recessive deafness; *Cx26*, *Connexin 26*; TORCHES, toxoplasmosis, other (syphilis, varicella-zoster, parvovirus B19), rubella, cytomegalovirus, and herpes infections.
a Standardly known at the age of screening.

TABLE 2 Characteristics of Infants With Inconclusive Results During the First and Second Vestibular Screening Test (n = 6 Infants)

Hearing Loss Characteristics	Underlying Etiology of Hearing Loss	Vestibular Deficit Confirmed at Later Age
1. Bilateral severe-profound congenital sensorineural	Genetic syndromic (CHARGE syndrome)	Yes
2. Bilateral severe-profound congenital sensorineural	Genetic nonsyndromic (DFNB35)	Yes
3. Bilateral severe-profound congenital sensorineural	Genetic syndromic (Usher syndrome type 1)	Yes
4. Bilateral severe-profound congenital sensorineural	TORCHES (cCMV)	Yes
5. Bilateral severe-profound congenital sensorineural	TORCHES (cCMV)	Yes
6. Bilateral severe-profound congenital sensorineural	Unknown	No[a]

DFNB, autosomal recessive deafness; TORCHES, toxoplasmosis, other (syphilis, varicella-zoster, parvovirus B19), rubella, cytomegalovirus, and herpes infections; cCMV, congenital cytomegalovirus.

a Parents declined vestibular follow-up as the child had epileptic attacks and motor therapy was already initiated because of severe motor retardation.

vestibular follow-up at a later age (Table 2). Abnormal results were found significantly more often in infants with unilateral or bilateral severe to profound hearing loss (20.8%, 32 of 154) compared with unilateral or bilateral mild-moderate hearing loss (3.0%, 3 of 100) ($P <$ .001) (Fig 2). Moreover, abnormal results were more frequently noticed in early-onset hearing loss (ie, only caused by meningitis and cCMV) (50.0%, 3 of 6) compared with congenital hearing loss (12.9%, 32 of 248) (P = .036) (Fig 2). cCMV-positive infants more often showed abnormal results (20.5%, 8 of 39) compared with infants without cCMV (12.6%, 27 of 215) (P = .207) (Fig 3). No major differences in screening results were noticed between infants with and without perinatal factors (P = .840) (Fig 3). In *Cx26*-infants, abnormal results were less common (3.1%, 1 of 32) compared with infants without *Cx26* (15.3%, 34 of 222) (P = .095) (Fig 3). cCMV detection was negative on the Guthrie card of the only *Cx26*-infant with abnormal results. In respect to the advanced etiological work-up, most abnormal results were found if the hearing loss was caused by meningitis (66.7%, 2 of 3), followed by syndromic hearing loss (ie, especially Usher type 1 and CHARGE syndrome) (28.6%, 8 of 28), hearing loss caused by TORCHES infections (ie, only in cases with cCMV) (20.0%, 8 of 40), and cochleovestibular anomalies (19.2%, 5 of 26) (Fig 4).

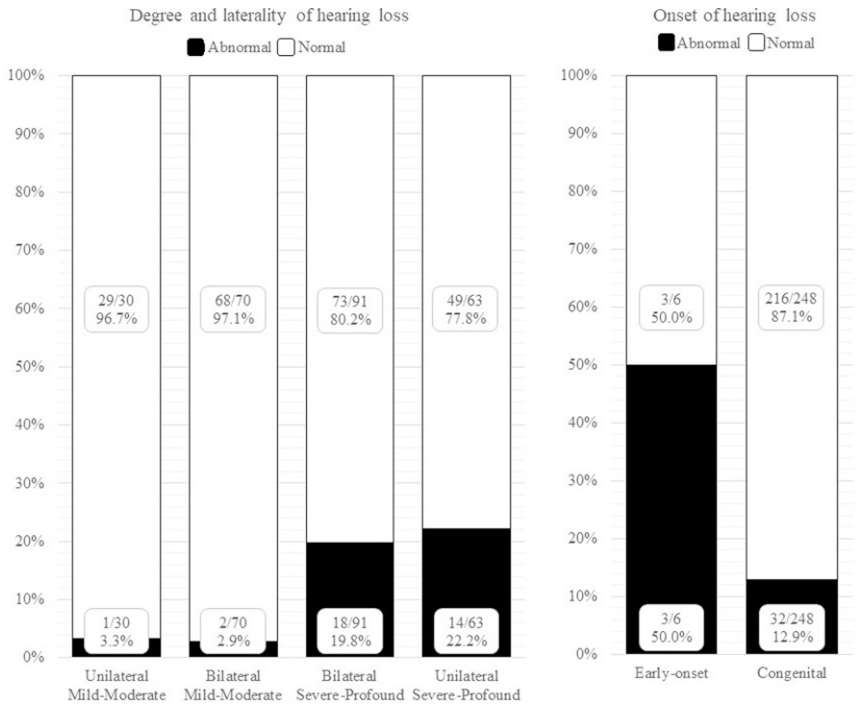

FIGURE 2
Vestibular screening results according to characteristics of hearing loss (n = 254 infants).

Multivariable Model Predicting Abnormal Screening Results

On the ear level, abnormal vestibular screening results were found in 9.6% (49 of 508) of the ears (Table 3). More in-depth analysis on ear level by means of generalized estimating equations modeling demonstrated that the odds ratios of an abnormal result were only significant for the degree of hearing loss (Table 4). More specifically, the odds of an abnormal result were about 9 times higher ($P <$ .001, OR = 9.16, 95% CI = 2.75–30.58) for ears with severe to profound hearing loss compared with the ears with normal hearing, for equal values on the other risk factors. No significantly increased risk (P = .76, OR = 0.83, 95% CI = 0.25–2.80) was found between ears with mild-moderate hearing loss and normal hearing. In 1 of the 3 normal hearing ears with abnormal results, the vestibular screening was normal for the contralateral hearing-impaired ear (ie, cCMV-positive). Moreover, the odds ratio of an abnormal result was almost 13 times higher but was on the border of statistical significance (P = .01, 95%

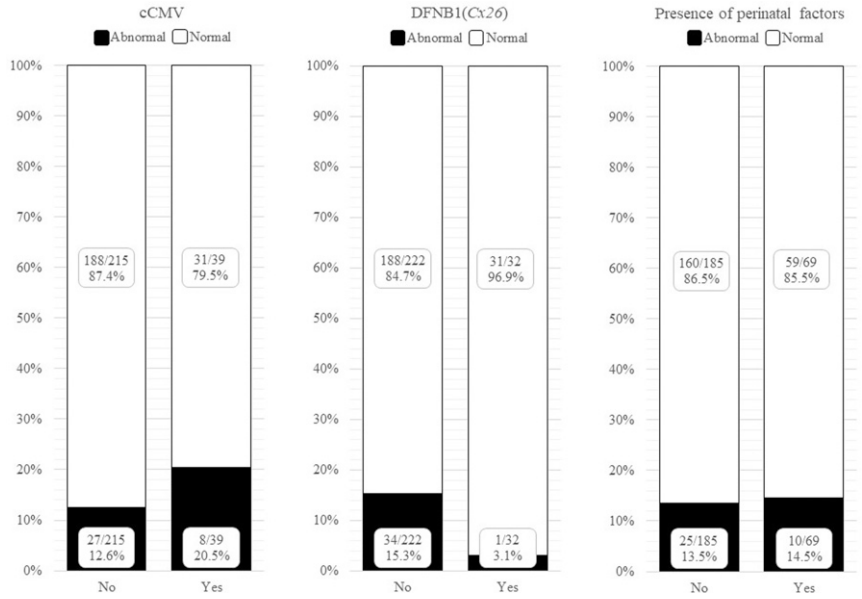

FIGURE 3
Vestibular screening results according to etiology of hearing loss as standardly known at the age of screening ($n = 254$ infants).

CI = 1.80–89.92) for the confined group of ears with early-onset hearing loss (ie, solely caused by cCMV and meningitis) in comparison with congenital hearing loss, for equal values on the other risk factors.

TABLE 3 Vestibular Screening Results According to Gender, Characteristics, and Etiology of Hearing Loss ($n = 508$ Ears)

	Vestibular Screening Results			
	Abnormal		Normal	
	(%)	(*n*/*N*)	(%)	(*n*/*N*)
Gender				
Female	10.1	(26/258)	89.9	(232/258)
Male	9.2	(23/250)	90.8	(227/250)
Degree of hearing loss				
Normal	3.2	(3/93)	96.8	(90/93)
Mild-moderate	2.1	(4/191)	97.9	(187/191)
Severe-profound	18.8	(42/224)	81.2	(182/224)
Onset of hearing loss				
Congenital	9.1	(45/496)	90.9	(451/496)
Early-onset	33.3	(4/12)	66.7	(8/12)
Laterality of hearing loss				
Unilateral	9.1	(17/186)	90.9	(169/186)
Bilateral	9.9	(32/322)	90.1	(290/322)
cCMV[a]				
No	8.8	(38/430)	91.2	(392/430)
Yes	14.1	(11/78)	85.9	(67/78)
DFNB1(*Cx26*)[a]				
No	10.6	(47/444)	89.4	(397/444)
Yes	3.1	(2/64)	96.9	(62/64)
Presence of perinatal factors[a]				
No	9.2	(34/370)	90.8	(336/370)
Yes	10.9	(15/138)	89.1	(123/138)

cCMV, congenital cytomegalovirus; DFNB, autosomal recessive deafness; *Cx26, Connexin 26.*
a Standardly known at the age of screening.

DISCUSSION

The authors of this pioneer study aimed to map the occurrence of and to identify the most important risk factors for abnormal vestibular screening results in a large group of infants with congenital or early-onset sensorineural hearing loss. The cVEMP was selected as the vestibular screening tool because saccular function is essential for the development of head control and gross motor milestones in young children.[9] Abnormal cVEMP results were found in 14% of all included infants, and in 21% of infants with severe to profound hearing loss, whereas higher percentages of abnormal cVEMP results (ie, between 17% and 91%) were reported in literature.[6,10,16,35–45] However, various test protocols and cut-off criteria have been used to evaluate cVEMP abnormality in literature, resulting in a wide range of cVEMP abnormalities.[8,25] Additionally, previous studies mainly focused on older children with severe to profound sensorineural hearing loss, and were mostly conducted in specialized CI centers, therefore dealing with a population of children more at risk for vestibular deficits. Since hearing losses with various degrees and etiologies were included in the current study, the results are more representative for the whole group of infants who fail the neonatal hearing screening. As only the cVEMP was used to screen the vestibular function, which only assesses 1 part of the vestibular system, ongoing longitudinal vestibular research at the Ghent University Hospital will map the sensitivity of the vestibular screening to evaluate the overall vestibular function in hearing-impaired infants.

The current study showed that infants with severe to profound

TABLE 4 Multivariable Model Predicting Abnormal Screening Results (n = 508 Ears)

	OR	95% CI	*P*
Gender			
Female[a]	—	—	—
Male	0.80	(0.36 – 1.74)	.56
Degree of hearing loss			
Normal[a]	—	—	—
Mild-moderate	0.83	(0.25 – 2.80)	.76
Severe-profound	9.16	(2.75 – 30.58)	< .001
Onset of hearing loss			
Congenital[a]	—	—	—
Early-onset	12.70	(1.80 – 89.92)	.01
Laterality of hearing loss			
Unilateral[a]	—	—	—
Bilateral	1.180	(0.51 – 2.69)	.70
cCMV			
No[a]	—	—	—
Yes	0.78	(0.27 – 2.27)	.65
DFNB1(*Cx26*)			
No[a]	—	—	—
Yes	0.17	(0.02 – 1.42)	.10
Presence of perinatal factors			
No[a]	—	—	—
Yes	1.18	(0.51 – 2.70)	.70

[a] Reference group.

OR, odds ratio; 95% CI, 95% confidence interval; cCMV, congenital cytomegalovirus; DFNB, autosomal recessive deafness; *Cx26*, *Connexin 26*; —, not applicable.

sensorineural hearing loss are the most important group at risk for abnormal cVEMP results, thereby confirming the preliminary VIS-Flanders results.[26] Consistent with these findings, Maes et al[43] reported significantly higher cVEMP abnormality rates in children with profound hearing loss compared with those with nonprofound hearing loss. Also the systematic review of Verbecque et al[8] concluded that pediatric vestibular loss was reported more frequently with increasing degrees of hearing loss as the auditory and vestibular end organs are closely related. Screening results did not differ significantly according to the laterality of hearing loss, which is supported by previous studies that described vestibular deficits in unilaterally hearing-impaired children.[44,46] In early-onset hearing loss, screening results seemed to be more abnormal compared with congenital hearing loss. However, only 6 infants with early-onset hearing loss could be included in the current study since infants were screened at an early age. In all infants with early-onset hearing loss, the underlying etiology was meningitis or cCMV, which are 2 etiologies repeatedly associated with a high risk for vestibular deficits in literature.[42,47–52] Besides cCMV and meningitis, abnormal screening results were noticed more often in infants with syndromic hearing loss, such as Usher type 1 and CHARGE syndrome, and cochleovestibular anomalies, which is in agreement with findings of previous studies and the recent review of Hazen et al.[42,53–57] No significant odds ratio for abnormal screening results was found in the group of cCMV-positive infants, because the group without cCMV also consisted of infants at risk for vestibular deficits, such as infants with meningitis, syndromic hearing loss, and cochleovestibular anomalies. Furthermore, infants with genetic nonsyndromic hearing loss were only at risk for abnormal vestibular screening results if the hearing loss was severe to profound (Table 5). Similar to the current findings, only a few pediatric cases with genetic nonsyndromic hearing loss and concurrent severe vestibular deficits have been described in literature.[10,38,42] However, a major limitation of the current study was that advanced etiological work-up was not performed in all included infants, resulting in a large group of infants with an unknown underlying etiology of hearing loss. Nevertheless, only a minority of the latter group showed abnormal screening results, which were mostly found in infants with severe to profound hearing loss (Table 5). Finally, abnormal screening results occurred approximately equally in hearing-impaired infants with and without perinatal factors. In line with the results of Zagólski et al,[58] abnormal cVEMP results of hearing-impaired infants with perinatal factors were mainly found in cases of severe to profound hearing loss (Table 5). Thus, it seems that perinatal factors measured in this study are only relevant in the light of predisposing the infant to hearing loss, because it is the degree of hearing loss that determines the risk for vestibular deficits.

CONCLUSIONS

This is the first study to report results after 3 years of vestibular screening in a group of infants with congenital or early-onset sensorineural hearing loss. Based on the current results, the authors highly recommend early vestibular screening for all infants with unilateral or bilateral severe to profound sensorineural hearing loss, and additionally for hearing-impaired infants with meningitis, syndromes, cCMV, and cochleovestibular anomalies. Hereby, vestibular deficits can be detected at a young age, which enables early referral for motor assessment and rehabilitation if needed. Future

TABLE 5 Overview of All Infants With Abnormal Screening Results ($n = 35$ Infants)

Final Screening Result	Degree and Laterality of Hearing Loss	Onset of Hearing Loss	Underlying Etiology of Hearing Loss	Presence of Perinatal Factors
Bilateral absent	Bilateral severe-profound	Congenital	Genetic syndromic (CHARGE syndrome)	No
Bilateral absent	Bilateral severe-profound	Congenital	Genetic syndromic (Johanson-Blizzard syndrome)	Yes
Bilateral absent	Bilateral severe-profound	Congenital	Genetic syndromic (Usher syndrome type 1)	Yes
Bilateral absent	Bilateral severe-profound	Congenital	Genetic nonsyndromic (DFNB1[*Cx26*])	No
Bilateral absent (left) decreased (right)	Unilateral severe-profound (right)	Congenital	TORCHES (cCMV)	No
Bilateral absent (left) decreased (right)	Unilateral mild-moderate (left)	Early-onset	Meningitis	Yes
Bilateral decreased	Bilateral severe-profound	Congenital	Genetic nonsyndromic (DFNB3)	No
Bilateral decreased	Bilateral severe-profound	Congenital	Unknown	No
Bilateral inconclusive	Bilateral severe-profound	Congenital	Genetic syndromic (CHARGE syndrome)	No
Bilateral inconclusive	Bilateral severe-profound	Congenital	Genetic nonsyndromic (DFNB35)	No
Bilateral inconclusive	Bilateral severe-profound	Congenital	Genetic syndromic (Usher syndrome type 1)	No
Bilateral inconclusive	Bilateral severe-profound	Congenital	TORCHES (cCMV)	No
Bilateral inconclusive	Bilateral severe-profound	Congenital	TORCHES (cCMV)	Yes
Bilateral inconclusive	Bilateral severe-profound	Congenital	Unknown	Yes
Unilateral absent (right)	Unilateral severe-profound (right)	Congenital	Genetic syndromic (Duane retraction syndrome)	No
Unilateral absent (left)	Unilateral severe-profound (left)	Early-onset	TORCHES (cCMV)	No
Unilateral absent (right)	Bilateral severe-profound	Congenital	TORCHES (cCMV)	No
Unilateral absent (right)	Unilateral severe-profound (right)	Congenital	TORCHES (cCMV)	No
Unilateral absent (left)	Unilateral severe-profound (left)	Congenital	Cochleovestibular anomalies (left)	Yes
Unilateral absent (left)	Bilateral severe-profound (left), mild-moderate (right)	Congenital	Bilateral cochleovestibular anomalies	Yes
Unilateral absent (right)	Unilateral severe-profound (right)	Congenital	Cochleovestibular anomalies (right)	No
Unilateral absent (left)	Unilateral severe-profound (left)	Congenital	Unknown	No
Unilateral absent (right)	Unilateral severe-profound (right)	Congenital	Unknown	Yes
Unilateral absent (right)	Unilateral severe-profound (right)	Congenital	Unknown	No
Unilateral decreased (right)	Bilateral severe-profound (right), mild-moderate (left)	Congenital	Genetic syndromic (Feingold syndrome type 2)	Yes
Unilateral decreased (right)	Bilateral severe-profound (right), mild-moderate (left)	Congenital	Genetic syndromic (Down syndrome)	No
Unilateral decreased (left)	Unilateral severe-profound (left)	Congenital	TORCHES (cCMV)	No
Unilateral decreased (left)	Unilateral severe-profound (right)	Congenital	TORCHES (cCMV)	No
Unilateral decreased (right)	Bilateral severe-profound (left), mild-moderate (right)	Early-onset	Meningitis	No
Unilateral decreased (right)	Bilateral severe-profound	Congenital	Bilateral cochleovestibular anomalies	No
Unilateral decreased (right)	Unilateral severe-profound (right)	Congenital	Cochleovestibular anomalies (right)	No
Unilateral decreased (right)	Unilateral severe-profound (right)	Congenital	Unknown	No
Unilateral decreased (left)	Unilateral severe-profound (left)	Congenital	Unknown	Yes
Unilateral decreased (right)	Bilateral mild-moderate	Congenital	Unknown	No
Unilateral decreased (left)	Bilateral mild-moderate	Congenital	Unknown	No

DFNB, autosomal recessive deafness; *Cx26, Connexin 26*; TORCHES, toxoplasmosis, other (syphilis, varicella-zoster, parvovirus B19), rubella, cytomegalovirus, and herpes infections; cCMV, congenital cytomegalovirus.

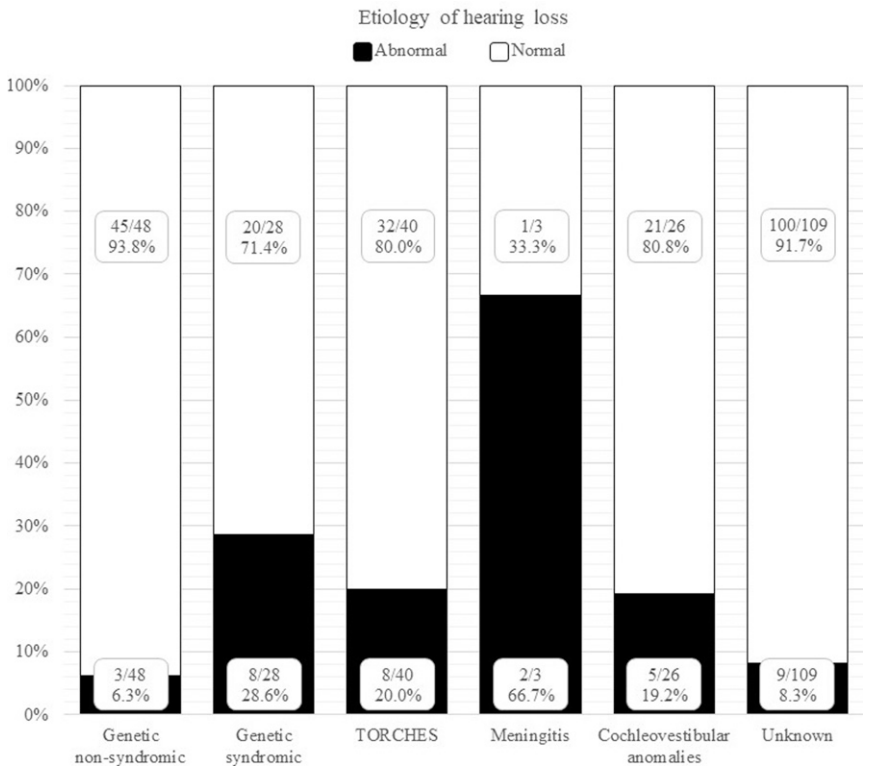

FIGURE 4
Vestibular screening results according to advanced etiological work-up of hearing loss ($n = 254$ infants).

research should map the sensitivity of the cVEMP as a vestibular screening tool in order to fine-tune this vestibular screening protocol.

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ABBREVIATIONS

95% CI: 95% confidence intervals
ABR: auditory brainstem responses
cCMV: congenital cytomegalovirus
CI: cochlear implant
cVEMP: cervical Vestibular Evoked Myogenic Potentials
Cx26: Connexin 26
DFNB: autosomal recessive deafness
OR: odds ratios
TORCHES: toxoplasmosis, other infections such as syphilis, varicella-zoster, parvovirus B19, rubella, cytomegalovirus, and herpes
UNHSP: Universal Newborn Hearing Screening Program
VIS: Vestibular Infant Screening

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Dr Martens collected data, coordinated data collection, conducted data analyses, drafted the initial manuscript, and revised the manuscript; Prof Dhooge conceptualized and designed the study, collected data, critically reviewed and revised the manuscript, and supervised the Vestibular Infants Screening – Flanders project; Dr Dhondt collected data, contributed to interpretation of data analyses, and critically reviewed and revised the manuscript; Ms Vanaudenaerde, Ms Sucaet, Prof Van Hoecke, Prof De Leenheer, Ms Rombaut, Prof Boudewyns, Prof Desloovere, Dr Vinck, Dr Janssens de Varebeke, Dr Verschueren, Dr Verstreken, Prof Foulon, Ms Staelens, Dr De Valck, Mr Calcoen, Dr Lemkens, Mr Öz, Ms De Bock, Ms Haverbeke, Dr Verhoye, Prof Declau, Dr Devroede, Prof Forton, and Prof Deggouj collected data and critically reviewed and revised the manuscript; Prof Maes conceptualized and designed the study, collected data, contributed to interpretation of data analyses, critically reviewed and revised the manuscript, and supervised the Vestibular Infants Screening – Flanders project. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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