A TUTORIAL ON CERVICAL VESTIBULAR MYOGENIC POTENTIAL

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19AUD007

This Dissertation is submitted as part

fulfilment for the Degree of Master of Science in Audiology

University of Mysore, Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

Manasagangothri, Mysuru 570 006

September 2021

CERTIFICATE

This is to certify that this dissertation entitled **'A tutorial on cervical vestibular myogenic potential'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 19AUD007. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

September 2021

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DECLARATION

This is to certify that this dissertation entitled **'A tutorial on cervical vestibular myogenic potential'** is the result of my own study under the guidance of Dr. Sujeet Kumar Sinha, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration Number: 19AUD007**

September 2021

DEDICATED TO PAPA, MAA,

MY BROTHERS AND SISTERS

AND MY GUIDE

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Throughout the writing of this dissertation I have received a great deal of support and assistance.

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Chapter 1

INTRODUCTION

The vestibular sensory organ comprises the saccule, utricle, and six semicircular canals (anterior, posterior, and lateral). The semicircular canal responds to rotational movement, and the saccule and utricle respond to translational movement of the head. The function of the otolith organ is primarily assessed by the vestibular myogenic evoked potential (VEMP). Two types of VEMP are used primarily in the clinics, cervical vestibular evoked myogenic potential (cVEMP) and ocular vestibular myogenic evoked potential (oVEMP). These potentials are short-latency responses elicited by a high acoustic stimulation level.

The pathway of the cVEMP is known as sacculocollic pathway, and the pathway of the oVEMP is known as otolith ocular pathway. The sacculocollic pathway is ipsilateral, whereas the oVEMP pathway is contralateral. In the sacculocollic pathway, when a high-intensity acoustic stimulus is given, it stimulates the saccule. The action potential is generated in the inferior branch of the vestibular nerve. From the inferior branch of the vestibular nucleus, the action potential reaches to the vestibular nuclei from where it is supplied to sternocleidomastoid muscle through the medial vestuibulospinal tract.

cVEMP has been found helpful in the assessment of pathology of the sacculocollic pathway in various vestibular disorders such as Meniere's disease (Sinha et al., 2015), noise-induced hearing loss (Khan et al., 2013), age-related changes (Singh et al., 2014), severe to profound hearing loss (Bansal et al., 2021), vestibular neuritis (Govender et al., 2011), auditory neuropathy spectrum disorder (Singh et al., 2016), diabetes mellitus (Sahu & Sinha, 2015) and superior canal dehiscence syndrome (Zuniga et al., 2013).

Colebatch and colleagues were the first to identify this evoked response (1992, 1994). VEMP can be recorded from several muscles, the most common of them is the sternocleidomastoid muscle (SCM) (Bath et al., 1999;Colebatch et al., 1994; Murofushi et al., 1995, 1996; Young et al., 1977). The test is simple to conduct in the clinic and can be done with most evoked potential recording systems. The lateral semicircular canals and the superior vestibular nerve are the only elements tested in the electronystagmography (ENG) battery.

1.1 Need of the Tutorial

There is a dearth of tutorials on cervical vestibular evoked myogenic potentials. There is a need for such tutorial on cVEMP, as this will be a quick reference guide for the students and clinicians. This tutorial will help the clinician find all the information about cVEMP in a single manual guide, which will save time and require less effort. The manual will also provide information on the usefulness of the cervical vestibular evoked myogenic potentials in different vestibular disorders.

1.2 Aim of the study

To formulate a tutorial on the cervical vestibular evoked myogenic potentials.

1.3 Objectives of the study

The main objectives of the study are as follows:

a. To compile all the information related to recording parameters available in the literature.
b. To describe each of the recording parameters and clinical applications of the cervical vestibular evoked myogenic potentials.

Chapter 2

METHOD

Tutorial is an important teaching-learning tool. It helps learners enhance their intellectual, communication and social skills. The Medical Council of India, in its latest reforms on medical curricula, has emphasized the need to increase small group teaching sessions.

For preparing the tutorial, text books named Balance Function Assessment and Management Second Edition by Gary P. Jacobson, PhD Neil T. Shepard, PhD and ISHA monograph: evaluation and management of vestibular dysfunction were used as reference. Also, the articles collected from various online sources like Google Scholar, PubMed, web of science, Science direct were collected. The following search strings were used: "Vestibular Evoked Myogenic Potential", "clinical application of cVEMP", "Factor affecting cVEMP" etc. A search for articles up to march 2021 was performed. Inclusion criteria for the articles were: articles reporting sufficient number of patients(>10subjects), sufficient and accurate description of cVEMP recording system, sufficient and accurate description of pathologies and clinical features. Exclusion criteria were: articles concerning different instrumental methods than cVEMP, lack of adequate analysis and presentation of data.

The tutorial has been broadly prepared under the following headings:

- Introduction of cervical Vestibular evoked myogenic potentials
- History and Pathway of cervical Vestibular evoked myogenic potentials
- Stimulus Parameters
    - Mode of Recording
    - Types of Stimulus
    - Stimulus Frequency
    - Stimulus Intensity
    - Stimulus Duration
    - Stimulus rate

- Monoaural/ Binaural Recording

❖ Acquisition Parameters

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- Electrode Placement
- Amplification and Filtering
- Muscle Contraction – Effects and method of recording

❖ Interpretation of cVEMP

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- Frequency Tuning
- Latency
- Threshold

❖ cVEMPs in clinical practice

- Benign paroxysmal positional vertigo (BPPV)
- Meniere's disease
- Superior semicircular canal dehiscence (SSCD)
- Vestibular neuritis
- Bilateral vestibulopathy
- Noise induced hearing loss (NIHL)
- Auditory Neuropathy spectrum disorder (ANSD)
- Vestibular schwannoma

Chapter 3

HISTORY AND PATHWAY OF cVEMP

3.1 History of Vestibular evoked myogenic potentials

It is now well known that sound can stimulate the vestibular system. Tullio (1931) was the first scientist to demonstrate the vestibular system's sensitivity to auditory stimuli. Tullio's experiments consisted of fenestrating the bony labyrinth of pigeons. Later Tullio subjected the pigeon to sound produced by a flute. He observed the labyrinthine fluids' motion (the frequency of the notes produced by the flute, matched the frequency of the movement of the endolymph) and eye movements. Tullio proved that the vestibular system could be stimulated using sound stimulus (Tullio, 1931).

Von Bekesy (1935) demonstrated that human subjects exposed to a high-intensity stimulus (122 to 134 dB SPL) have a corresponding head displacement toward the stimulated ear. Von Bekesy argued that the head's reflexive movement in response to an auditory stimulus is likely due to the endolymph movement stimulating the vestibular system. In the mid-1960s, (Bickford et al., 1964) reported the presence of a sound-evoked electrical potential (negative waveform peaking at approximately 30-ms) that could be recorded from an active electrode placed on the inion. Initially, this response was believed to be "neurogenic." However, the investigators demonstrated that the response's earlier components were significantly reduced in amplitude following a muscle paralyzing agent's administration. Additionally, it was noted that the response grew in amplitude with increases in the tonic level of electromyography (EMG) in the neck extensors. This evoked-potential response was subsequently named the *inion potential*.

Further studies by this group of investigators led to the theory that the vestibular system (i.e., the saccule) was the generation site for the potential recorded from the inion (Cody et al., 1964; Townsend & Cody, 1971). Researchers could not find any significant application of the potentials recorded from inion, and hence no more further recording of this potential was done. Colebatch & Halrnagyi, (1992) reported the presence of short-latency, large-amplitude myogenic potentials recorded from sternocleidomastoid mastoid muscle in response to a loud click sound. This response was characterized by a positive wave (P1) followed by a negative wave(N1) occurring ipsilateral to the ear that received the stimulus (Colebatch & Halrnagyi, 1992;Colebatch et al., 1994). Two more peaks were observed in succession namely, p34 (positive peak) and n44 (negative peak) after the initial biphasic response containing p13 and n23 peaks. The second wave complex (n34 - p44) was present in only 60-68% of the normal subjects (Colebatch et al., 1994; Robertson et al., 1995). Also, the second component lacked reproducibility, and hence only the first biphasic complex (p13-n23) is taken into consideration for clinical purposes (Su et al., 2004).

The responses to a high intensity sound could be recorded even in completely deaf individuals suggesting a vestibular origin. (Colebatch et al., 1994;Colebatch & Halrnagyi, 1992). The cVEMP is recorded using any evoked potential system by placing the electrode over an activated sternocleidomastoid muscle (Colebatch et al., 1994; Colebatch & Halrnagyi, 1992). The pathway between the saccule and the sternocleidomastoid muscle is also known as vestibulocollic responses (VCR). The corresponding changes in the tonic background EMG level in the neck extensors observed during head movements represent vestibular-driven muscle coordination in the neck used to stabilize the head (Lysakowski et al., 2005a). The afferent and efferent

limbs of the VCR have been described by several groups and are considered to represent the pathway for the clinical response we know as the cVEMP.

3.2 Pathway of Cervical Vestibular evoked Myogenic potentials

The saccullo-collic response is a reflexive adjustment of the neck musculature activated by saccule activation. The afferent limb of the cVEMP reflex stretches from the saccule (receptor organ) to Scarpa's ganglion, where neural projections pass through the inferior branch of the vestibular nerve (McCue & Guinan, 1995; Murofushi & Curthoys, 1997). The cVEMP reflex's efferent limb descends from the vestibular nucleus and travels across the medial vestibulospinal tract to the Spinal accessory nucleus. A branch of the spinal accessory nerve connects it with the sternocleidomastoid muscle (Fitzgerald et al., 1982). The solitary motor input to the SCM is CNXI, which originates in the anterior horn of the first five cervical segments of the spinal column (Krause et al., 1991). The pathway between the saccule and the sternocleidomastoid muscle has been verified by attenuating or ablation of the VEMP response following selective neurectomies and neural pathologies(Colebatch & Halrnagyi, 1992; Murofushi et al., 1999). The other pathway of the cervical vestibular evoked myogenic potentials is between the vestibular nucleus to gastrocnemius muscle. This pathway starts from the vestibular nuclei and descends via lateral vestibular spinal tract to the gastrocnemius muscle. The figure of both the pathways are shown in Figure 3.1.

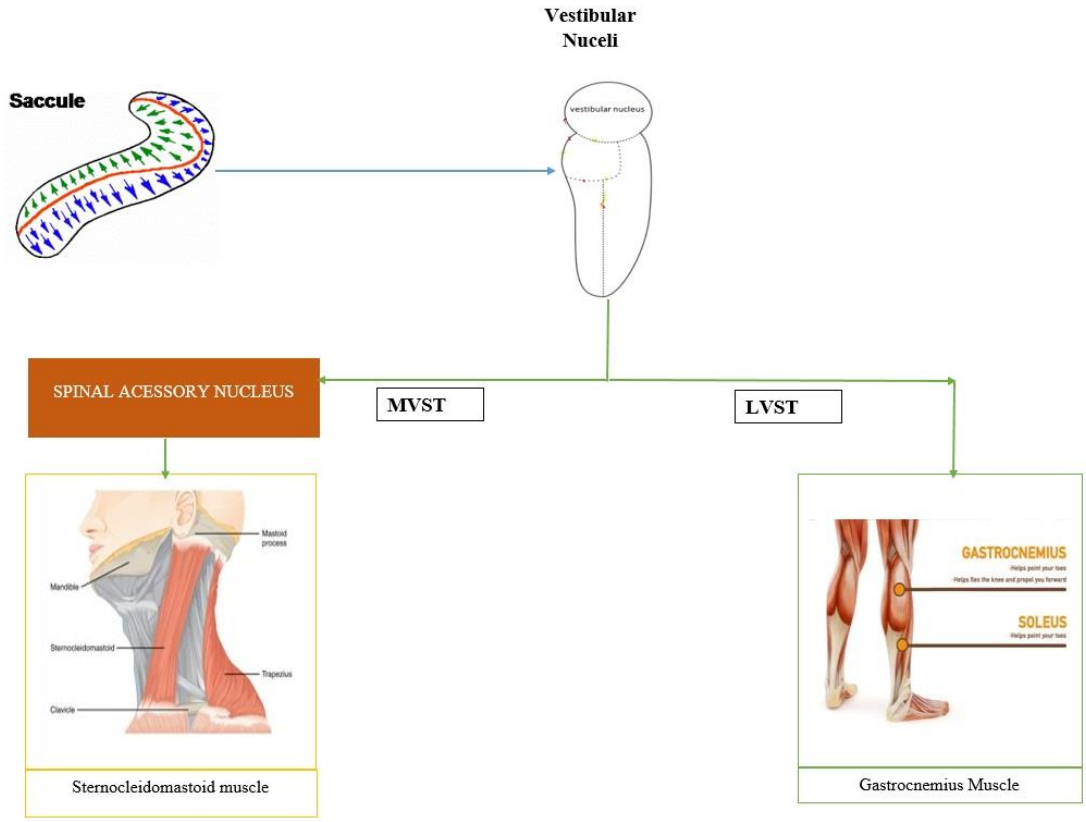

Figure 3.1 Pathway of the Cervical vestibular evoked myogenic potentials

Multiple choice questions

1. Who among the following was the first to demonstrate the vestibular system's sensitivity to auditory stimuli?
    a. Pietro Tullio
    b. Von Bekesy
    c. Bickford
    d. Colebatch and Halrnagyi
2. Who among the following reported the presence of short latency large amplitude myogenic potential recorded in response to a loud click with an electrode placed over the belly of a contracted SCM muscle?
    a. Cody
    b. Colebatch and Halrnagyi

c. Townsend

d. Bickford

3. Who led to the theory that the vestibular system (i.e. the saccule) was the inion potential's peripheral origin?

    a. Cody & Townsend

    b. Bickford

    c. Colebatch and Halrnagyi

    d. Carey & Amin

4. Tullio experiments consisted of fenestrating the bony labyrinth of

    a. Chinchilla

    b. Parrot

    c. Rat

    d. Pigeon

5. Among the following authors who reported the presence of a sound evoked electrical potential (negative peak) that could be recorded from active electrode placed on inion?

    a. King and colleague

    b. Bickford and colleague

    c. Tullio and colleague

    d. Cody and colleague

6. Who firstly used the term Vestibular evoked myogenic potential (VEMP) for response recorded from vestibular organ?

    a. Lysakowski and colleague

    b. Colebatch and Bickford

    c. Colebatch and Halrnagyi

d. Halrnagyi and Cody

7. The correct order of cVEMP pathway is
    a. Saccule - Inferior vestibular nerve - descending medial vestibulospinal tract - medial vestibular nuclei- motor nucleus of sternocleidomastoid muscle
    b. Saccule - Inferior vestibular nerve - medial vestibular nuclei - descending medial vestibulospinal tract - motor nucleus of sternocleidomastoid muscle
    c. motor nucleus of sternocleidomastoid muscle- Inferior vestibular nerve - descending medial vestibulospinal tract - medial vestibular nuclei - Saccule
    d. Inferior vestibular nerve- Saccule- medial vestibular nuclei - descending medial vestibulospinal tract - motor nucleus of sternocleidomastoid muscle
8. The cranial verve involved in cVEMP pathway are –
    a. 7^{th} and 11^{th}
    b. 6^{th} and 12^{th}
    c. 8^{th} and 11^{th}
    d. 3^{rd} and 8^{th}
9. Cervical Vestibular evoked myogenic potential assesses
    a. Saccule and superior vestibular nerve
    b. Saccule and inferior vestibular nerve
    c. Utricle and superior vestibular nerve
    d. Utricle and inferior vestibular nerve

Chapter 4

STIMULUS PARAMETER

4.1 Different recording methods/mode of recording

4.1.1 Air-Conducted Stimuli

The most common acoustic stimulus used for recording the vestibular evoked myogenic potentials is either click or tone burst stimulus (Papathanasiou et al., 2014). The sound pressure is routed through the middle ear system to the oval window into the vestibule when a high-intensity, a low-frequency acoustical transient is applied to the ear canal (Lysakowski et al., 2005b). This causes the endolymph in the vestibule to shift and the shearing of the vestibular hair cells (Type I and Type II), resulting in transduction (Murofushi et al., 1995). In individuals with conductive hearing loss, due to presence of a conductive component there is an attenuation of the energy and hence, the air conducted VEMP cannot be recorded. In individuals with conductive hearing loss a vibratory or mechanical stimulus is preferred.

4.1.2 Bone-Conducted Stimuli

Bone-conducted vibration (BCV) is an alternative stimulation that has been successfully used to stimulate the otolith organs and activate vestibular afferents (Goldberg, 2000). Through bone vibrator either a click or tone bursts stimulus can be delivered (McNerney et al., 2011). Bone-conducted tone bursts elicits reliable cVEMPs responses (Sheykholeslami et al., 2000; Yang & Young, 2003). When lower-frequency stimuli (i.e., 200 to 250 Hz) are used, cVEMPs have greater amplitudes in response to bone-conducted vibration compared to air conducted stimulus (Sheykholeslami et al., 2000; Welgampola et al., 2003).

Welgampola et al.(2003) showed that cVEMP responses using bone-conducted vibration stimulation are present bilaterally. However, the amplitude of the ipsilateral

cVEMP responses are larger. The latency of the contralateral responses is prolonged compared to ipsilateral responses by 1msec (Welgampola et al.,2003). Thresholds for cVEMPs generated using bone-conducted cVEMPs vibration are better than those obtained with air-conducted stimuli (Welgampola et al., 2003a). The authors also reported that the optimal placement for delivery of bone-conducted vibration was 3cm posterior and 2 cm superior to the external auditory canal as this location produced the largest amplitude of cVEMPs. In a similar study, Sheykholeslami et al. (2000) recorded cVEMPs using bone-conducted vibration at 100, 200, 400, 800, 1600, and 3200 Hz at an intensity of 70 dBnHL. The author reported that the largest amplitude of cVEMPs are present for 200-Hz stimuli. At other frequencies reliable cVEMPs responses are not obtained.

4.1.3 Mechanical Stimuli (Head taps)

VEMPs is also elicited by tapping the head in the midline frontally with a tendon hammer (Halmagyi et al., 1995). The amplitude of the cVEMP recorded with skull tap induced vibration is significantly larger and is present bilaterally. The skull tap cVEMP response is present despite the presence of conductive hearing loss.

cVEMP responses generated using taps can be recorded bilaterally. Skull Tap induced cVEMP has larger amplitudes compared to air-conducted stimuli and are measurable in the presence of conductive hearing loss. Skull taps help to identify peripheral vestibular end-organ impairments. cVEMPs recorded using air-conducted clicks, and skull taps are similar. It is noteworthy that the location (e.g., lateral versus forehead) of the tapping on the skull can produce different responses. Brantberg et al.(2003) showed that skull taps to the forehead produces bilateral cVEMP waveform similar to those generated by air-conducted stimuli. However, cVEMPs in response to lateral skull taps generates a typical looking cVEMP (i.e., P1–N1) from the contralateral

side but an antiphasic waveform from the ipsilateral side. The authors suggested that this bilateral response represented synchronized EMG activity from the SCMs analogous to what would occur during a natural translation on the head.

4.1.4 Short duration galvanic stimulation

Watson and Colebatch have first described Vestibulo-collic reflexes evoked by galvanic stimulation in man in 1998. Galvanic (DC) stimulation is a nonmechanical means of activating the vestibular apparatus (Camis & Creed, 1930) probably by a direct action on vestibular nerve endings (Goldberg et al., 1984; Watson & Colebatch, 1997). The vestibular apparatus has long been understood to be activated by low-level galvanic (DC) stimulation (Fitzpatrick & Day, 2004). A trans mastoid current of short length (2 ms) evokes a VEMP in the SCM ipsilateral to the cathode (Watson & Colebatch, 1998). There is also an excitatory response on the opposite side, partially due to a crossed reflex effect and a direct anode effect on that side. The primary technical challenge with this approach is the resulting stimulus artifact (Watson & Colebatch, 1998). As in galvanic VEMP a small current is applied to the mastoid region, it bypasses the inner ear and stimulates the vestibular nerve directly. Thus, a combination of cVEMP recorded with an air conducted stimuli and the galvanic stimulus can give information about the inner ear and the vestibular nerve. The galvanic VEMP is very useful in identifying the nerve lesion and separating it from the end organ lesions.

4.2 Type of stimulus

Short-duration tone bursts of 500Hz and clicks are the most commonly used stimuli for eliciting cVEMPs. Studies comparing clicks and short-duration tone-bursts showed that click-evoked cVEMPs had a higher amplitude and shorter latency compared to those evoked by 500 Hz tone-bursts (Cheng et al., 2003). However, other studies suggest tone-burst evoked cVEMP has longer latency and greater amplitudes than clicked evoked cVEMP (Isaradisaikul et al., 2012; Kumar et al., 2011; Welgampola & Colebatch, 2001; Wu et al., 2007). Tone bursts, rather than clicks, have lower VEMP thresholds (Janky & Shepard, 2009).

Logon, band-limited chirp stimulus, or chirp stimulus has also been used to record cVEMP (Trivelli et al., 2008; Viciana & Lopez-Escamez, 2012; Walther & Cebulla, 2015; Wang, Hsieh, et al., 2013). It has also been reported that 500 Hz logon stimulus is equally efficient in eliciting the cVEMP in adults (Özdek et al., 2012; Trivelli et al., 2008) as well as in children (Ozdek et al., 2009). The response rate of a 500 Hz logon-evoked cVEMP is comparable to that elicited by a click or tone burst stimulus. The latency of the P1 peak, the latency of the N1 peak, and the amplitude of the P1N1 complex of cVEMP do not vary significantly between 500 Hz tone burst and 500 Hz Logon stimulus (Özdek et al., 2012). A 500 Hz logon stimulation is superior to a click stimulus in eliciting cervical vestibular evoked myogenic potentials (Trivelli et al., 2008). Trivelli et al. (2008) also reported that the 500 Hz logon stimulus has a longer latency than the click stimulus. However, with a 500 Hz logon stimulus, the amplitude of cVEMP is greater than with a click stimulus. Since the saccular receptors are more sensitive to 500 and 750 Hz frequency acoustic stimuli than sounds of different frequencies, the amplitude of cervical vestibular evoked myogenic potentials using logon stimulus is high (Akin et al., 2003).

The chirp stimulus has also been used to record cVEMP (Murofushi et al., 2020; Özgür, 2015; Walther & Cebulla, 2015b;Wang, Hsieh, et al., 2013). The latency of the P1 and N1 peak of cVEMP elicited by a chirp stimulus is shorter than that of the click and the tone burst stimulus. cVEMP tone burst having the most prolonged latency of the three (Murofushi et al., 2020;Wang et al., 2013). Wang et al.(2013) reported that cVEMP elicited by the chirp stimulus has a higher amplitude than the click stimulus but is identical to the tone burst stimulus. However Ozgur et al. (2015), found that the amplitude of cVEMP elicited by chirp stimulus is lower than that elicited by click and tone burst stimulus. Murofushi et al. (2020) also found that the 500 Hz tone burst elicited a higher amplitude of cVEMP than the chirp stimulus. However, Ozgur et al. (2015) recommended using tone burst stimulus over chirp stimulus because of the higher response rate and amplitudes.

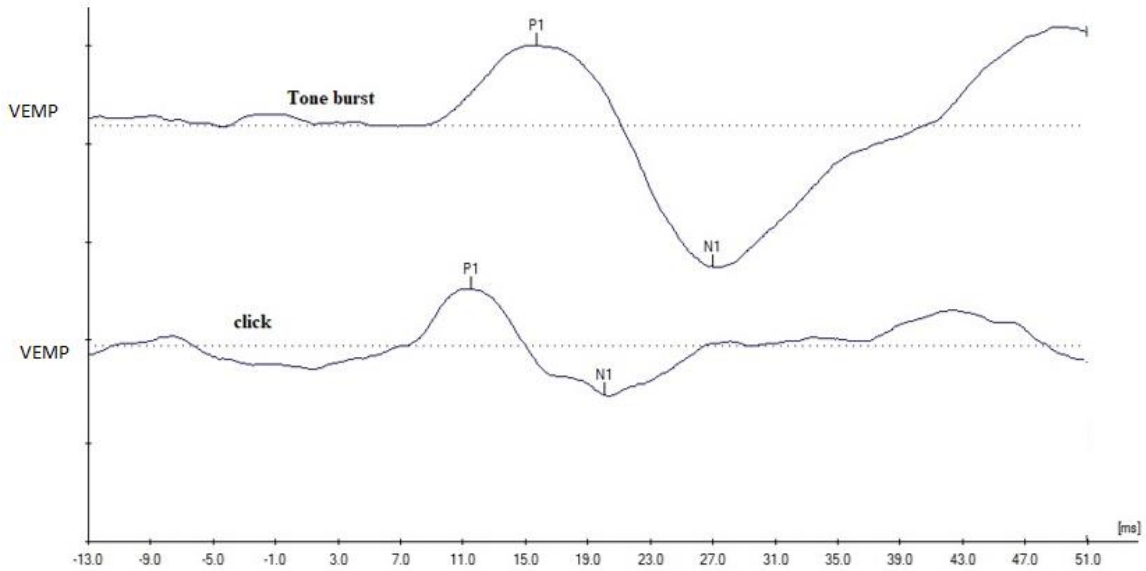

Figure 4.1: Effect of click and tone burst stimulus on cVEMP

4.3 Stimulus frequency

The air-conducted (AC) tone bursts in the 200–1000 Hz range produce the highest-amplitude/lowest-threshold cVEMP in normal subjects (Rauch et al., 2004;Todd et al., 2000;Welgampola & Colebatch, 2001b).Todd et al.(2000) used a single mass-spring system to model cVEMP tuning and found the resonant frequency of saccule around 300 Hz. Later research revealed that cVEMP tuning curves had a dominant peak between 400 and 800 Hz, with the least amplitude obtained above 1000Hz (Janky & Shepard, 2009; Murofushi et al., 1999; Rauch et al., 2004; Timmer et al., 2006;Todd et al., 2009;Welgampola & Colebatch, 2001a).

Todd et al. (2000) investigated the amplitude differences of cVEMPs observed with 100, 200, 400, 800, 1600, and 3200-Hz tone-bursts keeping the intensity constant (100 dB SPL). Todd et al.(2000) reported the maximum cVEMP amplitude between 300 and 650 Hz. Akin et al. (2003) investigated effect of stimulus frequency (500–750 Hz) on latency and the cVEMP response threshold. When the stimulus's rise and fall times are constant, changing the stimulus's frequency has little effect on latency (Akin et al., 2003;Welgampola & Colebatch, 2001a). Welgampola & Colebatch (2001a) used tone-bursts between 200 and 1000 Hz with 100-Hz increments to record cVEMP responses. cVEMPs with the largest amplitudes were produced in response to stimuli between 600 and 1000 Hz. The finding that low-frequency tone-bursts between 500 and 1000 Hz are the best auditory stimulus for generating a cVEMP has been repeated by numerous researchers (Akin et al., 2003; Wu & Murofushi, 1999). These results are consistent with neurophysiological recordings from the afferents of the inferior vestibular nerve in cats, which show that tuning is most sensitive between 500 and 1000 Hz (McCue & Guinan, 1995).

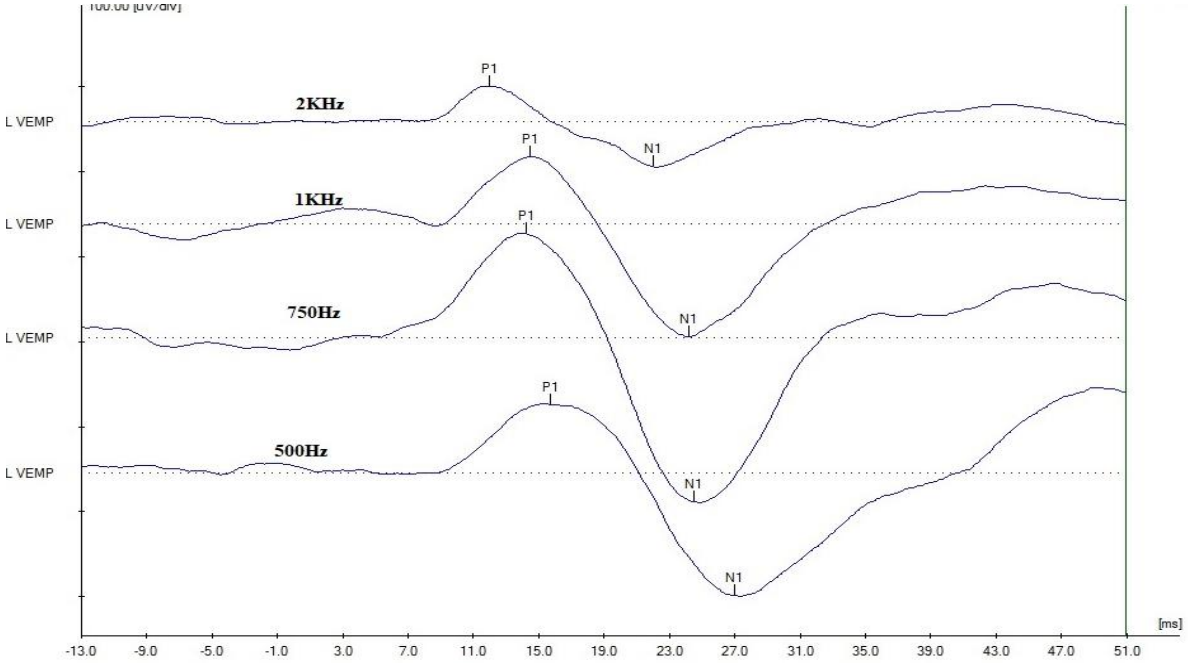

Figure 4.2 The influence of stimulus frequency on the amplitude of cVEMP

4.4 Stimulus Intensity

The dynamic range of cVEMP responses is narrow, and high precise amplitude replicable responses are only seen at very high stimulus intensities. The magnitude of a cVEMP response is directly influenced by the stimulus level. A high-intensity stimulation 95 to 100 dBnHL is needed to record a cVEMP response (Colebatch et al., 1994; Ochi et al., 2001). In most people with normal vestibular function, stimulus intensities near or below 75 dBnHL are insufficient to record a cVEMP (Akin et al., 2003; Papathanasiou et al., 2014). The response rate of cVEMP is 100% at 125dBSPL(Basta et al., 2005), 88% percent at 95dBnHL (Cheng et al., 2003) and 97% at 123 dB SPL (Janky & Shepard, 2009).

Ochi et al. (2001) reported substantial changes in the amplitude of the cVEMP with increasing stimulus level with no change in the latency of either P1 peak or N1 peak. In subjects with normal vestibular system, the threshold of cVEMP is about 75-85 dBnHL, or 105-110 dBpeSPL (Bath et al., 1998; Ochi & Ohashi, 2003;Wang et al.,

2008;Welgampola & Colebatch, 2001b; Zapala & Brey, 2004; Zhou & Cox, 2004). According to Janky & Shepard, (2009) mean cVEMP thresholds for young adults (ages 20–29 years) is 113 dB SPL at both 500 and 750 Hz tone burst (Rodriguez et al., 2019). Thresholds were obtained in children and adolescents, and mean cVEMP thresholds for both 500 and 750 Hz frequencies were below the high stimulation levels (i.e., 120 dB SPL) (Rodriguez et al., 2019).

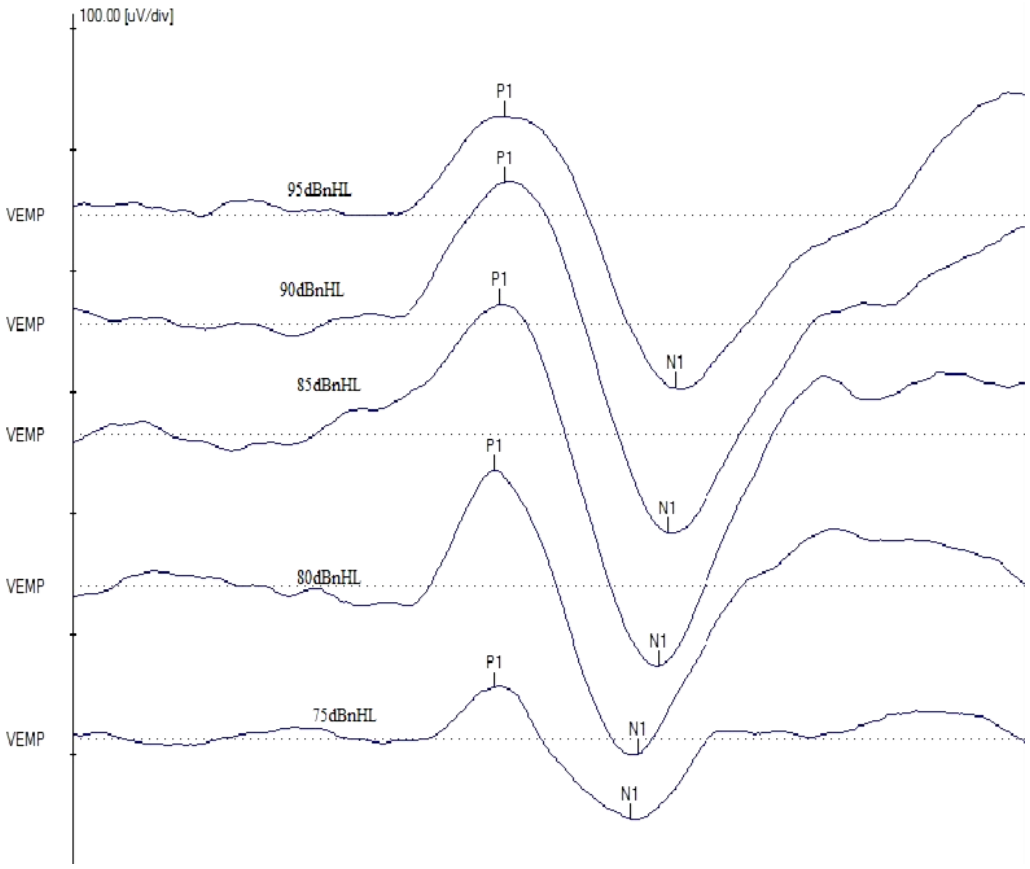

Figure 4.3 The effect of stimulus level on cVEMP amplitude.

4.5 Stimulus duration

cVEMP responses are elicited by both clicks and brief tone bursts. Tone bursts at 500 Hz, evoke more powerful and explicit cVEMP responses than tone bursts at 1000 and 2000 Hz and click stimulus (Murofushi et al., 1999; Viciana & Lopez-Escamez, 2012). Kumar et al. (2011) used a 2-ms rise/fall time and 0 ms plateau time for recording cVEMP, while Murofushi et al., (1999) used a 1 ms rise/fall time and 2-ms plateau time

for recording the cVEMP. Murofushi& Po-Wen Cheng (2001) reported that as the plateau time increased from 1 to 10 ms, latency of P13, N23 prolonged. Murofushi et al. (1999) reported that a plateau period of 2 ms provides the least variability and the largest cVEMP amplitude.

Murofushi (2001) also reported increase in cVEMP latency with increase in stimulus rise/fall time. Welgampola & Colebatch, (2001) reported stimulus duration of 7 milliseconds for eliciting the best cVEMP responses.

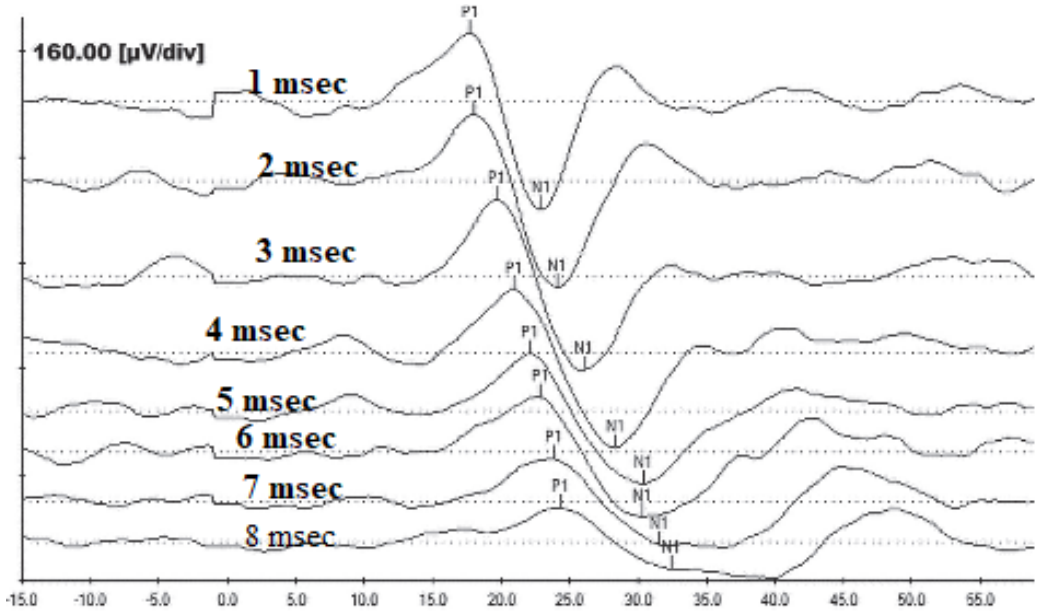

Figure 4.4 cVEMP waveforms from top to bottom in increasing order of rise/fall time from 1 to 8-ms with a pre-stimulus period of 15 milliseconds, [Adopted from Singh and Apeksha (2014)].

4.6 Stimulus Rate

The latency of cVEMP increases and the amplitudes decreases with increase in stimulus repetition rate (Brantberg & Fransson, 2001;Wu & Murofushi, 1999). Brantberg & Fransson (2001) reported increase in latency of P1 and N1 as the repetition rate increased from 6 to 20 Hz. Also, the presence of cVEMP responses decreased from 87% (six per second) to 56% (at 20 per second). The repetition rate of 5 Hz is the best for recording large-amplitude air-conduction tone-Burst evoked cVEMPs (Wu & Murofushi, 1999). They stated that responses could be recorded at 10 Hz and lower repetition rates. cVEMP responses are present in only 63% of the subjects when the stimulus is presented at a repetition rate of 20 Hz.

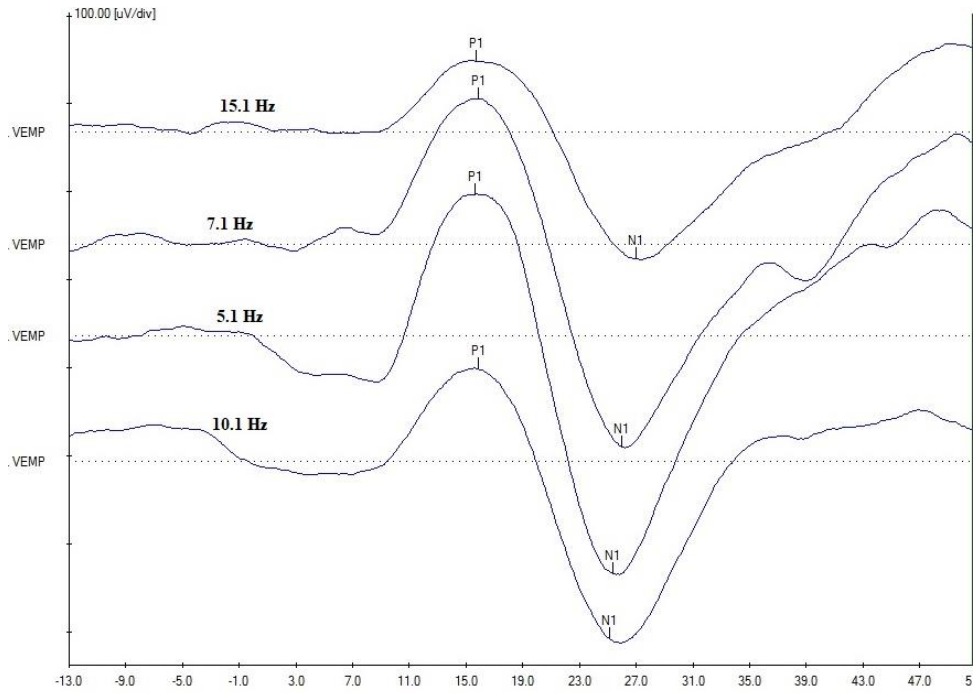

Figure 4.5 The effect of repetition rate on cVEMP amplitude

4.7 Stimulus (Monaural/Binaural)

There are equivocal findings with respect to the monaural and binaural cVEMP responses. Binaural cVEMP elicited with 500 Hz tone burst stimulus has the same latencies, inter-aural amplitude difference ratio (asymmetry ratio), and threshold as a monaural recording (Bhagat, 2006; McNerney et al., 2011;Wang & Young, 2004; Yang & Young, 2003). Some other studies have reported higher amplitude with binaural cVEMP compared to monaural cVEMP, particularly for the later peaks i.e. n33 and p44 (Wang & Young, 2004). Others also found no noticeable amplitude difference between monaural and binaural cVEMP recordings (Wang & Young, 2003).

Multiple choice questions

1. The most common stimulus for recording cVEMP is
    a. Click & logon
    b. Click & tone burst
    c. Tone burst & logon
    d. Logon & chirp
2. In case of middle ear pathology …… is an alternative stimulation that has been successfully used to stimulate the otolith organs and activate vestibular afferents
    a. Air conducted vibration
    b. Bone conducted vibration
    c. Short duration galvanic stimulation
    d. All the above
3. Bone conducted vibration stimulation produce bilateral responses with the ipsilateral ……. responses.

a. Smaller

b. Larger

c. Similar

d. None

4. The contralateral cVEMP BC responses is ……than ipsilateral

    a. Shorten

    b. Prolonged

    c. Similar

    d. All the above

5. The optimal placement for delivery of bone conducted stimulus is …. Posterior and … superior to the external auditory canal.

    a. 3cm, 2cm

    b. 2cm,3cm

    c. 1cm,2cm

    d. 2cm,4cm

6. cVEMP elicited by BC tone burst has a ……. latency than those elicited by AC tone burst

    a. shorter

    b. longer

    c. similar

    d. can be shorter or longer

7. BC stimuli have ……. cVEMP threshold than AC stimuli

    a. Lower

    b. Higher

    c. Similar

d. can be shorter or longer

8. In response to the same stimulation intensity, BC cVEMP has ……amplitude than AC cVEMP
    a. Poorer
    b. Better
    c. Similar
    d. None of the above
9. It is often possible to quantify a contralateral SCM response to unilateral acoustic stimulation
    a. True
    b. False
10. Contralateral SCM responses to unilateral acoustic AC stimulation is …… in polarity and…….. in amplitude than ipsilateral registered cVEMP
    a. Similar, larger
    b. Opposite, larger
    c. Opposite, smaller
    d. Similar, smaller
11. Contralateral response to BC stimuli is …… in polarity.
    a. Opposite
    b. Similar
    c. Can be similar or opposite
    d. None of the above
12. According to Halrnagyi VEMP is elicited by tapping the head in the ……. frontally with a tendon hammer
    a. Sideline

b. Midline

c. Backline

d. Anywhere on head

13. Head tap produce ……responses over the SCM with vestibular activation.

a. Unilateral

b. Bilateral

c. Both

d. None

14. cVEMP responses generated using taps has larger amplitude than AC stimuli.

a. Smaller

b. Larger

c. Similar

d. All of the above

15. Head taps cVEMP is measured in case of …….

a. Conductive hearing loss

b. Sensorineural hearing loss

c. Mixed hearing loss

d. Both a and c

16. The patients who failed to generate responses to skull tap has ……. conductive impairment.

a. True

b. False

17. The primary technical challenge with galvanic stimulation is the ……

a. Stimulus artifact

b. Muscle artifact

c. Both a and b

d. None of the above

18. The galvanic evoked cVEMP can be seen even more clearly when the ……is subtracted from the ……

    a. Active response, resting response

    b. Active response, active response

    c. Resting response, active response

    d. Resting response, resting response

19. Most of the studies comparing clicks and short duration tone burst showed that click evoked cVEMP had a ……. amplitude and ……latency than those evoked by 500Hz tone bursts.

    a. Higher amplitude, shorter latency

    b. Lower amplitude, shorter latency

    c. Lower amplitude, larger latency

    d. Higher amplitude, larger latency

20. The stimulus which can be used for recording cVEMP are

    a. Logon

    b. Tone burst and click

    c. Band limited chirp stimulus or chirp stimulus

    d. All of the above

21. The latency of P1 peak, N1 peak and amplitude of the P1N1 complex of the cVEMP do not vary significantly between 500Hz TB and 500 logon

    a. True

    b. False

22. Tone bursts and logon produce similar responses compared to click

a. True

b. False

23. cVEMP recorded with which stimulus will have most prolonged latency?

a. Click

b. Chirp

c. Tone burst

d. Logon

24. The latency of the P1 and N1 peak of the cVEMP elicited by chirp stimulus is ……. than that of click and Tone bursts.

a. Prolonged

b. Shorter

c. Similar

d. None of the above

25. cVEMP tuning curve has a dominant peak between

a. 200Hz and 1000Hz

b. 400Hz and 1600 Hz

c. 400Hz and 800 Hz

d. 100Hz and 800 Hz

26. A …… intensity stimulation with a…… duration is needed to record a cVEMP responses.

a. Low, short onset

b. High, short onset

c. High, steady state

d. Low, steady state

27. Changing the plateau time from 1 to 10 ms causes P13, N23 and P13-N23 inter peak latencies to be …….

    a. Shorter
    b. No change
    c. None
    d. Longer

28. For recording of cVEMP, combination of ……rise/fall time and…. plateau time is recommended.

    a. 4ms,2ms
    b. 2ms, 1ms
    c. 1ms,0ms
    d. 1ms,2ms

29. As the repetition rate increases the latencies ……and amplitude…….

    a. Shorten, decreases
    b. Lenghten, decreases
    c. Shorten, increases
    d. Lengthen, increases

30. The repetition rate of …….is best for recording air conduction tone burst evoked cVEMP.

    a. 10Hz
    b. 15Hz
    c. 5Hz
    d. 20Hz

31. A 20 Hz repetition rate is suggested to detect ……in the bone conducted mode.

a. Mass related pathology

b. Stiffness related pathology

c. Both

d. None

32. Galvanic cVEMP responses appear only at ……in all the test ears.

a. 10Hz

b. 15Hz

c. 20Hz

d. 5Hz

33. The use of bilateral testing has the potential to cut recording time by half.

a. True

b. False

Chapter 5

ACQUISITION PARAMETER

5.1 Total number of sweeps

The signal-to-noise ratio of each recording determines the optimal number of sweeps. However, the specific number should be about 100–200. Patients with higher amplitude of cVEMP need fewer repetitions, and the recording can be stopped early. Patients with limited or absent responses can require further repetitions. By averaging out more of the background contraction with two longer trials (e.g., at least 150–200 repetitions) rather than several shorter trials (e.g., 50–100 repetitions), the signal-to-noise ratio is increased(Rosengren et al., 2019). To get a good cVEMP response, total number of sweeps should be between 100 and 250 for each trial (Brantberg et al., 2007; Ushio et al., 2009; Versino et al., 2001).

5.2 Electrode placement

Surface EMG electrodes of good quality should be used to record cVEMPs. Cody and Bickford (1969) used a reference electrode on the nose or earlobe and an inverting electrode on the forehead to assess vestibular responses from inion, but this montage did not evoke responses from individuals with vestibular disorders. Colebatch (2001) altered the montage by placing an active electrode on the upper third of the *sternocleidomastoid muscle* and a reference electrode just above the sternum. All of the participants generated repeatable p13-n23 waveforms as a result of this montage. The recording is done from many different positions along the length of the SCM. Sheykholeslami et al. (2000) investigated the impact of electrode position on cVEMP amplitude and latency. A positive peak (P1) is followed by a negative peak (N1) in the response (Piker et al., 2013a). Several studies have positioned the inverting electrode near the sternal tendons or at the sternoclavicular junction (Rosengren et al.,

2010). The chin has been shown to provide reliable, reference-free cVEMP responses (McCaslin et al., 2013, 2014). Since the SCM is a large muscle, electrode placement has ample space, and it can vary widely. The response latency are most stable when recorded from the belly (i.e., middle) of the muscle, either mid-way or at the upper one-third (Basta et al., 2005; Murofushi et al., 2004; Sheykholeslami et al., 2001; Sheykholeslami & Kaga, 2002). Therefore, placement of non-inverting electrodes at halfway or one-third from the mastoid, inverting at the sternoclavicular junction and ground on the forehead is recommended. The recording from the middle part of SCM was recommended by Sheykholeslami et al.(2001) because it produces the most reliable performance.

Rudisill & Hain (2008) used noninverting electrodes on the right and left gastrocnemius, inverting electrodes on the right and left medial malleolus, and a ground electrode on the right or left lateral malleolus to monitor lower extremity myogenic potentials from the gastrocnemius. When recorded from the gastrocnemius muscle, there are multiple peaks generated. The peaks generated from gastrocnemius muscles are p1, n1, p2, n2 and p3. The latency of these peaks is longer compared to recorded from the sternocleidomastoid muscle. However, the amplitude is much lesser compared to the VEMP recorded from the gastrocnemius muscle.

Wu et al. (1999) also recorded VEMP from the splenius muscle. Wu et al. (1999) reported that there are two peaks (P1 and N1) generated from the splenius muscle. However, the peaks are in reverse order, i.e. VEMP recorded from the SCM muscle has the first peak as positive peak whereas, the VEMP generated from the splenius muscle has the first peak as negative. This could be due to the fact that splenius muscle is an antagonist to the SCM muscle (Wu et al., 1999). The latency of P1 and N1

peak are identical. However, the amplitude is larger for the VEMP recorded from SCM muscle compared to the splenius muscle.

Ferber-Viart et al. (1997) compared cVEMP recorded from SCM muscle and trapezius muscle in sixteen individuals with the normal vestibular system. The latency of P1 and N1 peaks were identical for cVEMP recorded from SCM and trapezius muscle. Also, the waveforms are reproducible for cVEMP recorded from both the SCM and trapezius muscle. However, the overall amplitude of the cVEMP recorded from the trapezius muscle is lesser compared to the SCM muscle in all the subjects. Overall, the highest cVEMP amplitudes are obtained when the electrodes are placed on SCM muscle's midpoint, compared to any other electrode site. This is why in most of the vestibular clinics, the VEMP is recorded from the SCM muscle. The electrode placement of the SCM muscle is shown below in figure.

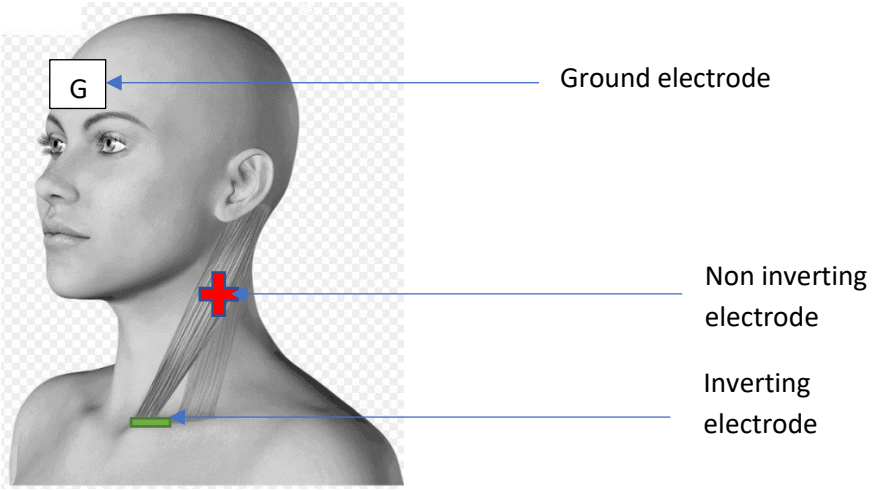

Figure 5.1 Electrode Placement for cVEMP

Ground- Forehead

Non-Inverting- upper ⅓ rd of SCM

Inverting - sterno-clavicular junction

5.3 Amplification and Filtering

The magnitude of the neurogenic auditory evoked potential is one to two orders smaller than the cVEMP (Marioni, 2015). Studies have recommended only 5,000 amplification to record the cVEMP. The cVEMP response involves a synchronized attenuation of tonic EMG activity. During the recording of cVEMP the artifact rejection must be disabled (Marioni, 2015). If artifact rejection is disabled, the examiner should monitor the amplifier input to the signal average to ensure that amplitude saturation does not occur (i.e., clipping of the raw EMG) (Marioni, 2015). If amplifier saturation occurs during the cVEMP recording, it is recommended to reduce the amplifier gain (e.g., from 5000 to 3000) (Marioni, 2015)

There are equivocal findings regarding the effect of the different band pass filter on latency and amplitude of the cVEMP (McCaslin et al., 2013; Ochi et al., 2001; Robby Vanspauwen et al., 2006). Previous studies have used a filter setting of 20–2000 Hz to record cVEMP (Murofushi et al., 1996b; Welgampola et al., 2008), filter settings of 30–3000 Hz (Wang et al., 2008), filter settings of 20–1500 Hz (Basta et al., 2007), filter settings of 10–1500 Hz (Robby Vanspauwen et al., 2006), and filter settings of 5–1500 Hz (Ochi et al., 2001). These authors have reported good replicability of the cVEMP responses with the bandpass filters used.

McNerney et al.(2011) used a Neuro Scan Evoked potential method to record cVEMPs from eight subjects to describe the optimum filter setting for recording the cVEMP. cVEMPs were obtained by presenting 500Hz tone-bursts at 120 dBpSPL (2-1-2, Blackman window) at a rate of 5 Hz. Each recording was repeated twice to see the replicability of the responses. McNerney et al.(2011) reported that the dominant energy of recorded cVEMP lies between 15 and 70 Hz. As a result, the authors suggested to

use a low-pass cut-off of 100 to 150 Hz and a high-pass cut-off of 5 to 15 Hz to record cVEMP.

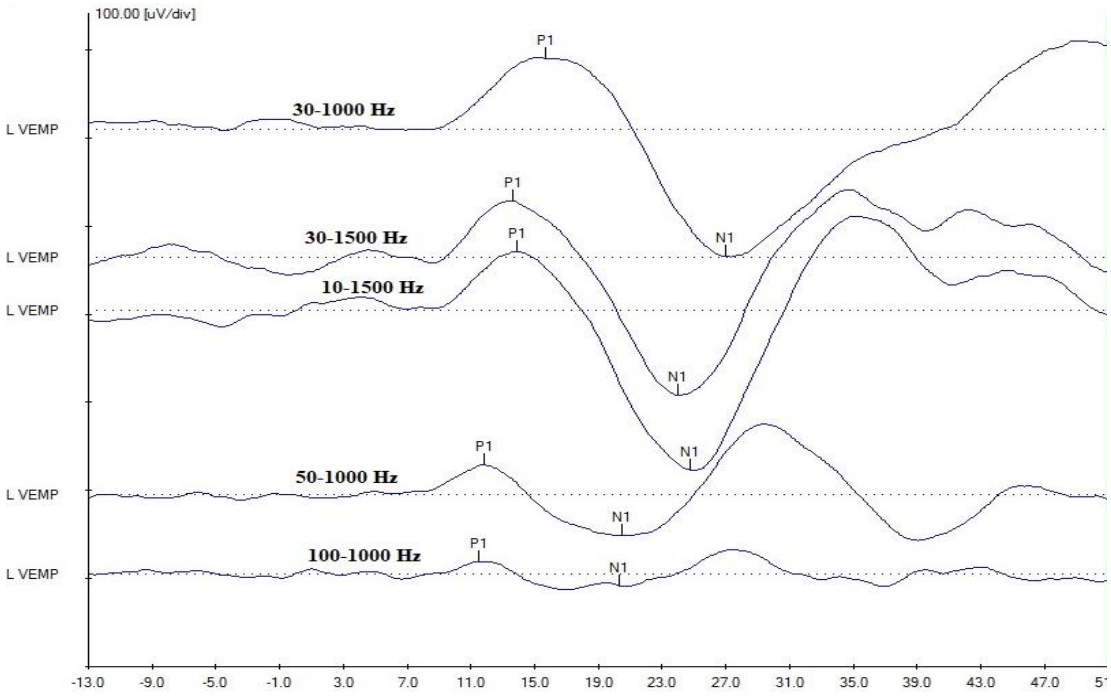

Figure 5.2 The effect of different filter settings on cVEMP amplitude

5.4 The effect of muscle contraction on cVEMPs

The strength of the muscle contraction is an important factor in measuring the cervical vestibular evoked myogenic potentials. The cervical vestibular evoked myogenic potential is an inhibitory response, and hence muscle contraction becomes essential. Every stimulus of cVEMP inhibits the activity in the sternocleidomastoid muscle for several milliseconds (Colebatch & Rothwell, 2004b). The inhibition of the sternocleidomastoid muscle due to sound stimulus represents a greater change if the muscle is very active. The activity of any muscle will be stronger during the contraction phase of the muscle. Hence a stronger contraction of the sternocleidomastoid muscle will produce a larger amplitude of the cervical VEMP. Several authors have reported that as the muscle contraction is increased, the amplitude of the cVEMP also increases

and vice versa (Akin et al., 2003; Sally M. Rosengren et al., 2015). While recording the cVEMP the symmetrical muscle contraction on two sides are very important. A higher amplitude asymmetry ratio is suggestive of a vestibular pathology in individuals. We might get false results if we do not have symmetrical muscle contraction on two sides while recording the cVEMP. Hence the contraction of the SCM plays a major role in diagnosing various vestibular pathology.

5.5 Methods of muscle contraction

An adequate level of muscular contraction can be achieved by a variety of methods. The first method is to make the patient sleep in supine position and then recline the patient to around 30 degrees from supine and then elevate the head against gravity with suitable strategy. Depending on the angle of the head, this usually results in a weak to moderate contraction of both SCM muscles (Rosengren et al., 2015). This technique is easy for the clinicians to perform; however, it is not very comfortable for the patients.

Examining reflexes in both SCM muscles at the same time is possible by lifting the head and facing forward. This is useful during AC stimulation since the contralateral SCM can sometimes have an inverted "crossed response," especially in patients with SCD (Colebatch et al., 1994; Welgampola & Colebatch, 2001b). This contraction approach is also often utilized during BC stimulation, particularly stimulation to the forehead, because it permits reflexes from both muscles to be evaluated simultaneously. If required, apply pressure on the patient's forehead to increase the contraction. Lifting and turning the patient's head away from the stimulated ear is a straightforward approach to get stronger contractions. This causes moderate to strong contractions in the ipsilateral SCM (Rosengren et al., 2015), which improves recording but decreases

activity in the contralateral SCM, allowing only the ipsilateral (contracted) side be recorded.

The SCM can also be activated by having the patient sit upright and move their head away from the stimulated ear. A simple axial head movement to the right or left approaching 90 degrees can occasionally create sufficient EMG for cVEMP recording. The head turn method necessitates testing each side separately. The preference for greater contractions vs. bilateral recordings and the available equipment and setting will influence the technique of activation. A common reason for employing the sit-and-turn approach is a lack of space for a bed. One of the methods of muscle contraction is given below in the figure

Figure 5.3 One of the methods of muscle contraction, where the subject has turned the head to the opposite side of the recording.

5.6 Methods of recording cVEMP

5.6.1 Unrectified method

We have learnt that there is a major effect of muscle contraction on the cVEMP amplitude. However, for a perfect recording of cVEMP one needs to separate the neural responses from the muscle responses. In early days of cVEMP such a facility was not available and hence many of the researchers have utilised unrectified method of recording cVEMP. In unrectified method of cVEMP the clinician does not subtract the neural responses from the muscle response. The patient is simply asked to turn the head towards opposite side and whatever the responses comes is recorded. Hence at any point of time the unrectified method of cVEMP has the highest amplitude of cVEMP compared to any other methods of recording. However, to ensure the adequate muscle contraction from patients, authors have utilised fabricated materials to get an adequate muscle contraction (Anoop B.J & Singh, 2011). Test retest reliability of Vestibular evoked myogenic potentials. Unpublished dissertation.). One such material has been shown in the figure below.

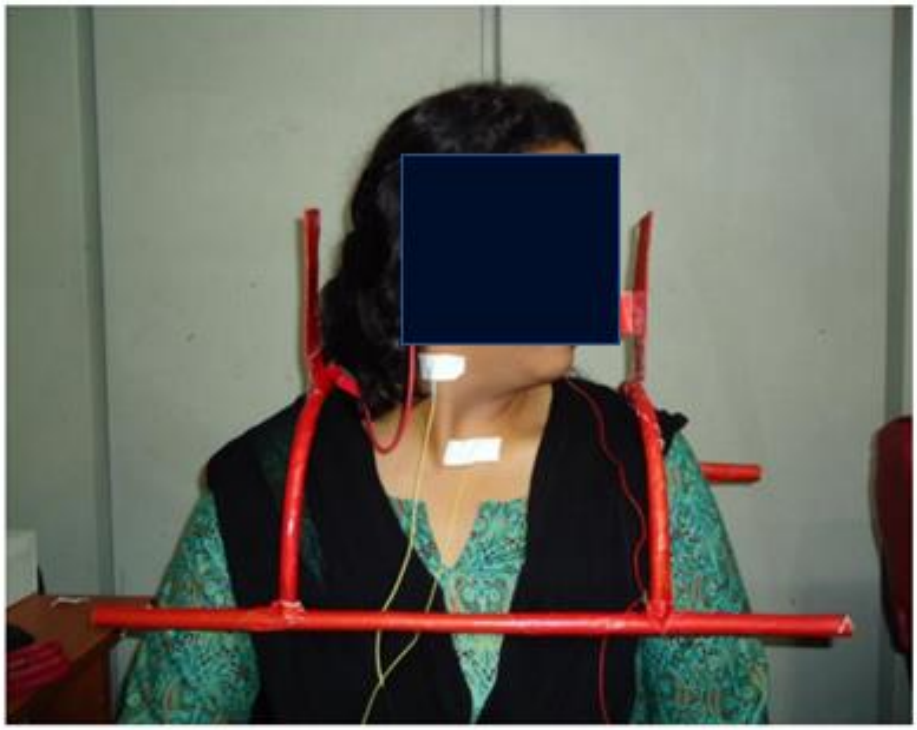

Figure5.4 Unrectified method of recording cVEMP (Anoop B.J & Singh, 2011)

5.6.2 Rectified VEMP

The amplitude is significantly affected by changes in contraction of the SCM muscle, the outcomes of these parameters could be susceptible to erroneous inferences. The commonly used methods of controlling the effects of changes in muscle contractions levels are visual monitoring and EMG normalization. cVEMPs obtained using these methods are often called rectified cVEMP.

Visual monitoring systems provide the clients with visual feedback about the range of EMG which they need to maintain, whereas EMG normalization subtracts the RMS EMG of the pre-stimulus baseline from post stimulus recordings to eliminate the effects of muscle tension variations. While Kumar et al.(2014) reported no difference in latency and amplitude of cVEMP response with and without visual feedback, others have reported better reliability of cVEMP when obtained with visual monitoring than without it (Isaradisaikul et al., 2008;Vanspauwen et al., 2006). The rectified cVEMP is

obtained as the unrectified VEMP signal is divided by an averaged pre-stimulus rectified surface EMG. Sometime the word rectification is also used to indicate normalization. Rectified VEMP has been reported to have lower amplitude and asymmetry ratio than unrectified (Lee et al., 2008). Chang et al. (2007) discovered that those with more subcutaneous tissue (fat) in their necks have lower cVEMPs. Adjusting these parameters may help to lessen the variability caused by these technical issues. This method appears to be a reasonable way to compensate for discrepancies in electrode location and neck architecture.

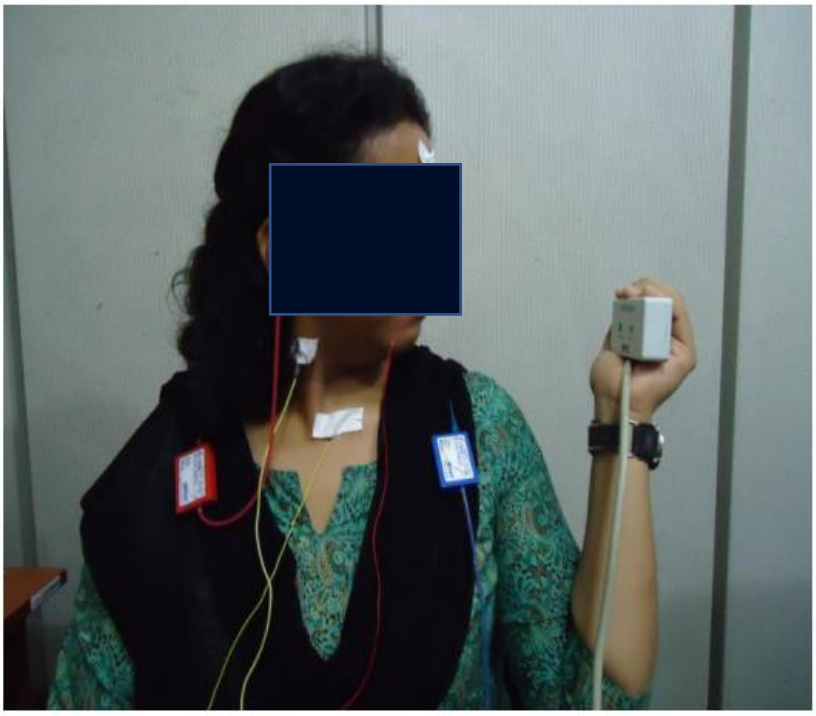

Figure 5.5 EMG muscle monitoring method of recording cVEMP (Anoop B.J & Singh, 2011)

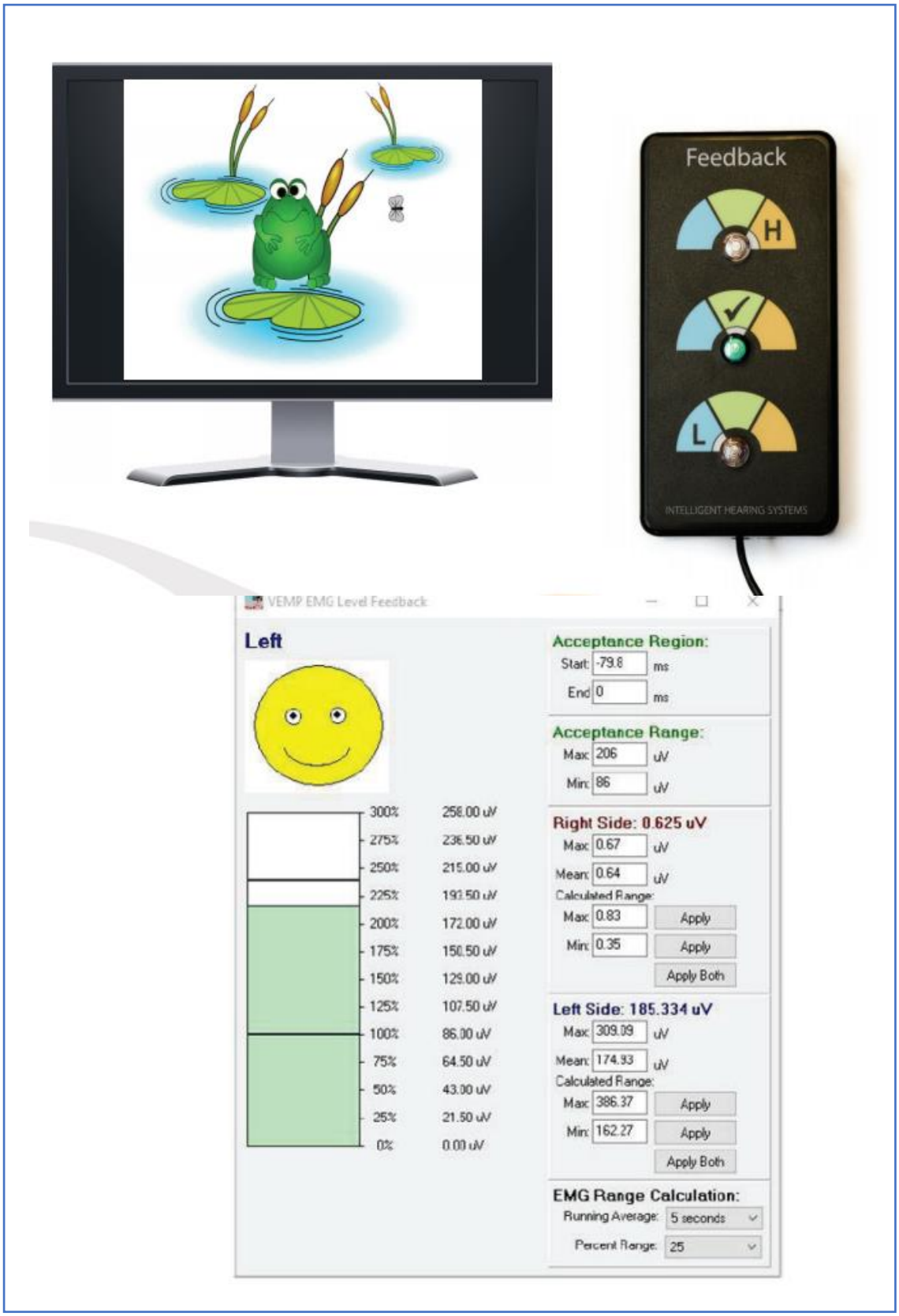

Figure 5.6 EMG muscle monitoring system in one of the commercial equipment

Multiple choice questions

1. Which of the following determines the optimal number of sweeps?
    a. Gender
    b. Signal to noise ratio
    c. Ear
    d. Electrode placement
2. Clinically, approximately ……number of sweeps is required for recording cVEMP to see the response is obvious.
    a. 400
    b. 600
    c. 200
    d. 800
3. Tendon hammer taps required few repetitions because the stimulus usually elicits ……
    a. Strong responses
    b. Stressful if repeated too frequently
    c. Both a and b
    d. Only a
4. The average amplification needed to record cVEMP is typically
    a. 1000
    b. 50000
    c. 10000
    d. 5000

5. The filter setting in cVEMP is typically –
    a. 10-1500
    b. 1-1500
    c. 0.1-1500
    d. 50-1500
6. Which one of the following electrode placements is most recommended for cVEMP recording?
    a. Non inverting- at halfway or one third towards the mastoid, Inverting- at the sternoclavicular junction and Ground-on the forehead
    b. Non inverting- at the sternoclavicular junction, Inverting- at halfway or one third from the mastoid and Ground-on the forehead
    c. Non inverting- at the mastoid, Inverting- at the sternoclavicular junction and Ground-on the forehead
    d. Both a and c

Chapter 6

cVEMP ANALYSIS AND NORMATIVE DATA/ MEASUREMENT OF cVEMPs

Four important parameters are used to analyze cVEMP responses: peak latency, response threshold, amplitude asymmetry ratio (AR) and frequency tuning. Each laboratory should establish or confirm its own set of normative values (Papathanasiou et al., 2014).

6.1 Amplitude

Two ways the cVEMP amplitude has been measured, first is the absolute amplitude of P1 and N1 peak separately, and second is peak to peak amplitude of P1-N1 complex. The absolute amplitude of the P1, N1 response shows a very high degree of interindividual variability. Hence, in most clinical setups, the measurement of absolute amplitude is not done (Li et al., 1999). During the cVEMP analysis, the peak to peak amplitude of P1-N1 complex is considered.

Another important amplitude parameter that is used for the clinical diagnosis is the interaural amplitude asymmetry ratio. The interaural amplitude asymmetry ratio is calculated for measuring side-to-side disparities to compensate for inter-subject variability in the amplitude of cVEMP responses (Welgampola & Colebatch, 2001). The amplitude asymmetry ratio (AR) is always positive and stated as a percentage. An amplitude ratio of more than 35% is considered abnormal(Lee et al., 2008; Nguyen et al., 2010; Shin et al., 2013; Wang et al., 2010).

The following equation determines the cVEMP asymmetry ratio:

$$\left\{\frac{\textbf{(Better ear amplitude of cVEMP – poorer ear Amplitude of cVEMP)}}{\textbf{(Better ear amplitude of cVEMP + poorer ear Amplitude of cVEMP)}}\right\} \text{X100}$$

The affected side is usually the weaker side (i.e., the side with the smaller response). The weaker side usually represents a pathology of the inner ear. Only in patients with superior canal dehiscence syndrome the ear with pathological side has larger amplitude. Inter aura asymmetry metrics should be determined once the EMG level has been corrected (Lysakowski et al., 2005a;Welgampola & Colebatch, 2001b). In healthy patients, side-to-side amplitude disparities have been reported to range from 20% to 45%, depending on the methodology used (e.g., monaural or binaural stimulation) and whether or not EMG amplitude correction was applied(Brantberg & Fransson, 2001; McCaslin et al., 2013b;Welgampola & Colebatch, 2001b; Zapala & Brey, 2004).

6.2 Latency

The latency of the p13 (P1) and n23 (N1) peaks is essential because central lesions such as Multiple Sclerosis can cause a delay in cVEMP latency (Colebatch, 2012). Peak latency of cVEMP is also utilized to diagnose diseases confined to the cVEMP pathway.

Murofushi et al. (2001) reported that the latency is prolonged in patients with acoustic schwannoma and multiple sclerosis. However, the latency remains normal in patients with Meniere's disease and vestibular neuritis. Bansal et al. (2013) reported that in individuals with profound sensorineural hearing loss, the amplitude of the cVEMP is affected, but the latency of the cVEMP remains normal. Sinha et al. (2015) also reported that in individuals with Meniere's disease, the amplitude of the cVEMP is affected. However, the latency of both the P1 and N1 peaks remains normal in Meniere's disease. To conclude, the latency of the cVEMP should be measured in all the patients with vestibular disorders. The prolonged latency of P1 and N1 peak suggests a pathology of the cVEMP neural pathways.

6.3 Frequency Tuning of cVEMP

In individuals with a normal vestibular system, the amplitude of cVEMP is highest for 500 Hz tone burst stimulus compared to another stimulus. cVEMP recorded with 500 Hz has the lower threshold, high amplitude and a high response rate (Akin et al., 2003; Park et al., 2010). However, the literature suggests that Meniere's disease might influence the frequency sensitivity of the VEMP response. In individuals with Meniere's disease the best amplitude of cVEMP is usually obtained at higher frequencies (750 Hz and 1000 Hz). This shift in frequency tuning can help in the identification of Meniere's ear from that of non-Meniere's ear (Sandhu et al., 2012; Zhu et al., 2014). Sandhu et al. (2012) also reported that the shift in frequency tuning of cVEMP is observed only for individuals with definite Meniere's disease. The shift in frequency tuning is not observed for probable Meniere's disease and normal subjects. Piker et al.(2013) also reported the shift in frequency tuning of cVEMP in older individuals. The shift in cVEMP is similar to the patients with endolymphatic hydrops. Thus, the frequency tuning is an important parameter in evaluating the saccule function using cVEMP.

6.4 Threshold

When analyzing the response, cVEMP thresholds are also a significant measuring parameter that can help narrow down the differential diagnosis. The lowest level at which a cVEMP reaction can be measured and reproduced is the cVEMP threshold. Typically, the intensity of the stimulus is reduced in 10-dB steps until no more extended reproducible response exists, then increased by 5dB until the response is detected. This effectively serves as the limit. cVEMPs are often not detectable below 75 to 80 dBnHL in ordinary people (Streubel et al., 2001). The occurrence of a cVEMP with an intensity below these thresholds is frequently indicative of disease such as

superior canal dehiscence (SCD). The cVEMP has now been utilized to check the presence of SCD (Brantberg et al., 1999; Cremer et al., 2000; Zuniga et al., 2013b).

cVEMPs recorded from the affected side, i.e. the side with SCD are often measurable at a substantially lower sound pressure level than predicted in individuals with SCD and other third window disorders (e.g., fistulas or lateral canal dehiscence). VEMP recordings from SCD ears generally provide greater P1 and N1 amplitudes than VEMP recordings from ears without SCD when stimulus intensity remains constant (Brantberg et al., 1999). It is important to emphasize that when performing cVEMP testing, thresholds should always be obtained. The existence of a greater amplitude response on the impaired side could be interpreted as impairment on the intact side in circumstances where a patient has a unilateral SCD (i.e., the smaller response from the normal ear).

Multiple choice questions

1) The amplitude of cVEMP …….as a function of EMG level
   A) decreases
   B) increases
   C) remains same
   D) none of the above
2) The increases in cVEMP amplitude with increase in EMG is limited up to an RMS EMG of-
   A) 100μV
   B) 150μV
   C) 50μV
   D) 200μV

3) An electromyography level of ……to …….is believed to be most advantageous for the clinical recording of cVEMP as it produces smaller tonic electromyography variability.

   A) 100μV to 200μV

   B) 30μV to 50μV

   C) 200μV to 400μV

   D) 400μV to 800μV

4) Which of the following muscle contraction method produces higher response rate and larger peak to peak amplitude-

   A) Head elevation

   B) Head rotation

   C) Both

   D) Head down

5) The commonly used method of controlling the effects of changes in muscles contraction levels are –

   A) Visual monitoring

   B) EMG normalization

   C) Both a and b

   D) None of the above

6) The cVEMP obtained using visual monitoring and EMG normalization is called-

   A) Rectified cVEMP

   B) Unrectified cVEMP

   C) Both a and b

   D) None of the above

7) Which method of cVEMP recording typically gives better amplitude?

   A) Unrectified method

   B) Rectified method

   C) EMG muscle monitoring method

   D) All of the above

8) The correct equation to determine the cVEMP asymmetry ratio is –

   A) (poor ear Amplitude of cVEMP - Better ear amplitude of cVEMP)/ (Better ear amplitude of cVEMP + poor ear Amplitude of cVEMP) *100

   B) (Better ear amplitude of cVEMP – poor ear Amplitude of cVEMP)/ (Better ear amplitude of cVEMP + poor ear Amplitude of cVEMP) *100

   C) (Better ear amplitude of cVEMP + poor ear Amplitude of cVEMP)/ (Better ear amplitude of cVEMP - poor ear Amplitude of cVEMP) *100

   D) (Better ear amplitude of cVEMP)/ (poor ear Amplitude of cVEMP) *100

9) The typical asymmetry ratio exceeding …….is considered abnormal-

   A) 40%

   B) 50%

   C) 60%

   D) 30%

10) The extended cVEMP latency may be indicative of

   A) Retro labyrinthine pathology

   B) Labyrinthine pathology

   C) Auditory nerve pathology

   D) Cerebellum pathology

Chapter 7

cVEMPs IN CLINICAL PRACTICE

In patients with vertigo and imbalance, cVEMPs are now commonly used to assess the otolith function. It is used to detect otolith dysfunction in various vestibular diseases like Meniere's disease (MD), vestibular neuritis (VN), labyrinthitis, vestibular schwannoma (VS), superior canal dehiscence syndrome or stroke.

The endolymph-filled membranous labyrinth is located within the bony labyrinth in the inner ear or labyrinth. The vestibular and cochlear end organs make up the membranous labyrinth. Vertigo, imbalance, hearing loss, tinnitus, aural fullness, and other audio-vestibular symptoms result from labyrinth lesions. An audiologist will benefit significantly from a thorough knowledge of the different diseases/disorders affecting the labyrinth to make appropriate diagnoses and prompt referrals to the medical community, allowing for holistic patient care.

7.1 Benign paroxysmal positional vertigo (BPPV)

BPPV (benign paroxysmal positional vertigo) is one of the most common disorders that cause episodic vertigo. BPPV is characterized by episodes of vertigo that last anywhere from a few seconds to a minute. Sudden changes in head position or postural changes cause vertigo, often followed by nausea or vomiting.

cVEMP has been used to assess the saccular function in individuals with BPPV. The incidence of abnormal results on various cVEMP response parameters (such as response rate, latency, amplitude, and interaural amplitude difference ratio) has been investigated in studies (IADR). Scarpa et al. (2019) reported that the latency of P1N1 peak are prolonged for Individuals with BPPV. Kim et al. (2015) reported an abnormal cVEMP response rate of 30.8 percent in the BPPV group and 15.6 percent in the control group. In contrast, Batista et al.(2013) observed no significant variations in the cVEMP

diagnostic indices in BPPV-affected ears compared to the control group (Batista et al., 2013). Singh et al. (2014) evaluated the effectiveness of cervical vestibular evoked myogenic potentials (cVEMP) in detecting benign paroxysmal positional vertigo (BPPV)-related changes in the peripheral vestibular system. Singh et al. (2014) reported no difference in latency or amplitude measurements between healthy people and people with BPPV. Singh et al. (2014) questioned the effectiveness of cVEMP in detecting BPPV-related changes in the peripheral vestibular system.

7.2 Meniere's disease

Meniere's disease is an idiopathic labyrinth disease first identified by Prosper Meniere in 1861. Fluctuating hearing loss, roaring tinnitus, episodic vertigo, and aural fullness are the four main signs of Meniere's disease (symptom tetrad). These are often followed by nausea or vomiting or end in nausea or vomiting.

Patients with Meniere's disease have cVEMP anomalies in both the affected and unaffected ears. Compared to affected ears, abnormalities are lesser in unaffected ears. Most researchers have found reduced response rates, amplitude variations, IADR modifications, and tuning curve alterations with no impact on P1 and N1 latency in Meniere’s disease (Murofushi et al., 2001; Rauch et al., 2004; & Young et al., 2003). The rate of abnormal cVEMP response in the affected ears with Meniere's disease ranges between 34% to 82 percent (Waele et al., 1999; Murofushi et al., 2001; & Young et al., 2003). As in Meniere's disease, reduced amplitude, elevated thresholds, and increased IAD (greater than 33%) are diagnostic of saccular pathology.

Young et al. (2003) reported that majority of stage I Meniere's disease patients have regular or enhanced cVEMP. Individuals with Meniere’s disease also have greater interaural amplitude asymmetry (IAD >33 percent, with greater amplitude in the affected ear). The amplitude of cVEMP is affected early as the saccule gets affected

early compared to other vestibular structures in Meniere's disease. In the very early stages of Meniere's disease, there is dilation of saccule, which rests against the stapes footplate. This results in increased cVEMP amplitude in Meniere's disease (Young et al., 2003). The endolymphatic hydrops also increases the stiffness of the saccular membrane. An increase in stiffness raises the saccule's resonance frequency, thereby altering the tuning (Singh & Barman, 2016). As a result, the cVEMP amplitude is higher at 1000 Hz or 1500 Hz in Meniere's disease patients. This shift in frequency tuning helps in distinguish Meniere's disease from BPPV (Singh & Barman, 2016).

However, the cVEMP responses are not affected in all the patients with Meniere's disease. Huang et al. (2010) reported abnormal cVEMP in forty five percent of the patients with Meniere's disease. The abnormality of cVEMP in the unaffected ear is only fifteen percent. The abnormal cVEMP in unaffected ear also suggests the involvement of normal ear also in Meniere's disease.

7.3 Superior semicircular canal dehiscence (SSCD)

Sound energy transmitted through the ossicular chain enters the inner ear through the oval window, passes through the incompressible perilymph within the Scala vestibule and Scala tympani to produce outward motion of the circular window in a structurally normal ear. Sound pressure is shunted away from the cochlea and into the vestibule when a third mobile window, such as SSCD, is present, resulting in vestibular hypersensitivity to sound and decreased hearing.

Most of the study in literature reported abnormally increased cVEMP response with a low threshold in patients with superior semicircular canal dehiscence (Brantberg et al., 1999, 2004; Colebatch et al., 1998; Roditi et al., 2009; Streubel et al., 2001;Watson et al., 2000).Compared to the non-dehiscent ear, the third mobile window produced by dehiscence reduces the impedance to sound, resulting in further

stimulation of the saccular macula. In the SSCD ears, this results in lower thresholds and greater amplitude cVEMP. Using CT scan as the standard gold test for diagnosis of SSCD, Zhou et al., (2007) found that cVEMP had a sensitivity of 91.4 percent and a specificity of 95.8% in detecting ears with SSCD.

In SSCD, cVEMPs are amplified with a low threshold and a high amplitude (Rosengren et al., 2008; Welgampola et al., 2008). BC VEMPs are still uncommon, the threshold reductions for BC cVEMPs are less pronounced (Welgampola et al., 2008). When using typical stimulus intensities, cVEMPs, which are inhibitory potentials, have amplitudes that are likely to saturate, requiring lower stimulus levels to increase their pick-up rates for SSCD using amplitude parameters (Fife et al., 2017). A tone-burst with 2,000 to 4,000 Hz frequency can be particularly effective (Manzari et al., 2013).

Noij et al., (2019) evaluated twenty-one patients with SSCD with cVEMP testing at 500, 750, 1,000 and 2,000 Hz. Sound level functions were obtained at all frequencies to acquire threshold and to calculate normalized peak-to-peak amplitude (VEMPn) and VEMP inhibition depth (VEMPid). Comparing metrics at all frequencies revealed that 2,000-Hz stimuli were most effective in differentiating SSCD from normal ears. ROC analysis indicated that for 2,000-Hz cVEMP threshold 100% specificity could be achieved with a sensitivity of 92.0%.

7.4 Vestibular neuritis (VN)

Vestibular neuritis (also known as vestibular neuronitis) is a common condition characterized by a single episode of long-term vertigo that subsides after two weeks (Møller, 2012). However, some people continue to have dizzy spells after this time has passed. It can be differentiated from Labyrinthitis because it usually has no auditory symptoms (Møller, 2012). VN is thought to be caused by an inflammatory phase of the

vestibular nerve, which must be separated from infarctions of the posterior inferior cerebellar artery at times (Møller, 2012).

In inferior vestibular nerve neuritis, cVEMP is missing on the affected side. In 34 to 72 percent of patients with vestibular neuritis, VEMPs are either absent or abnormal (Halmagyi et al., 1995; Krempaska & Koval, 2012;Murofushi et al., 1996, 2001a). In patients with Vestibular neuritis, the absence or abnormality of VEMP shows that the inferior *vestibular* nerve is involved. Only inferior VN or cases of viral neuro labyrinthitis, in which both superior and inferior branches are affected, may produce abnormal cVEMP result. Shin et al. (2012) compared data from 60 normal controls to data from 30 patients with superior vestibular neuritis (SVN), 3 patients with inferior vestibular neuritis (IVN), and 8 patients with both branches affected. Patients with SVN had no oVEMPs or caloric responses but normal cVEMPs. Patients with IVN had normal caloric responses and oVEMPs, but absence/abnormal cVEMPs.

7.5 Bilateral vestibulopathy

Bilateral vestibulopathy is a peripheral vestibular disease in which both the labyrinths or bilateral vestibular nerves are damaged. Postural imbalance and oscillopsia are two symptoms of the disorder. The diagnosis of bilateral vestibulopathy (BV) is usually made based on the dysfunction of the semicircular canals. The extent of otolith organs—the saccule and utricle—that are also affected in BV is unknown.

Rosengren et al. (2018) administered cVEMP in three patients with bilaterally absent ice water caloric responses. The authors reported that the cVEMPs were missing in five of the six ears, implying that the disease had also infected the saccule and inferior vestibular nerve.

Brantberg (2003) identified a family with suspected early-onset vestibulopathy in which the father and two sons had reduced caloric responses. Father had absence of AC

cVEMPs. Brantberg theorized that the vestibulopathy affected the canals first, then the otoliths, but not the cochlea. Brantberg (2003) presented a series of five patients with symptoms of unsteadiness and oscillopsia, as well as absent caloric responses, who were diagnosed with idiopathic BVP. They discovered that, despite one patient's asymmetric amplitudes, all five patients had well-formed cVEMPs on both sides, indicating that saccular function in BVP was largely spared.

Agrawal et al. (2013) investigated peripheral vestibular system activity in patients with bilateral vestibular system dysfunction and bilateral Meniere's disease due to aminoglycoside ototoxicity. The otolith organs were evaluated using the cVEMP tests. According to the researchers, the VEMP test results had the strongest correlation with a self-reported dizziness disability/handicap. Agrawal et al. (2013) also reported that the patients with BV are less likely to have saccular (61 %) or utricular (64 %) dysfunction relative to canal dysfunction (100 %). Utricular function differed significantly between patients by etiologic group.

Matsuzaki & Murofushi, (2001) reported absence of cVEMPs in five of the six ears with vestibulopathy, suggesting that the saccule and inferior vestibular nerve are also affected by the disease. A further two patients reported by the same group had unilateral cVEMP abnormalities using both AC sound and galvanic vestibular stimulation (Fujimoto et al., 2005).

7.6 Noise induced hearing loss

Noise-induced hearing loss (NIHL) occurs when the hair cells of the inner ear are damaged by loud sound. It can be caused by a one-time exposure to an intense “impulse” sound, such as an explosion, or by continuous exposure to loud sounds over an extended period of time, such as noise generated in a woodworking shop, industries, road traffic noise etc.

The abnormality of cVEMP in NIHL varies from 30% to 70% depending upon the sacculocollic reflex pathway damage. There is positive correlation with degree of hearing loss and abnormality of cVEMP response (Akin et al., 2012; Kumar et al., 2010; Tseng & Young, 2013;Wang & Young, 2007). The cochlea and saccule are more vulnerable to noise exposure than utricle and semicircular (Tseng & Young, 2013). El-Salam et al., (2017) reported statistically significant prolonged cVEMP latency of the P13 and N23 waves and also reduced amplitude of p13-n23 complex in individuals exposed to noise.

7.7 Auditory neuropathy spectrum disorder (ANSD)

Auditory neuropathy spectrum disorder is a clinical condition in which the outer hair cells usually functions are normal, but the auditory nerve function is impaired. Since the 8th nerve is made up of nerve fibers from both the auditory and vestibular branches, the vestibular nerve can also be affected.

cVEMP is either absent or has a decreased amplitude and longer latencies in individuals with auditory neuropathy (Sinha, et al., 2014; Sujeet et al., 2014). EL-Badry et al.(2018) in a research comparing pre lingual and post lingual ANSD found that the vast majority of pre-lingual ANSD children have bilateral intact C-VEMP responses with C-VEMP parameters (amplitude, asymmetric ratio, latency, and interaural latency difference) that were not statistically different from the control children. On the other hand, most post-lingual ANSD children had bilaterally absent C-VEMP responses. The reason for such finding was given as the saccule and inferior vestibular nerve are spared in the vast majority of pre-lingual ANSD children, but they are involved in most post-lingual ANSD children, indicating separate sites of the lesion between the two ANSD groups.

Hu et al. (2020) reported that the majority of ANSD patients had no VEMP response, and only a few had VEMP responses with normal parameters. The abnormality of cVEMP is up to 91% in individuals with auditory neuropathy (Hu et al., 2020).

7.8 Vestibular Schwannoma (VS)

Vestibular Schwannoma is a benign tumor of the nerve sheath that develops from the Schwann's cell that covers the axon of the eighth cranial nerve (cited in the text, (Møller, 2012). This has often been referred to as neuromas, neurofibromas, neurinomas, and neurolemmomas in the past (Lustig, 2010).

Depending on whether the inferior, dominant, or both vestibular nerve branches are involved, cVEMP can display prolonged latencies and reduced amplitude on the affected side. On the affected hand, cVEMP can be completely absent in some situations. Lin et al. (2014) in a study to correlate with the size of vestibular schwannoma with the cVEMP findings. Lin et al. (2014) reported that when the vestibular schwannoma is less than 2.0 cm, the superior/inferior vestibular nerve feature shown by the cVEMP test are preserved. As a result, cVEMP test may be used as a supplement to determine options in vestibular schwannoma patient. Fröhlich et al. (2020) found that cVEMPs are absent or reduced in 47% of the patients with vestibular schwannoma, normal in 32%, and enhanced in 21%. VEMP amplitudes can be increased in patients with intracochlear schwannoma, mimicking the third window syndrome, a novel, and unexpected findings. Chiarovano et al. (2014) abnormal cVEMP in 65.1% of non-operated vestibular schwannoma patients in response to tone bursts stimulus, and 49.2 percent of patients in response to AC clicks.

Valame & Gore (2017) in a research to determine the efficacy of cVEMP in the diagnosis of vestibular schwannoma when combined with the ABR and to see whether

the size of the lesion has any impact on the cVEMP measures. In four out of five patients with large unilateral tumors, decreased amplitude or absence of cVEMP was found on the contralateral side. Six out of eight unilateral small tumors, on the other hand, had a typical cVEMP response in the contralateral ear. cVEMP test sensitivity and specificity to detect vestibular schwannoma was same as caloric test (Ushio et al., 2009). As the tumor size increases, there is diminished cVEMP amplitude in intermediate and medial type of tumor. Prolongation of latencies seems to be not only causing tumor compression to brainstem or vestibular spinal tract but also by tumor compression isolated to the inferior vestibular nerve (Suzuki et al., 2008).

Multiple choice questions

1) The most common finding of cVEMP in people with BPPV is-
    a) Prolong latency and greater amplitude
    b) No difference in latency and amplitude measurement
    c) Shorter latency and grater amplitude
    d) prolong latency and shorter amplitude
2) There is ……. after repositioning maneuver in BPPV patient-
    a) Noticeable improvement in P23 latency
    b) Noticeable improvement in P13 latency
    c) Noticeable improvement in P13 and N23 latency
    d) Greater amplitude of P13 and N23 peak
3) The four tetrad symptoms of Meniere's disease are-

a) Fluctuating hearing loss, roaring tinnitus, episodic vertigo and aural fullness

b) Sudden hearing loss, roaring tinnitus, episodic vertigo and aural fullness

c) Sudden hearing loss, roaring tinnitus, episodic vertigo and aural fullness

d) Fluctuating hearing loss, roaring tinnitus, episodic vertigo and ear discharge

4) Decreased cVEMP responses in stage II and III indicates …… while the absence of response in later stage indicates permanent changes in sensory receptors with ….

a) Utricular macula atrophy, reissner's membrane collapse

b) Saccular macula atrophy, reissner's membrane collapse

c) Saccular macula atrophy, Basilar membrane collapse

d) Both a and b

5) The frequency tuning in MD changes from low frequency say 500 Hz to 1000 Hz due to-

a) Stiffening of utricular membrane hence raising resonance frequency

b) Stiffening of saccular membrane hence raising resonance frequency

c) Both a and b

d) None of the above

6) cVEMP in SSCD has-

a) Lower threshold and lower amplitude

b) Lower threshold and greater amplitude

c) Greater threshold and greater amplitude

d) Greater threshold and lower amplitude

7) Standard gold test for diagnosis of SSCD is-

a) cVEMP

b) CT scan

c) oVEMP

d) MRI

8) Vestibular neuritis differentiates from labyrinthitis in term of no-

   a) Vestibular symptoms

   b) Auditory symptoms

   c) Audio vestibular symptoms

   d) All of the above

9) In inferior vestibular neuritis, cVEMP is-

   a) Normal

   b) Absent or abnormal

   c) Present with prolonged latency

   d) None of the above

10) In Superior vestibular neuritis in cVEMP is-

   a) cVEMP is affected, caloric responses are affected

   b) Both cVEMP and oVEMP are normal

   c) Absent oVEMP, absent caloric responses, absent cVEMP

   d) Normal, but caloric responses are absent

11) In bilateral vestibulopathy condition, which of the following part of inner is damage?

   a) Both labyrinth/ both vestibular nerve

   b) Both SCC, utricle and saccule

   c) Both cochlea

   d) Both a and b

12) Brantberg's theorized that the bilateral vestibulopathy affects –

   a) Canal first then otolith but not the cochlea

   b) Canal first then cochlea but not otolith

   c) Canal first then otolith and followed by cochlea

d) Canal first then cochlea followed by otolith

13) cVEMP in ANSD is

a) Higher amplitude and longer latency

b) Missing /decreased amplitude and higher latencies

c) Lower amplitude and longer latency

d) None of the above

14) The approximate finding of cVEMPs in pre-lingual and post lingual ANSD children are-

a) Intact cVEMP in pre linguistic and absent cVEMP responses in post linguistic ANSD children

b) Absent cVEMP in pre linguistic and Intact cVEMP responses in post linguistic ANSD children

c) Intact cVEMP responses in both the group

d) Impaired cVEMP responses in both the group

15) Vestibular Schwannoma is a benign tumor of nerve sheath that develops from-

a) Schwann's cell

b) Outer hair cell

c) Inner hair cell

d) Boettcher cell

16) When the tumor size in vestibular schwannoma is less than …. the superior/inferior vestibular nerve feature shown by cVEMPs test may be preserved-

a) 2cm

b) 4cm

c) 6cm

d) 8cm

Table 7.1

Protocol for recording cVEMP

Stimulus parameters		**Acquisition parameters**	
Stimulus type	Tone burst	**Analysis time**	62 ms (10ms pre stimulus)
Frequency	500 & 1000 Hz	**Filter setting**	10 to 1500 Hz
Intensity	125 dB SPL or 95 dbHL	**averages**	200 per recording
Gating	Blackman window	**amplification**	5000 times
Stimulus duration	2-1-1 ms	**No. of channel**	1
Onset phase	Alternating	**Electrode montage**	Ground-Forehead Non-Inverting-⅓rd of SCM Inverting - sterno-clavicular junction
rate	5.1/sec		
mode	monoaural		
transducer	Insert earphone		

Multiple choice questions answer key

Chapter 3

History and pathway of cVEMP

Question number	Key Answer	Question number	Key Answer
1.	a	6.	c
2.	b	7.	b
3.	a	8.	c
4.	d	9.	b
5.	b		

Chapter 4

Stimulus parameter

Question number	Key answer	Question number	Key answer	Question number	Key answer	Question number	Key answer
1.	b	10.	c	19.	b	28.	b
2.	b	11.	b	20.	d	29.	b
3.	b	12.	b	21.	a	30.	c
4.	b	13.	b	22.	a	31.	a
5.	a	14.	b	23.	b	32.	d
6.	a	15.	d	24.	b	33.	a
7.	a	16.	b	25.	c		
8.	b	17.	a	26.	b		
9.	a	18.	c	27.	d		

Chapter 5

Acquisition parameter

Question number	Key answer	Question number	Key answer
1.	b	4.	d
2.	c	5.	a
3.	c	6.	a

Chapter 6

cVEMP analysis and normative data

Question number	Key answer	Question number	Key answer
1.	b	6.	a
2.	c	7.	a
3.	b	8.	b
4.	a	9.	d
5.	c	10.	a

Chapter 7

cVEMP in clinical practice

Question number	Key answer	Question number	Key answer	Question number	Key answer	Question number	Key answer
1.	b	5.	a	9.	b	13.	b
2.	b	6.	b	10.	d	14.	a
3.	a	7.	b	11.	d	15.	a
4.	b	8.	b	12.	a	16.	a

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