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Mastoid and vertex low-frequency vibration-induced oVEMP in relation to medially directed acceleration of the labyrinth

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HIGHLIGHTS

- oVEMP in response to low-frequency bone-conducted vibration is dependent on stimulus direction and consequently on stimulus site and configuration.
- Low-frequency bone-conducted vibration at vertex might serve for simultaneous oVEMP testing of both ears.
- oVEMP in response to low-frequency bone-conducted vibration may have a fundamental dependency on medially directed accelerations of the labyrinth.

ABSTRACT

Objective: To explore the stimulus site and stimulus configuration dependency for bone-conducted low-frequency vibration-induced ocular vestibular evoked myogenic potentials (oVEMPs).
Methods: oVEMPs were tested in response to 125 Hz single cycle bone-conducted vibration in healthy subjects ($n = 12$) and in patients with severe unilateral vestibular lesions ($n = 10$). The stimulus sites were the mastoids and vertex. Both directions of initial stimulus motion were used.
Results: At mastoid stimulation, the oVEMP to initial laterally directed acceleration of the labyrinth was delayed approximately the length of time of a stimulus half-cycle, as compared with the response to initial medially directed acceleration. At vertex stimulation, the oVEMP to positive initial acceleration was similar to the oVEMP to mastoid stimulation causing lateral initial acceleration. Likewise, the oVEMP to vertex negative initial acceleration was similar to mastoid stimulation causing initial medial acceleration. Further, patients with unilateral vestibular loss had, compared to healthy subjects, similar oVEMP from the healthy labyrinth.
Conclusions: A fundamental dependency on medially directed accelerations of the labyrinth, based on the latency differences revealed, may theoretically account for oVEMP in response to low-frequency stimulation.
Significance: Low-frequency bone vibration stimulation at vertex might serve for simultaneous oVEMP testing of both ears.

1. Introduction

Vestibular evoked myogenic potentials (VEMPs) are short-latency electrical muscle responses to different vestibular stimuli (for review: Rosengren et al., 2010). Nowadays, recordings from sternocleidomastoid muscles (cervical VEMPs, cVEMPs) in response to sounds are used to test for saccular and inferior vestibular nerve function. More recently, recordings from extra-ocular muscles using electrodes attached below the eyes (ocular VEMPs, oVEMPs) have been suggested as a vestibulo-ocular test (Rosengren et al., 2005; Todd et al., 2007; Iwasaki et al. 2007). oVEMPs depend on the integrity of the superior division of the vestibular nerve (Iwasaki et al., 2009; Curthoys et al., 2011; Govender et al., 2011a; Shin et al., 2012). oVEMPs have also been suggested to be mainly related to utricular function, at least in response to lateral impulses (Todd et al., 2008a; Govender et al., 2011a). Further, an easily conducted utricular test is warranted, which would supplement semicircular canal tests (caloric and head impulse test) and the saccular test (cVEMP) at clinical evaluation of vestibular function.

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oVEMPs are more easily recordable in response to bone-conducted (BC) stimuli compared to air-conducted (AC) sound (Rosengren et al., 2011). oVEMP amplitude in response to mastoid stimulation is largest for BC vibration in the frequency range of approximately 100 Hz (Todd et al., 2008b, 2009). Further, the best stimulus site for clinical testing of BC-induced oVEMPs has not yet been established. Most clinical data available are either from stimulations at the midline forehead, or stimulations at the mastoids (Iwasaki et al., 2009; Manzari et al., 2010; Govender et al., 2011b). Midline stimulations may stimulate both ears equally, provided that the stimulus is delivered perpendicular to the midline site. Because oVEMPs appear to be an almost completely one-sided crossed response i.e., oVEMPs recorded from under one eye reflect labyrinthine function in the opposite ear (Iwasaki et al., 2007; Chihara et al., 2007; Weber et al., 2012), it is likely that utricular function can be evaluated independently for both ears in response to simultaneous stimulation, as in midline BC vibration.

However, from a physiological standpoint, mastoid stimulation i.e., causing a lateral head acceleration in the horizontal plane, might be more appealing than e.g. vertex stimulation because utricular afferents are most sensitive in the interaural axis (Fernández and Goldberg, 1976). By contrast, oVEMPs are critically dependent on the direction of the imposed acceleration (Todd et al., 2008a; Holmeslet et al., 2011; Cai et al., 2011; Jombik et al., 2011). As a consequence, subsequent mastoid stimulations behind both ears are probably necessary to obtain comparable oVEMPs from the two labyrinths.

The aim of the present study was to compare mastoids and vertex as stimulus sites for oVEMPs in response to low-frequency BC vibration, and to further explore which stimulus direction triggers the oVEMP. Vertex as midline stimulus site was chosen because we have found it unproblematic to standardize with regard to the static force of the used BC stimulator and the head position during the test.

2. Materials and methods

This study received prior approval from the institutional review board. Each subject/patient gave their informed consent to participate.

2.1. Subjects

The study group consisted of twelve healthy 23–63 year old subjects (mean age 41 years, 8 women and 4 men). According to their own statements, none of the subjects had any history of vestibular or neurologic disorders or any chronic ear disease. Data were also obtained from ten 52 to 70 year old patients (mean age 62 years, 3 women and 7 men). All ten patients were selected for the study based on the assumption of severely impaired unilateral vestibular function. They had been treated with unilateral intratympanic gentamicin ($n = 7$) or had undergone a surgical unilateral labyrinthectomy ($n = 3$). Further, post-treatment evaluation, including caloric and cVEMP testing, had suggested complete vestibular loss on the affected side and normal function on the non-treated side.

2.2. oVEMP stimuli

A commercially available "bone-conduction vibrator" (Bruel and Kjaer "Minishaker" 4810) was used for stimulation. It was fitted with a 5.5 cm long rod made of polyoxymethylene (Delrin), 2 cm in diameter. The end of the rod is flat and it is with this section that contact is made with the subject/patient (contact area = 175 mm^2). During the recording, each subject maintained a sitting position. The head was held so that Reid's plane, an imaginary line between the inferior orbital rim and the opening of the outer ear canal, was approximately horizontal. The subject was asked to look forwards and upwards as much as possible during each stimulus sequence, which lasted approximately 15 s. The subject was encouraged to not blink.

The handheld "Minishaker" was placed at the vertex and supported with no additional force (static force = 10 N) so that the longitudinal axis of the vibrator was approximately in line with gravity. For mastoid stimulation, the stimulator was placed directly behind the tragion and pinna (Rosengren et al., 2005). An interconnected load cell (Measurement Specialties Inc., ELFF-T4E-50N), placed between the Minishaker and the polyoxymethylene rod, was used to monitor/maintain static force at 10 N.

A Medelec Synergy signal averager generated the bone-conducting stimuli signals. Single cycle 125 Hz tone-bursts were used for stimulation. The stimulus intensity was 135 dB peak-to-peak equivalent force level re 1 μN (settings = 115 dB in the Medelec program with an additional 20 dB from an amplifier (Power Amplifier Type 2718, Brüel and Kjaer)). A total of 64 stimuli were given during each sequence, consisting of 5 stimuli per second. This cycle was repeated three times with a short break in between, hence a total of 192 stimuli were given to each subject/patient for each stimulus mode.

All subjects and patients were tested using both polarities i.e., a positive first phase is when the rod attached to the "Minishaker" is moving towards the head, while a negative first phase is when the rod is moving away from the head. The stimulus order was systematically varied.

2.3. Accelerometry

Head acceleration responses to determine the main axis of the used BC vibration stimuli were evaluated in 7 subjects on a separated day from the oVEMP testing. A small ($4 \times 4 \times 1.45$ mm) triaxial accelerometer (Analog Devices ADXL335, One Technology Way, Norwood, MA, USA) was placed normal to the skull directly behind the tragion and pinna on the right side. The accelerometer was secured using a tape fastener (4910F, 3 M™ VHB™ Tapes, St. Paul, MN, USA). The head accelerations to left mastoid stimulation and to vertex stimulation were recorded, and both initial stimulus directions were applied. Head acceleration was measured over 60 ms and averaged over 16 stimuli for each stimulus polarity and stimulus site.

2.4. oVEMP recordings

The Medelec Synergy signal averager was used to measure surface electromyographic activity using small self-adhesive skin electrodes (Neuroline 720, Ambu and Ballerup, Denmark). Two pairs of electrodes were placed underneath each eye along an imaginary vertical line directly below the pupils. The active (inverting) electrode was placed in the area of the infra-orbital ridge. The reference electrode was placed approximately 2 cm below the active electrode.

The ground electrode was placed on the uppermost part of the sternum. The attachment sites were gently rubbed with fine sandpaper (Trace Prep, 3M Dot, Ontario, Canada) to minimize skin resistance. In most cases electrode impedance was less than 7 kΩ.

2.5. oVEMP analysis

For analysis, the unrectified response was amplified and analogue filtered (pass-band 20–2000 Hz). The latency for the first negative peak (n1), the first positive peak (p1) and the peak-to-peak