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Ocular and cervical vestibular evoked myogenic potentials produced by air- and bone-conducted stimuli: Comparative properties and effects of age

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- oVEMPs and cVEMPs evoked by air-conducted sounds, bone-conducted vibration and lateral accelerations were compared in 61 normal subjects.
- oVEMP response rates varied widely (59–96%) for the different stimulus modalities, while cVEMP rates were more consistent (91–100%).
- Significant declines with age were present only for the AC stimuli and BC mastoid 500 Hz vibration, but not forehead taps or lateral accelerations.

A B S T R A C T

Objective: To compare amplitudes, latencies, symmetry and the effects of age for both ocular and cervical vestibular evoked myogenic potentials (oVEMPs and cVEMPs) produced by different types of air- (AC) and bone-conducted (BC) stimuli.
Methods: Sixty-one normal subjects aged 18–80 years participated. Both reflexes were recorded in response to AC clicks, AC and BC 500 Hz tone bursts, forehead taps and lateral mastoid accelerations.
Results: AC tone bursts, clicks and BC tone bursts evoked oVEMPs in 81%, 59% and 65% of ears, respectively. The AC stimuli had higher thresholds for oVEMPs than for cVEMPs and all three stimuli produced higher asymmetry for the oVEMP than for the cVEMP. Forehead taps and lateral pulses evoked oVEMPs in 96% and 92% of cases. AC click- and BC tone burst-evoked oVEMPs showed a significant decline with age.
Conclusions: AC stimulation and BC tone bursts delivered to the mastoid are less effective in evoking oVEMPs than in evoking cVEMPs, have high degrees of asymmetry in normals and appear to decline with age. Forehead taps and lateral accelerations produce more symmetrical effects and showed no significant decline with age.
Significance: Stimulus properties need to be considered when deciding the most appropriate way to investigate vestibular function using oVEMPs.

1. Introduction

Vestibular evoked myogenic potentials (VEMPs) have become an accepted test of vestibular function. Recorded from the sternocleidomastoid (SCM) muscles in the neck (cervical VEMPs, cVEMPs), they are a measure of the short-latency vestibulo-collic reflex (Colebatch et al., 1994). In recent years VEMPs recorded from the extraocular muscles (ocular VEMPs, oVEMPs) have also gained interest in the field of vestibular neurophysiology. Although they are measured by surface electrodes placed near the eyes, they are not eye movements (i.e. shift of the corneoretinal dipole), but represent the activity of the eye muscles preceding an eye movement (Todd et al., 2007).

Although cVEMPs and oVEMPs share many similarities, there are also significant differences between the reflexes. While the dominant cVEMP is seen in the ipsilateral SCM and has an initial positive (inhibitory) peak at approximately 13 ms (i.e. the p13 or p1; Colebatch et al., 1994), the primary oVEMP projection appears to be crossed and is usually an initial negative peak at about 10 ms (i.e. n10 or n1). For both reflexes bilateral responses are sometimes present, due to a bilateral projection and/or because both sides are stimulated simultaneously. While the myogenic origin of the cVEMP is known to be the SCM muscle, the extraocular muscles involved in the oVEMP are less clear, but are thought to usually reflect inferior oblique muscle activity (Rosengren et al., 2005; Iwasaki et al., 2007; Govender et al., 2009).

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There is also uncertainty concerning which vestibular end organ is responsible for each reflex under different stimulation conditions. Many animal studies suggest that saccular afferents are activated by air-conducted (AC) sound (McCue and Guinan, 1994; Young et al., 1977), although some utricular afferents will likely also be activated (Murofushi and Curthoys, 1997). Similarly, irregular afferents from both otoliths are sensitive to bone-conducted (BC) vibration at 500 Hz (Curthoys et al., 2006). However, the relative sensitivities of the saccule and utricle to sound and vibration have not been determined. Human studies support both cVEMPs and oVEMPs evoked by different forms of BC stimulation being mediated at least in part by utricular afferents (i.e. including forehead 500 Hz vibration and taps as well as taps delivered to the mastoid: Brantberg and Mathiesen, 2004; Govender et al., 2011; Iwasaki et al., 2009; Manzari et al., 2010). The cVEMP evoked by AC sound appears to be mostly saccular in origin, with a contribution from other (probably utricular) afferents (Welgampola and Colebatch, 2001). By contrast, the AC oVEMP follows a similar pattern to the BC oVEMP in vestibular neuritis, suggesting that it is also mediated by afferents coursing through the superior nerve (Curthoys et al., 2011; Govender et al., 2011).

Although there has been recent debate about the origins of the cVEMP and oVEMP to AC and BC stimulation, there has been relatively little comparison of the reflexes evoked using different types of stimulation. Many studies use one stimulus for the cVEMP (usually AC sound) and another for the oVEMP (usually BC stimulation). Many papers on BC cVEMPs used a B-71 clinical bone conductor, but this stimulator has not been taken up for the oVEMP (Iwasaki et al., 2007). Evidence suggests that the properties of the stimulus are critical determinants of both cVEMP and oVEMP characteristics. In particular, for BC stimulation the direction, frequency and site of stimulation have a significant effect on the polarity and latency of the reflexes (Cai et al., 2010). Finally, it is known that age can have significant effects on cVEMPs, which differ for different stimulus types (Welgampola and Colebatch, 2001). As such, it is important to understand the characteristic responses evoked by these stimuli, their variability and the effects of age. We therefore compared the cVEMPs and oVEMPs evoked by a range of effective vestibular stimuli in a large sample of normal subjects aged between 18 and 80 years of age.

2. Methods

2.1. Subjects

Sixty-one normal, community-dwelling volunteers participated, with 10 in each decade from 20 to 80 years of age (28 females, 33 males; age range 18–80 years). We also tested an 18 year old male who was included in the 20–29 year group. Exclusion criteria included conductive hearing loss, middle ear disease or surgery, a diagnosis of vestibular disease, vertigo that lasted for more than a day or required hospitalization or neurological disease. Screening audiograms were conducted in all subjects using 500 Hz AC and BC tones and subjects with more than a 20 dB air-bone gap were excluded. This value incorporated the error due to the acoustically unshielded room. All participants gave informed consent according to the Declaration of Helsinki and the study was approved by the local ethics committee.

2.2. Stimuli

All subjects were stimulated with AC clicks and tone bursts, BC tone bursts delivered to the mastoids and head taps delivered to the forehead. Impulsive acceleration applied to the mastoid was added slightly later to the study ($N = 51$). The clicks and tone bursts were matched for sound energy (i.e. in dB $L_{Aeq\ (1s)}$). This allowed accurate comparison between stimuli as the differing energy content was taken into account (Rosengren et al., 2009b). The clicks were 0.2 ms square waves of 105 dB $L_{Aeq\ (1s)}$ (2.72 V input, 135 dB peak SPL) and the tone bursts were 500 Hz, 2 ms unshaped sine waves of 105 dB L_{Aeq} (3.83 V peak to peak input, 132 dB peak SPL) delivered with calibrated headphones (TDH 49, Telephonics Corp., Farmingdale, USA). The BC tone bursts were 500 Hz, 4 ms unshaped sine waves of 136 dB peak FL (6.3 N peak) and alternating polarity delivered by a B-71 bone conductor placed over the mastoid (B-71, Radioear Corp., New Eagle, PA, USA). Taps were delivered near the hairline using a reflex tendon hammer with an electronic trigger (model 842-116700, Nicolet Biomedical Inc, Madison, USA). Impulsive head acceleration was produced by a hand-held 'minishaker' (model 4810, Brüel & Kjaer, Denmark). The minishaker input was a third order gamma distribution with 4 ms rise time and peak amplitude of 131 dB FL (3.55 N peak; Todd et al., 2008). The minishaker was held behind the external auditory meatus by the experimenter with ~1 kg force. The stimulus had positive polarity, i.e. the rod moved the head away from the motor, similar to a tap to the mastoid. The pulses produced ~0.13 g head acceleration and the taps ~0.45 g (Rosengren et al., 2009a). A total of 256 stimuli were delivered at a rate of 5 Hz, except for the forehead taps, for which 40 stimuli were delivered at ~2 Hz.

2.3. oVEMP recordings

Subjects sat upright and directed their gaze to a target located ~3 m away at an elevation of 20 deg. In some trials subjects were also asked to adopt maximal up-gaze (see below). The active electrode was placed on the orbital margin below the eye and referred to an electrode 15 mm below it on the cheek, with the earth placed on the sternum. Our recording parameters have been reported in detail previously (Govender et al., 2009). Amplitudes were measured from baseline to peak (for the n1) and also peak to peak (n1-p1).

2.4. cVEMP recordings

Subjects reclined to 30 deg above horizontal and lifted their heads to activate the SCM muscles. The active electrode was placed over the muscle belly, the reference over the medial clavicle, and the earth on the sternum. Rectified EMG was monitored and recorded, and care was taken to ensure similar background activation of the SCM between sides of the neck and trials. Standard recording parameters were used and have been reported in detail previously (Rosengren et al., 2009a). Amplitudes were measured from peak to peak (pp: p1-n1), and expressed as the ratio of pp amplitude to the background mean rectified activity measured over the 20 ms pre-stimulus period. For the acceleration pulses, the ipsilateral cVEMP was measured peak to peak, while the contralateral cVEMP was measured from baseline to p1 peak, as only the first peak is vestibular-dependent (Rosengren et al., 2009a).

2.5. Procedure

Screening audiograms were conducted before the VEMPs. The order of VEMP tests was counterbalanced. Half of the subjects underwent cVEMP testing first and half oVEMP testing first. AC stimuli were delivered first (counterbalanced for clicks vs tone bursts), and one ear of each subject was chosen *a priori* for threshold testing with both types of AC stimuli (half left and half right in each decade). Thresholds were measured using a 10–5 dB bracketing technique and responses were accepted when present on two