Vestibular evoked myogenic potentials: They are the same as an auditory evoked potential, only different

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Normative Aspects

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What is the VEMP?

A myogenic response from muscles of the neck (or eyes), in response to high-level acoustic stimulation. Based on various lines of evidence, it is believed that the VEMP is primarily, if not solely, the result of vestibular end-organ stimulation (likely the saccule and/or utricle).
Anatomy of the Peripheral Auditory/Vestibular System

Semicircular Canals (Crista in Ampulla): Angular Acceleration

Otolith End Organs: Saccule/Utricle

Oticonia- mass greater than endolymph

Linear acceleration: $1 \text{ g} = 9.8 \text{ m/s}^2$
Sensory Evoked Potentials, VsEPs

Burkard and Secor (2002)

Can elicit true sensory (neurogenic) potentials from stimulation of virtually any sensory system: Auditory, somatosensory, visual, gustatory, olfactory

These potentials are typically to rapidly changing stimuli: Auditory: clicks, tonebursts; Visual: pattern reversal, flashes; Somatosensory: brief electrical pulses

Historically, synchronous activation if the vestibular system has been a challenge, especially in humans—Linear or angular acceleration of human head.

It is just plain difficult to move the head quickly.

The VEMP, as it records a muscle response, is appropriately considered a reflex, like the acoustic reflex, rather than a true sensory evoked (neurogenic) potential.
Short latency vestibular responses to linear acceleration that have been recorded in birds and rodents (VsEP); the effective stimulus is jerk (g/ms):

![Diagram of VEMP](image)

Jones and Jones (2007), in Burkard, Don and Eggermont (2007)

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**The Inion Response**

The VEMP, as recorded from the neck muscles, was first reported by Colebatch et al. (1994).

“The inion response is obtained with the active on or near the external occipital protuberance (inion) and is probably derived from the cervical musculature. Because it can be obtained from deaf patients with intact vestibular function (Cody et al., 1964; Gibson, 1964), it would be unwise to use the response to predict hearing acuity. Attempts to associate this response with the function of vestibular semicircular canals has met with little success (Tabor et al., 1968; Pignatro, 1972), so Townsend and Cody (1971) have suggested a generator site in the saccule”. (Gibson, 1978, p.133, Essentials of Clinical Electric Response Audiometry).
Why does the Vestibular system respond to sound?

One Theory: The Law of specific Energies at work?

The Law of Specific Nerve Energies, first proposed by Johannes Peter Müller in 1826, is that the nature of perception is defined by the pathway over which the sensory information is carried. Hence, the origin of the sensation is not important. For example, pressing on the eye elicits sensations of flashes of light because the neurons in the retina send a signal to the occipital lobe. Despite the sensory input's being mechanical, the experience is visual.

Wikipedia, downloaded February 2, 2008

At a high enough sound pressure, the inner ear fluids become compressible, and the vestibular end organ can be stimulated.

Theory 2: The Saccule/Utricle ARE Vestigial Hearing End Organs in Humans: In fishes, the saccule, legena and in some cases, the utricle, are thought to be responsive to sound.
In animal studies, single-unit responses to sound from Vestibular Afferents (Inferior Vestibular Nerve)- Low frequency, high threshold

There is considerable evidence that the vestibular system responds to sound


Superior Canal Dehiscence:

Creates a ‘round window’ for vestibular system- so that vestibular end organ can be more easily stimulated by acoustic stimulation

Clinical Otolaryngologists/Audiologists have long known about auditory stimuli apparently activating the Vestibular system:

Tullio’s phenomenon: high level acoustic stimuli leading to vertigo

Hennebert’s sign: Ear-canal pressure leading to eye movements
Auditory evoked potentials have been reported in experimental animals with complete loss of cochlear hair cells following aminoglycoside treatment (e.g., Cazals et al. 1980, 1983a,b)

http://snuzzy.com/15-guinea-pig-pictures/


Ocular VEMP (oVEMP):

Courtesy of Devin McCaslin
oVEMP

![Graph of oVEMP Reflex Arc](image)

Burkard et al., IERASG (2011)

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**cVEMP Reflex Arc:**
- Outer/middle ear (if AC)
- Saccule
- Inferior Vestibular Nerve
- Vestibular nuclei
- Vestibulospinal Tract
- CN XI Spinal Accessory
- Sternocleidomastoid M.

**oVEMP Reflex Arc:**
- Outer/middle ear (if AC)
- Utricle
- Superior Vestibular Nerve
- Vestibular nuclei
- Medial Longitudinal Fasciculus
- CN III- Oculomotor
- Inferior Oblique M.

Jacobson and McCaslin (2007); Akin and Murnane (2008); Curthoys (2010)

- It appears that both the saccule and the utricle are stimulated by high-level air-conduction or bone-conduction low-frequency stimuli.
- Saccular stimulation provides a robust inhibitory response to the ipsilateral SCM (and hence cVEMP recording requires contraction of the SCM)
- Utricular stimulation leads to excitation of the inferior oblique and inferior rectus of the contralateral eye and excitation from the superior rectus or superior oblique of the ipsilateral eye (Suzuki et al. 1969; Tokumasu et al. 1971).

Curthoys (2010)
• Stimuli Used: Typically either clicks or low-frequency tonebursts

• Thresholds are typically well above perceptual threshold– via air conduction.

• Recordings: cVEMP: Typically from the ipsilateral SCM, but the Trapezius is also used. For oVEMP: infraocular placement of electrodes, typically from the contralateral eye.

• Can record from either one or both SCM for cVEMP (below one or both eyes for oVEMP)

• cVEMP: Responses are prominent only if the muscle is tensed, and responses are largest from the muscle ipsilateral to stimulation. For oVEMP, contralateral responses are largest.

cVEMP Amplitude depends on SCM contraction

Bogle, Zapala, Criter and Burkard (2013)
Subjects can show linear cVEMP growth, or saturation, with increasing EMG.

There is considerable across-subject variability in cVEMP amplitude and normalized (to EMG) amplitude for a given EMG level.
cVEMPs often evaluated by asymmetry ratio
(Can be used with both absolute and corrected cVEMP amplitude)

\[
\text{Asymmetry Ratio} = \frac{\text{cVEMP (L)} - \text{cVEMP (R)}}{\text{cVEMP(L)} + \text{cVEMP (R)}}
\]

Bogle, Zapala, Criter and Burkard (2013)

Low-level SCM contraction
Moderate-Level SCM Contraction
High-Level SCM Contraction

Bogle, Zapala, Criter and Burkard (2013)
**Stimulus Parameters:**

VEMP is Largest for Low Frequency Tonebursts

Wu and Murofushi (1999) showed that with increasing stimulus rates from 1 to 10 Hz— all subjects showed a VEMP. At rates of 20 Hz, only 63% of the ears showed VEMPs. VEMP amplitudes were largest at rates of 1-5 Hz.

**Risetime and Duration:**

With increasing risetime up to 10 ms, response latency increases, response amplitude remains stable; increasing stimulus plateau duration increased VEMP peak latencies (Chang et al. 2001).
Bone conducted Stimuli and VEMPs

Recording and stimulation parameters similar

Responses to low-frequency, bone-conducted tonebursts—thresholds occur closer to 30-35 dB nHL, rather than the 85-90 dB nHL for air conducted stimuli (e.g., Welgampola et al. 2003)

There are emerging reports that oVEMPs might be more reliably elicited using bone-conduction stimuli than for air-conduction stimuli.

The VEMP in Response to Air-Conducted vs. Bone-Conducted Stimuli

Kathleen McNerney, Robert Burkard

Purpose:
To make a direct comparison between the VEMP in response to 500 Hz tonebursts presented via AC and BC, using the same stimulus parameters and recording parameters in the same subjects.

Subjects: N = 22
Stimuli:
500 Hz TB, 1-2-1 ms, AC: ≤ 120 dB pSPL; BC ≤ 120 dB pFL, 5 dB steps; 5 Hz, 2 reps, 200 trials/rep
Electrodes for Recording the cVEMP
Right and Left SCM muscle; Upper forehead; Lower forehead
EMG Monitoring Electrodes
Delsys EMG Monitor; 75% Maximum EMG activity was target
TECA EP system
Results

VEMPs in response to AC and BC stimuli from an individual subject.

- Near threshold, there are some small changes in cVEMP latency with changes in stimulus level for AC stimuli.
- VEMP latency is slightly shorter for BC stimuli.

McNerney and Burkard (2011)
• Amplitude increases with increasing intensity for both AC and BC stimuli
• Input/output functions for BC stimuli start to saturate at the highest stimulus level; cVEMPs to AC stimuli show a more monotonic increase in amplitude with increasing stimulus level.
• Thresholds for BC VEMPs ranged from 80 – 115 dB pFL (mean = 99.47), and 95 – 115 dB pSPL (mean = 104.47) for AC VEMPs.

McNerney and Burkard (2011)

Recording parameters:

Time window: up to 50 ms

Number of averages: up to maybe a few hundred (for cVEMP, let patient relax after 20-30 seconds of muscle contraction).

Noninverting Electrode:
cVEMP: SCM; oVEMP: under eyes

Bioamplifier filters: ???
Spectral analyses of the vestibular evoked myogenic potential (VEMP)

Robert Burkard, Devin McCaslin, Kathleen McNerney, Mary Lou Coad, Gary Jacobson

• The optimal filtering bandwidth for the cVEMP and oVEMP has not been systematically investigated.
• The present study sought to determine the optimal recording filter bandwidth for cVEMPs and oVEMPS.

Methods: Data Collection
8 young adult subjects
120 dB pSPL 500 Hz tonebursts, 2-1-2 cycle Blackman
Just less than 5 Hz rate; 250 stimuli, 2 replications
4 channels: R/L SCM (inverting: dorsum of hand); R/L inferior oblique (inverting: infra-orbital, below non-inverting)
(common: forehead)
5000 Hz A/D rate, 5-1000 Hz (Neuroscan)
4 Positions: Supine, Sitting, Left Lateral, Right Lateral
SCM: Head lifted (when supine, or tilted forward when sitting) and turned away from the stimulated ear
Inferior Oblique: Subject looks upward
**Methods: Analysis**

Windowed: 0-204.6 ms, 10 ms Hanning window at onset and offset

Obtained grand mean average across 8 subjects

Fourier transform, resulting in spectrum with ~4.88 Hz resolution

Spectra of grand-mean time-domain cVEMPs and oVEMPs will be shown
Normative Subject Variables: Gender and Age

- Studies have not found any effects of Sex on the response.

- However, effects of AGE have been reported.
  - Welgampola and Colebatch (2001) and Ochi et al. (2003) reported that VEMP response amplitude decreases while VEMP threshold increases in subjects over the age of 50, as compared to younger individuals.
Hearing Loss:

- Colebatch and Halmagyi (1994) reported that the cVEMP was still present in individuals with a severe sensorineural hearing loss, supporting the view that it arises from the vestibular, rather than the auditory, system.
- Halmagyi et al. (1994) reported that a conductive hearing loss with as little as a 10 dB threshold shift at 1000 Hz can cause a decrease in the amplitude of the cVEMP.
- Bath et al. (1999) tried to record the cVEMP from 23 ears with a conductive hearing loss. They found a 95% response rate in the normal group as compared to a 8.9% response rate in those individuals with a conductive hearing loss.

Vestibular Schwannoma

- Murofushi et al. (1998) studied the cVEMP in 21 patients diagnosed with a vestibular schwannoma.

- They found that 80% of these patients produced an abnormal cVEMP (71% = no response, 9% = reduced response amplitude).

- The authors concluded that the cVEMP could be used to diagnose which portion of the vestibular nerve is affected (superior vs. inferior) in patients with a vestibular schwannoma.
Meniere’s Disease

- DeWaele et al. (1999) found that the cVEMP was absent from 54% of patients with Meniere’s Disease.
- Young et al. (2003) found that the “interaural amplitude difference (IAD) ratio” depended on what stage of Meniere’s Disease they were in.
- Seo et al. (2003) found that 40% of Meniere’s patients showed a marked improvement in cVEMP amplitude following the administration of furosemide.

Vestibular Neuritis

- Vestibular neuritis is generally thought to affect the superior portion of the vestibular nerve, leaving the inferior portion intact.
- Symptoms of the disorder may include bouts of severe vertigo, nausea, vomiting, imbalance, and spontaneous nystagmus.
- These patients generally do not present with any auditory or neurological insufficiencies.
- Patients with this disorder often present with absent or severely reduced caloric results unilaterally, in addition to showing signs of spontaneous nystagmus.
- However, Halmagyi et al. (2002) reported on two patients who had either normal or only slightly abnormal results on caloric and ENG testing, and no signs of spontaneous nystagmus. A cVEMP could not be obtained in these patients from the affected side. The authors concluded that these patients were suffering from vestibular neuritis which affected the inferior vestibular nerve.
The cVEMP in Patients with Multiple Sclerosis

Shimizu et al. (2000) obtained the cVEMP from three patients with multiple sclerosis

• They found that while all of the subjects produced a VEMP, the response latencies were prolonged relative to normative data.

The cVEMP in Patients with the Tullio Phenomenon

• Patients with this disorder often experience vestibular symptoms (vertigo, nystagmus, and imbalance: Tullio’s) in response to loud sounds.

• They also may show eye movements in response to changes in static pressure applied to the ear canal, ex. during tympanometry (Hennebert’s sign).

• In patients with this disorder, the section of the temporal bone which overlies the superior semicircular canal is thinner than normal, which creates a third “mobile window” (Superior Canal Dehiscence). This results in a lower impedance pathway for sound, and (in some instances) lower cVEMP threshold and increased cVEMP amplitude.
Mayo Clinic cVEMP and oVEMP Parameters and Protocols

The protocols suggested below come from a variety of peer reviewed articles together with our own work being developed for publication. The newest of the works is by Taylor et al (in press)

Tone burst parameters for either cervical or ocular VEMPs – air conduction stimulus:
- 250, 500, 750, 1k, 2k Hz
- 13.3 / sec rate
- Blackman-gated: 1 ms rise / fall, 2 ms plateau
- Stimulus max per that set on the equipment for each of the frequencies used
- 100-200 averages typical for the development of the response not to exceed 250 averages

Electrode montage

cVEMP --- + (non-inverting) on the upper 1/3 of the SCM the (-) on the clavicular insert of the SCM with ground (common on the forehead) – this is ipsilateral to the ear stimulated

OVEMP --- + at the infra-orbital rim with the – 1 cm inferior and the common on the forehead – this is contralateral to the ear stimulated

Filter setting

cVEMP --- 2-1000
OVEMP --- 20-2000

Gain setting for either o & cVEMP start with 5k

Trace window for either o & cVEMP -25 to 80 ms
To activate the SCM – options available in order of preference:

- Turn and lift --- from 30° position off horizontal
- Lift only --- from 30° position off horizontal
- Turn only --- as far as comfortable --- from 30° position off horizontal
- Turn against BP cuff with meter starting at 20 mm Hg and going to -45 -- from 30° position off horizontal or from sitting with mild neck flexion

To bring the inferior oblique muscle as close to the electrode as possible for oVEMP recordings --- have the patient gaze up as far as comfortable (approximately 30° gaze up)

If patient is able to perform the activation of the SCM and the movement of the inferior oblique muscle the oVEMP and cVEMP can be done simultaneously.

Routine VEMPs performed whenever caloric irrigations are being used:

- oVEMP and cVEMP at 500 Hz if oVEMP is absent
- Repeat at 1 kHz
- Maximum and threshold for each

Protocol for abnormally large 3rd window effect:

- Using threshold with abnormally low being < 70 dB nHL
- Do maximum and then threshold search for o & cVEMP at 250 & 2 kHz
- If any of the 4 shows and abnormally low threshold the study is interpreted as positive “suspicious for”
- Using amplitude – only for oVEMPs – amplitudes > 15 microvolts at 250 or 2 kHz would be “suspicious for”
Protocol for possible endolymphatic hydrops:

cVEMP threshold response curve 250 – 1 kHz
Under age 60 to be positive for a shift up in frequency the level in dB SPL at 1 kHz must be <= level at 500 Hz
For 60 and over to be positive the level at 1 kHz must be < than that at 500 Hz. The older the subject the caution is needed in suggesting an abnormal upward shift since it has now been shown that the tuning by cVEMPs (and oVEMPs) starts to shift upward with age.

Clinical Applications

There are 3 primary clinical application:

The independent assessment of saccule (cVEMPs) and with this the inferior division of the vestibular portion of the VIII n and the independent assessment of the utricles (oVEMPs).

Identification of a potential superior canal dehiscence and if confirmed with high resolution CT the determination of whether the SCD is active – both oVEMPs & cVEMPs.

Use cVEMP threshold response curve in the determination of Meniere’s disease.
CASE 1

54 yo Female

Symptoms of constant unsteadiness, sensation of self motion, when asked she reported autophony and straining / pressure induced vertigo, loud sound induced vertigo

A-B gaps bilaterally with normal immittance

Had high resolution CT that was read as negative for dehiscence

Had vestibular & balance studies with all normal findings on VNG, rotary chair and postural control BUT oVEMP & cVEMP with abnormally low thresholds (55-65 dBNHL) and abnormally high amplitudes on oVEMPs bilaterally (30 microvolts) (> 3-4 STD DEV above the mean)

Eye movements in the plane of the superior canals bilaterally with pneumatic otoscopy

These findings forced a repeat interpretation in the CT with recognition of definite SCD bilaterally – surgery by round window ablation bilaterally – asymptomatic but with SCD signs continuing (explained by changes in impedance within the labyrinth with change back to 2 active windows from 3)
CASE 2

47 yo male
Reports a sudden onset of vertigo with nausea and vomiting as he awakened SEP 22 2010. The nausea and vomiting resolved in 8 hours with the vertigo constant into the next day. He was seen in the local ED and released with Meclizine.

The symptoms of the vertigo slowly improved and by the end of the 2nd day the vertigo was present only with head movements. Otherwise he had a constant sensation of unsteadiness.

Over the next 3 weeks the vertigo with head movement resolved but he was left with the unsteadiness and sensation of self movement in the head worsened by head movements, visual motion, visual complexity and reading.

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CASE 2

Seen by local ENT with diagnosis of Vestibular Neuronitis ? side VNG now 3 months out was normal (VEMPs were not performed) – started in vestibular therapy – 6 months no significant changes in his symptoms

1 year out seen at Mayo for continuing symptoms. VNG, rotational chair and postural control assessment were normal with HADS positive for anxiety. cVEMPs were normal bilaterally. oVEMP was normal on the right and absent on the left.

The findings with the initial history supported the diagnosis of superior division Vestibular Neuronitis on the left with continuing symptoms the result of developing Chronic Subjective Dizziness Syndrome (CSD). Treated for CSD with resolution of symptoms in 4 months.

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CASE 3

55 yo Male

Presents with spontaneous spells of vertigo with nausea and vomiting that last 2-6 hours with return to normal baseline by the next day. Spells are 1-2 every 3 months over the last 3 years.

He reports tinnitus, aural fullness and documented fluctuant hearing on the left. The auditory symptoms change with the spells. He also develops a focal headache with the spells about an hour after the vertigo is over. His last outside hearing test showed hearing now having returned to normal bilaterally.

VNG showed a 35% left RVR and rotary chair showed a mildly abnormal phase lead with normal gain and symmetry. oVEMPs were normal bilaterally. cVEMPs at 500 Hz were normal bilaterally.

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CASE 3

cVEMP threshold response curve for the right was normal and for the left showed a shift upward in the most sensitive frequency from 500 Hz to 1 kHz.

While his presentation was suggestive of left side Meniere’s the lack of a permanent hearing loss with the report of headaches with the spells could be suggestive of migraine related dizziness. The shift upward in the cVEMP threshold curve with his caloric asymmetry significantly increases the argument that Meniere’s is the active disorder with migraines stimulated by the stress of the spells. The probability that the shift is secondary to chance is 10% - highly specific for Meniere’s with the caloric asymmetry.

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