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Single motor unit responses underlying cervical vestibular evoked myogenic potentials produced by bone-conducted stimuli

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HIGHLIGHTS

- Bone-conducted (BC) stimulation is a useful cVEMP stimulus in patients with conductive hearing loss as it bypasses the middle ear.
- Our single motor unit data show that the mainly inhibitory cVEMP may change polarity with different directions of BC stimulation to become an excitatory reflex.
- In some conditions the BC cVEMP is likely to receive contributions from end organs in addition to the saccule, such as the utricle.

ABSTRACT

Objective: Cervical vestibular evoked myogenic potentials (cVEMPs) are muscle reflexes recorded from the sternocleidomastoid (SCM) neck muscles following vestibular activation with air- or bone-conducted (BC) stimulation. We investigated the effect of different forms of BC stimulation on the single motor unit response underlying the cVEMP.

Methods: We tested 8 healthy human subjects with 5 different stimuli. Motor units were recorded with thin concentric needle electrodes; surface potentials were recorded simultaneously.

Results: The polarity of the initial change (at approx. 15 ms) in single motor unit activity reflected the polarity of the surface cVEMPs: a short-latency decrease in activity (inhibition) was seen with the four stimuli that produced a positive surface potential (p13), while an initial increase in activity (excitation) was seen with the stimulus that produced a negative surface potential.

Conclusions: BC stimulation with common clinical stimuli usually produces an inhibition in single motor unit activity in the ipsilateral SCM muscle. However the projections activated by BC stimulation are not exclusively inhibitory in nature and depend upon the shape and direction of the stimulus.

Significance: The utricle is likely to contribute to some BC cVEMPs, as some stimuli clearly evoke an excitation that is not likely to be saccular in origin.

1. Introduction

Vestibular evoked myogenic potentials (VEMPs) are muscle reflexes elicited by activation of the vestibular system with short bursts of sound, vibration or galvanic stimulation. They were first

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described in the sternocleidomastoid (SCM) neck muscles in response to stimulation with loud air-conducted (AC) clicks (Colebatch and Halmagyi, 1992) and are now often called cervical VEMPs (cVEMPs) to distinguish them from more recently reported reflexes in the extraocular (ocular VEMPs) and masseter muscles (see Rosengren et al., 2010 for review). The cVEMP is recorded from an active surface electrode placed over the middle to upper third of the SCM muscle belly and a reference over the medial clavicle. The reflex usually consists of a short-latency, biphasic positive–negative potential with peak latencies of approximately 13 and 23 ms, respectively (i.e. p13–n23).

For clinical purposes, cVEMPs are most commonly evoked by AC sound stimulation and recorded in the muscle ipsilateral to the stimulated ear. cVEMPs are not dependent upon hearing and are therefore present in patients with sensorineural hearing loss. However, they are attenuated or absent in patients with conductive hearing loss, as the air-conducted stimulus requires efficient transfer through the outer and middle ear to the vestibule (Bath et al., 1999). To overcome this disadvantage of air-conducted sound, Halmagyi et al. (1995) demonstrated that cVEMPs could also be elicited by tapping the forehead with a clinical reflex hammer. Following this, Sheykholeslami et al. (2000, 2001) reported that a clinical bone-conductor normally used to test hearing could also evoke cVEMPs. The advantages of the bone-conductor are that it allows control of stimulus shape and frequency, enables threshold determination and is less ‘operator-dependent’ than a reflex hammer. Using either stimulus, the shortest-latency response has the same biphasic waveform as the AC cVEMP and is vestibular-dependent, though it is followed by a second, non-vestibular biphasic wave, now hypothesised to be produced by activation of neck stretch receptors. Importantly, the bone-conducted (BC) cVEMP is present in patients with conductive hearing loss, as the stimulus bypasses the conductive mechanism of the middle ear. As a result, BC stimulation is considered a good substitute for AC sound in patients with conductive hearing loss. BC stimulation has been used in several clinical studies, for example in patients with otitis media (e.g. Monobe and Murofushi, 2004; Seo et al., 2008; Yang and Young, 2003), but has not become a standard cVEMP stimulus, possibly due to the need for an additional amplifier to provide sufficient drive to the bone conductor.

There has been a recent increase in interest in BC cVEMPs as a result of the popularity of more powerful vibrators used to elicit ocular VEMPs. These stronger vibrators have a greater effective frequency range, extending to lower frequencies than the audiological bone conductors. The most common types of stimulus delivered by these vibrators to evoke cVEMPs are: sine waves, often at 500 Hz and sometimes delivered to the forehead near Fz (e.g. Cai et al., 2011; Manzari et al., 2010, 2012); square waves, either delivered to the forehead (e.g. Taylor et al., 2011, 2012) or inion (e.g. Huang et al., 2011); and controlled taps delivered to the mastoid (stimulus drive in the form of a gamma distribution, directed either toward the mastoid [inward taps] or away from it [outward taps] Rosengren et al., 2009; Govender et al., 2011).

Both air-and bone-conducted vestibular stimuli are thought to activate similar populations of irregularly firing otolith afferents (Curthoys et al., 2006). There are, however, two properties of skull vibration that render BC cVEMPs more complicated than those evoked by AC sound. First, during BC stimulation both ears are stimulated simultaneously and, second, BC stimuli can be applied to different sites on the head and therefore produce linear acceleration in different directions. When a BC stimulus is applied to the midline (e.g. the forehead), the vibration reaching the vestibule is likely to be relatively equal on both sides and deflect vestibular hairs cells in a similar direction, producing symmetric reflexes (e.g. Halmagyi et al., 1995). When applied to lateralised sites on the skull, the stimulus strength may not be equal and the direction of hair deflection will be different in each ear. For example, vibration applied at the mastoid differentially activates the two ears. When the stimulus is a sine wave of around 500–1000 Hz, cVEMPs are present bilaterally in normal subjects and have the same polarity on both sides of the neck, but the skull acceleration and reflex amplitude are usually larger on the side of the bone conductor (McNerney and Burkard, 2011; Welgampola et al., 2003). In contrast, when the stimulus has a lower dominant frequency, such as a tendon hammer tap, the skull acceleration is approximately equal on both sides but is oppositely-directed (e.g. both sides move away from the hammer, causing the ipsilateral ear to move medially and the contralateral ear to move laterally) and the cVEMPs have similar size but different polarity and/or peak latency in the ipsilateral and contralateral SCM muscles (Brantberg et al., 2002, 2003, 2008, 2009; Cai et al., 2011; Rosengren et al., 2009; Todd et al., 2008). Therefore different types of AC and BC stimulation probably activate distinct, although often overlapping, populations of vestibular otolith afferents.

Given the recent interest in BC cVEMPs we wished to systematically examine the motor unit response to skull vibration in human SCM muscles. The change in muscle activity that underlies the cVEMP evoked by AC sound and galvanic stimulation was determined by Colebatch and Rothwell (2004), who recorded the responses of single motor units in SCM muscles in normal volunteers. They found that the initial surface positivity (p13) seen for the SCM ipsilateral to click or cathodal galvanic stimulation was associated with a brief decrease or gap in motor unit firing, i.e. a short inhibition of the motoneurone supplying the motor unit. This determined the basis of the cVEMP reflex and demonstrated the nature of the projection to the ipsilateral SCM evoked by AC sound and galvanic stimulation in humans. To extend these findings, we investigated the single motor unit response to BC stimulation using several commonly used stimulus types: a 500 Hz BC tone burst evoked by a traditional B-71 bone conductor on the mastoid, the same shape 500 Hz BC tone burst delivered to the forehead using a minishaker and inward and outward taps delivered to the mastoid with a minishaker. Responses to these stimuli were compared to those evoked by AC sound. All of these stimuli, except for the outward tap, have been shown to evoke cVEMPs with typical positive–negative (i.e. p13–n23) polarity (Cai et al., 2011; Colebatch et al., 1994; Rosengren et al., 2009), while the outward tap produces a cVEMP with the opposite polarity (negative–positive) (Rosengren et al., 2009). We predicted that the single motor unit responses would mirror the surface responses and change with changing stimulus type. In particular, we hypothesised that some surface cVEMPs would be associated with an increase in muscle activity, i.e. an excitation of the muscle, as the surface responses are known to sometimes have inverted polarity.

2. Methods

2.1. Subjects

Eight healthy human subjects were studied over multiple sessions (4 females, 4 males; mean age 36 years, range 24–49 years). All subjects were tested with each type of stimulus, except one subject who only completed one session with sound stimulation and was not tested further. The subjects had no history of conductive hearing loss or vestibular or neurological disease. Participants were staff and students at University Hospital Zurich and all gave written informed consent according to the Declaration of Helsinki. The study was approved by the local ethics committee (ethics committee of the canton of Zurich, 2010-0177/3).