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Differing response properties of cervical and ocular vestibular evoked myogenic potentials evoked by air-conducted stimulation

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HIGHLIGHTS

- cVEMPs and oVEMPS were recorded simultaneously from 15 healthy volunteers and 1 patient with superior canal dehiscence (SCD) using air conducted (AC) sound over a 30 dB range.
- The SCD patient had larger amplitude responses at all intensities except for the cVEMP at the loudest intensity.
- Whilst the cVEMP p13/n23 response was well fitted by a power law relationship the oVEMP n10/p16 response showed a change in gradient for the louder intensities and this may relate to differences in the pathways responsible.

ABSTRACT

Objective: To determine the amplitude changes of vestibular evoked myogenic potentials (VEMPs) recorded simultaneously from the neck (cVEMPs) and eyes (oVEMPs) in response to 500 Hz, 2 ms air-conducted sound pips over a 30 dB range.
Methods: Fifteen healthy volunteers (mean age 29, range 18–57 years old) and one patient with unilateral superior canal dehiscence (SCD) were studied. The stimulus was reduced in increments to 105 dB pSPL for the normals (81 dB pSPL for the SCD patient). A statistical criterion was used to detect responses.
Results: Ipsilateral (i-p13/n23) and contralateral (c-n12/p24/n30) peaks for the cVEMP montage and contralateral (c-n10/p16/n21) and ipsilateral (i-n13) peaks for the oVEMP montage were present for the baseline intensity. For the lowest intensity, 6/15 subjects had responses for the i-p13 cVEMP potential and 4/15 had c-n10 oVEMP responses. The SCD patient showed larger responses for nearly all intensities. The cVEMP potentials were generally well fitted by a power law relationship, but the oVEMP c-n10, p16 and n21 potentials showed a significant increase in gradient for the higher intensities.
Conclusion: Most oVEMP and cVEMP responses follow a power law relationship but crossed oVEMP responses showed a change in gradient above a threshold.
Significance: The pattern of response to AC stimulation may be a property of the pathways underlying the potentials.

1. Introduction

The vestibular apparatus has strong connectivity to both the eyes and neck mediating the vestibulo–ocular and vestibulocollic reflexes. Developments in vestibular research have given rise to non-invasive methods for assessment of these pathways by means of short latency evoked responses in the target muscles. Originally recorded over the sternocleidomastoid (SCM) muscles, the earliest response was termed a vestibular evoked myogenic potential (or VEMP) (Colebatch et al., 1994). These potentials are now commonly referred to as a cervical VEMP (CVEMP or cVEMP). A subsequently discovered myogenic response in peri-ocular locations was termed by analogy ocular VEMPs (OVEMPs or oVEMPs: Rosengren et al., 2005; Todd et al., 2007). Both recording sites are characterised by a series of short latency positive and negative waves which occur both ipsilaterally and contralaterally to a monaural air-conducted (AC) stimulus. For the cVEMP montage these include the ipsilateral p13, n23 (or i-p13/n23) and contralateral n12, p24 and n30 peaks (or c-n12/p24/n30), and for the oVEMP

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montage these are the contralateral n10, p16, n21 (or c-n10/p16/n21) and ipsilateral n13 peaks (or i-n13). Only the earlier potentials have been firmly established as being vestibular-dependent and, for the cVEMP montage in particular, the later peaks are unlikely to be of vestibular origin (Colebatch et al., 1994). VEMPs have proven to have useful diagnostic applications as well as providing a tool to investigate the properties of the human vestibular system (see Rosengren et al., 2010 for review).

It is generally agreed that VEMPs when activated by acoustic stimulation are a manifestation of the otolith-ocular or otolith-collic pathways but different modes of acoustic stimulation may produce different patterns of end-organ activation (Todd et al., 2007). There is evidence that mid-frequency AC sound stimulation (best frequency 500–1000 Hz) may be selective for the saccule, whilst low-frequency vibration of the head (best frequency 80–100 Hz) appears to be more selective for the utricle, especially if the direction of vibration is aligned within the plane of morphological polarisation of utricular hair-cells (Todd et al., 2008a,b, 2009). Recent work by Zhang et al. (2011, 2012) has provided evidence that both sound and vibration may produce distinct resonances at about 100 and 500 Hz, suggestive that the two resonance peaks are not specific to the two modes of stimulation, but to the different dynamic responses of the vestibular end organs. The matter remains controversial, however. Whilst the saccule has been shown to be responsive to acoustic stimuli (McCue and Guinan, 1997; Murofushi and Curthoys, 1997), the projections to the eyes have been reported to be weak (Isu et al., 2000) and the utricle has been proposed as an alternative source of the AC oVEMP (Curthoys, 2010). At this stage there is consensus that the responsible fibers are likely to arise from the otolith organs and travel via the superior vestibular nerve (e.g., Govender et al., 2011).

A fundamental property of any reflex is the input–output relationship – how the reflex response varies as a consequence of changes in the afferent input. An early study of the cVEMP identified the adequate air-conducted stimulus as being of high intensity, with larger responses occurring with higher stimulus intensities (Colebatch et al., 1994). Lim et al. (1995) reported a linear relationship between click intensity, measured in decibels (dB), and reflex cVEMP amplitude. No similar study has been performed for the oVEMP using AC stimuli, although Todd et al. (2008b) showed that low-frequency vibration-evoked oVEMPs followed a power-law relationship. The present study was designed to explore systematically the behaviour of the cVEMP and oVEMP reflexes and associated potentials to changes in stimulus amplitude whilst controlling for the effects of background activation. Our objective was to determine whether the relationship between intensity and reflex amplitude was the same for the different peaks recorded using the cVEMP and oVEMP montages and, more specifically, between the early cVEMP and oVEMP potentials, a finding that might be expected if both arose from the same receptor. A possible complicating factor is saturation of the cVEMP, which is known to be an inhibitory reflex (Colebatch and Rothwell, 2004). In addition, we wished to compare the thresholds for the responses as this might also indicate whether the same end organ was likely to generate both. One patient with superior canal dehiscence (SCD: Minor et al., 1998) was studied to compare with our findings in healthy subjects.

2. Methods

2.1. Subjects

Fifteen healthy adults aged 18–57 with no history of vestibular dysfunction participated in this study. Eleven subjects were tested at Prince of Wales Hospital, Sydney (7 men, 4 women; mean age 29 ± 14 years) and 4 subjects at University of Manchester (1 man, 3 women; mean age 31 ± 15 years). One patient with unilateral superior canal dehiscence (SCD) also participated (female; age 50 years) and was tested in Sydney. Dehiscence of the left superior canal had been previously confirmed in this patient using high-resolution CT imaging of the temporal bone and VEMP testing. Subjects gave written consent according to the Declaration of Helsinki before the experiment and the study was approved by the local ethics committees in Sydney and Manchester.

2.2. Stimuli

Stimuli were generated using custom software and a CED laboratory interface (1401plus, Cambridge Electronic Design, Cambridge, UK), and signal amplification was achieved using a custom amplifier. Subjects were presented with sinusoidal 500 Hz, 2 ms tone bursts (0 ms rise and fall) at a rate of ~5 Hz. Stimuli were delivered using audiometric headphones (TDH 49, Telephonics Corp., Farmingdale, USA). The output was calibrated using a type 4192 pressure field microphone with a 4153 artificial ear and a 2260 sound level meter (Brűel & Kjær, Naerum, Denmark). The stimulus polarity was alternated to reduce stimulus artefact.

2.3. cVEMP and oVEMP montages

Electromyographic (EMG) activity was recorded simultaneously from the SCMs and below the eyes using self-adhesive Ag/AgCl electrodes (Cleartrace 1700-030, Conmed Corp., NY, USA). AC cVEMPs and oVEMPs obtained concurrently or separately yield the same results (Chou et al., 2009), and we have employed the simultaneous recording technique to shorten the procedure and to ensure the same conditions were applied to both reflexes. For the cVEMP montage, the active recording electrodes were placed on the upper third of the muscle belly and the reference electrodes on the sternal end of the clavicles. An earth electrode was placed above the lateral third of the clavicle. Subjects reclined to ~30 degrees above horizontal and were required to lift their heads to activate the SCM muscles for the duration of the recording. For the oVEMP montage, electrodes were placed on the orbital margin inferior to both eyes and reference electrodes were positioned approximately 3 cm below them. A custom-made headband was used to secure a small laser pointer that projected a red spot onto the ceiling (Fig. 1). The pointer was positioned to produce an elevated gaze of ~30 degrees for each subject and this was used as a constant point of reference for eye elevation regardless of slight changes in head position. Amplitudes were measured from the extraocular muscles both contralateral and ipsilateral to the stimulated ear. EMG was recorded for both the cVEMP and oVEMP montages from 20 ms before to 100 ms after stimulus onset and averaged over 200–250 individual trials using SIGNAL software (version 3, Cambridge Electronic Design, Cambridge, UK). Peaks were named using polarity and mean latency. For clarity, as we have analysed a number of peaks for both recording sites, we have used the prefix i- or c- when referring to a peak ipsilateral or contralateral to the stimulus. For the SCD patient, fewer individual trials were conducted at the high intensities (30–100) due to the response being easily detected and also to minimise patient discomfort.

2.4. Stimulus protocol

Each subject was stimulated in one ear which was chosen using a pseudo-randomised approach (11 on the left and 4 on the right). The SCD patient was stimulated using her left (affected) ear. Electrode impedance was maintained below 10 kΩ before recordings