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FOR CLINICAL AUDIOLOGY
November 2008

Cervical and Ocular Vestibular Evoked Myogenic Potentials (VEMPs) in Vestibular Hypersensitivity

by Todd B. Sauter

Bio:

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Vestibular Evoked Myogenic Potentials (VEMPs) have recently become a popular component of the audiovestibular test battery of many neurology, otolaryngology, and audiology laboratories and clinics. Traditional VEMPs, resulting from the vestibulo-collic reflex, are evoked by intense acoustic stimuli presented via air or bone conduction and recorded from the activated ipsilateral neck musculature via surface electrodes (Welgampola & Colebatch, 2005). The test has achieved its popularity for two principal diagnostic reasons. The first reason is its ability to directly assess the function of an otolithic organ, specifically the saccule, which is not directly assessed during most standard vestibular (ENG/VNG) evaluations. The second reason is its unique ability to quantify the vestibular hypersensitivity effects of so-called "third mobile window" inner-ear malformations, in particular superior semicircular canal dehiscence (SSCD) (Minor, 2005).

SSCD, or Minor syndrome, is a missing or significant thinning of the bony covering over the superior semicircular canal in one or both ears. This dehiscence creates a third mobile window into the inner ear, altering the intra-labyrinthine impedance mechanism and directing higher-than-normal levels of sound pressure into the vestibule. Potentially disabling symptoms of SSCD may include: severe sound- or pressure-induced imbalance (Tullio's phenomenon), oscillopsia, autophony (the abnormal enhancement and reverberation of one's own voice), a sense of fullness in the affected ear, and hearing loss, usually characterized by the presence of a low- to mid-frequency air-bone gap that is unexplained by middle ear status (Zhou, Gopen, & Poe, 2007). A surgical correction for SSCD has proven to be a successful treatment in cases with severe symptoms, involving a plugging and/or resurfacing of the superior canal after gaining access via a middle fossa craniotomy (Mikulec, Poe, & McKenna, 2005). SSCD is currently confirmed by a specialized high-resolution CT scan in the plane of the superior canal. Due to the complexity of this technique and the current scarcity of radiologic centers with a protocol in place, a

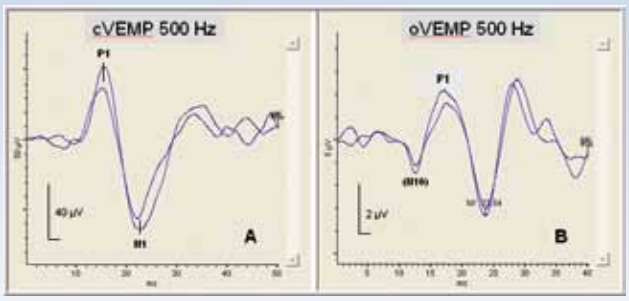

Figure 1: *(a) 100 µV cervical VEMP waveform elicited by a 95 dBnHL 500-Hz tone burst. (b) 5 µV ocular VEMP waveform elicited by a 95 dBnHL 500-Hz tone burst.*

sensitive but simple to perform functional test which may identify candidates for radiologic confirmation of SSCD is of significant importance. In addition, false positive imaging cases of SSCD have been documented (Mikulec & Poe, 2006), demonstrating the need for positive tests of both structure and function before proceeding with surgical exploration and correction.

The most commonly applied VEMP technique involves recording the vestibulo-collic reflex potential over the contracted ipsilateral sternocleidomastoid musculature (SCM) in response to air- or bone-conducted acoustic stimulation. This cervical VEMP (cVEMP) response is characterized by a short latency waveform (Figure 1a) which is extremely variable in terms of amplitude, even within the normal population. Some of this variability is explained by age effects. Another source of variability is the differences in strength of SCM contractions produced between subjects (Akin, Murnane, Panus, Caruthers, Wilkinson, & Proffitt, 2004). Due to these differences, it is recommended that clinicians use EMG monitoring to ensure sufficient contraction strength of the SCM musculature. Some manufacturers of auditory evoked potential equipment have built this EMG monitoring technology into the hardware and software of their testing equipment. Others have included an algorithm to calculate "corrected" VEMP amplitudes by dividing the gross VEMP amplitude by a baseline measure of EMG activity. These techniques have the goal of normalizing VEMP amplitudes and reducing variability to make for more valid inter- and intra-subject comparisons.

The cervical VEMP has proven to be a sensitive test of vestibular hypersensitivity, with responses characterized by abnormally high amplitudes and abnormally low thresholds. While thresholds in most normal subjects fall at 70 dBnHL or greater for low-frequency tone burst stimulation, thresholds in SSCD patients can be significantly below this level, with thresholds as low as 50 dBnHL reported (Zhou, Gopen, & Poe, 2007). There is significant overlap in suprathreshold amplitude between the SSCD and non-SSCD populations, even if contraction strength of the SCM musculature is normalized by monitoring and/or rectification (Welgampola, Oluwaseun, Minor, & Carey, 2008). Therefore, a threshold search is necessary to improve the sensitivity and specificity of the test, which requires a longer evaluation in which patient fatigue can become a factor.

A newer VEMP technique has recently been studied that measures the vestibulo-ocular reflex in response to similarly intense acoustic stimuli. This potential is recorded from electrodes placed inferior to the eye contralateral to the side of auditory stimulation. This potential has been described as the ocular VEMP (oVEMP). The patient participation for oVEMP is much easier than for the cVEMP, requiring only an upward gaze during the testing instead of an active contraction of the SCM musculature (Figure 2), which is often fatiguing for patients. The oVEMP amplitude

Figure 2: *(a) Electrode positioning for right ear cervical VEMP. (b) Electrode positioning for the right ear ocular VEMP testing. (Note that for oVEMP, electrodes are contralateral to the side of stimulation.)*

Stimulus parameters	**cVEMP**	**oVEMP**
Type:	500-Hz tone burst	500-Hz tone burst
Rate:	5.1/sec (max), 13.1/sec (threshold search)	5.1/sec
Intensity (air-conduction):	95 dBnHL and threshold search	95 dBnHL only
Recording parameters	**cVEMP**	**oVEMP**
Amplifier gain:	1000-5000x	100,000-150,000x
Bandpass filtering:	10-750 Hz	10-250 Hz
Recording Epoch:	30-50 ms	30-50 ms
Signal averaging:	100-400 sweeps	100-200 sweeps
Electrode montage	(+) middle 1/3 ipsilateral SCM	(+) just below contralateral lower eyelid
	(-) Sternoclavicular notch	(-) 1 cm below (+) site
	(Ground) forehead	Ground) forehead

Table 1: *Suggested stimulus and recording parameters for cervical and ocular VEMPs.*

is very small (typically 3-6 microvolts) relative to the cVEMP (often well over 100 microvolts). However, since it is recorded from a resting state rather than derived from a large active EMG, the signal-to-noise ratios are not extraordinarily different. Stimulus and recording parameters are similar to cVEMP (Table 1), with the exception of the amplifier gain. Since cVEMP is derived from a large active electromyogram of over 100 microvolts, little amplification of the response is necessary (usually 5000×). The oVEMP however, recorded from a resting muscular state, requires gain similar to that of other auditory evoked potentials (100,000× to 150,000×). The oVEMP response waveform is similar to that of the cVEMP. The two waveforms differ in that the oVEMP has an initial negative deflection that occurs in the 10 ms region (Figure 1b), while the cVEMP has an initial positive deflection in the 13-16 ms region, if the electrode montages described in Table 1 are used. Like the cVEMP, the oVEMP response takes very little signal averaging to resolve the waveform to a satisfactory signal-to-noise ratio, typically requiring only 100-200 sweeps. In our clinic, oVEMP response amplitude is currently the only parameter being utilized for clinical diagnosis. Other parameters of oVEMP are still under investigation.

oVEMP amplitude measurements have the potential to markedly improve differential diagnosis for SSCD. Like the cVEMP, oVEMP thresholds for patients with superior semicircular canal dehiscence are reported to be more sensitive (lower) than normal thresholds. Unlike the cVEMP, however, there appears to be essentially no suprathreshold amplitude overlap between the normal and SSCD populations (Welgampola, Oluwaseun, Minor, & Carey, 2008). If this finding is verified, using oVEMP for these patients could eliminate the need for a time-consuming threshold search, which would significantly improve the efficiency of the test.

Case Study:

A 60-year-old woman presented to our clinic with main complaints of valsalva-induced vertigo and non-lateralizing

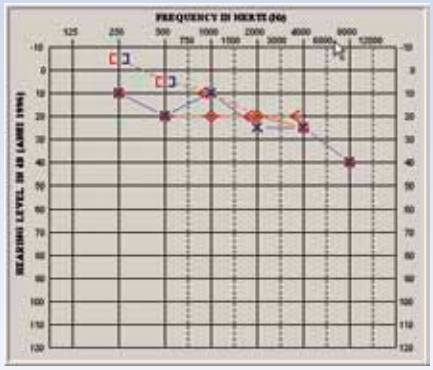

Figure 3: *Audiogram for case study patient. Note the low-frequency air-bone gaps despite normal immitttance measures.*

autophony for over two years. She reported that in addition to the bothersome sound of her own voice, her cardiac pulse was almost always audible, and she reported that she could even hear her joints creaking. Her audiogram (Figure 3) demonstrated borderline normal hearing with slight low-frequency air-bone gaps noted. Tympanometry and ipsilateral middle ear muscle reflexes were normal bilaterally.

Both cVEMP and oVEMP testing was administered. The stimulus for both tests was a Blackman-gated 500-Hz tone burst with two cycles for rise and fall time with no plateau. Initial stimulus intensity was 95 dBnHL (117 pSPL in ER-3A insert phones). The cVEMP (Figure 4) amplitudes at 95 dBnHL were 222 microvolts (µV) in the right ear and 91 µV in the left ear. As we consider the range of normal cVEMP amplitude to be 50-300 µV in our clinic, these results were not significant for hypersensitivity, though the clear asymmetry was noted. Thresholds were found to be 65 dBnHL in the right ear and 75 dBnHL in the left ear. Our clinic considers any cVEMP threshold below 70 dBnHL to be abnormally low, and so this test would be positive for vestibular hypersensitivity in the right ear only.

Ocular VEMP testing (Figure 5) at 95 dBnHL yielded amplitudes of 55 µV in the right ear and 19 µV in the left ear. These values are significantly greater than normal for both ears, as our clinic mean for oVEMP amplitude is 5 µV, and our clinic cutoff for vestibular hypersensitivity is 10 µV, based on our own data and the work of Welgampola and colleagues (2008). This patient was referred by the neuro-otologist for a high resolution CT scan which confirmed clear dehiscences of both superior semicircular canals (Figure 6). This case study is interesting for several reasons:

- cVEMP values were only clearly indicative of vestibular hypersensitivity in the right ear, despite the bilateral superior canal dehiscence.

- oVEMP was correctly positive for bilateral vestibular hypersensitivity, while the asymmetric response also demonstrated more significant affects on the right side. This may be of great importance if unilateral surgical repair of the dehiscence is considered and a side must be chosen, since the patient reported no lateralizing symptoms.

- In addition to being more sensitive to the pathology, oVEMP testing was performed in less than half the time of cVEMP testing while also being more comfortable for the patient.

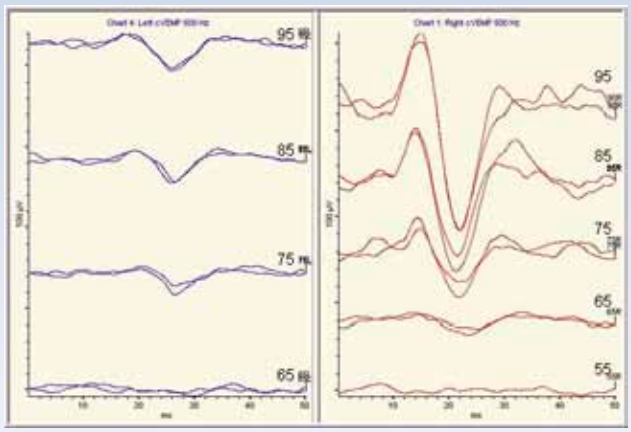

Figure 4: *Cervical VEMP responses for case study patient. The left ear responses were normal for both amplitude and threshold. The right ear response amplitude was within the normal range despite being significantly larger than the left ear, but threshold (65 dBnHL) was significant for vestibular acoustic hypersensitivity.*

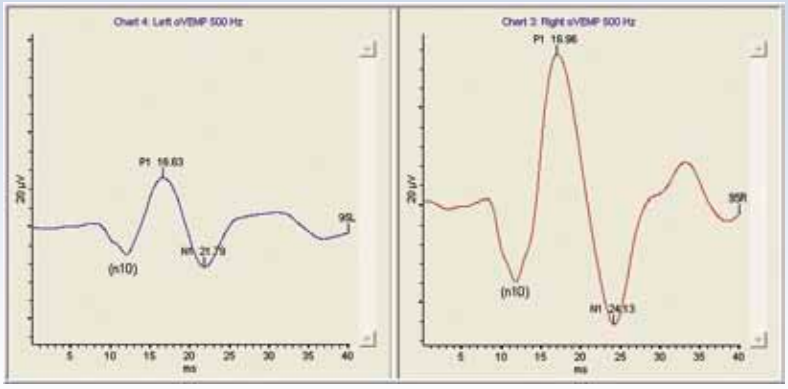

Figure 5: *Ocular VEMP responses for case study patient evoked by 95 dBnHL 500-Hz tone bursts. Amplitudes (19 µV left and 55 µV right) are diagnostic for bilateral vestibular acoustic hypersensitivity.*

Ocular VEMPs offer a new alternative to conventional cervical VEMP testing as a functional measure of vestibular hypersensitivity to sound. It appears that oVEMP sensitivity and specificity, as well as clinical efficiency, may be superior to cVEMP for diagnosis of SSCD. It should be emphasized, however, that oVEMP testing is not an outright replacement for cVEMP testing. The VEMP response is affected by many other vestibular pathologies in addition to SSCD, including Meniere's disease, acoustic neuroma, large vestibular aqueduct, and vestibular neuritis (Hall, 2007). Cervical VEMP testing with EMG monitoring remains the standard technique for test sensitivity to this entire range of vestibular pathologies, particularly since recent work does not indicate 100% agreement between the two tests for all patients (Chihara, Iwasaki, Ushio, & Murofushi, 2007). Our clinic currently practices routine cVEMP testing for all patients undergoing a vestibular workup, with oVEMP testing used as a supplemental technique, particularly in patients with symptoms suspicious of superior semicircular canal dehiscence.

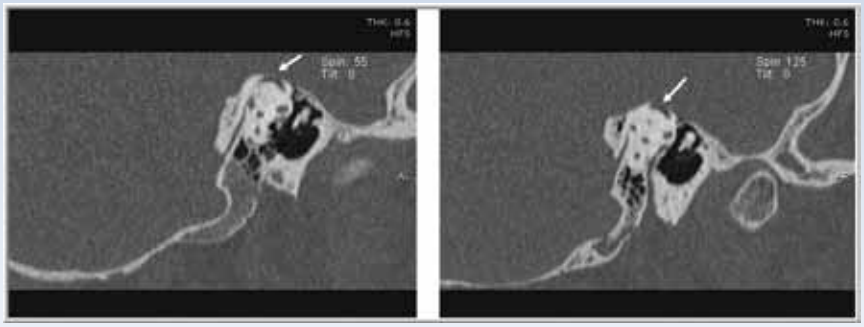

Figure 6: *High resolution CT scan images in the Poschel orientation (parallel to the superior canal). Arrows point to the missing bone above the superior semicircular canal.*

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