Information Document

Performing Cervical Vestibular Evoked Myogenic Potential Measurements

British Society of Audiology Balance Interest Group

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General forward

This document presents a Recommended Procedure by the British Society of Audiology (BSA). A Recommended Procedure provides a reference standard for the conduct of an audiological intervention that represents, to the best knowledge of the BSA, the evidence-base and consensus on good practice given the stated methodology and scope of the document and at the time of publication.

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1. Scope

This document covers the technical procedures for recording and analysing air conduction mediated c-VEMPs in adults and older children. It recommends stimulus and acquisition parameters, as well as methods for analysis and interpretation of results. It is written as a BSA information document as a consensus on good practice and techniques from Clinicians that have successfully recorded c-VEMPs. It is not a British Society of Audiology (BSA) Recommended Procedure1, although after wider professional and public consultation, it is likely to be adapted as such.

Although this document focuses on c-VEMPs in adults, the authors acknowledge that the response can be recorded in neonates and infants. The reader is directed to the literature for further information on this topic. There is also the ocular VEMP (o-VEMP), the details of which will be made available in a subsequent publication.

2. Introduction

The c-VEMP is an inhibitory myogenic response that can be measured at the tonically contracted sternocleidomastoid muscle (SCM) in response to acoustic stimuli or mechanical vibratory stimuli such as those delivered by a tap to the head or via a bone vibrator2. This document focuses on air conduction c-VEMPs and the reader is directed to the literature for information on vibratory stimulus evoked c-VEMPS. The c-VEMP is a non-invasive and relatively quick test providing information about the function and integrity of the ipsilateral saccule and ipsilateral inferior vestibular nerve. It provides a useful adjunct to the caloric test, which measures the function of the horizontal (lateral) semicircular canal and superior portion of the vestibular nerve. It is also a useful tool to aid the diagnosis of superior semicircular canal dehiscence (SSCD) and large vestibular aqueduct syndrome. Recent research suggests there may be a role for the c-VEMP in the diagnosis of Ménière’s disease (although research in this area is in its infancy).

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A typical c-VEMP response is shown in figure 1. It is biphasic, with a positive component at 13 ms (p13), followed by a negative component at 23 ms (n23), with more variable later waves. The supra-threshold amplitude is typically 20-150 microvolts\(^3\). (It should be noted that in the fields of neurology and neurophysiology convention is to have p13 as a downwards deflection and n23 as an upwards deflection i.e. the reverse of what is shown below)

![Figure 1: Example of a typical c-VEMP consisting of a positive component at 13 ms (p13), followed by a negative component at 23 ms (n23)](image)

The pathways involved in the c-VEMP are well established\(^4\). The ascending pathway involves stimulation of the saccule, which projects to the vestibular nucleus via the inferior vestibular nerve. The descending pathway is via the medial vestibulospinal tract to the ipsilateral SCM, where inhibition from contraction occurs. Other muscle groups are also involved but the SCM provides the most reliable and robust recording site.

### 2.1. Equipment Setup

Standard clinical auditory evoked response equipment can be used to record the c-VEMP, and since the response is dependent on the level of contraction, a method of monitoring muscle activity is recommended both when comparing c-VEMP amplitudes from each side (see section 3.1) and to ensure there is

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sufficient muscle activity to elicit a response (necessary before reporting the absence of a response). This is less important if only the demonstration of the presence or absence of a response is required.

2.2. Stimulus Parameters

The acoustic stimulus needed to elicit the c-VEMP is a high level (up to 100 dB nHL) acoustic transient. It is important that the stimulus is correctly calibrated (appendix A) and that maximum permissible levels are not exceeded (appendix B). Additionally, care must be taken to ensure that the subject does not experience any subjective loudness discomfort.

There are a range of stimulus parameters documented in the literature. Table 1 indicates recommended parameters used by the authors and which have been widely published to date.

**Table 1 Suggested stimulus parameters for c-VEMP recording**

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>500 Hz tone burst 2:1:2 cycle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polarity</td>
<td>Single polarity, i.e. either condensation or rarefaction**</td>
</tr>
<tr>
<td>Level</td>
<td>95-100 dB nHL re. ISO 389-6*** ****</td>
</tr>
<tr>
<td>Rate</td>
<td>4.9-5.1/s</td>
</tr>
<tr>
<td>Artefact rejection limit</td>
<td>Not required as there is no need to reject an epoch on basis of excessive EMG activity (but see comment below regarding gain/sensitivity)</td>
</tr>
<tr>
<td>Filters</td>
<td>10-1000 Hz</td>
</tr>
<tr>
<td>Recording epoch</td>
<td>-20 ms to +60 ms *****</td>
</tr>
<tr>
<td>Repetitions</td>
<td>100-150 x 2 and average</td>
</tr>
<tr>
<td>Gain/sensitivity</td>
<td>This will vary from one system to another, so use of the manufacturers recommended values is suggested. Alternatively, a trial run, with appropriate adjustment of the gain/sensitivity if the EMG is unusually large or small can be used. In choosing the gain it is important to realise that it should be sufficiently small so as to avoid the rejection or clipping of the recorded signal. A gain which is 1/100th of that used for ABR measurements should be sufficient.</td>
</tr>
</tbody>
</table>

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5 The unit of dB nHL is only valid if a 2:1:2 cycle tone burst calibrated to ISO 389-6 is used. Since the c-VEMP can be recorded in subjects with no hearing the unit of dB nHL is not directly relevant. Instead the dB nHL unit provides a method of standardizing the stimulus level and exploits the fact that most electrophysiological equipment in the UK is calibrated to ISO 389-6.
*There are a number of studies that have demonstrated optimum c-VEMP responses at 500 Hz\(^6\)\(^7\).  
**The importance of polarity of the stimulus is unknown. An alternating polarity stimulus will reduce any stimulus artefact. However as this is not an issue with a response of this latency, a non-alternating polarity stimulus is recommended as it may yield a larger response\(^8\). 
***The unit dB nHL is only applicable if a 2:1:2 cycle tone burst, which has been calibrated to ISO 389-6, is used. For all other stimuli the level must be measured in peSPL. 
****See Appendix B on maximum safe stimulus level 
***** It is suggested that pre-stimulus recording is always performed, either for EMG scaling purposes or to demonstrate the level of background activity when determining the presence/absence of a response.

2.3. Patient preparation

2.3.1. Contraindications/limitations to testing

Subjects with cervical spine problems should be carefully assessed to ensure that they are able to maintain adequate SCM contraction without causing any pain or discomfort. If there is any doubt, then a medical opinion should be sought prior to testing.

The response amplitude is known to be sensitive to the stimulus level reaching the inner ear. The response is often abolished by a modest conductive hearing loss caused by middle ear problems\(^9\) such as middle ear effusion, perforations or otosclerosis, since the loss attenuates the stimulus reaching the inner ear. However the c-VEMP will be present in a conductive hearing loss of non-middle ear origin e.g. with abnormal third window effects such as SSCD\(^10\) and widened vestibular aqueduct syndrome. Thus c-VEMPs can be performed in conductive hearing losses where there is a normal tympanogram and acoustic reflexes are present.

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\(^8\) Lightfoot, G, Personal communication. (Jan 2011)


Given the high level of the acoustic stimulus, care should be taken with subjects with tinnitus, hyperacusis or any other sensitivity to sounds. In all cases the test should be terminated if any signs of discomfort are displayed.

2.3.2. Prior to testing

Tympanometry and acoustic reflexes should be performed to ensure that a conductive hearing loss of middle ear origin is not present. c-VEMPs can be recorded in patients with a severe-profound sensori-neural hearing loss\textsuperscript{11}.

2.3.3. Achieving Sternocleidomastoid contraction

There are a number of different methods to achieve effective SCM contraction (see Table 2), with insufficient evidence to recommend one over another. Figure 2 shows two techniques which have been widely employed. The specific method of contraction should be selected before testing, with the patient being able to maintain SCM contraction for one minute periods with ease. Factors such as the patient’s age, neck mobility issues and the setup available must therefore be considered. Further information is available on this subject\textsuperscript{12}.

<table>
<thead>
<tr>
<th>Method of SCM contraction</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck torsion with head turned away from side being stimulated at $\geq 45^\circ$ whilst sitting with slight head flexion at $\sim 30^\circ$</td>
<td>Easy for most to do, but may be uncomfortable for patients with neck problems. Patients with thoracic/lumbar spine problems find this position preferable to head raise from caloric test position</td>
</tr>
<tr>
<td>Neck torsion with use of an inflated blood pressure manometer to monitor contraction strength. This can be done with patient pushing against the inflated cuff held in their hand or mounted on fixed surface</td>
<td>This method has been described in detail\textsuperscript{13} and allows basic monitoring of muscle contraction strength</td>
</tr>
</tbody>
</table>


Head raised from the caloric test position (30° from horizontal) | Achieves equal bilateral contraction. May be easier for those with difficulty performing the requisite neck torsion such as those with immobile necks. However some (especially the elderly) find it difficult to perform and can cause significant and unnecessary fatigue. Head raised from supine is not recommended as this causes excessive fatigue

Head raised with neck torsion from the caloric test position | Consistent, strong contraction achieved and easy to maintain for short periods. It is easy to adjust the degree of contraction by asking the patient to turn their head by a greater or lesser amount.

**Figure 2:** Contraction of the SCM (indicated by arrow) via neck torsion (A) and head raised from the caloric test position (B).

### 2.4. Electrode Montage

Figure 3 shows a standard electrode configuration for recording c-VEMP s, which is as follows:

- Non-inverting (+ve): Upper 1/3rd of the SCM (approximately 10 cm below the mastoid).
- Inverting (-ve): Sternoclavicular junction or dorsum of the hand
- Common (Ground): Forehead
This will lead to p13 appearing as a peak and n23 as a trough as indicated in Figure 1. Swapping the non-inverting and inverting electrodes will make p13 appear as a trough and n23 as a peak. Both of these electrode configurations are valid and have been commonly reported in the literature.

![Figure 3: Electrode configuration for c-VEMP recording. 1A: Non-inverting (+ve) electrode on the SCM; 2: Common electrode on forehead; 3: Inverting (-ve) electrode on the sternoclavicular junction; 1B: Additional non-inverting electrode for recording ongoing EMG activity to ensure consistent muscle contraction.](image)

Whilst this electrode configuration is suggested, it is by no means the only option that may be used to record c-VEMPs. Indeed the suggested electrode montage may differ from manufacturer to manufacturer.

### 2.5. Transducers

For air-conducted c-VEMPs, either insert earphones (e.g. ER-3A) or supra-aural earphones (e.g. TDH-39) may be employed. Careful positioning of the transducer must be ensured in order to avoid stimulus attenuation.
3. Recording c-VEMPs

The patient should be warned that the stimulus may be loud and must be advised to let the clinician know if discomfort occurs either from the stimulus or through maintaining SCM contraction.

For each side, two recording runs of 100-150 sweeps should be completed to assess the repeatability of any response and the extent of residual noise. The two runs may be combined (using a weighted add function if available) to create a grand average from which measurements of amplitude and latency can be made.

Simultaneous binaural recording is not recommended as although the response is predominantly unilateral, evidence suggests a crossed response or a volume conduction response from the ipsilateral side may be apparent at the contralateral electrode in some subjects (see Appendix C).

3.1. The effects of EMG level

The amplitude of the c-VEMP is directly proportional to the strength of the SCM contraction, i.e. the background electromyographic (EMG) potential. It is therefore important that muscle contraction is sufficient to record a good response and also that equal EMG activity is maintained between left and right measurements in order to ensure accurate side-to-side comparisons. Prolonged measurements can result in muscle fatigue and therefore a reduction in response amplitude may result in some patients. Methods for monitoring and maintaining consistent muscle contraction within an optimal range may include:

- Visual feedback via a computer display, hand-held EMG meter or light box
- Auditory feedback using a tone or other sound

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In addition, accuracy in comparing c-VEMP traces from the two sides may be improved by using pre-stimulus normalisation (also termed ‘EMG scaling’), which involves correcting the amplitude of the c-VEMP by the mean-rectified EMG activity in a pre-stimulus time period e.g. 20ms prior to every stimulus\(^\text{19}\). An example of this calculation is shown in Figure 4. Some equipment manufacturers have integrated this function, as well as visual and auditory feedback, into recent software. In addition, the importance of rectifying individual raw traces within the pre-stimulus window before calculating the mean has been highlighted, i.e. it is incorrect to rectify the mean pre-stimulus trace\(^\text{20}\).

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure4.png}
\caption{c-VEMP recorded from the right SCM of a normal subject. (P1 denotes the p13 and N1 the n23 waveform). The upper trace shows the raw c-VEMP response and the lower trace indicates the c-VEMP normalised for the mean-rectified pre-stimulus EMG level. The corrected amplitude (or ratio) is calculated by dividing the peak-peak \ldots\}
\end{figure}

\footnotesize
\begin{itemize}
\end{itemize}
p13-n23 amplitude (94.5 μV) by the mean rectified EMG level calculated over the pre-stimulus interval (24.5 μV). This gives a value of 4 μV which can be compared against the similarly derived response from the left side.

3.2. Common pitfalls

The c-VEMP should be relatively easy to record, however, responses may be absent or non-repeatable due to the following:

- Incorrect electrode placement because of difficulties in identifying the SCM
- Insufficient SCM contraction
- Use of sub-threshold stimulus levels
- Insufficient sound reaching the saccule due to occluding wax or other causes of a conductive hearing loss.
- Insufficient stimulus levels due to incorrectly fitted insert earphones and headphones

4. Analysis and Interpretation

4.1. Normative data

As practise in recording c-VEMP currently varies, particularly with respect to the stimulus parameters used, Departments are encouraged to collect their own normative data for the test set up they employ.

4.2. Presence/absence of the response

c-VEMPs have been shown to be present in otologically normal subjects up to the age of 40, and in 95% of those aged from 41-50, with the amplitude generally decreasing with age21. Additional studies have confirmed VEMPs in subjects up

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to the age of 60. Care should be taken in interpreting the absence of a c-VEMP, and the overall clinical picture must be taken into consideration when reporting absent or reduced activity of the saccule/inferior portion of the vestibular cochlear nerve.

4.3. C-VEMP amplitude and measurement of ‘saccular paresis’

Comparison of c-VEMP responses from each side has led to the proposal of calculating a ‘saccular paresis’, analogous to the canal paresis determined from caloric testing and which would be equal to the percentage difference in c-VEMP amplitudes between the right and left sides. However, such analysis currently requires a highly cautious approach, since the literature reports varying values for what might constitute a significant paresis. One study has reported differences of up to 35% between the two sides in normal subjects below the age of 60. Others consider c-VEMPs to be asymmetrical when ‘one is two times or more as large as the other, low in amplitude (less than 70 µV for a young population), or absent’. A similar conservative approach is employed by another group, which does not use amplitude asymmetry as an indicator of abnormality unless it is greater than 50% and fits with the clinical picture. Further work is certainly required in this area.

4.4. c-VEMP Threshold

A major utility of the c-VEMP threshold is to aid in the diagnosis of superior semicircular canal dehiscence (SSCD). In this condition, which is usually detected via high resolution CT scanning, abnormally low c-VEMP thresholds have been typically found. Thresholds are ≥ 10 dB below normal levels for a given stimulus. An example is shown in Figure 5. The mechanism underlying a reduction in c-VEMP thresholds has been well described and it appears that c-VEMP thresholds return to normal when a dehiscence is plugged. Other

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25 Shepard, N. Personal communication (Jan 2011)

26 Personal communication Dr James Colebatch and Dr Sally Rosengren (February 2011)


causes of a third window such as a dehiscent posterior canal or a large vestibular aqueduct should be considered when patients have lowered c-VEMP thresholds and symptoms, but no evidence of SSCD on the CT scan.

**Figure 5A:** c-VEMP threshold traces showing threshold of 85 dB HL on the left and an abnormally low threshold of 65 dB HL on the right. **Figure 5B:** High resolution CT of same patient showing SSCD on the right (arrowed).

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4.5. **Tuning curves**

The c-VEMP has been shown to be most robustly elicited by using a 500 Hz tone-burst, with the response reducing either side of this frequency. Research published by several groups\(^{30} \)\(^{31} \)\(^{32}\) suggests that this frequency tuning is altered in patients with Ménière’s disease. Further work is needed in this area but early data is promising and suggests that tuning curves may be potentially used as a method of diagnosing the disease.

5. **Effect of age & gender on c-VEMP amplitude and latency**

5.1. **Amplitude**

Several studies have shown a decrease in c-VEMP amplitude in patients 60 years\(^{33}\) and above. Tampas et al\(^{34}\) showed that this was due to degenerative effects on the vestibular system rather than SCM tone. However, in cases where a patient finds it difficult to achieve or maintain a good level of SCM contraction, then bilaterally absent responses should be interpreted with caution. There appears to be no gender effect on c-VEMP amplitude.

5.2. **Latency**

Current evidence suggests that latency measurements are not as clinically useful as amplitude measurements, however, increases in c-VEMP latency have been found in some cases of multiple sclerosis, brainstem lesions and other central pathologies\(^{35}\). Studies in adults have indicated no age-related effects on c-VEMP latency\(^{36}\).

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\(^{34}\) Tampas JW, Clinard C, Murnane OD, Akin FW. The effect of aging on tonic EMG levels and VEMP. Poster session presented at the annual meeting of of the American Academy of Audiology, Minneapolis MN


Appendix A. The Specification & calibration of air conduction c-VEMP stimuli

The recommended stimulus for the c-VEMP is a 500 Hz 2:1:2 tone burst at a level in the range 85–100 dB nHL.

Early work on the c-VEMP used a click stimulus but more recent evidence suggests that a tone burst at 500 Hz evokes a larger response than a click of the same loudness and is now considered the stimulus of choice.

Since the equipment used for c-VEMP studies is normally that used for ABR, it has been common practice to use the same tone pip (burst) characteristics as used for ABR tests: a 2:1:2 cycle (rise/plateau/fall) burst with either a linear or Blackman envelope. The 2:1:2 ABR stimulus is a compromise between the conflicting requirements of a stimulus that is sufficiently abrupt to achieve good neural synchrony whilst containing sufficient cycles to achieve reasonable frequency specificity for audiological use (a narrow spectrum). The latter is unimportant for evoking a c-VEMP, and in theory a more abrupt stimulus such as a 1:1:1 tone burst will give more neural synchrony. However, frequency specificity of the stimulus is required when plotting the tuning curve of the response, as in the investigation of Ménière’s disease. Given the likely application of VEMPs in this area, the recommended stimulus of choice is therefore the 2:1:2 tone burst.

It is recommended that the stimulus should be calibrated to the same reference level as that used for conventional ABR stimuli (ISO 389-6, 2007). This is for pragmatic reasons: in the UK it is likely that the equipment will already be calibrated to this standard and the maximum peak-peak sound pressure level of the stimulus is therefore defined. Note that if the stimulus is expressed in dB peSPL and inserts are used, one must also specify the type of acoustic coupler used to measure the stimulus since the reference levels for stimuli delivered via inserts differ for HA-2 couplers (2cc, IEC 60318-5) and occluded ear simulators (711, IEC 60318-4).

For convenience, the table below provides the peak-peak equivalent SPL of stimuli at 90 dB nHL, which is from ISO 389-6 (2007). HA-2 figures are not given.

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in this standard but are quoted by the English Newborn Hearing Screening Programme using transfer data. See: http://hearing.screening.nhs.uk/audiologyprotocols (audiology calibration and equipment)

Table 3: Peak equivalent sound pressure levels of a 2:1:2-cycle tone burst at 90 dB nHL

<table>
<thead>
<tr>
<th></th>
<th>Click</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDH-39</td>
<td>121.0</td>
<td>113.0</td>
<td>108.5</td>
<td>115.0</td>
<td>117.5</td>
</tr>
<tr>
<td>Insert, HA-2</td>
<td>116.5</td>
<td>109.5</td>
<td>106.5</td>
<td>110.0</td>
<td>113.0</td>
</tr>
<tr>
<td>Insert, 711</td>
<td>125.5</td>
<td>113.5</td>
<td>111.5</td>
<td>118.5</td>
<td>122.5</td>
</tr>
</tbody>
</table>

Note that these levels are high. Prolonged test sessions using stimuli over 100 dB nHL may constitute a noise hazard and are to be avoided. (See appendix B)

Appendix B. Noise Dose

As c-VEMP recording requires a high level stimulus, it is important to ensure that patients are not exposed to levels exceeding those stipulated in the Noise Regulations shown below.

For c-VEMP recordings, an upper limit for the 500 Hz tone burst stimuli of 100 dB nHL is recommended.

For determining the presence or absence of a c-VEMP, only two repeatable traces are needed per ear and therefore it is very unlikely that maximal permissible levels of noise exposure will be reached. However when more extensive testing such as tuning curve measurements are made, it is important that the overall exposure time is monitored to ensure excess exposure (as specified by the Noise Regulations, ‘Control of Noise at Work Regulations 2005”) does not occur.

When the equalization concept is applied, the upper noise exposure limits are as follows:

- 85 dB (A) for 8 hours
- 88 dB (A) for 4 hours
- 97 dB (A) for 30 minutes
- 100 dB (A) for 15 minutes
Appendix C. Binaural recording

Binaural stimulation and recording using a bilateral muscle tone method such as the straight head lift could in theory halve the test time, yield more symmetrical muscle tone and avoid any muscle fatigue that could give rise to an order effect.

This could be performed via a simultaneous bilateral stimulus or an alternating interleaved stimulus. The former is not recommended, as evidence suggests that a contralateral response can be recorded in some subjects. This may be produced by a spread of the stimulus to other vestibular, e.g. utricular, afferents, which have bilateral projections to the SCM. Furthermore volume conduction may also affect the response. Interleaved stimulation would overcome this problem but has yet to be provided by equipment manufacturers.

Appendix D. Acknowledgments

Many thanks to Dr Neil Shepard, Dr Sally Rosengren, Dr James Colebatch, and members of the Department of Neuro-Otology, Queens Square, London who gave a fresh perspective and advice on this document, and to members of the group who produced the document:

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