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The Effect of Increased Intracranial Pressure on Vestibular Evoked Myogenic Potentials in Superior Canal Dehiscence Syndrome

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Abstract

Objective—To determine if vestibular evoked myogenic potential (VEMP) responses change during inversion in patients with superior canal dehiscence syndrome (SCDS) compared to controls.

Methods—Sixteen subjects with SCDS (mean: 43, range 30–57 years) and 15 age-matched, healthy subjects (mean: 41, range 22–57 years) completed cervical VEMP (cVEMP) in response to air conduction click stimuli and ocular VEMP (oVEMP) in response to air conduction 500 Hz tone burst stimuli and midline tap stimulation. All VEMP testing was completed in semi-recumbent and inverted conditions.

Results—SCDS ears demonstrated significantly larger oVEMP peak-to-peak amplitudes in comparison to normal ears in semi-recumbency. While corrected cVEMP peak-to-peak amplitudes were larger in SCDS ears; this did not reach significance in our sample. Overall, there was not a differential change in o- or cVEMP amplitude with inversion between SCDS and normal subjects.

Conclusions—Postural-induced changes in o- and cVEMP responses were measured in the steady state regardless of whether the labyrinth was intact or dehiscent.

Significance—VEMP responses are blunted during inversion. Although steady-state measurements of VEMPs during inversion do not increase diagnostic accuracy for SCDS, the

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Conflict of Interest:

The authors have no conflicts of interest to declare.

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findings suggest that inversion may provide more general insights into the equilibration of pressures between intracranial and intralabyrinthine fluids.

Keywords

Vestibular evoked myogenic potential; superior canal dehiscence; intracranial pressure

Introduction

Superior canal dehiscence syndrome (SCDS) consists of an opening in the bony roof over the superior semicircular canal (Minor et al. 1998). This dehiscence is considered a pathologic third window in the labyrinth and is thought to produce inner ear conductive hearing loss by shunting air-conducted energy through the dehiscence while enhancing bone conducted energy due to the lower impedance of scala vestibuli (Merchant and Rosowski 2008; Minor et al. 2003). The dehiscence also serves as a conduit for energy transmission to and from the cranial cavity, resulting in other unique patient symptoms such as increased sensitivity to bone conducted physiological sounds (i.e., hearing their eyes move, digestive sounds, etc) and an increased sensation in the loudness of one's own voice (autophony) (Crane et al. 2010). Further evidence of this pressure transduction through the dehiscence is the presence of eye movements in the plane of the superior canal in response to loud sounds (Tullio phenomenon) or pressure changes (Hennebert sign) (Minor et al. 1998; Minor et al. 2001). These symptoms usually improve or resolve upon canal plugging (Crane et al. 2010; Minor et al. 2003; Minor 2005).

SCDS is typically diagnosed using a combination of ocular and cervical vestibular evoked myogenic potential (VEMP) testing, audiometric testing and computed tomography (CT). The VEMP measures muscle potential changes at either the inferior oblique muscle for the ocular VEMP (oVEMP), or the sternocleidomastoid muscle for the cervical VEMP (cVEMP) (Colebatch et al. 1994; Weber et al. 2012). Considerable work has been published regarding the clinical utility of these responses; however, the origin and response patterns remain debated. While the cVEMP has been regarded as an inhibitory response, primarily saccular in origin and the oVEMP regarded as an excitatory response, primarily utricular in origin (Colebatch et al. 1994; Curthoys et al. 2011; Manzari et al. 2010a; Manzari et al. 2010b), there is debate that the origin and response patterns are not this concrete (Todd 2014). Evidence exists suggesting that the utricle may have both inhibitory and excitatory contributions to the cVEMP (Rosengren et al. 2009) and the saccule extends projections centrally via both the inferior and superior vestibular nerves (Terasaka et al. 2000; Todd 2014). Nonetheless, SCDS results in hypersensitivity of these responses, which is demonstrated by lower thresholds and higher amplitudes on both c- and oVEMP testing (Brantberg et al. 1999; Janky et al. 2012; Manzari et al. 2012; Rosengren et al. 2008; Streubel et al. 2001; Welgampola et al. 2008; Zuniga et al. 2012). In addition, patients with SCDS may also demonstrate conductive hearing loss that is not of middle ear origin and visible dehiscence on CT.

The current clinical challenge in SCDS diagnosis is determining when sufficient energy transfer is occurring through the dehiscence to warrant surgical intervention. In cases with

obvious nystagmus induced by loud sounds or changes in intracranial or middle ear pressure, there is little question that the dehiscence is responsible for abnormal cupular stimulation from fluid motion within the labyrinth as a response to these stimuli, especially in light of the fact that evoked nystagmus and vertigo resolve with surgical correction of the dehiscence (Crane et al. 2008). However, when patients present with a CT scan showing apparent dehiscence, but lack validating clinical findings (i.e., inducible nystagmus) of a patent dehiscence, the decision to initiate surgical intervention is difficult. In some of these patients, the isolated finding of bony conductive hyperacusis can indicate a patent dehiscence. In this cohort, low-frequency air-bone gaps and negative bone conduction thresholds may provide diagnostic evidence to justify surgery as patients with hyperacusis indeed benefit from SCDS surgery (Crane et al. 2010). The patients who particularly present a dilemma for surgery candidacy are those having apparent dehiscence on CT with subjective symptoms of imbalance, sound sensitivity, and autophony, but without definitive evidence of SCDS on secondary vestibular and audiometric tests. For this group of patients, there is a need for more objective measures of actual pressure transmission through their apparent dehiscence prior to surgical candidacy.

The present study seeks to fill this gap with a novel measure that might reflect pressure transmission through a dehiscence: postural changes in VEMPs. We sought first to build upon our recent finding that cases of surgically-proven SCDS usually have abnormal preoperative VEMP responses. Findings indicate that cVEMP thresholds and suprathreshold oVEMP amplitudes provide excellent sensitivity and specificity when obtained in response to air conducted sound (ACS) stimulation (500 Hz tonebursts or click stimuli) compared to an age-matched population (Janky et al. 2012; Zuniga et al. 2012). These VEMP responses are believed to be enhanced in SCDS due to lower overall input impedance for ACS to enter the otic capsule (Merchant and Rosowski 2008). We reasoned that pressure transmission across the dehiscence could be modulated by changing intracranial pressure (ICP) with postural changes because increasing ICP should increase the overall input impedance, bringing it closer to the impedance of the labyrinth without SCDS. For this reason, we sought to determine whether we could document a change in the VEMP response going from a semi-recumbent to inverted position, a measure that should reflect the degree of pressure transmission through the dehiscence. Specifically, the goal of this study was to determine if changes in VEMP responses during a postural change (inversion, causing increased ICP) would provide further information regarding the functional status of a radiographically apparent dehiscence.

Methods

Subjects

Sixteen subjects diagnosed with SCDS (mean 43 years, range 20 – 57 years, 9 females) and 15 age-matched control subjects with no history of balance or dizziness complaints (mean 41 years, range: 22–57 years, 11 females) participated in the study. HRCT was the gold standard for diagnosis of SCDS, combined secondarily with other auditory and vestibular signs and symptoms (audiometry, semi-recumbent VEMP, and bedside assessment consisting of head impulse test, tullio test, Hennebert sign, and 512 Hz tuning fork

localization). All subjects diagnosed with SCDS had HRCT demonstrating apparent dehiscence as well as at least one physiologic sign (either auditory or vestibular) of a third mobile window in the affected labyrinth. Six subjects were diagnosed with unilateral SCDS and 10 with bilateral SCDS. Of the 10 subjects diagnosed with bilateral SCDS, 3 subjects had already undergone unilateral canal plugging and were being seen for signs and symptoms referable to the contralateral ear; 6 subjects had signs and symptoms primarily referable to 1 ear; and 1 subject had signs and symptoms referable to both ears, which were included as independent SCDS ears. Thus, a total of 17 ears with SCDS were used for analysis. Additionally, only the left ears ($n = 15$) of normal subjects were used for analysis.

Vestibular Evoked Myogenic Potential (VEMP) Testing

VEMP stimuli and recording techniques have been previously described (Nguyen et al. 2010). In short, a commercial electromyographic (EMG) system (Medelec Synergy, Care Fusion, software version 14.1, Dublin, OH) was used for VEMP testing. ACS stimuli were delivered monaurally via intra-auricular speakers from VIASYS Healthcare (Madison, WI) with foam eartips (Aearo Company Auditory Systems, Indianapolis, IN). Two types of ACS stimuli were delivered: (1) 0.1-ms, 105 dB nHL (140 dB peak SPL) clicks of positive polarity at a repetition rate of 5 per second; and (2) 500 Hz, 125 dB SPL tone bursts of positive polarity, with a linear envelope (1 ms rise/fall time, 2 ms plateau), at a repetition rate of 5 per second. One hundred sweeps were averaged for each ACS test. Two types of midline vibration stimulation (i.e., midline taps) were delivered at Fz (in the midline at the hairline, 30% of the distance between the inion and nasion): (1) manual taps delivered with the VIASYS system's reflex hammer fitted with an inertial microswitch trigger; and (2) "mini taps," as described by Iwasaki et al. (Iwasaki et al. 2007) were delivered with a *Brüel* and *Kjær* Mini-Shaker Type 4810 (1-ms clicks of positive polarity, with a repetition rate of 5 per second, at 115 dB (7 Newtons)). EMG signals were amplified (2500 μ V) and band-pass filtered (20 Hz – 2000 Hz for cVEMPs; 3 Hz – 500 Hz for oVEMPs). Fifty sweeps were averaged for each midline vibration test.

VEMP testing was completed in two conditions: Semi-recumbent and inverted. For the semi-recumbent condition, subjects laid with their upper bodies elevated at a 30 degree angle from horizontal for all VEMP testing. For the inverted condition, subjects were placed on an inversion table (EP-550 TM, Teeter Hang Ups; Puyallup, WA) and then slowly transitioned from upright to approximately 45° head down (Figure 1A). Each subject lay in the inverted position 30 seconds before VEMP testing was initiated. This time frame was chosen as otoacoustic emission (OAE) measurements during inversion suggest that increased ICP should fully equilibrate with intralabyrinthine pressure in less than 30 seconds (Buki et al. 2000; de Kleine et al. 2001).

Cervical VEMP (cVEMP) measurements were completed in response to click stimuli only. For cVEMP recording, subjects were instructed to lift their heads from the head rest by flexing their necks to provide tonic background muscle activity (Figure 1C). The p13 and n23 latencies and p13 and n23 amplitudes were recorded. The corrected peak-to-peak amplitude was calculated by dividing the raw peak-to-peak amplitude by the rectified

background EMG activity recorded during the 10-ms interval prior to stimulus onset. This correction factor accounts for the varying tonic muscle tone that affects cVEMP amplitudes.

Ocular VEMP (oVEMP) were completed in response to 500 Hz tonebursts, Mini-Shaker and reflex hammer stimuli. Before oVEMP testing, 20° vertical saccades were performed to ensure that symmetrical signals were recorded from both eyes. If the signal change showed > 25% asymmetry, the electrodes were removed and new ones applied. For oVEMP, subjects were instructed to maintain maximum upgaze during all oVEMP recording (i.e., eye in orbit position, looking at the floor during inversion, Figure 1B). The n10 and p16 latencies and peak-to-peak amplitude were recorded. While oVEMP amplitudes demonstrate less variability when a target at a set angle is used, a set angle target was impossible to implement during inversion given variations in subject height.

Statistics

To examine the difference between normal control ears and ears with SCDS, a 3-way between groups factorial analysis of variance (ANOVA) was conducted. The independent variable was oVEMP peak-to-peak amplitude and the dependent variables were group (SCDS ears and normal control ears), stimulus type (500 Hz, Mini-Shaker, and reflex hammer), and position (inverted versus semi-recumbent). To examine the difference between normal control ears and ears with SCDS for cVEMP outcome parameters and mean muscle rectification, separate mixed groups ANOVAs were conducted. The independent variables were corrected peak-to-peak amplitude and mean muscle rectification. The dependent variables were group (SCDS ears and normal control ears) and position (inverted versus supine). Post hoc comparisons were made using Tukey's honest significant difference (HSD). A significance level of 0.05 was used for all analyses. All statistical analysis was performed using SPSS 18.0.

Results

Ocular VEMP

Mean (1 SD) oVEMP peak-to-peak amplitudes for each group, across all stimuli are summarized in Table 1. As anticipated, there was a significant main effect for group $F(1, 27) = 5.184, p = 0.031$, with SCDS ears demonstrating significantly higher oVEMP peak-to-peak amplitudes compared to control ears. A significant 2-way interaction for group and stimulus was also found, $F(2, 54) = 8.51, p = 0.001$. Post hoc analyses (using HSD = 15.177) indicated that ears with SCDS demonstrated significantly higher oVEMP peak-to-peak amplitudes than normal control ears in response to 500 Hz tone burst stimuli only; however, not for Mini-Shaker or reflex hammer stimuli. There was no significant 3-way interaction, $F(2, 54) = 0.865, p = 0.427$.

A significant main effect was demonstrated for condition, $F(1, 27) = 37.38, p < 0.001$, with oVEMP peak-to-peak amplitudes being significantly lower in the inverted condition. However, the 2-way interaction between group and condition did not reach significance $F(1, 27) = 1.151, p = 0.887$, suggesting that while oVEMP peak-to-peak amplitudes are reduced in response to inversion, there is not a differential change in oVEMP amplitude with

inversion between ears with SCDS and normal control ears. Likewise, the 2-way interaction between condition and stimuli did not reach significance $F(2, 54) = 2.047$, $p = 0.139$, suggesting that oVEMP amplitudes decreased equally independent of the type of stimulus used (i.e., midline taps versus ACS stimuli).

In summary, SCDS ears demonstrated higher oVEMP amplitudes compared to control ears for 500 Hz tone bursts. In response to inversion, oVEMP amplitudes were significantly smaller; however, this amplitude reduction was the same for SCDS ears and normal control ears and across all stimuli.

Cervical VEMP

Mean (1 SD) cVEMP corrected peak-to-peak amplitudes for each group are summarized in Table 1 and Figure 2. Again as expected, there was a significant main effect for group (SCDS ears versus normal control ears), $F(1, 27) = 8.341$, $p = 0.008$, with SCDS ears demonstrating significantly larger corrected cVEMP peak-to-peak amplitudes. When examining corrected peak-to-peak amplitudes, there was no significant interaction for group (SCDS ears versus normal control ears) and condition (semirecumbent versus inverted) $F(1, 27) = 0.25$, $p = 0.314$. There was no significant main effect for condition (semi-recumbent versus inverted) $F(1, 27) = 1.249$, $p = 0.274$. However, contrary to oVEMPs, where mean amplitudes were reduced in response to inversion, corrected cVEMP amplitudes increased in response to inversion in both groups. While this increase in cVEMP amplitude was not significant, it appears to be related to the overall mean increase in mean rectification of SCM muscle contraction during inversion. When examining mean rectification using a mixed groups ANOVA with HSD follow-ups ($HSD = 91.034$), there was a significant interaction between condition and mean rectification, $F(1, 27) = 5.036$, $p = 0.033$. It was hypothesized that muscle contraction to lift the head would be higher in both groups in the inverted condition; however, only the normal controls demonstrated significantly higher SCM muscle contraction in the inverted condition. There was no significant main effect for condition; however, there was a significant main effect for group $F(1, 27) = 8.339$, $p = 0.008$, with the normal controls demonstrating significantly higher SCM muscle contraction. Again, this was the case only for the inverted condition.

In summary, SCDS ears demonstrated higher cVEMP amplitudes compared to control ears. In response to inversion, cVEMP corrected amplitudes increased; however, this increase was not significant and did not differentiate between normal and SCDS ears.

Discussion

The purpose of the present study was to determine the effect of body and head inversion on the normal VEMP response and to determine if VEMP testing during inversion could be used as an assay of the extent of pressure transmitted through a superior canal dehiscence. The significant decrease in oVEMP amplitude, regardless of stimulus type, and increase - albeit not significant - in corrected cVEMP amplitude during inversion suggest that inversion does affect both o- and cVEMP amplitudes. However, there was not a differential change in either type of VEMP amplitude between SCDS ears and normal control ears.

One possible effect of inversion is to increase ICP. Some measures of intact inner ear function have demonstrated sensitivity to increased ICP. In patients with increased ICP secondary to hydrocephalus, intracranial tumors, etc, differences in tympanic membrane displacement during stapedial reflex testing were noted when compared to individuals with normal ICP (Reid et al. 1990). OAEs, electrocochleography (ECoG), and recently oVEMP have also been measured in normal subjects after being placed on an inversion table (Buki et al. 2000; Buki et al. 2009; de Kleine et al. 2000; de Kleine et al. 2001; Deppe et al. 2013; Jerin and Gürkov 2014; Voss et al. 2006). ICP increases as a result of inversion, and because of the cochlear and vestibular aqueducts, intralabyrinthine pressure is increased in response to rises in ICP. When intralabyrinthine pressure is increased, OAEs have been documented to show phase and magnitude changes (Buki et al. 1996; Buki et al. 2000; Buki et al. 2009; de Kleine et al. 2000; Deppe et al. 2013; Voss et al. 2006). Similarly, phase changes have also been documented in ECoG measurements (Buki et al. 2009). However, these changes occur slowly, over 30–60 seconds, in most normal human subjects (Buki et al. 2000; de Kleine et al. 2001). Thus, equilibrium between ICP and intralabyrinthine pressure is normally achieved slowly after postural changes. We hypothesized that SCDS might serve as an additional low-impedance channel for equilibration of ICP and intralabyrinthine pressures, and that differences in VEMPs during inversion might be observed in control ears vs. ears with SCDS. However, this was not the case. The negative finding might be explained by the insensitivity of our present VEMP techniques to dynamic changes in intralabyrinthine pressures on this time scale. VEMP testing in the current study was completed once ICP had equilibrated (after 30 seconds), and indeed the need for averaging over a sufficient number of trials would preclude precise VEMP recordings in shorter time intervals in normal subjects. Potentially, this may serve as an explanation of why we did not find a differential change in VEMP amplitude between SCDS ears and normal control ears. It may be that both SCDS ears and normal control ears reached the same final intralabyrinthine pressure; therefore, a uniform reduction in VEMP amplitude was noted between groups. Future experiments investigating dynamic changes in VEMPs or other inner ear reflexes may demonstrate a differential behavior for SCDS or other mobile third window syndromes.

The mechanisms proposed to account for these response changes in the cochlea are that increased ICP may alter the biomechanics of the basilar membrane or the stiffness of the annular ligament, which in turn alters sound transmission, particularly for low frequency stimuli as a result of middle ear stiffness changes (Buki et al. 2009; Olzowy et al. 2008; Voss et al. 2006). Evidence to support this second hypothesis is that OAEs are sensitive to positional changes, specifically in the low frequencies (de Kleine et al. 2001; Voss et al. 2006). However, previous reports documenting changes in OAE, ECoG, and oVEMP in response to postural changes have been limited to ACS stimuli (Buki et al. 2009; de Kleine et al. 2001; Jerin and Gürkov 2014; Voss et al. 2006). In the present study, equal reduction in oVEMP amplitude regardless of stimulus type (ACS versus midline taps, Table 1), was found, suggesting that in addition to the cochlea, increased intralabyrinthine pressure may directly affect sensory structures in the vestibular system.

It is also plausible that VEMP responses are not affected by increases in intralabyrinthine pressure so much as by changes in the pattern of activation of the otolith receptor afferents

during inversion, or a combination of both factors. A variety of recent investigations have studied the effect of gravitational changes on the oVEMP response with conflicting conclusions (Gurkov and Kantner 2013; Iwasaki et al. 2012; Jerin and Gürkov 2014; Taylor et al. 2014; Wang et al. 2014). In response to head tilt in the roll plane, reduced oVEMP amplitudes in response to ACS (Gurkov and Kantner 2013; Taylor et al. 2014) and bone conduction vibration (BCV) (Taylor et al. 2014) stimuli have been reported. With respect to oVEMP asymmetry ratio, Iwasaki et al. (2012) show that oVEMP amplitudes become significantly asymmetric in response to BCV, but are unaffected by ACS; whereas, Taylor et al. (2013) show the reverse – unaffected asymmetry ratios to BCV and significantly reduced asymmetry ratios to ACS. While these findings appear to conflict, Iwasaki et al. (2012) report that BCV oVEMP amplitudes *increase* (right ear down, right ear BCV amplitude increases) while Taylor et al. (2013) report that ACS oVEMP amplitudes *decrease* (lower amplitudes in ear down), suggesting that the same patterns of findings (with roll plane head tilt, BCV oVEMP increases while ACS oVEMP decreases) were reported with differences in overall statistical significance. Differences in the response patterns between ACS and BCV in roll tilts raise speculation regarding the afferent innervation patterns being measured in response to each stimuli. These differences may indicate that the relative contribution of regular versus irregular afferents is different for ACS versus BCV or that one stimuli (in particular, the suprathreshold BCV) has greater influence on the ocular counterroll affecting oVEMP amplitude.

In response to pitch plane changes, asymmetry ratios do not appear to be significantly affected (Wang et al. 2014); however, conflicting results regarding oVEMP amplitude have been reported. In the current investigation, we noted uniform reductions regardless of stimulus type in oVEMP amplitude from semi-recumbent to inversion. Supportive evidence comes from Taylor et al. (2013) who also report decreased oVEMP amplitudes in response to both ACS and BCV in the upside down position and Jerin and Gürkov (2014) who report sequentially decreased oVEMP amplitudes in response to 0°, 10°, 20° and 30° inversion; however, contrary to our findings Wang et al. (2013) report significantly larger oVEMP amplitudes in the head hanging position compared to sitting upright in response to BCV, not ACS. One potential source accounting for this difference in response pattern is the degree of increased intralabyrinthine pressure. In the current investigation and that reported by both Taylor et al. (2013) and Jerin and Gürkov (2014), participants entire body was put in the inverted position, while with Wang et al. (2013) only the participant's head was hanging. In the steady state, one possibility may be that increased intralabyrinthine pressure significantly reduced oVEMP amplitudes, discrediting any changes in the pattern of otolith receptor activation due to gravity. Further supporting this, Jerin and Gürkov (2014) demonstrate less reduction in oVEMP amplitudes during inversion if the head remains horizontal.

The effect of gravitational changes on the cVEMP response has not been reported by others to our knowledge. The differential effects of inversion on the c- and oVEMP responses serve as both an additional control on the possibility that inversion simply changed middle ear pressure and dampened transmission of sound and also suggest that these responses are providing complimentary information. If altered middle ear impedance were the explanation for the change in VEMPs, then amplitudes for both c- and oVEMP responses should have

been reduced in parallel. It should also be noted that use of the “corrected” cVEMP amplitude – corrected for baseline EMG activation – should have addressed the greater work of lifting the head for cVEMP recordings in the inverted versus semi-recumbent positions. While the source of the oVEMP remain unresolved –in response to both ACS and BCV (Todd 2014), one potential hypothesis for the differential responses between o- and cVEMP is that they provide complimentary information, consistent with Todd (2013) utricle only hypothesis, suggesting the oVEMP is a utriculo-ocular response. Should this be the case, inversion may have resulted in greater “loading” of the vertically oriented saccule and “unloading” of the horizontally oriented utricle, giving a trend toward increase in the corrected cVEMP response (from the saccule) but decrease in the oVEMP response (from the utricle). However, further study differentiating the origin of these responses is warranted.

SCDS has consistently been documented to demonstrate significantly higher c- and oVEMP amplitudes when compared to control ears (Brantberg et al. 1999; Janky et al. 2012; Manzari et al. 2012; Rosengren et al. 2008; Streubel et al. 2001; Welgampola et al. 2008; Zuniga et al. 2012). In the present study, corrected cVEMP amplitude in response to click stimuli and peak-to-peak oVEMP amplitudes in response to 500 Hz tone bursts were significantly larger in SCDS when compared to normal controls. These findings are consistent with previous reports. However there was no significant difference in oVEMP amplitudes between groups in response to either type of mid-line tap stimuli. While oVEMP amplitudes were larger in SCDS compared to normal controls in response to both types of mid-line tap stimuli, this did not reach significance. In a comparison study looking at the sensitivity of various stimulus types, mid-line tap stimuli have been found to be the less sensitive stimulation type for diagnosing SCDS (Janky et al. 2012) and of the various stimulus types yields oVEMP response of only fair-to-good reliability (Nguyen et al. 2010). The lack of significantly higher oVEMP peak-to-peak amplitudes in response to mid-line tap stimuli in SCDS is attributed to these two factors.

Conclusion

Postural-induced changes occur in o- and c-VEMP responses measured in the steady state, which suggests that VEMP responses are subject to changes in intralabyrinthine pressure or head orientation relative to gravity regardless of the stimulus modality. Our results do not support the conclusion that SCDS causes greater *final* pressure in the intralabyrinthine compartment during steady-state inversion. Future work with dynamic measurements of intralabyrinthine pressure may, however, be able to demonstrate more rapid equilibration (i.e., shorter time constant) to the steady state intralabyrinthine pressure when the relatively large channel of a superior canal dehiscence contributes to the usual channels of the cochlear and vestibular aqueducts. VEMP changes that occur during inversion suggest a possible new line of investigation for non-invasive measurement of intracranial pressure changes.

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Highlights

1. In normal controls and patients with superior canal dehiscence syndrome (SCDS), ocular VEMP amplitudes significantly decreased in response to inversion.
2. There was not a differential change in VEMP amplitude with inversion between SCDS and normal subjects.
3. Consistent with previous findings, subjects with SCDS demonstrated significantly higher ocular VEMP amplitudes than control subjects.

Figure 1.

A: Participants were slowly transitioned from upright to approximately 45° head down for inverted VEMP testing. B: Depiction of cVEMP testing during the inversion condition. Subjects were instructed to lift their head while inverted. C: Depiction of oVEMP testing during the inversion condition using the Mini-shaker device. Subjects were instructed to maintain maximum upgaze (i.e., eye in orbit position, looking at the floor during inversion).

Figure 2. Corrected cVEMP amplitudes in response to click stimuli in normal control ears and ears with SCDS. Open circles are outlying data.

Table 1

Ocular VEMP peak-to-peak amplitudes in response to 500 Hz, Mini-Shaker, and reflex hammer stimuli and cervical VEMP corrected amplitudes in response to click stimuli in normal control ears and ears with SCDS in the inverted and semi-recumbent position. The percent change in o- and cVEMP amplitudes in response to inversion is also provided. The negative percent change indicates larger mean amplitudes in the inverted condition, on average.

Stimulus	Normal Controls			SCDS		
	Semi-recumbent	Inverted	Percent Change	Semi-recumbent	Inverted	Percent Change
	Ocular VEMP peak-to-peak Amplitudes					
500 Hz	14.78 (7.61)	7.52 (4.94)	31% (23)	39.64 (28.74)	34.75 (32.47)	18% (28)
Mini-Shaker	13.92 (7.79)	11.44 (5.91)	12% (21)	29.12 (26.26)	22.53 (20.29)	13% (29)
Reflex Hammer	31.68 (15.39)	20.07 (12.83)	27% (26)	35.63 (23.33)	26.73 (23.65)	20% (28)
	Corrected Cervical VEMP Amplitudes					
Click	0.95 (0.48)	1.2 (1.4)	8% (40)	2.00 (1.37)	2.66 (2.34)	-10% (46)