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# Properties of 500 Hz air- and bone-conducted vestibular evoked myogenic potentials (VEMPs) in superior canal dehiscence

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## HIGHLIGHTS

- In superior canal dehiscence (SCD), the amplitudes of AC and BC-evoked cVEMP reflexes usually saturate whereas oVEMP amplitudes do not.
- Thresholds for AC-cVEMPs and BC-oVEMPs and amplitudes of AC-oVEMPs and cVEMPs (at 105 dB pSPL) separated SCD with sensitivities of over 83% and high specificity.
- In contrast, AC oVEMP thresholds and BC cVEMP thresholds and amplitudes showed 62% or lower sensitivity in detecting SCD patients.

## ABSTRACT

*Objectives:* To compare threshold and amplitude properties for air- (AC) and mastoid bone-conducted (BC) cervical (cVEMP) and ocular (oVEMP) vestibular evoked myogenic potentials in superior canal dehiscence (SCD).

*Methods:* Thirteen patients (53 ± 14 yrs) clinically diagnosed with SCD were tested using AC 500 Hz sound and BC 500 Hz transmastoid vibration. Baseline intensities of 135 dB pSPL and 138 dB pFL respectively were used and reduced until the response amplitudes were less than 2.5 standard deviations of the prestimulus baseline mean. SCD VEMP amplitudes, response gradients and threshold parameters for the initial peaks for the cVEMP (ipsilateral) and the oVEMP (contralateral) were compared with results for normal subjects over a range of intensities.

*Results:* Despite higher amplitudes, reflex gradients against intensity for AC and BC cVEMPs were significantly less in SCD than normals ($P \ll 0.001$) while AC and BC oVEMP gradients were not significantly different between the groups. Abnormally low thresholds for AC 500 Hz were present for 85% of cVEMPs and 62% of oVEMPs. Abnormally low BC 500 Hz thresholds were seen for 33% of cVEMPs and 83% of oVEMPs. Amplitudes for AC 500 Hz were compared over the 135–105 dB pSPL intensity range. The cVEMP showed more pathologically large amplitude responses with the lower stimulus intensities (135 dB pSPL: 5%, 105 dB pSPL: 100%) whereas the oVEMP demonstrated high rates of amplitude increases for all intensities (129–111 dB pSPL: 92%). The pattern of pathologically large amplitudes evoked by BC 500 Hz was similar for both reflexes such that both cVEMPs and oVEMPs showed maximum prevalence of abnormally large responses around 117 dB pFL (cVEMP: 58%, oVEMP: 83%).

*Conclusions:* In SCD, both AC and BC evoked cVEMPs show evidence of saturation but this is not evident for oVEMPs. Both cVEMPs and oVEMPs show frequent abnormalities of amplitudes and thresholds in SCD compared to normal subjects but the sensitivities differed between measures.

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*Significance:* Previous evidence of saturation of cVEMP responses in SCD was confirmed. For diagnosis, AC cVEMP amplitudes at 105 dB pSPL or AC-evoked oVEMP amplitudes both have over 90% sensitivity in separating SCD from normal responses.



## 1. Introduction

VEMP recordings comprise of short latency surface EMG potentials recorded from over the sternocleidomastoid muscles of the neck (termed cervical VEMPs or cVEMPs; Colebatch et al., 1994) and the inferior oblique muscles below the eyes during upgaze (termed ocular VEMPs or oVEMPs; Rosengren et al., 2005; Iwasaki et al., 2007; Todd et al., 2007). Our recent investigations have explored the relationship between stimulus intensity and VEMP reflex amplitude to air-conducted (AC) sounds and bone-conducted (BC) vibrations (Dennis et al., 2014, 2015). Using a statistical criterion to determine the presence or absence of a response, Dennis et al. (2014) showed a power law relationship fitted the AC cVEMP response but not the initial oVEMP potentials. More recently, the input–output properties of AC 500 Hz and BC 500 Hz stimulus modalities were compared by Dennis et al. (2015) who showed no difference in intensity gradients between modalities for the cVEMP, whereas the earliest oVEMP potentials showed differences that were modality dependent.

Superior canal dehiscence (SCD) syndrome is a neurotological disorder which affects normal sound and pressure transmission within the inner ear and is due to thinning or fenestration of the temporal bone overlying the superior semicircular canal (Minor et al., 1998). Clinical presentations of SCD encompass a wide spectrum of vestibular and/or auditory symptoms, sometimes mild (Minor, 2005). The defect causes a larger amount of acoustic energy to be diverted to the vestibular apparatus, thereby causing more intense stimulation. The diagnosis of SCD is usually based on a combination of clinical findings and includes signs and symptoms of sound/pressure induced vertigo (i.e. the Tullio phenomenon), the presence of dehiscence on high-resolution CT imaging, and typical abnormalities on vestibular evoked myogenic potential (VEMP) testing. VEMPs are an important part of the assessment of possible SCD because radiological findings alone cannot determine whether a bony defect is sufficient to have functional consequences. Dennis et al. (2014) reported a single patient with SCD over a range of intensities and found large responses with evidence of saturation for the cVEMP and possibly for the oVEMP.

VEMP reflexes elicited by AC and BC stimuli have been used to investigate vestibular function in SCD (Brantberg et al., 1999; Watson et al., 2000; Rosengren et al., 2008; Welgampola et al., 2008). Initial reports identified pathologically low AC cVEMP thresholds to click and tone burst stimuli in SCD while AC cVEMP amplitudes were reported to be enlarged but overlapped between SCD patients and controls (Brantberg et al., 1999; Watson et al., 2000). Like cVEMPs, oVEMPs also demonstrate low thresholds and enlarged amplitudes in SCD. AC oVEMP amplitudes have been suggested to be more useful in identifying SCD as they demonstrate less overlap with normals (Rosengren et al., 2008; Welgampola et al., 2008).

In this study, we sought to determine the properties of AC and BC VEMPs in a larger group of SCD patients in response to changing stimulus intensities. It has been suggested that the cVEMP may saturate due to it being an inhibitory response (Colebatch and Rothwell, 2004), while for the oVEMP it is possible that SCD may not be simply an enhancement of the normal pattern of response. In the case of the oVEMP there is evidence that activation of superior semicircular canal afferents by AC sound occurs in SCD and contributes to the oVEMP potential (Rosengren et al., 2008). While the diagnostic sensitivity of AC cVEMP and AC oVEMP amplitudes differ in SCD, both reflexes show pathologically lowered AC thresholds (Welgampola et al., 2008). It has been suggested that cVEMPs evoked by low intensity AC stimuli are more useful in diagnosis of SCD than conventional amplitudes, and also avoid the time taken to determine actual thresholds (Brantberg and Verrecchia, 2012). Welgampola et al. (2008) found BC stimuli to be less useful in detecting SCD as both cVEMPs and oVEMPs showed overlap with normals for both threshold and amplitude parameters.

We have studied the patterns of response in SCD to changing intensity for both AC and BC stimuli and have compared these with corresponding data previously collected for normal subjects. Although VEMPs have been previously studied in SCD, ours is the first study to systematically define the input–output properties using both AC and BC stimuli for both cVEMPs and oVEMPs. We were also able to assess the value of amplitudes and thresholds for cVEMPs and oVEMPs for both AC and BC 500 Hz stimulation in separating SCD responses from normals. Thus we are the first to have compared the diagnostic value of alterations in thresholds and amplitudes, over a range of intensities, for both AC and BC stimuli and both cVEMPs and oVEMPs.

## 2. Methods

### *2.1. SCD patients*

Fourteen patients were recruited from the Prince of Wales and Royal Prince Alfred Hospitals. The inclusion criteria consisted of clinical features typical of SCD diagnosis; a pathologically low cVEMP threshold, dehiscence confirmed by high-resolution temporal bone CT imaging and clinical signs and symptoms associated with SCD (Minor, 2005). Thirteen patients (28–77, mean 52.7 years) met these criteria and were included in the final study (Supplementary Table S1). SCD patients were tested using AC sound ($n = 13$) and BC vibration ($n = 12$). SCD responses were compared with those of normals previously collected using the same AC 500 Hz (Dennis et al., 2014) and BC 500 Hz stimuli (Dennis et al., 2015). All study participants gave informed consent prior to testing and the study was approved by the local ethics committee.

### *2.2. AC and BC 500 Hz stimuli*

Both stimulus modalities consisted of unmodulated 2 ms, 500 Hz sinusoidal tone bursts which were generated using customised software and a CED laboratory interface (1401plus, Cambridge Electronic Design, UK). A custom power amplifier was used for AC 500 Hz and a type 2718 (Brüel & Kjær, Denmark) for BC 500 Hz. Alternating AC 500 Hz tones were delivered using calibrated headphones (TDH 49, Telephonics Corp., Farmingdale, USA). BC 500 Hz tones were delivered over the mastoid using a customised hand-held mini-shaker (model 4810, Brüel & Kjær, Denmark). An initially positive polarity (i.e. movement of the mini-shaker towards the head) was used during BC recordings.