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Vestibular-evoked extraocular potentials produced by stimulation with bone-conducted sound

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Abstract

Objective: To investigate the origin, whether ocular or extraocular, of the short latency frontal potential (N15) reported by Todd et al. (2003) following vestibular stimulation.

Methods: Fourteen subjects with low VEMP thresholds (V_T) and 9 patients with vestibular or ocular disorders were stimulated at the mastoid with bone-conducted tone bursts (500 Hz, 8 ms) above vestibular threshold, using a B71 bone vibrator. Surface potentials were recorded from Fpz and around the eyes and referred to linked earlobes.

Results: The N15 was present at Fpz, but was largest around the eyes (mean amplitude 2.6 μV, peak latency 13.4 ms, with stimulation at + 18 dB above threshold) and was generally in phase above and below the eyes. The response was vestibular-dependent and modulated by alteration of gaze direction. The potentials were delayed in a patient with Miller Fisher syndrome and were larger in patients with superior canal dehiscence than in controls.

Conclusions: We report a new vestibular-evoked extraocular potential. Its properties are not consistent with an eye movement. It is likely to be produced, mainly or exclusively, by synchronous activity in extraocular muscles (i.e. a myogenic potential).

Significance: Vestibular-evoked extraocular potentials extend the range of vestibular pathways that can be assessed electrophysiologically, and may be a useful additional test of vestibular function.

Keywords: Vestibular reflexes; VEMP; Ocular reflexes; Oculomotor; Bone conduction

1. Introduction

Short latency vestibular evoked potentials (VsEPs) have been recorded from over the brain in humans in response to both imposed head movements (Sohmer et al., 1999) and direct vestibular nerve stimulation (de Waele et al., 2001). Recently, Todd et al. (2003) demonstrated that VsEPs could also be produced by an acoustic stimulus capable of activating the vestibular apparatus (500 Hz, high intensity BC tone bursts). The vestibular apparatus is known to be activated by loud sounds, including clicks and low frequency bone-conducted (BC) tone bursts (Colebatch et al., 1994; Sheykholeslami et al., 2001). The sound-evoked VsEPs included a positivity at 10 ms (P10), which was maximal at the vertex (Cz), and a negativity at 15 ms (N15), which was distributed frontally. Both potentials had thresholds similar to the vestibular evoked myogenic potential (VEMP) threshold, a short latency *myogenic* response recorded in the anterior neck following vestibular stimulation (Colebatch et al., 1994). The P10 and N15 were present in a patient with profound hearing loss but preserved vestibular function, and were absent in a patient with hypovestibular function but preserved hearing.

Todd et al. (2003) also recorded VsEPs to sound in a patient with superior canal dehiscence (SCD) and the Tullio phenomenon, characterised by vestibular hypersensitivity to sound (Minor et al., 1998). In SCD patients, sound and/or pressure produce vestibular symptoms, such as vertigo,

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disequilibrium and oscillopsia. A characteristic feature of SCD is VEMP responses with large amplitude and low threshold (Brantberg et al., 1999; Colebatch et al., 1998; Watson et al., 2000). In Todd et al.'s patient, the N15 became increasingly dominant with increasing stimulus intensity, and had an amplitude in excess of 10 μV with maximal stimulation (approximately 40 dB above the patient's VEMP threshold). Such large amplitudes are very unusual for neurogenic potentials and, coupled with the frontal distribution and the observation that the patient described oscillopsia in response to the louder stimuli, suggested that the potential may have had an ocular, rather than neurogenic, origin.

Previous observations suggest at least two possible origins for the N15 potential. Several authors have demonstrated eye movements in Tullio or SCD patients in response to loud sounds (Bronstein et al., 1995; Cremer et al., 2000; Halmagyi et al., 2003; Minor et al., 1998; Vogel et al., 1986). Thus the N15 could be due to displacement of the retinal-corneal dipole (Peters, 1967). Alternatively, the N15 could be due to synchronous activity in extraocular muscles, similar to VEMPs recorded from neck muscles. We wished to investigate the origin of the N15 potential, by measuring vestibular-evoked surface potentials from extraocular electrodes in normal subjects and patients. A potential primarily generated by displacement of the eye would be expected to cause a phase reversal between pairs of electrodes situated on opposite sides of the eye.

2. Methods

2.1. Subjects

Twenty four normal subjects with no known vestibular disorders were screened for their VEMP threshold (V_T) to BC tone bursts (see below). Due to individual differences in vestibular sensitivity (i.e. VEMP threshold), varying numbers of subjects participated in each part of the experiment. Twelve subjects had BC VEMP thresholds low enough in at least one ear (side) to enable stimulation at a minimum of 12 dB above threshold (6 females and 6 males, 25–55 years). Eight of these 12 subjects had thresholds low enough on at least one side to enable stimulation at a higher intensity (18 dB above threshold) and were studied in most of the remaining parts of the study. The other 4 subjects were only used in sections requiring less intense stimulation (at +12 dB re V_T). Five additional normal subjects who did not have sufficiently low thresholds for BC VEMPs were stimulated with air-conducted (AC) clicks (5 males, 25–61 years).

We studied 7 patients with inner ear abnormalities. Two patients with unilateral vestibular neurectomies participated. One (male, 43 years) had undergone a left vestibular neurectomy 6 months prior, and another (male, 66 years) had undergone complete division of the right vestibulocochlear nerve for Meniere's disease 40 years prior. Both had absent VEMPs on the operated side. We studied one patient (female, 63 years) with profound hearing loss bilaterally but preserved vestibular function. She had a mean of 100 dB hearing loss in both ears from rubella infection in utero. Four patients with SCD participated (all female; 40–60 years; 2 with bilateral SCD, 2 with right SCD). All had dehiscence of the bone overlying the superior semicircular canal on CT imaging. One was in remission from previous systemic lupus erythematosis with cerebral involvement. All were stimulated on an affected side (3 right, 1 left).

We also studied two patients with oculomotor disorders: the first, a male (67 years old) had undergone craniofacial resection and exenteration of the right eye and extraocular muscles 13 years previously to treat an ethmoid sinus carcinoma; the second, a male (63 years) with Miller Fisher syndrome, had elevated levels of anti-GQ1b antibody (8242 Buhlmann Titre Units; normal value <2400) and near complete ophthalmoplegia. Written, informed consent was obtained from all normals and patients, according to the Declaration of Helsinki, and the study was approved by the local ethics committee.

2.2. Experimental procedure

Prior to the main experiment, VEMP thresholds were determined in all participants and used as a measure of 'vestibular sensitivity'. In the main experiment, evoked potentials were recorded from around the eyes following stimulation at fixed levels above the subjects' individual VEMP thresholds (e.g. 18 dB above VEMP threshold (+18 dB re V_T)). We first performed a 'mapping' study to determine optimal electrode placement around the eyes. We then systematically investigated the effects of stimulus intensity, direction of gaze, stimulus frequency and air-conducted stimulation.

2.2.1. Vestibular evoked myogenic potentials

Subjects lay supine on a chair, with the backrest tilted to 30–45 degrees from the horizontal, and lifted their heads to activate the sternocleidomastoid (SCM) muscles. VEMPs were recorded to a 500 Hz, 8 ms BC tone burst (1 ms rise time, 6 ms hold time, 1 ms fall time, alternating polarity). This was the standard BC stimulus used in subsequent parts of the experiment. The BC tone bursts were delivered behind each ear, with the bone conductor placed approximately 3 cm posterior and 1 cm superior to the external auditory meatus (model B71 Radioear Corporation). The peak force level (FL) produced by the bone conductor was measured using an artificial mastoid (model 4930, Brüel & Kjær, Denmark) and expressed in dB using a 1 μN reference. The maximum input was 20 Volts peak to peak (V_{pp}: 138 dB FL peak at 500 Hz). Thresholds were obtained by reducing the voltage of stimulation in 3 dB steps over successive trials. V_T was defined as the smallest voltage