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The Recordability of Two Sonomotor Responses in Young Normal Subjects

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Background: It has been reported that up to 40% of patients over age 60 fail to generate a vestibular evoked myogenic potential (VEMP; Su et al, 2004). When this occurs it is difficult to determine whether the absent VEMP represents evidence of bilateral impairment of the vestibulocollic reflex pathway or a normal age-related variant (i.e., idiopathic absence).

Purpose: The purpose of the present investigation was to determine whether both VEMPs and PAMs could be recorded reliably in a sample of neurologically and otologically intact young adults. If both could be obtained with high reliability in normal subjects, then the bilateral presence of PAM in the bilateral absence of VEMP, at least in younger patients, could be used to support the contention that the absent VEMP represented evidence of bilateral impairment.

Research Design: A descriptive study.

Study Sample: Attempts were made to record both the VEMP and a second sonomotor response, the postauricular muscle potential (PAM) from 20 young adults.

Results: Results showed both the VEMP and the PAM were present in 90% of the ears. Both the VEMP and PAM responses were bilaterally absent for one subject. Also, the VEMP and PAM were unilaterally absent for two subjects. Subjects who generated VEMPs also generated a PAM in at least one ear.

Conclusions: The present investigation represents an initial step in the determination of whether the presence of PAMs in the absence of VEMPs can be used as a method of validating the presence of an impairment affecting the vestibulocollic reflex pathway.

Key Words: Dizziness, inferior vestibular nerve, saccule, sonomotor, vertigo, vestibular evoked myogenic potential

Abbreviations: CDP = computerized dynamic posturography; EMG = electromyography; PAM = postauricular muscle; SCM = sternocleidomastoid muscle; VEMP = vestibular evoked myogenic potential

Sumario

Antecedentes: Se ha reportado que hasta un 40% de los pacientes con edad por encima de 60 fallan en generar un potencial miogénico vestibular evocado (VEMP; Su y col., 2004). Cuando esto ocurre es difícil determinar si la ausencia de VEMP representa una evidencia de trastorno bilateral de la vía del reflejo vestibulocólico o una variante normal relacionada con la edad (p.e., ausencia idiopática).

Propósito: El propósito de la presente investigación fue determinar si tantos los VEMP como los PAM podían ser registrado confiablemente en una muestra de adultos jóvenes neurológica y otológicamente intactos. Si ambos pueden ser obtenidos con alta confiabilidad en sujetos normales, luego, la presencia bilateral de los PAM y la ausencia bilateral de los VEMP, al menos en pacientes jóvenes, podría ser usada para apoyar la noción de que un VEMP ausente representa la evidencia de un trastorno bilateral.

Diseño de Investigación: Un estudio descriptivo.

Muestra del Estudio: Se hicieron intentos para registrar tanto los VEMP como una segunda respuesta sonomotora: el potencial muscular postauricular (PAM) de 20 adultos jóvenes.

Resultados: Los resultados mostraron que el VEMP y el PAM estaban presentes en el 90% de los oídos. Tanto las respuestas del VEMP como del PAM estuvieron ausentes bilateralmente para un

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sujeto. También, los VEMP y los PAM estuvieron ausentes unilateralmente en dos sujetos. Los sujetos que generaban VEMP también generaban PAM al menos en un oído.

Conclusiones: La presente investigación representa un paso inicial en la determinación de si la presencia de PAM en ausencia de VEMP puede ser usada como un método de validar la presencia de un trastorno que afecte la vía del reflejo vestibulocólico.

Palabras Clave: Mareo, nervio vestibular inferior, sáculo, sonomotor, vértigo, potencial miogénico vestibular evocado

Abreviaturas: CDP = posturografía dinámica computarizada; EMG = electromiografía; PAM = músculo postauricular; SCM = músculo esternocleidomastoideo; VEMP = potencial miogénico vestibular evocado

The vestibular evoked myogenic potential (VEMP) is a short latency sonomotor response evoked by acoustical stimulation of the vestibular system. This evoked response was first described by Colebatch and colleagues (e.g., 1992, 1994). The VEMP can be recorded from a number of muscles including the sternocleidomastoid muscle (SCM). The response is generated as a stimulus-induced reduction in the electromyographic (EMG) activity in an activated muscle. The VEMP consists of a prominent positive wave that occurs at approximately 13 msec (i.e., referred to as P13) and is followed by a negative-going wave that occurs at approximately 23 msec (i.e., that is referred to as N23). The most effective stimuli to elicit VEMPs are low frequency tone bursts (e.g., 500 Hz tone bursts) or unfiltered clicks that are presented in the neighborhood of 85–100 dB nHL (Todd et al, 2000; Welgampola and Colebatch, 2001; Akin et al, 2003). There is general agreement that the peripheral receptor for the VEMP is the saccule (Young et al, 1977; Colebatch et al, 1994; Murofushi et al, 1995; Murofushi et al, 1996; Bath et al, 1998) and that high intensity acoustical stimulation results in translation of the otoliths on the otolith membrane that results in transduction. The electrical signals generated by the saccular macula are then routed through the inferior vestibular nerve to the inferior, medial, and probably lateral vestibular nuclei and from there to the descending medial vestibulospinal pathway to the nucleus of the spinal accessory nerve to cranial nerve XI to terminate in the SCM (Fitzgerald et al, 1982; Buttner-Ennevera, 1999; Zhou and Cox, 2004).

It has been suggested that the cochlea may have developed phylogenetically from the saccule (Kevetter and Perachio, 1989). It is known that the saccule is the most sound-sensitive of the vestibular end organs (Halmagyi et al, 2004). It is positioned beneath the stapes footplate, and there are neural projections that extend from the vestibular nerve to the cochlear nucleus in gerbils and guinea pigs (Burian et al, 1989; Kevetter and Perachio, 1989).

Like the vestibular evoked myogenic potential, the postauricular muscle potential (PAM) represents a sound-evoked attenuation of EMG activity generated in the postauricular muscle (i.e., it is another sonomotor response). However unlike the VEMP, the peripheral generator of the PAM is the cochlea. The PAM is generated by patients who have absent peripheral vestibular function and normal auditory sensitivity (Yoshie and Okudaira, 1969; Gibson, 1978). The PAM is absent in deaf individuals who have normal vestibular function (Yoshie and Okudaira, 1969). The evoked response consists of two primary peaks. The first peak is a negativity that occurs between 12.5 and 15 msec and is designated N13 (O'Beirne and Patuzzi, 1999). The second peak is a positive peak that occurs between 15 and 18 msec (O'Beirne and Patuzzi, 1999) and is designated P16. Unlike the VEMP, the PAM is best recorded using high frequency tone bursts or click stimuli (O'Beirne and Patuzzi, 1999). Like the VEMP, the amplitude of the PAM increases with background muscle activity and higher intensity levels. The PAM can also be recorded bilaterally. Activity initiated in the cochlea is routed through the cochlear division of cranial nerve VIII to the ventral cochlear nucleus and from there to the superior olivary complex, to the inferior colliculus and/or reticular formation, to the nucleus of the VIIth nerve (Gibson, 1978). From the VIIth nerve nucleus, the activity is routed through the VIIth nerve to the PAM. Unlike the VEMP, the PAM is bilaterally generated to monaural stimulation (Yoshie and Okudaira, 1969).

The VEMP has been reported to be bilaterally absent in up to 40% of neurologically and otologically intact adults over 60 years (Su et al, 2004). It has been reported to be present 100% of the time for younger subjects. The PAM has been reported to be unilaterally absent in 32%, and bilaterally absent in 7%, of normal subjects (Cody and Bickford, 1969). However, Patuzzi and O'Beirne (1999) reported that the PAM could be recorded 96% of the time in normal subjects when a subject's gaze is deviated toward the ear stimulated during data collection. This finding was recently supported by Purdy et al (2005). In fact, eye deviation almost doubled the magnitude of the response. This phenomenon (i.e., the activation of the PAM by eye deviation) may represent a vestigial remnant of how, during hunting, cats deviated their ears and eyes in the direction of a sound (e.g., of prey) they are attempting to localize (Poplin and Yin, 1998).

There are several nonpathological reasons why a VEMP might be bilaterally absent. Since VEMP amplitude is proportional to the background EMG activity, an absent VEMP would occur if the patient was unable to generate sufficient EMG activity (Lim et al, 1995). Also, presence of an impairment affecting sound conduction through the middle ear could result in a bilaterally absent VEMP (Bath et al, 1999). However, bilaterally absent VEMPs have been reported in a number of disease states including bilateral Meniere's syndrome, vestibulotoxicity, mutations of Connexin 26, and brainstem stroke (Perez et al, 2000; Matsuzaki and Murofushi, 2001; Young et al, 2002; Chen and Young, 2003; Todt et al, 2005). By recording both the VEMP and PAM, it might be possible to determine whether a bilaterally absent VEMP represented the presence of disease or variability found in a normal population. For example, if a bilaterally normal PAM is recorded in the presence of a bilaterally absent VEMP, we might feel more comfortable stating that the patient has an impairment affecting the vestibular system within the pathway underlying the VEMP. If both the PAM and VEMP were absent in a patient with normal auditory sensitivity, we might be more cautious in our interpretation. Such a finding could occur if the patient was unable to generate sufficient EMG activity to record the PAM and the VEMP, or if the patient may have disease affecting the neuromuscular junction. Moreover, since the PAM and VEMP are larger, myogenic responses, they can be recorded in very little time (i.e., seconds instead of minutes for sensory evoked potentials). There is currently no data attesting to the reliability of recording both responses in normal subjects.

The purpose of the present investigation was to determine whether both VEMPs and PAMs could be recorded reliably in a sample of neurologically and otologically intact young adults. If both could be obtained with high reliability in normal subjects, then the bilateral presence of PAM in the bilateral absence of VEMP, at least in younger patients, could be used to support the contention that the absent VEMP represented evidence of bilateral impairment.

METHODS

Subjects

Subjects were 20 young adults (mean age = 23.38 years, sd = 1.38 years, 2 male). None of the subjects reported a history of otologic or neurologic disease. All subjects in the study demonstrated normal auditory sensitivity (i.e., audiometric thresholds of <20 dB HL) for octave and interoctave frequencies from 250 to 8000 Hz. All electrophysiological recordings were conducted in the research electrophysiological laboratory at the Vanderbilt Bill Wilkerson Center.

Procedures

Subjects were seated in a comfortable reclining chair. An electrode montage similar to that reported previously by Zapala and Brey (2004) was used to record the VEMP. Disposable silver/silver-chloride electrodes were applied to the ipsilateral (i.e., with reference to the ear stimulated) sternocleidomastoid muscles midway between the insertion at the mastoid and the sternum (noninverting input). The inverting electrode was placed on the dorsum of the hand in an attempt to avoid reference contamination. A ground electrode was placed at Fpz.

An electrode montage identical to that reported by O'Beirne and Patuzzi (1999) and Patuzzi and O'Beirne (1999) was used to record the PAM. A noninverting electrode was placed over the PAM ipsilateral to the side of the stimulus presentation. The inverting electrode was placed on the middle dorsum of the pinna ipsilateral to the noninverting electrode. The ground was the electrode placed at Fpz.

An unfiltered, alternating polarity click of 125 usec duration was used to evoke both the VEMP and the PAM. Stimuli were presented monaurally through an ER3-A insert phone for all participants. The stimulus intensity was 95 dB nHL. Clicks were presented at a rate of 8/sec.

To record the VEMP, each subject was reclined fully (i.e., supine) and asked to lift their head fully off the headrest and then turn their heads sharply away from the ear that was being stimulated. That is, if stimuli were delivered to the right ear the subjects were asked to lift their head and turn it to the left prior to data collection. We and others (Zapala and Brey, 2004; Isaacson et al, 2006) have found that this method has produced the greatest magnitude background electromyographic (EMG) activity (and VEMP amplitude) and data reproducibility. As previously stated, the magnitude of the VEMP is dependent on the magnitude of the background muscle activity of the SCM (Colebatch et al, 1994; Akin et al, 2004).

To record the PAM, and consistent with the methods described by Patuzzi and O'Beirne (1999) and Purdy et al (2005), supine subjects were instructed to deviate their eyes laterally (i.e., horizontally) as far as was comfortable to the side of the ear stimulated.

For each evoked potential (i.e., PAM and VEMP), single-channel evoked potentials were acquired. Additionally, artifact rejection circuitry was disabled prior to data collection. The EMG activity for VEMP recordings was amplified, analog bandpass filtered (30–3000 Hz), and signal-averaged over a 100 msec interval using a commercial clinical evoked potentials system (Bio-logic NavPro). Consistent with the methods described by Patuzzi and O'Beirne (1999), the EMG activity for PAM recordings was amplified, analog bandpass filtered (10–5000 Hz), and signal-averaged

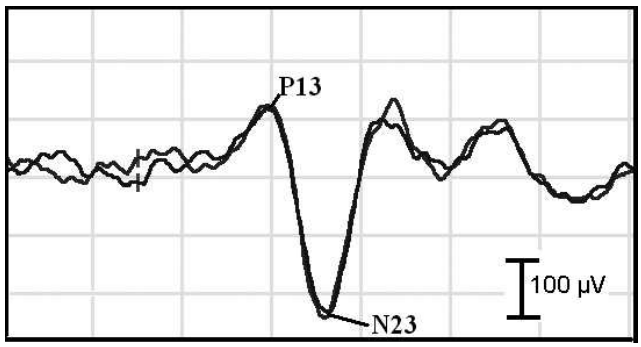

Figure 1. VEMP recording with P13 and N23 labeled.

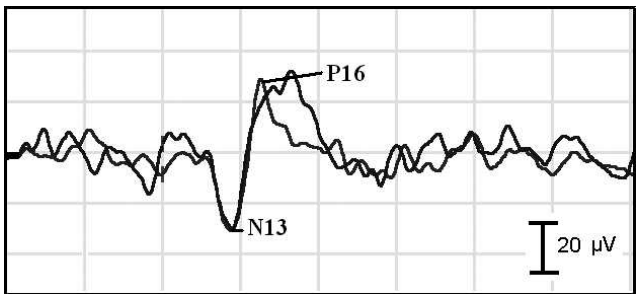

Figure 2. PAM recording with N13 and P16 labeled.

over a 125 msec interval. Each single tracing represented the average of at least 100 individual samples. All traces were replicated a minimum of one time so that repeatability of the data could be assessed.

RESULTS

VEMP and PAM waveforms recorded from a normal subject are shown in Figures 1 and 2. The study sample consisted of 20 subjects (40 ears). Both the VEMP and the PAM were present in 36 of 40 ears (i.e., 90% of ears). The VEMP and the PAM were bilaterally absent for one subject (i.e., 5% of sample) although not for the same subject. For two other subjects (10% of subjects), the response was unilaterally absent. The VEMP and PAM were present bilaterally for 15 subjects (75% of sample).

The mean latency and amplitude data for left and right ears separately for the PAM and the VEMP is shown in Table 1. A t-test showed that the mean differences for the latencies of the PAM and VEMP peaks and the peak to peak amplitudes of the N13 and P16 for the PAM and the P13 and N23 for the VEMP were not statistically significant. Accordingly, the mean data collapsed across ears is shown in Table 2.

DISCUSSION

The present investigation was conducted to determine whether both the PAM and VEMP could be recorded consistently in a sample of young, normal subjects. The results suggested that 95% of the time, a PAM was present in at least one ear of patients who had VEMPs present. The PAM was present in both ears in 85% of the subjects. Both the VEMP and PAM were bilaterally present in 75% of subjects. Our findings support the contention that the PAM might be helpful as an external measure to validate the results from VEMP testing. Previous investigators (Colebatch et al 1994; Ochi and Ohashi, 2003; Su et al, 2004) have reported that the VEMP is present in 100% of young, neurologically and otologically intact normals. We found the VEMP to be bilaterally absent in 5% of the subjects and at least unilaterally absent in 15% of our subjects. Previous investigators also have reported that the PAM is present in bilaterally absent in 7%, and unilaterally absent in 32% of normal subjects (Cody and Bickford, 1969). We found the PAM to be bilaterally absent in 5% of normal subjects and unilaterally absent in 10% of subjects, which is closer to the published experience of Patuzzi and O'Beirne (1999). It is not clear why for a single individual sonomotor, responses would be bilaterally absent. Since both the VEMP and PAM represent a stimulus-synchronized attenuation of EMG activity, it is possible that responses would be absent if a suitably high EMG background was not present. Additionally, since the responses are stimulus-evoked, if the attenuation of EMG was not synchronized (i.e., if there was present temporal "jitter" in the response), the evoked potentials would be absent. Since in each case supine subjects clearly elevated their heads from the examination table, and the SCM was clearly in a contracted state, we feel it is unlikely the young subjects were not developing an adequate level of background EMG from which to evoke the VEMP. Unfortunately, since it is so small, contraction of the PAM is impossible to see.

In 1976, Jerger and Hayes described the cross-check principle and its application to the audiological assessment of the pediatric population. This principle states that the results of one test should be cross-checked against the results of a second independent measure. The concept was framed with the idea that

Table 1. Latencies and Peak-to-Peak Amplitudes (sd) for N13-P16 (PAM) and P13-N23 Waveforms (VEMP) for Left and Right Ear Stimulation

PAM	Left	Right	VEMP	Left	Right
N13 latency (msec)	11.52 (1.04)	11.78 (1.33)	P13 latency (msec)	12.06 (2.14)	12.24 (3.50)
P16 latency (msec)	16.89 (2.13)	16.99 (1.59)	N23 latency (msec)	19.07 (2.56)	17.97 (2.01)
N13-P16 amplitude (uV)	33.75 (24.06)	26.13 (19.09)	P13-N23 amplitude	102.25 (70.43)	103.92 (74.18)

Table 2. Latencies and Peak-to-Peak Amplitudes (sd) for N13-P16 (PAM) and P13-N23 Waveforms (VEMP) for Data Collapsed across Ears

PAM		VEMP	
N13 latency (msec)	11.65 (1.19)	P13 latency (msec)	12.15 (2.82)
P16 latency (msec)	16.94 (1.85)	N23 latency (msec)	18.55 (2.35)
N13-P16 amplitude (uV)	29.69 (3.62)	P13-N23 amplitude (uV)	103.04 (71.19)

using a single test to evaluate hearing loss in very young children could result in misdiagnosis and mismanagement of children with hearing loss. We have extended this principle to include the assessment of function in the pathway underlying the VEMP. Such an application is illustrated in Figure 3. This patient demonstrated bilaterally absent VEMPs (Figure 3, top). However, the same patient generated PAMs following left and right ear stimulation (Figure 3, bottom). The presence of the PAMs bilaterally shows that although the patient cannot generate a sonomotor response from stimulation of the vestibular end organ, they are capable of generating a sonomotor response from stimulation of the auditory system. This, we feel, suggests that the bilaterally absent VEMP represents evidence of vestibular system impairment.

We considered two other measures that could be used to validate a bilaterally absent VEMP. In 2001, de Waele found patients with abnormal VEMPs tended to be more dependent on visual information to maintain their postural stability. They demonstrated increased sway in conditions 3, 5, and 6 of the sensory organization test (SOT) of computerized dynamic posturography. However, CDP instrumentation is expensive and not generally available in audiology clinics that have evoked potential instrumentation. The stapedial reflex also might be useful as a cross-check for bilaterally absent VEMPs. However, the stapedial reflex represents a stimulus-evoked *increase* in EMG activity, not a *decrease*, as is the origin of the VEMP and the PAM.

There is at least one significant disadvantage to using the PAM as a modality for cross-checking bilaterally absent VEMPs. The PAM is dependent on the presence of auditory function and, accordingly, cannot be recorded in deaf subjects. However, to our knowledge, the limits of auditory sensitivity loss where a PAM can be recorded have not been reported.

Also, there are conditions that would be expected to yield both absent PAMs and VEMPs. Anything that would attenuate sound (e.g., bilateral cerumen impaction or bilateral middle ear disease) would be expected to produce bilaterally absent VEMPs and PAMs. Diseases that affect the neuromuscular junction such as myasthenia gravis could also produce bilaterally absent sonomotor responses. Patients who are unable to sustain, even for seconds, muscle tension sufficient to generate a VEMP may be unable to generate a PAM as well.

SUMMARY

When a VEMP is bilaterally absent, the question may be asked whether this finding represents the presence of bilateral impairment or whether the finding represents evidence of the variability in the normal population. We have attempted to address this question by using the cross-check principle. Like the VEMP, the

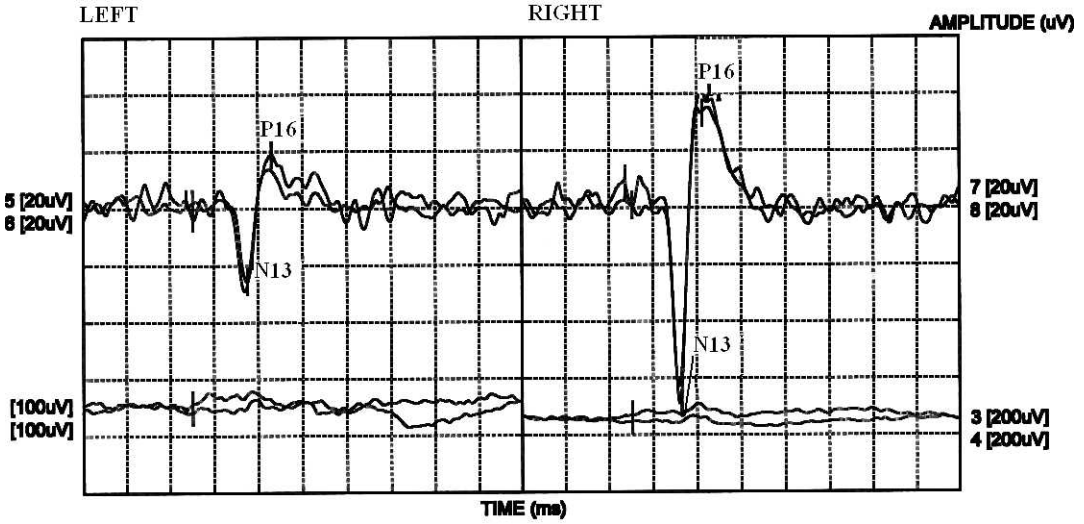

Figure 3. VEMP and PAM recordings from a patient with bilaterally absent VEMPs, most likely from vestibulotoxic drug exposure. Note that whereas the VEMPs are bilaterally absent, the PAMs are bilaterally present.

PAM is another signal-averaged sonomotor response. However, unlike the VEMP, the PAM is generated by the auditory system. It is almost always present unilaterally and often is present bilaterally in a normal sample. The present investigation represents an initial step in the determination of whether the presence of PAMs in the absence of VEMPs can be used as a method of validating the presence of an impairment affecting the vestibulo-collic reflex pathway. A next step will be to determine how often PAMs are present in a sample of patients with absent VEMPs and documented impairments affecting the saccule and/or inferior vestibular nerve.

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