BONE CONDUCTION TONE BURST EVOKED MASSETER VESTIBULAR EVOKED MYOGENIC POTENTIALS

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REG NO: P01II21S0059

A Dissertation Submitted in Part Fulfilment of the Degree of

Master of Science

(AUDIOLOGY)

University of Mysore

All India Institute of Speech and Hearing

Manasagangothri, Mysuru – 570006

September 2023

CERTIFICATE

This is to certify that this dissertation entitled "**Bone conduction tone burst evoked masseter vestibular evoked myogenic potentials**" is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student with Registration Number P01II21S0059. 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.

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September, 2023

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CERTIFICATE

This is to certify that this dissertation entitled "**Bone conduction tone burst evoked masseter vestibular evoked myogenic potentials**" has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Bone conduction tone burst evoked masseter vestibular evoked myogenic potentials**" is the result of my own study under the guidance of Dr Sujeet Kumar Sinha, Associate Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration Number: P01II21S0059**

September, 2023

ACKNOWLEDGEMENT

"***I will give you thanks in the great assembly;***
Among the throngs, I will praise you."

- ***Psalm 35:18***

I am profusely thankful to the lord almighty for this eccentric opportunity. For the wisdom and strength he has provided me to complete this research.

I am forever grateful to you, Mom; with you, I have a person who always believes in me. Thank you for your unwavering encouragement, love, and sacrifices, which have been my constant source of inspiration. You have fueled my determination to reach this milestone in my academic journey.

I am deeply thankful to my guide, **Dr. Sujeet Kumar Sinha**, whose guidance, support, and expertise were invaluable throughout this journey. Thank you for believing in me and making this a smooth and knowledgeable experience, sir. Your dedication to mentoring and your insightful feedback have been pivotal in shaping this work.

I want to express my heartfelt gratitude to **Dr. Pushpavathi**, Director, AIISH, for this opportunity to conduct the research.

I am immensely grateful to **Dr. Devi. N**, HOD, Dept of Audiology, AIISH, for permitting me to use the facilities to conduct this research. Thank you, mam, for always being approachable and attending to our concerns.

Yamini, and Mohan, without you guys, I cannot imagine my MSc days, but especially regarding this research, thank you for motivating me when I felt this was not my cup of

tea. Thank you for staying there in FAAR only for me, even when you guys did not have work there, and for helping me understand things when I approached you guys with anything. All the weekends spent there in FAAR collecting data together will always be my favourite MSc experience. Please know that you guys are also partly responsible for completing this dissertation.

I am incredibly grateful to **Vinayagar sir, Kalaiyarasan sir, Adithya mam and Aishwarya mam** for helping me whenever I asked them a doubt. Despite your hectic data collection work, thank you for allowing me to use the instrument and always being there to open FAAR. I cannot express with my words how thankful I am that I have such helpful seniors to look up to; even if I had made mistakes during data collection or the writing part, you have given your time to sit with me to correct and help me understand better.

Special and sincere thanks to **Kriti mam, Gowri mam, Durga mam, and Shezeen mam** for sacrificing almost all of your weekends for us to come open FAAR.

To my beloved **Chithi, Grandma and Grandpa**, thank you for the support. You guys made it all better with your calls.

I extend my gratitude to all the participants and individuals who were willing to be there when I requested and for doing it with a smile when I called them again for a reliability test.

Thank you, **Anirban,** for your help during the data collection and for being a supportive dissertation partner. Heartfelt thanks to **Hrishitha, Nutan, Sudharshana, Suraj, and Thejaswini** for your encouragement, discussions and words of motivation.

I am obliged to acknowledge the significant impact that all my audiology department staff had on helping me learn the concepts in audiology and balance beforehand to better understand this study.

Thanks to my '**RESONATORS**' batch, I could not have asked for anything more. We have always stood together, and that was all that was needed.

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ABSTRACT

Introduction: Masseter vestibular evoked myogenic potential (mVEMP) is an inhibitory potential elicited from masseter muscles in healthy subjects in response to electric/acoustic stimuli. There are a few gaps in research done in the area of masseter VEMPs. The mVEMP elicited by bone conduction (BC) stimuli and its reliability are yet to be studied.

Aim and objectives: This study aimed to investigate BC-evoked mVEMP while contrasting gender differences and the reliability of the BC mVEMP.

Methods: The study included 30 (15 females and 15 males) healthy individuals in the age range of 18 and 30 years without hearing or vestibular impairments. mVEMP testing was performed on each subject utilizing 500 Hz, 750 Hz and 1000 Hz tone-burst stimuli using a B71 bone vibrator at 115 dB FL. Within a month of the initial test, fifteen subjects underwent mVEMP a second time.

Results: The results showed that the BC-evoked mVEMP had a 100% response rate in all three frequencies. In both females and males, there was no significant difference across frequencies for P1 and N1 latencies ($p > 0.05$). There was also no gender difference for P1 latency, but N1 latency was shorter in females. The P1 – N1 amplitude was found to have significant differences across frequencies but no gender difference. Using intraclass correlation coefficient (ICC) values, the reliability of the BC-elicited mVEMP test-retest was assessed. It was observed that there is varied reliability for different response parameters ranging from poor to good. However, N1 latency was found to have the highest reliability among all the parameters ($ICC > 0.75$).

Conclusions: The masseter VEMP can be recorded using a bone vibrator B71 transducer. However, the reliability of the masseter VEMP using the B71 bone vibrator is poor.

CHAPTER - I

INTRODUCTION

The vestibular system helps in the maintenance of balance. The vestibular system also provides information about the body's movements, allowing the brain to process rapid compensatory responses to maintain stability. Although it is one of the most connected sensory systems through the body, this system was only recognized in the mid of the 19th century as a separate entity. The vestibular system is essential in maintaining the relationship between the human body, the earth's force of gravity, and everyday life in the physical world. Therefore, this system also plays a vital role in behaviour.

The vestibular organ provides head motion, equilibrium, and spatial orientation information. The vestibular system is a part of the inner ear. The vestibular and cochlear systems are connected with a small opening named ductus reunions. Each ear includes five vestibular receptors: two otolith receptors for linear accelerations and three semicircular canals for rotational angular accelerations (Lindeman, 1969). Together, these receptors can react to head movements and maintain a still head position about gravity in three dimensions.

Any disturbance to this system can give rise to vertigo, head motion intolerance, spontaneous nystagmus, unsteady gait, postural instability, nausea, vomiting, and cognitive changes (Dougherty et al., 2023; Smith & Zheng, 2013). Consequently, before treatment for patients with these symptoms, it is essential to include diagnostic testing of the vestibular system. There are numerous tests for evaluating the vestibular system. The semicircular canal has historically been the primary vestibular sensory organ assessed.

One of the most used tests in the clinical diagnosis of vestibular disorders is the vestibular evoked myogenic potentials (VEMP). Two forms of VEMPs, namely ocular vestibular evoked myogenic potentials and cervical vestibular evoked myogenic potentials

are used to evaluate the saccule and utricle in certain vestibular disorders. VEMP test has been used in diagnosing the saccular and utricular lesions in various vestibular disorders such as vestibular neuroma (Murofushi et al., 1998), Superior semicircular canal dehiscence (Brantberg et al., 1999), Multiple sclerosis (Murofushi et al., 2001), Meniere's disease(Iwasaki et al., 2005; Murofushi et al., 2001), vestibular neuritis (Ochi et al., 2003), auditory neuropathy (Kumar et al., 2013), noise-induced hearing loss (Fakharnia et al., 2009), and cerebellopontine angle tumours (Iwasaki et al., 2005).

cVEMP is recorded from the ipsilateral sternocleidomastoid muscles in response to a loud sound stimulus. Similarly, the oVEMP is recorded from the contralateral inferior oblique muscle by placing a surface electrode. The sound is delivered to the contralateral ear to the side of the electrode placement. It has been recently reported that loud sound can elicit vestibular evoked myogenic potential from the active masseter muscles. This vestibular potential recorded from the masseter muscle is known as the masseter VEMP. Studies have utilized the mVEMP as a tool in the assessment of brainstem dysfunction in certain neurological conditions like Parkinson's disease and multiple sclerosis (Hickenbottom et al., 1985; Janky & Shepard, 2009; Magnano et al.,2014., 2016)

Need of the study

1) Need for bone conduction masseter VEMP

The masseter muscles support the jaw against gravity during the head movement. Through the complex vestibular-trigeminal connection, auditory stimuli can activate the masseter muscles. Additionally, with vestibular stimulation at the end organ level, the masseter muscles may exhibit an inhibitory EMG response with short latency. Initially, it was demonstrated as a bilateral, symmetric p11-n15 biphasic wave after unilateral or bilateral transmastoid electrical stimulation(de Natale et al., 2019; Deriu et al., 2003); this

response has since been referred to as the vestibulo-masseteric reflex (VMR) and, more recently, the masseteric VEMP (mVEMP).

Anatomical studies on rats have demonstrated a monosynaptic link between the medial vestibular nuclei and the trigeminal motor nucleus, as well as a multisynaptic vestibular-trigeminal route that may mediate long-latency excitatory trigeminal responses to vestibular stimulation(de Natale et al., 2019). Masseter VEMP has been utilized to evaluate the brainstem lesions in idiopathic random eye movement disorder (de Natale et al., 2018), multiple sclerosis (Magnano et al., 2014., 2016), and Parkinson's disease (de Natale et al., 2015a). mVEMP aids in the detailed understanding of brainstem degeneration (Puligheddu et al., 2019).

Although there is ample research done in the area of masseter VEMPs, there are few research gaps in the recording of mVEMP.

1. The recording protocol for masseter VEMP has not yet been optimized.
2. Masseter VEMP's amplitude and latency for bone conduction stimulation have not been investigated.

2) Need for test-retest reliability in mVEMP

To be effective, a clinical tool must be clinically dependable. Hence, getting normative data about any clinical instrument's reliability is vital. Both air conduction and bone conduction can be used to record mVEMP. Although there are studies on air conduction-evoked mVEMP test-retest reliability, the studies on test-retest reliability of bone conduction mVEMP are sparse. Therefore, it is necessary to develop normative values for the tone burst bone conduction evoked masseter VEMP and assess its test-retest reliability.

Aim of the study

This research aimed to determine normative values and test-retest reliability of the bone conduction evoked mVEMP.

Objectives of the study

1) To study the latency of p11, n21 peak and amplitude of p11-n21 peak of mVEMP for BC stimulation mode.
2) To compare the gender differences to establish normative values for bone conduction mVEMP.
3) To research the test-retest reliability of the masseter VEMP.

CHAPTER - II

REVIEW OF LITERATURE

The vestibular-evoked myogenic potential (VEMP) is a surface potential used to assess the vestibular-dependent reflexes, such as the vestibulocollic reflex and the vestibulo-ocular reflex from the sternocleidomastoid muscle and inferior oblique muscles. These reflexes are essential to regulate head and neck movement. However, there are also other muscles from where VEMPs have been recorded, such as the triceps, trapezius, and gastrocnemius muscles. VEMP is a synchronized stimulus-evoked inhibition or excitation of electromyographic (EMG) activity that follows the activation of vestibular end organs.

Traditionally, reflexive eye movements elicited by stimulation of the semicircular canals were used to examine the vestibular system in humans. There were no vestibular tests that assessed the functions of the otolithic organs. VEMP is a simple, non-invasive way of measuring otolith functions in various vestibular disorders using high-intensity acoustic stimuli. Two widely utilized VEMPs are: cervical VEMP (cVEMP) and the ocular VEMP (oVEMP). Among these, the cVEMP is a conventional method to check the integrity of the saccule and its end organ, whereas the ocular VEMPs are a method to assess the integrity of the utricle and its end organ.

2.1 Masseter vestibular evoked myogenic potentials

The utmost sound-sensitive component of the vestibular structure is the saccule. Through air conduction, acoustic energy reaches the labyrinth and activates the saccular hair cells. (Cazals et al., 1983; McCue & Guinan, 1994; Murofushi et al., 1995). These saccular hair cells then synapse in the ipsilateral lateral vestibular nucleus (Murofushi et al., 1996; Murofushi & Curthoys, 1997). Acoustic energy activates saccular hair cells resembling natural linear acceleration by exciting hair cells of the stria on one side and inhibiting hair cells on the opposite side, and subsequently, these different inputs from each

side of the striola are delivered to secondary vestibular neurons (Deriu et al., 2005; Ogawa et al., 2000; Uchino et al., 1997).

Earlier investigation studied sound-evoked reflex responses in cranial muscles, providing evidence that most of the muscles (orbicularis oris, mylohyoideus, temporalis, orbicular oculi, postauricular, frontalis, and masseter muscles) were ascribed to activation of cochlear afferents (Meier-Ewert et al., 1974). Later, the study recognized that auditory stimulation evoked a prolonged dual inhibitory response in humans, which was then identified as the jaw-acoustic reflex due to active masseter muscle (Meier-Ewert et al., 1974). The author established that this response originated in the cochlea rather than the vestibule. Subsequently, (Deriu et al., 2003) showed that electrical stimulation of the vestibular system evoked short-latency, brief-duration reflexes in masseter muscles.

There was also an investigation on the effects of click stimulation with high intensity in unrectified and rectified mean electromyography and single motor units in the masseter muscles (Deriu et al., 2005). The author proposed that high-intensity clicks induced two brief latency responses in masseter muscle EMG, a p11/n15 reflex response, which is of vestibular source, and a p16/n21 reflex response, corresponding to the formerly defined jaw-acoustic reflex (Meier-Ewert et al., 1974). This p11-n15 biphasic wave after unilateral or bilateral trans mastoid electrical stimulation has since been referred to as the vestibulo-masseteric reflex (VMR) and, more recently, the masseteric VEMP (mVEMP).

Since mVEMP is inhibitory, it is hypothesized that it may be able to prevent the individual from biting their tongue when startled. It was demonstrated that the afferent reflex arc of this response was the auditory nerve, ruling out any vestibular involvement. Monosynaptic projections from the vestibular system to the masseter motor neurons have been established in experimental animals. However, this neural pathway to the masseter

muscle from vestibular receptors has not yet been characterized in humans. (Cuccurazzu et al., 2007; de Natale et al., 2015a; Giaconi et al., 2006).

The masseter muscles assist in elevating the mandible by cooperating on both sides, whereas the sternocleidomastoid muscle helps stabilise the head by acting as an antagonist. Along with mastication, the masseter muscles also have a supporting function in holding the jaw against gravity. Meier-Ewert et al. (1974) described the acoustic jaw reflex in the masseter muscle. According to (Hickenbottom et al., 1985), a whole-body rotation similarly raises the output of masseteric motor neurons. The auditory stimulus can activate the vestibular inputs through the intricate trigeminal system. Studies in mVEMP have demonstrated that monaural auditory stimulation with high-intensity stimulation elicits symmetrical and bilateral responses with short latency in active masseter muscles of healthy participants (Deriu et al., 2005). It is expected that mVEMP will be used for the functional integrity test of the vestibulotrigeminal neural pathways because it is rapidly gaining recognition as a reliable test of saccular function.

2.2 Trigeminal nerve and vestibular system

The motor neurons of the trigeminal nerve play a central role in mastication. They also have a crucial antigravity role in preserving the jaw's position under static and dynamic circumstances. According to studies on anaesthetized guinea pigs, a polysynaptic route connects these motor neurons to the vestibular system, where they receive tonic, bilateral excitatory inputs (Deriu et al., 1999; Tolu et al., 1994; Tolu & Pugliatti,1993). Additionally, these investigations demonstrate that activation of ampullary receptors elicits bilateral polysynaptic excitatory responses in masseter and digastric motor neurons and that macular inputs influence the jaw muscles bilaterally and asymmetrically with respect to head motions in space. (Deriu et al., 2000) demonstrated that a static tilt results in bilaterally

asymmetric alterations in masseter muscle EMG activity. Similarly, Deriu et al. (2003) defined the vestibulomasseteric reflex elicited through trans mastoid electrical stimulation.

The vestibular receptors explicitly reliant on gravity are the otolith organs that stand sensitive to tilt and can be activated by sound. In the same way, the vestibulomassetric reflex responds to abrupt head movement upward or downward. Such as, if the head is abruptly pitched downward, it may be beneficial to inhibit the masseter. If the head is abruptly moved upward, the masseter muscle will be excited (Deriu et al., 2005). An influence of the vestibular receptors on the masseter muscle may help in stabilizing the jaw during movement or maintaining forces equivalent on both sides of the mandible while mastication with the head tilted to a side (Deriu et al., 2007). The pathway of the vestibulomassetric reflex is bilateral. The stimulus from the otolith organs travels to the vestibular nuclei. From the vestibular nuclei, there is ipsilateral and contralateral supply to the trigeminal motor nuclei. From the trigeminal nuclei, there are ipsilateral connections to the masseter muscle. A schematic diagram of the vestibulomassetric reflex is given in Figure 2.1.

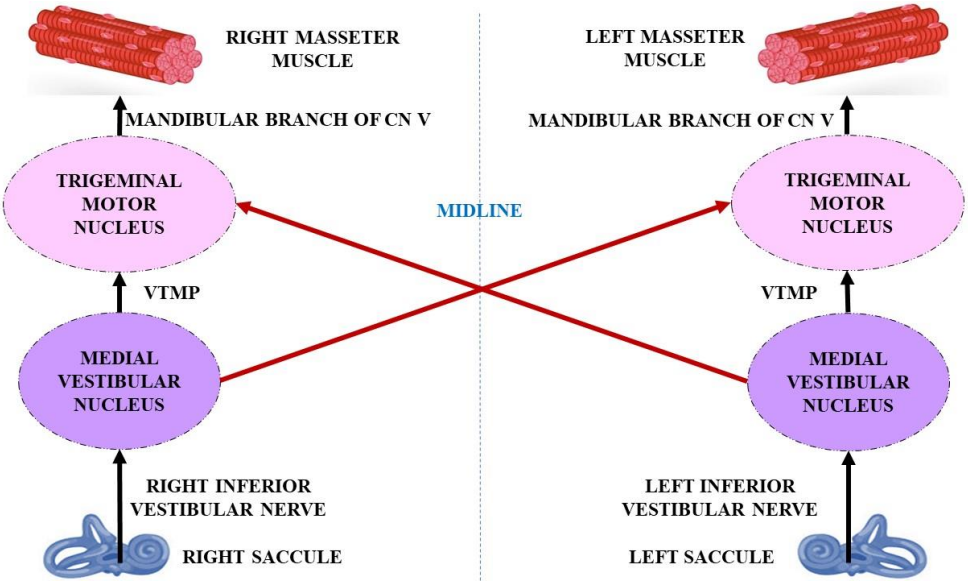


Figure 2.1 – Vestibulo masseteric reflex pathway. VTMP - Vestibulo-trigeminal monosynaptic pathway.

Activation of vestibulomasseteric reflex (VMR) through high-intensity acoustic stimulus produces stimulus-synchronized attenuation of the masseteric EMG characterized as bilaterally symmetrical biphasic p11-n21 responses in the mVEMP (Vignesh et al., 2021). The masseter muscle reflex is primarily inhibitory and has short latency. There is also an argument regarding this reflex being a di or trisynaptic pathway(Deriu et al., 2003).

There is an auditory masseteric reflex pathway reported in studies(Deriu et al., 2005; Meier-Ewert et al., 1974), which is also seen to have effects on the masseter muscle potential that can be recorded as an inhibitory response. A sound stimulation to the cochlea sends information via the auditory nerve fibres to the ipsilateral dorsal cochlear nucleus (DCN), and from this nucleus, there are ipsilateral and contralateral pathways carrying information to the bilateral trigeminal motor nucleus leading to stimulation of masseter muscles via the mandibular branch of the trigeminal nerve. The pathway is represented in Figure 2.2 below.

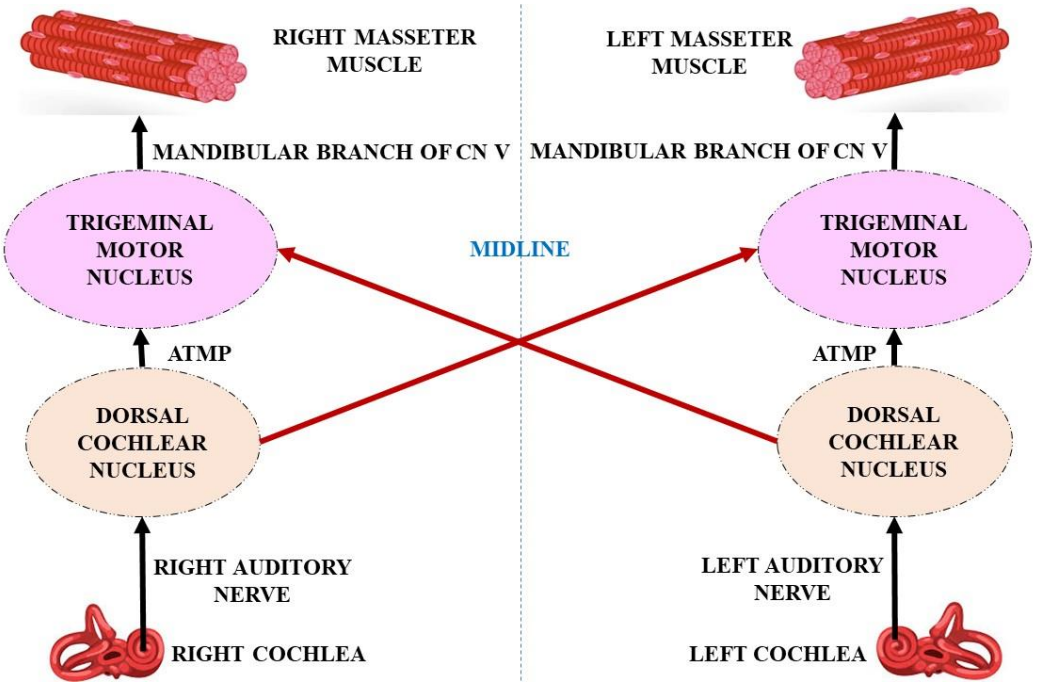


Figure 2.2 represents the auditory masseteric reflex pathway. ATMP – Auditory trigeminal monosynaptic pathway

2.3 Parameters used for recording mVEMP

2.3.1 Stimulus Type and Frequency

Compared to cVEMP and oVEMP, mVEMP is a new test, and there is ongoing research to find the best suitable stimulus to elicit reliable responses in normal individuals. Initial investigations used electrical vestibular stimulation over the mastoid to elicit vestibulomassetric reflex(Deriu et al., 2003), and then studies were done to see the effect of acoustic click stimuli to elicit VEMP (de Natale et al., 2019; Ginatempo et al., 2013). A study comparing electrical stimulation with click stimulation provided evidence of a better detectable response with click stimuli in rectified EMG(Deriu et al., 2005). However, it is proven that 500 Hz tone burst stimuli are more reliable and have lower thresholds in frequency tuning investigations, and thus, this stimulus has typically been used in clinical settings to elicit cervical and ocular vestibular evoked myogenic potentials.

Therefore, studies were also conducted in mVEMP using 500 Hz tone burst stimuli, which suggest that the responses are more robust, with prolonged latency but higher amplitude than the click stimuli(Kılınç et al., 2023; Ravichandran, 2020; Vignesh et al., 2021; Vinayagar & Sinha, 2023). The amplitude of mVEMP is higher for 500 Hz tone burst than click stimulus for ipsilateral, contralateral and bilateral stimulations.

2.3.2 Stimulus Intensity

It is known that using higher stimulus intensity is ideal for eliciting a VEMP response. Research has found that the average threshold needed to evoke cervical and ocular reflex responses from the vestibular system ranges around 114 dB pSPL (Dennis et al., 2013). de Natale et al. (2019) recommended that the best acoustic stimulation to elicit vestibulomassetric reflex is 128-138 dB when using clicks as the stimulus. A study in mVEMP has found that the intensity needed to elicit responses is around 90 – 100 dB NHL, and the higher the intensity, the better the amplitude (Deriu et al., 2005). Studies in mVEMP

have also used 125 dB pe SPL, which abides by the protocol proposed in research concerning the safety level for recording VEMP without losing out response rates (Singh et al., 2019). At AIISH, the mVEMP has recently been recorded with 125 dB SPL intensity (Thirusangu & Sinha, 2022; Vinayagar & Sinha, 2023).

2.3.3 Stimulus Duration

Investigations in cVEMP and oVEMP have found that increasing the tone burst duration will also increase the response amplitude. However, an increase in the duration of more than 6-8 ms in cVEMP tended to reverse the increase in amplitude, but oVEMP amplitude decreased with increasing stimulus duration (Lim et al., 2013). A study on cVEMP found that increasing the duration from 1 to 8 ms resulted in a latency prolongation and the largest amplitudes were obtained for 2 to 3 ms (Singh & Apeksha, 2014). Considering the trade-off between duration and intensity, increasing the intensity needs to be decreased to keep the sound exposure within acceptable limits. Applying the same concept, studies in masseter VEMP have used 500 Hz Blackman-gated tone burst with a duration of 4 msec (2-0-2 cycles) (Romero et al., 2022; Vignesh et al., 2021). A study has also used a 500 Hz tone burst with a rise/fall time of 2-1-2 cycles (Ravichandran, 2020; Thirusangu & Sinha, 2022).

2.3.4 Stimulus Rate

Wu & Murofushi (1999) determined the influence of repetition rate on cervical vestibular-evoked myogenic potentials, and the amplitude was higher at 1 Hz and 5 Hz stimulus rates. The author advised a 5 Hz stimulus rate for a shorter examination time and a higher signal-to-noise ratio. In order to prevent potentials from being acquired in phase with the frequency of the 50 Hz Indian electricity grid coding, stimulation rates are typically not set as integer numbers. Therefore, studies in masseter VEMP also use a stimulation rate of 5.1 Hz since there has been limited research directly on the mVEMP (Kılınç et al., 2023;

Ravichandran, 2020; Vignesh et al., 2021). A study has also used a stimulus rate of 5.4 per second to evoke mVEMP (Romero et al., 2022).

2.3.5 Electrode Montage

Cup electrodes or disc electrodes are usually used to test vestibular-evoked myogenic potentials. Two distinct belly tendon montages are employed in earlier investigations with which the mVEMP has been recorded. One is the mandibular electrode montage, where the reference electrode is positioned on the mandibular angle (Deriu et al., 2003, 2005). The other is the zygomatic electrode montage, where the reference electrode is placed in the mid of the zygomatic arch. In both electrode montages, the active electrode is positioned on the lower third of the masseter muscle, and the ground electrode is positioned on the forehead (de Natale et al., 2019; Ginatempo et al., 2013; Loi et al., 2020; Thirusangu & Sinha, 2022; Vinayagar & Sinha, 2023).

Ginatempo et al. (2013) reported that the zygomatic electrode montage provided more consistent responses and had a larger amplitude. A study comparing both montages described a higher elicitation rate with zygomatic montage, which is considered to be due to the larger inter-electrode distance (de Natale et al., 2019). Larger amplitude mVEMPs and better test-retest reliability for zygomatic montage were also reported in another study (Loi et al., 2020). One study compared these montages to record mVEMP with a 500 Hz tone burst as the stimulus, revealing no significant difference in latency or amplitude (Thirusangu & Sinha, 2022).

2.3.6 Bilateral VS Unilateral stimulation

The vestibulomassetric reflex is a bilateral pathway, and it is shown that unilateral acoustic stimulus can evoke bilateral and symmetrical short-latency responses from the masseter muscle. When compared, bilateral stimulation could evoke responses with a larger amplitude than unilateral stimulus (de Natale et al., 2019; Deriu et al., 2003, 2005;

Ginatempo et al., 2013). Clinically, it is necessary to evaluate each pathway separately since assessing the amplitude asymmetry ratio, which could be obscured with bilateral stimulation, as will add the ipsilateral and contralateral responses together. Vinayagar and Sinha (2023) reported a better mVEMP amplitude for bilateral stimuli than ipsilateral and contralateral stimulations.

2.3.7 Bandpass Filter

Studies have used a 0.3 – 2000 Hz bandpass filter to elicit masseter vestibular evoked myogenic potential (Deriu et al., 2003, 2005, 2007; Vignesh et al., 2021). (De Natale et al., 2019; Loi et al., 2020; Ravichandran, 2020) have used a 5 – 5000 Hz bandwidth to evoke mVEMP response. A study has used a bandpass filter of 0.1 -3000 Hz (Thirusangu & Sinha, 2022). A bandpass filter of 10 -1000 Hz was used in another study (Kılınç et al., 2023). (Romero et al., 2022) used bandwidth filtered between 5 – 1500 Hz.

2.4 Characteristics of mVEMP in healthy individuals

2.4.1 Latency

The mVEMP has a biphasic deflection with an initial positive peak (~ 11 -12 msec) followed by a negative peak (~21 msec). Initial reports with electrical stimulation proposed a p11/n15 response (Deriu et al., 2003). Masseter response to click stimulation had a bilateral p11 peak with an onset latency of 8.4 ± 0.7 ms, a peak latency of 11.9 ± 0.9 ms, and a n15 peak that was less defined and had a poor response rate. The p16 peak was also symmetrical, with an onset latency of 12.0 ± 1.3 ms and a peak latency of 16.6 ± 1.1 ms. It was also seen in the same study that the p11/n15 peaks appeared only at higher stimulation intensity, even though n15 was not very clear. Therefore, suggesting a saccule as the activating receptor of p11/n15 while cochlear is the receptor of p16/n21 (Deriu et al., 2007).

de Natale et al. (2019), in a study of zygomatic montage with click stimulation, found the mean ipsilateral p11 latency to be 11.17 ± 0.98, contralateral p11 latency to be

11.38 ± 0.9 and the ipsilateral n21 latency of 19.68 ± 1.81 and contralateral n21 latency of 19.53 ± 1.9. The study also defined normative for a mandibular montage with mean ipsilateral p11 latency of 11.37 ± 0.91, contralateral p11 latency of 11.5 ± 0.87, and mean ipsilateral n21 latency of 19.75 ± 1.84, contralateral latency of 19.5 ± 1.84. mean interpeak latency was also mentioned in the study for both the montages: the ipsilateral zygomatic montage mean value of 8.52±1.78, the contralateral value of 8.15±1.87 and the ipsilateral mandibular montage mean value of 8.38±1.65 with contralateral latency of 7.99±1.73.

One of the studies investigated the normative data for click and tone burst evoked mVEMP. They specified a click-evoked p11 latency of 11.45 ± 0.87, n21 latency of 21.85 ± 1.65 and interpeak latency of 10.4 ± 0.78, and a tone burst-evoked p11 latency of 12.13 ± 0.81, n21 latency of 22.54 ± 1.30 and interpeak latency between p11 – n21 to be 10.42 ± 0.49(Ravichandran, 2020). Vignesh et al. (2021), in their study with tone burst as the stimuli, reported an ipsilateral p11 mean latency of 13.20 ± 1.25 and contralateral p11 latency of 13.48, ipsilateral n21 latency of 21.40 ± 1.27, contralateral n21 response of 21.55 ± 1.32. The study also observed that the tone burst stimuli elicitation tended to prolong the latency of the mVEMP response. A study with the stimulus of 100 dB nHL reported that the mVEMP had mean P1 latency of 15.90 ± 1.68 ms, N1 latency of 25.86 ± 1.48 ms, and interpeak latency of 9.96 ± 1.50 ms. It was also observed that with stimulus intensity decreased, P1 and N1 latencies were prolonged (Kılınç et al., 2023).

2.4.2 Amplitude

The presence and amplitude of the VEMP response are related to the integrity of the vestibular reflex pathway. (de Natale et al., 2019) Their study with zygomatic and mandibular montages reported a peak-to-peak rectified ipsilateral amplitude of 0.72 ± 0.31 (μV), a contralateral amplitude of 0.74 ± 0.31 (μV) and an amplitude asymmetry ratio of 14.56 ± 11.8 for the zygomatic montage. For mandibular montage, the authors reported an

ipsilateral peak-to-peak rectified amplitude of 0.68±0.33 (μV), a contralateral amplitude of 0.68±0.35 (μV) and an amplitude asymmetry ratio of 0.68±0.35. (Vignesh et al., 2021) Defined amplitude for tone burst stimuli, with an ipsilateral peak-to-peak amplitude of 0.86 ± 0.38, amplitude asymmetry ratio of 15.07 ± 11.40, and contralateral peak-to-peak rectified amplitude of 0.83 ± 0.31 with an asymmetry ratio of 15.48 ± 9.83. A study with 100 dB nHL as the stimulus intensity reported a p11 – n21 amplitude of 97.89 ± 37.34 μV and an asymmetry ratio of 0.13 ± 0.07 (Kılınç et al., 2023).

It is vital to use amplitude correction to effectively neutralize the variability factor in tonic EMG level on the VEMP responses (McCaslin et al., 2014). Romero et al., (2022) also showed in their study that the impact of EMG on the response was reduced using rectified amplitudes. They also established that average rectified amplitude asymmetry ratios were small and did not depend on the EMG target level. They also observed no difference between p11 amplitude (vestibular component) and peak-to-peak amplitude at the suprathreshold level.

2.4.3 Test-Retest Reliability

The study evaluating the test-retest reliability of masseter VEMP reported peak latencies being highly reliable and unrectified amplitude with the lowest reliability compared to corrected amplitude. It was also observed that there was better reliability with the zygomatic montage than with the mandibular montage(Loi et al., 2020). A study on tone burst evoked mVEMP showed high reliability, with p11 exhibiting excellent test-retest reliability and n21 displaying fair test-retest reliability, but also noted differences across participants, which were hypothesized to be related to changes in the degree of masseter muscle activation. (Vignesh et al., 2021).

2.5 Characteristics of mVEMP in individuals with various brainstem disorders

The masseter VEMP indirectly studies a substantial portion of the brainstem, which can provide additional information along with cervical and ocular VEMPs.

2.5.1 Parkinson's disease

de Natale et al. (2015) Provided evidence that the masseter VEMP in individuals with Parkinson's' disease was altered with an abnormal rate of 42.8 % in the early stages and 63.2% in the later stages. Another study comparing cVEMP, oVEMP and mVEMP in assessing individuals with Parkinson's disease found a relatively higher abnormality rate of 66.7 % with mVEMP. In contrast, it was 41.7 % with cVEMP and 45.8 % with oVEMP testing, suggesting mVEMP is a valid measure(de Natale et al., 2015).

2.5.2 Multiple sclerosis

A study investigating click-evoked vestibulo masseteric reflex in patients with multiple sclerosis reported that the vestibulomassetric reflex was more affected than the vestibulo-collic reflex, which is thought to be because of greater involvement of the vestibulo-trigeminal than the vestibulospinal pathway (Magnano et al., 2014). In brainstem reflex recordings with evoked potentials in patients with multiple sclerosis, the vestibulomassetric reflex showed the highest frequency of abnormalities, with a rate of 57.8 %. The abnormality worsened in follow-up recordings(Magnano et al., 2016). A study aiming to examine oVEMPs, cVEMPs, mVEMPs and MRI findings in multiple sclerosis found a higher rate of abnormalities seen in mVEMP (82.4%) than in the other two VEMPs or MRI. Thus suggesting that mVEMP had clinical significance in identifying silent brainstem dysfunction, which can remain undetected by MRI findings.

2.5.3 Sleep disorder

Investigating the brainstem function in idiopathic REM sleep behaviour disorder with VEMPs, a study observed that the patients with this disorder had alterations such as

significant delay in the first wave latency and onset wave latency of mVEMP. The rate of alterations was also higher in masseter VEMP (65%), but the absence of response in mVEMP was 50%, which was lesser than the absence rate in oVEMP with 81.2 % and cVEMP with 70% (de Natale et al., 2018). In another study measuring VEMP in patients with REM sleep behaviour disorder, the authors found an abnormal response with p11 peak latency prolongation in mVEMP(Puligheddu et al., 2019).

2.5.4 Amyotrophic Lateral Sclerosis

Liu et al. (2019), In their study to find the clinical value of VEMPs in diagnosing brainstem integrity in patients with amyotrophic lateral sclerosis, found that there were alterations in all the three VEMPs with a higher rate of abnormality in cVEMP (67%) followed by oVEMP (45%) and mVEMP (40%). The study suggested combining all three VEMPs to provide a valuable understanding of amyotrophic lateral sclerosis pathophysiology, as cVEMP indicates the integrity of the lower brainstem. In contrast, the oVEMP and mVEMP abnormality can indicate upper brainstem involvement.

To summarise, the mVEMP has been recorded using various stimulus and acquisition parameters. All these studies have utilized air conduction stimulation to record mVEMP. No studies have utilized bone conduction to record mVEMP in normal and clinical populations. Hence, the present study was conducted to record the mVEMP using a BC vibrator and test its reliability in the normal population.

Chapter- III

METHOD

The study aimed to evaluate the bone conduction-evoked mVEMP's normative values and test-retest reliability.

Participants

The current study comprised 30 healthy individuals (15 males and 15 females) within the age range of 18 years – 30 years.

Participant selection criteria

- All the Participants had bilateral normal hearing sensitivity.
- Participants did not have a history or presence of middle ear problems such as ear discharge, ear pain, etc.
- Participants had no signs and symptoms related to any vestibular disorders.
- Participants did not have any neurological disorders.
- No oromandibular problems were present in the participants.
- Participants had no retrocochlear pathology, as evidenced by the presence of normal auditory brainstem responses.
- Participants did not have uncomfortableness with loud sounds.

Instrumentation

- Pure tone audiometry was administered to each participant using a calibrated Inventis Piano audiometer with TDH-39 headphones placed in MX-41/AR (Telephonics, Farmingdale, NY, USA) ear cushions.
- Radio ear B71 bone transducer (Radio ear, KIMMETRICS, Smithsburg, Maryland, USA) headset was used to estimate the threshold for bone conduction.

- Tympanomtery and Reflexometry was performed using the middle ear analyzer Grandson-Stadler Incorporated (GSI) Tympstar (GSI VIASYS Healthcare, WI, USA).
- Neuro-Audio Neurosoft was used to record auditory brainstem responses to rule out retro cochlear pathology, and a Radio ear B-71 bone vibrator was used to record bone-conducted mVEMP responses.

Test Environment

The noise levels were within acceptable limits throughout the testing, conducted in an electrically and acoustically shielded chamber (ANSI S3.1; 1991).

Test Procedure

1. **Case history**

All participants completed a thorough case history, which included investigations about conductive hearing loss symptoms, any history of middle ear pathology, and medications taken. Questions regarding vestibular symptoms like vertigo, nausea/vomiting, and imbalance were asked.

2. **Pure tone audiometry**

Pure tone audiometry was used to determine each participant's hearing thresholds for bone conduction between 250 Hz and 4000 Hz and for air conduction in all octaves between 250 Hz and 8000 Hz using a modified version of the Hughson and Westlake approach (Carhart & Jerger, 1959). The ascending method was used to obtain UCL in both ears for air-conducted speech stimuli.

3. **Immittance**

Tympanograms were recorded in both ears using a 226 Hz probe tone, and 500, 1000, 2000, and 4000 Hz stimuli were used to assess the acoustic reflex 4thresholds for ipsilateral and contralateral recording.

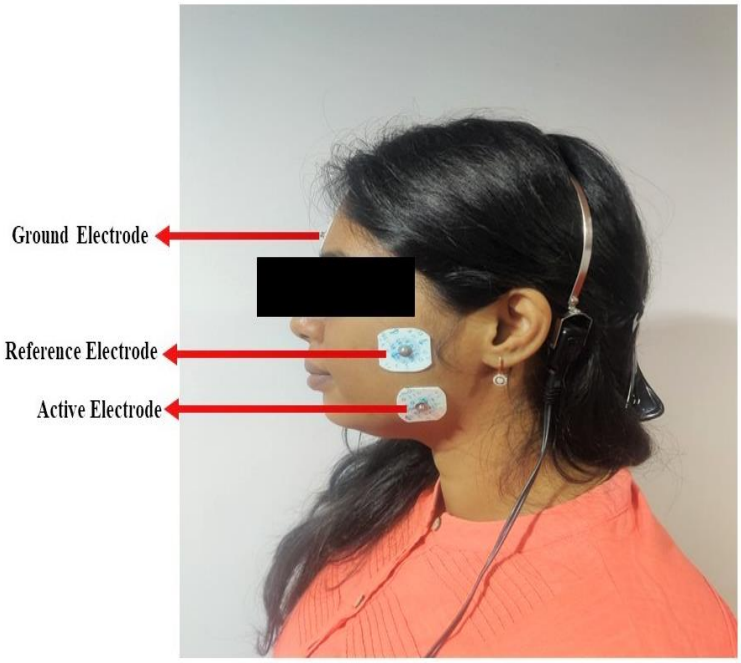
4. Auditory Brainstem Response

Clicks at 90 dBnHL were used for the ABR-Site of Lesion testing. Electrodes were placed in Fz, M1, and M2. The stimulus was delivered via ER-3A insert earphones, and the repetition rate was kept at 11.1/sec and 90.1/s. A total of 1500 stimulus was presented, and the obtained responses were filtered between 100 Hz and 3000 Hz.

5. Masseteric vestibular-evoked myogenic potential

A dual channel diagnostic evoked potential instrument (Neurosoft, Russia) was used for mVEMP testing. The participants assumed an upright position in comfortable chairs. Using a zygomatic montage, the active electrode was positioned on the bottom one-third of the masseter muscle to record the mVEMP. The ground electrode was on the forehead, and the reference electrode was on the middle of the zygomatic arch. The electrode placement site was prepared with skin prep gel, and silver chloride disc electrodes with conduction gel were used. The electrode was secured in place using surgical tape. Figure 3.1 represents the electrode placement for evoking masseter vestibular evoked myogenic potential.

Figure 3.1



The interelectrode and absolute impedance were kept below 5 and 2 KΩ, respectively. Visual input was provided on the computer screen via an integrated visual display of the EMG needle deflection. Maximum EMG needle deflection was measured during the forceful bite of the jaw before recording, and the maximum voluntary contraction of the masseter muscle was estimated. The baseline for muscle contraction was kept at 30 to 50 % of maximum voluntary contraction. After each recording, the participant was given a brief break of about two minutes to prevent fatigue. The mVEMP was elicited with a Radio ear B71 bone transducer placed on the mastoid with tone bursts of 500 Hz, 750 Hz and 1000 Hz delivered at 115 dB FL. The equipment was calibrated prior to the recording of mVEMP. The details of the protocol used for recording mVEMP are given in Table 3.1.

Table 3.1

Stimulus and Acquisition parameters used for recording masseter VEMP

STIMULUS PARAMETERS	
STIMULUS	**SETTINGS**
Stimulus Type	Tone burst
Frequency	500 Hz, 750 Hz, 1000 Hz
Intensity	115 dB FL
Stimulus Polarity	Rarefaction
Stimulus Rate	5.1/s
ACQUISITION PARAMETERS	
Transducer	Bone vibrator B71
TIME WINDOW	
Pre stimulus	20 ms

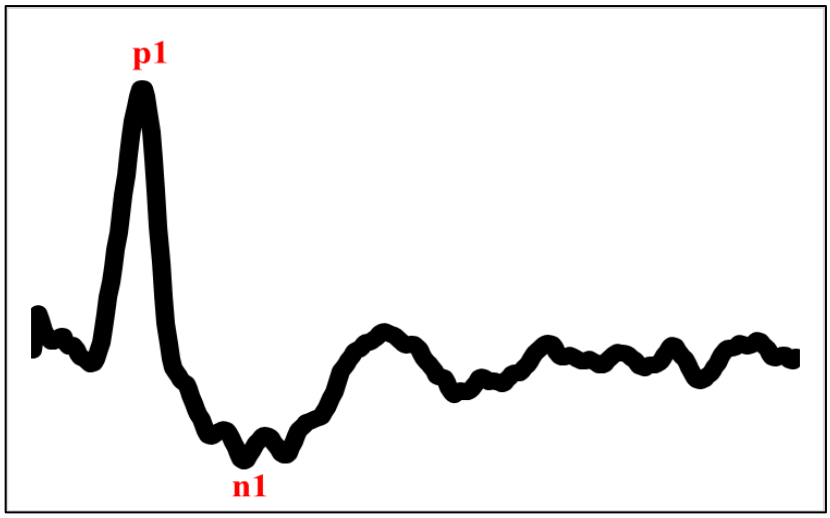
Post stimulus	50 ms
Filter Setting	0.1 – 2000 Hz
Amplification	5000
ELECTRODE PLACEMENT	
Inverting electrode (-)	Masseter muscle
Non-inverting electrode (+)	Zygomatic arch
Ground electrode	Nasion

Analysis

Analysis of vestibular evoked myogenic potentials

The resultant waveform consisted of two potentials. An initial positive or inhibition at around 11 ms post-stimulation, known as the "p1 or p11" peak, was followed by a negative or excitation at around 21 ms post-stimulation, known as the "n1 or n21" potential. Each waveform of masseter vestibular evoked myogenic potential was analyzed by an experienced audiologist to identify P1 and N1 peaks. Figure 3.2 is a representative waveform of an mVEMP response showing all the peaks.

Figure 3.2



- Absolute latency P1 and N1 were noted for each participant at 500 Hz, 750 Hz, and 1000 Hz in both ears.
- Peak-to-peak amplitude was noted for all the participants at all frequencies.
- The test-retest reliability for mVEMP for fifty percent of the participants (n=15) was determined.

Statistical analysis

The Statistical Package for Social Sciences (SPSS) software version 20 was used for the statistical analyses. Following statistical analyses were done.

- Descriptive statistics were done to get the mean and standard deviation for the absolute latency of P1 and N1 peaks and the peak-to-peak amplitude of the P1-N1 complex.
- The Shapiro-Wilk test of normality was used for all the parameters to determine if the data had a normal distribution.
- A paired sample t-test was performed to see for any individual ear differences at each frequency.
- Descriptive statistics were done to obtain mean and standard deviation for the combined ear data.
- Repeated measures ANOVA was done with gender as the between-group factor for P1 and N1 latency measures. Post hoc tests could not be performed for gender as there are fewer than three groups.
- An Independent t-test was done for the N1 latency measure to find the difference between males and females.
- Repeated measures ANOVA with gender as a between-group factor was done for amplitude measure.

- Repeated measure ANOVA within the female group and within the male group was done.
- The Bonferroni test was then performed to find the individual frequency difference between gender P1 – N1 amplitude measure.
- The intraclass correlation coefficient (ICC) was used to assess the test-retest reliability of bone conduction mVEMP.

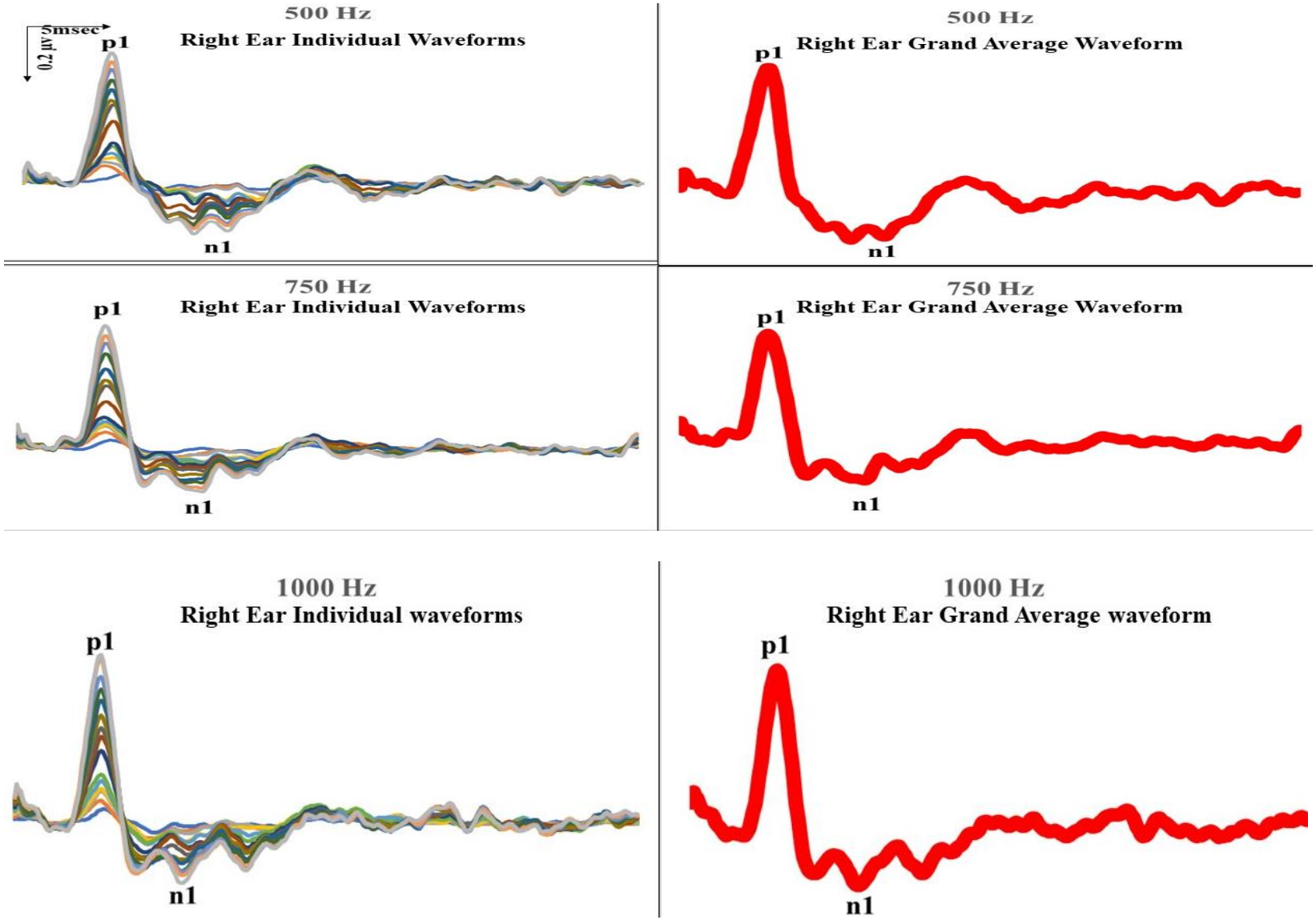
CHAPTER – IV

RESULTS

The present study was designed to study the latency and the amplitude of masseter VEMP using bone conduction and to assess the test-retest reliability. Thirty young, healthy subjects (60 ears) with normal hearing sensitivity were included in the study. Masseter VEMP was re-recorded for 15 subjects (30 ears) after one week of the first test.

Response Rate:

The latency of P1, N1 peaks and amplitude of the P1-N1 complex were measured at 500 Hz, 750 Hz and 1000 Hz with tone burst stimuli. B-71 bone conduction bone vibrator was utilized to record masseter VEMP. The bone conduction evoked masseter VEMP had a 100% (30/30) response rate at all three frequencies. The individual and grand averaged waveform of masseter VEMP for the left and right ears of females and males are given in Figure 4.1 and Figure 4.2, respectively.


500 Hz
Right Ear Individual Waveforms
5msec
0.2 μV
p1
n1
500 Hz
Right Ear Grand Average Waveform
p1
n1
750 Hz
Right Ear Individual Waveforms
p1
n1
750 Hz
Right Ear Grand Average Waveform
p1
n1
1000 Hz
Right Ear Individual waveforms
p1
n1
1000 Hz
Right Ear Grand Average waveform
p1
n1

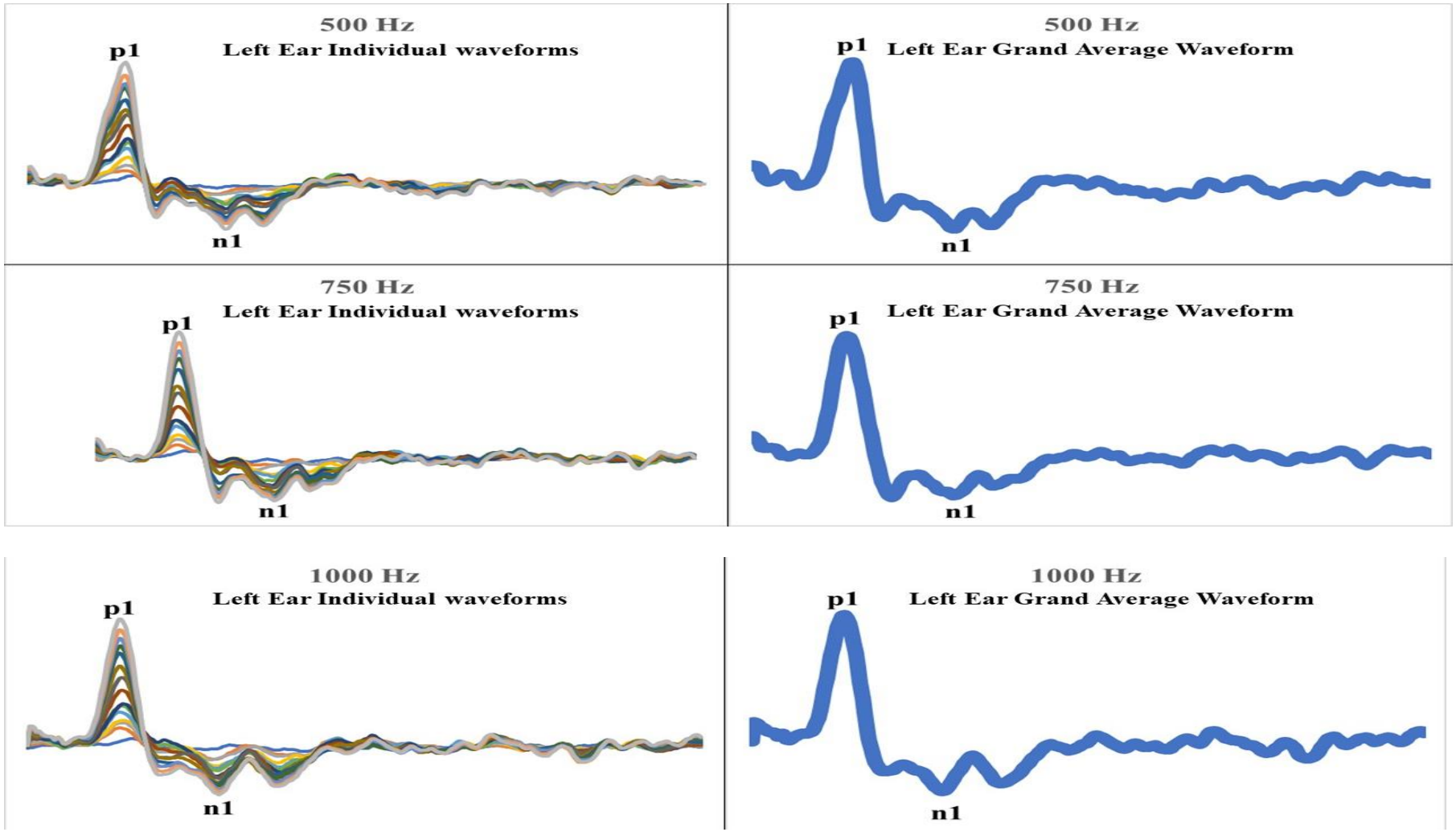
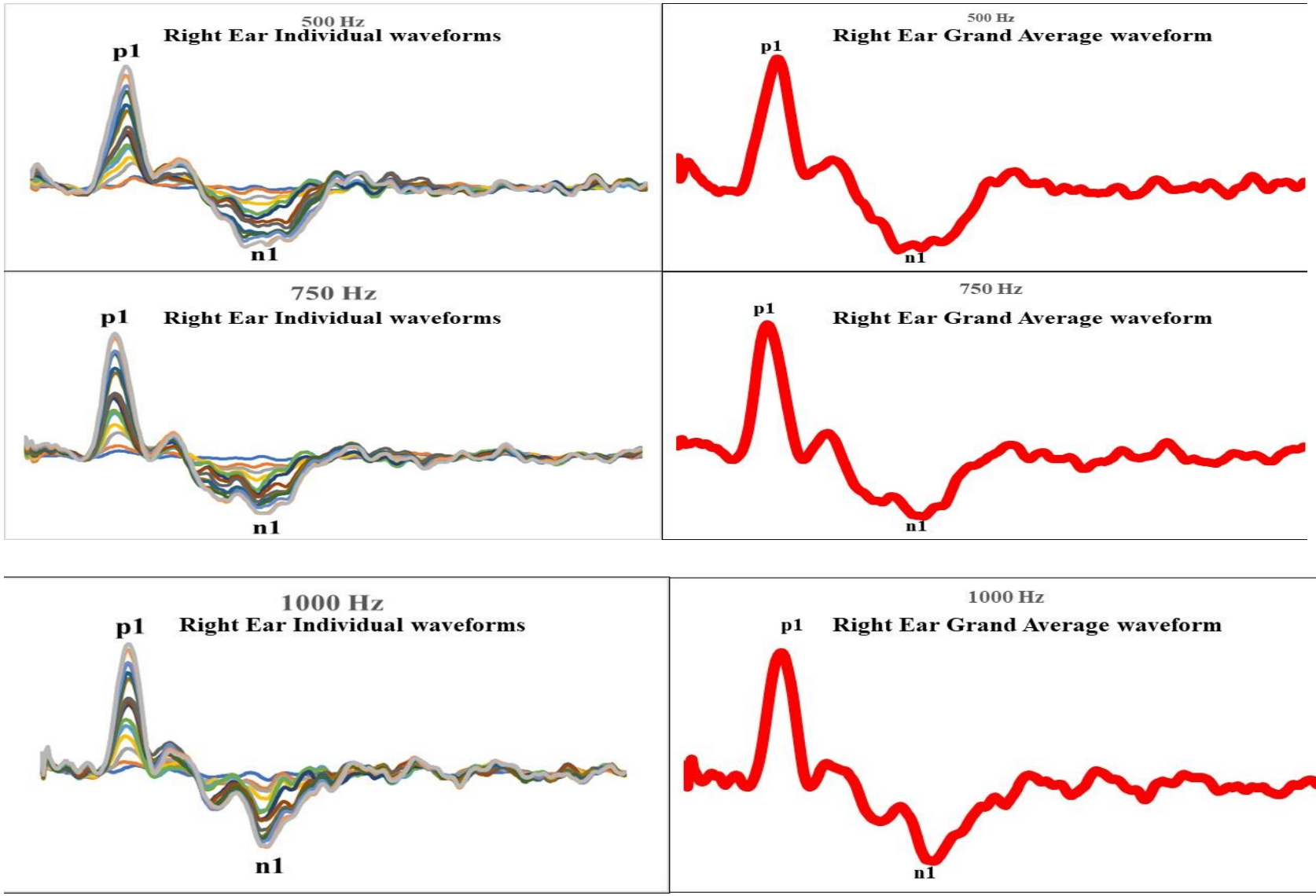


Figure 4.1. Individual and grand averaged waveforms of masseter VEMPs for right and left ear for females


500 Hz
Right Ear Individual waveforms
p1
n1
500 Hz
Right Ear Grand Average waveform
p1
n1
750 Hz
Right Ear Individual waveforms
p1
n1
750 Hz
Right Ear Grand Average waveform
p1
n1
1000 Hz
Right Ear Individual waveforms
p1
n1
1000 Hz
Right Ear Grand Average waveform
p1
n1

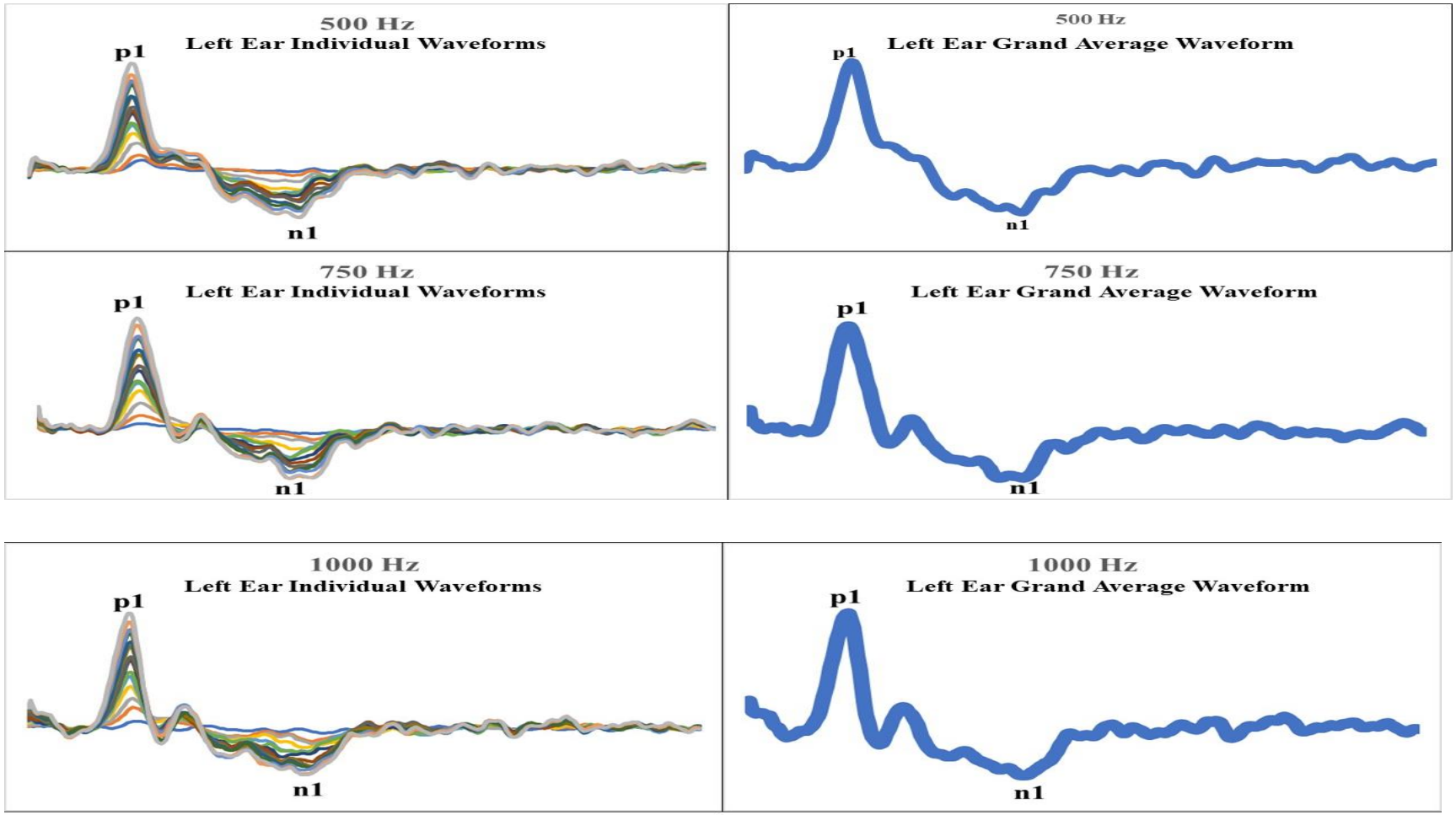


Figure 4.2. Individual and grand averaged masseter VEMP waveforms at different frequencies of right and left ear for males

4.1 Latency measure of Bone conduction evoked mVEMP

The mean and SD of the P1 and N1 latency in females and males are shown in Table 4.1 and 4.2, respectively.

Table 4.1

Mean and Standard deviation of latency measures of P1 and N1 of mVEMP in females.

Parameters		**P1 peak**				**N1 peak**			
		Min	Max	Mean (ms)	SD	Min	Max	Mean (ms)	SD
500Hz	Right	11.10	16.00	12.24	1.19	16.70	22.90	20.40	1.56
	Left	10.80	13.00	11.90	0.53	15.50	23.30	20.28	1.76
750Hz	Right	11.10	15.20	11.99	1.07	16.80	22.60	20.46	1.53
	Left	11.00	15.30	11.97	1.06	15.50	22.80	20.27	1.76
1000Hz	Right	10.70	14.90	11.95	1.14	17.10	22.90	20.43	1.55
	Left	11.00	15.30	11.92	1.04	16.80	22.40	20.45	1.348

Table 4.2

Mean and Standard deviation of P1 and N1 latency measures of mVEMP in males.

Parameters		**P1 peak**				**N1 peak**			
		Min	Max	Mean (ms)	SD	Min	Max	Mean (ms)	SD
500Hz	Right	10.60	13.60	12.35	0.89	18.10	25.50	21.64	1.81
	Left	11.40	13.90	12.46	0.73	19.30	25.50	21.53	1.56
750Hz	Right	11.40	14.20	12.28	0.85	20.00	26.20	21.98	1.55
	Left	11.50	16.50	12.64	1.23	19.60	25.50	22.10	1.48
1000Hz	Right	11.10	16.10	12.40	1.29	19.80	23.00	21.42	1.03
	Left	11.50	13.10	12.32	0.53	20.10	25.00	21.51	1.40

The Shapiro-Wilk test revealed a normal data distribution for all frequency responses as part of the normality test. Parametric test measures were utilized for studies since the Shapiro-Wilk test showed that the data had a normal distribution.

Paired sample t-test was done to find if there were any significant differences between the right and left ear responses. The results of the paired sample t-test for the frequencies in both females and males are given below in Tables 4.5 and 4.6, respectively.

Table 4.3

Paired sample T test for all three frequencies in females.

Parameters	P1 peak		N1 peak	
	t	Significance (2- tailed)	t	Significance (2-tailed)
500Hz	1.249	0.232	0.371	0.716
750Hz	0.061	0.952	0.616	0.548
1000Hz	0.116	0.909	-0.065	0.949

Table 4.4

Paired sample T test for all three frequencies in males.

Parameters	P1 peak		N1 peak	
	t	Significance (2-tailed)	t	Significance (2-tailed)
500Hz	0.515	0.615	0.192	0.850
750Hz	1.541	0.146	0.349	0.732
1000Hz	1.005	0.333	0.192	0.851

Tables 4.3 and 4.4 show no significant difference in the P1 and N1 peak latencies between the right and left ear for both females and males. Thus, the data from both ears were combined for all the frequencies, and descriptive statistics were done to get the mean

and standard deviation of the combined data. The combined ear data of P1 and N1 latency for the three frequencies for females and males are given below in Tables 4.5 and 4.6, respectively.

Table 4.5

Mean and standard deviation of combined ears p1 and n1 latency for all the frequencies in females.

Parameters	p1 peak				n1 peak			
	Min	Max	Mean (ms)	SD	Min	Max	Mean (ms)	SD
500Hz	10.80	16.00	12.07	0.92	15.50	23.30	20.34	1.63
750Hz	11.00	15.30	11.98	1.05	15.50	22.80	20.37	1.63
1000Hz	10.70	15.30	11.93	1.07	16.80	22.90	20.44	1.43

Table 4.6

Mean and standard deviation of combined ears p1 and n1 latency for all the frequencies in males.

Parameters	p1 peak				n1 peak			
	Min	Max	Mean (ms)	SD	Min	Max	Mean (ms)	SD
500Hz	10.60	13.90	12.41	0.80	18.10	25.50	21.59	1.66
750Hz	11.40	16.50	12.46	1.06	19.60	26.20	22.04	1.49
1000Hz	11.10	16.10	12.36	0.98	19.80	25.00	21.46	1.20

The mean and standard deviation data show no latency differences between 500 Hz, 750 Hz and 1000 Hz within female and male groups.

Repeated measures ANOVA revealed statistically no significant main effect of frequency on P1 latency [F (2,114) = 0.252, p = 0.77] and N1 latency [F (2,114) = 1.32, p = 0.270] peaks of mVEMP across 500 Hz, 750 Hz and 1000 Hz frequencies. Repeated measure ANOVA also revealed no significant interaction effect between gender and frequency on both P1 [F (2,114) = 0.192, p = 0.826] and N1 latency [F (2,114) = 1.711, p = 0.185]. Repeated measure ANOVA also revealed statistically no significant latency difference for gender for P1 latency [F (1, 58) = 11957.10, p>0.05], but a statistically significant effect of gender on N1 latency [F (1, 58) = 14918.92, p < 0.001] was noted. A post hoc test is not done for gender because fewer than three groups were there. The P1 latency effect is depicted in Figure 4.3, and the N1 latency effect is shown in Figure 4.4.

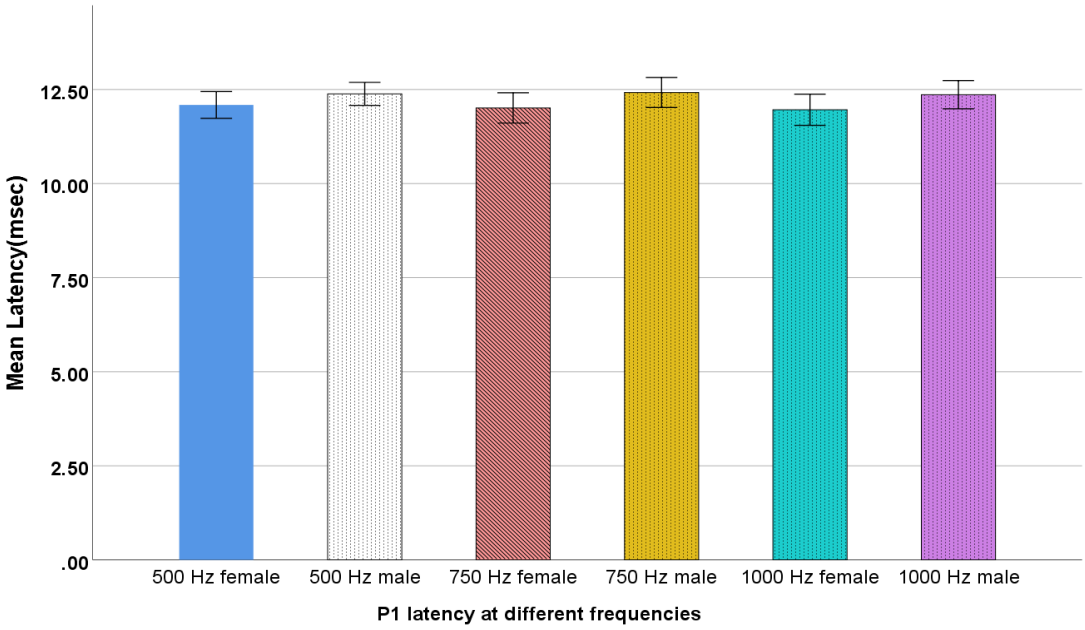


Figure 4.3 shows P1 latency across frequencies for females and males.

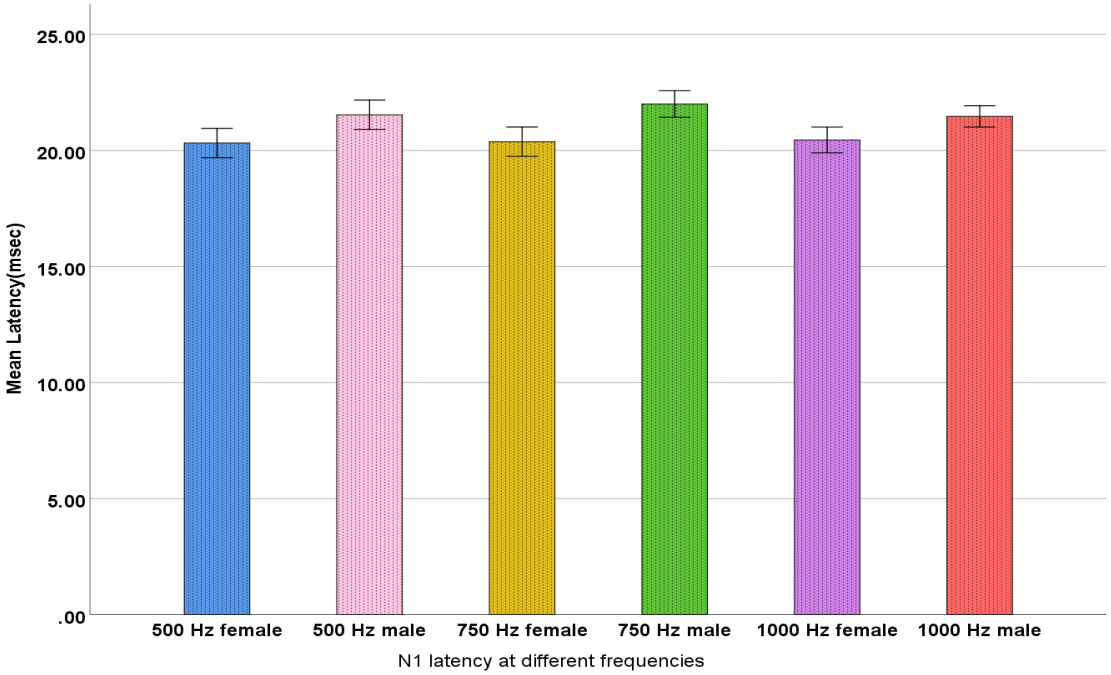


Figure 4.4 shows N21 latency across frequencies for females and males

An independent t-test was done to find the effect of gender on the three frequencies. Independent sample T-test revealed a gender difference at 500 Hz [t (59) = 2.920, p = 0.005], 750 Hz [t (59) = 4.146, p < 0.001] and 1000 Hz [t (59) = 2.960, p = 0.004]. The N1 latency is significantly higher in males than females in all three frequencies.

4.2 Amplitude Measure of Bone Conduction mVEMP:

For the responses, the amplitude of the P1-N1 peak complex was determined. Descriptive statistics were used to determine the mean and standard deviation of the amplitude of the P1-N1 peak complex. The mean and standard deviation of the amplitude measure in females and males are mentioned below in Tables 4.7 and 4.8, respectively.

Table 4.7

Mean and standard deviation of the amplitude of p1- n1 peak complex for all four frequencies of both ears in Females.

Parameters		Amplitude of p1-n1 peak complex			
		Min	Max	Mean(μv)	SD
500Hz	Right	0.60	1.40	1.0000	0.27775
	Left	0.50	1.40	0.8400	0.27464
750Hz	Right	0.40	1.80	1.0467	0.35024
	Left	0.50	1.30	0.9000	0.23299
1000Hz	Right	0.40	1.20	0.9267	0.25204
	Left	0.60	1.40	0.8600	0.22928

Table 4.8

Mean and standard deviation of the amplitude of p1- n1 peak complex for all four frequencies of both ears in Males.

Parameters		Amplitude of p1-n1 peak complex			
		Min	Max	Mean(μv)	SD
500Hz	Right	0.40	1.80	0.9867	0.38520
	Left	0.40	1.50	0.9533	0.37582
750Hz	Right	0.40	1.80	0.8933	0.38816
	Left	0.30	1.60	0.9467	0.36029
1000Hz	Right	0.30	1.30	0.6600	0.25579
	Left	0.30	1.30	0.8143	0.30849

Paired sample t-test was done to find any significant difference between right and left ears responses. The results of the paired sample t-test for all three frequencies are depicted below in Tables 4.9 and 4.10.

Table 4.9

Paired sample T test for all the frequencies in Females.

Parameters	Amplitude of p1-n1 peak complex	
	t	Significance
500Hz	2.138	0.51
750Hz	1.798	0.09
1000Hz	1.022	0.32

Table 4.10

Paired sample T test for all the frequencies in males.

Parameters	Amplitude of p1-n1 peak complex	
	t	Significance (2-tailed)
500Hz	0.383	0.70
750Hz	-0.774	0.45
1000Hz	0.657	0.51

It can be seen from the tables that there is no significant difference in the amplitude of the P1-N1 peak complex of the right and left ears for the frequencies. Thus, the data from both ears were combined for the three frequencies, and the mean and standard deviation data were derived from descriptive statistics. The mean and standard deviation data of the P1 – N1 peak complex are given below in Tables 4.11 and 4.12

Table 4.11

Mean and standard deviation of the amplitude of p1- n1 peak complex for all three frequencies of combined ears for females.

Parameters	Amplitude of p1-n1 peak complex			
	Min	Max	Mean(μv)	SD
500Hz	0.50	1.40	0.9200	0.28333
750Hz	0.40	1.80	0.9733	0.30164
1000Hz	0.40	1.40	0.8933	0.23916

Table 4.12

Mean and standard deviation of the amplitude of p1- n1 peak complex for all three frequencies of combined ears for males.

Parameters	Amplitude of p1-n1 peak complex			
	Min	Max	Mean(μv)	SD
500Hz	0.40	1.80	0.9700	0.37430
750Hz	0.30	1.80	0.9200	0.36897
1000Hz	0.30	1.30	0.7345	0.28819

The mean and the standard deviation for P11 N21 peaks can also be seen in Figure 4.5

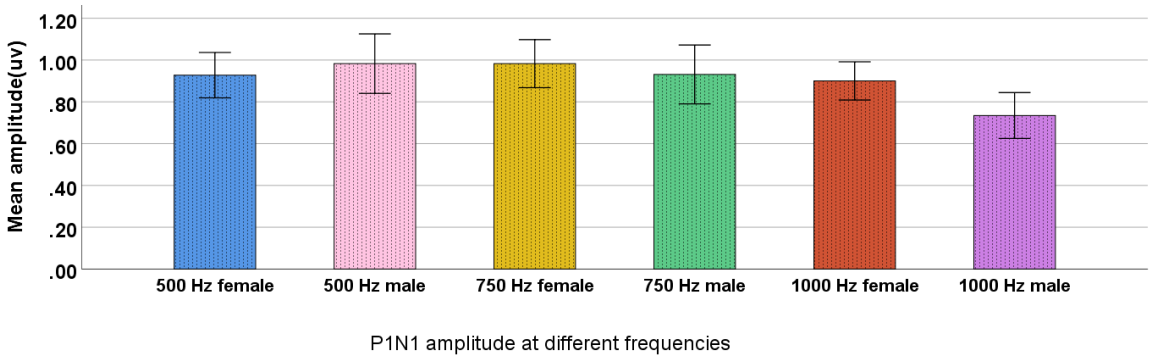


Figure 4.5. Amplitude of P11-N21 peak complex for the combined data

A repeated measures ANOVA revealed a statistically significant main effect of frequency on P1-N1 amplitude [F (2,114) = 10.92, p< 0.001], a significant interaction effect of gender and frequency on amplitude [F (2, 58) = 645.75, p < 0.001], but there was no significant effect of gender on amplitude [F (2,114) = 5.29, p = 0.006].

Repeated measures ANOVA was done separately within females and males to find which of the two genders affects the amplitude. The repeated measures ANOVA for female data show no significant difference in P1-N1 amplitude [F (2,58) =1.89, p<0.05]. The result of within male data shows statistically significant differences in amplitude across frequencies [F (2, 58) = 11.717, p < 0.05].

Bonferroni pairwise comparison was carried out to check the frequency-dependent difference in the P1-N1 amplitude complex in males. Table 4.13 below represents the pairwise comparison of the amplitude across different frequencies.

Table 4.13

Bonferroni pairwise comparison test for the amplitude of p1-n1 peak complex in males.

Frequency	500Hz	750Hz	1000Hz
500Hz		P > 0.05	P < 0.05
750Hz			P < 0.05
1000Hz			

Table 4.13 shows that the amplitude of the P1-N1 complex of 500 Hz is not significantly different from the amplitude complex of 750 Hz but significantly different from the amplitude response of 1000 Hz. The P1-N1 amplitude complex of 1000 Hz is significantly different from the 750 Hz amplitude response.

4.3 Test-Retest reliability of Bone conduction evoked mVEMP

Bone conduction-evoked mVEMP was tested again for the second time in 15 normal-hearing individuals within one month of the first test. The mean, standard deviation and intraclass correlation coefficient were all determined. Tables 4.14 and 4.15 below show the right and left ear's mean, standard deviation and ICC values, respectively.

Table 4.14

Mean and Standard deviation (SD) of p1, n1 latency and P1-N1 amplitude complex of the first and the second session of mVEMP and ICC values for the right ear

Response parameters	**Frequency**	**T1**		**T2**		**α**	**ICC**	**p-value**
		Mean	SD	Mean	SD			
p1 latency	500 Hz	11.90	0.68	12.13	0.45	0.59	0.57	0.05
	750 Hz	11.83	0.61	11.36	2.90	-0.09	-0.10	0.56
	1000 Hz	11.73	0.83	11.98	0.42	0.41	0.41	0.16
n1 latency	500 Hz	20.81	2.05	21	1.87	0.87	0.87	<0.001
	750 Hz	20.70	1.74	21.14	1.75	0.93	0.92	<0.001
	1000 Hz	20.52	1.65	21.04	1.71	0.90	0.88	<0.001
p1-n1 amplitude	500 Hz	1.20	0.31	1.15	0.31	0.69	0.69	0.018
	750 Hz	1.19	0.31	1.11	0.30	0.76	0.76	0.005
	1000 Hz	0.98	0.19	0.92	0.15	-0.28	-0.29	0.67

Table 4.15

Mean and Standard deviation (SD) of p1, n1 latency and P1-N1 amplitude complex of the first and the second session of mVEMP and ICC values for the left ear

Response parameters	**Frequency**	**T1**		**T2**		**α**	**ICC**	**p-value**
		Mean	SD	Mean	SD			
p1 latency	500 Hz	12.15	1.01	12.27	0.47	0.73	0.74	0.009
	750 Hz	12.16	1.00	12.22	0.68	0.75	0.76	0.006
	1000 Hz	12.12	1.04	12.28	0.74	0.84	0.84	0.001
n1 latency	500 Hz	20.46	1.78	21.00	1.57	0.90	0.88	<0.001
	750 Hz	20.78	2.01	21.44	1.54	0.86	0.84	<0.001
	1000 Hz	20.60	1.50	21.44	1.98	0.79	0.75	0.003
p1-n1 amplitude	500 Hz	0.98	0.28	1.02	0.23	0.43	0.45	0.146
	750 Hz	1.06	0.29	1.06	0.32	0.76	0.77	0.005
	1000 Hz	0.96	0.21	0.90	0.25	0.16	0.16	0.375

Tables 4.14 and 4.15 show that the p1 latency of the right ear has poorer reliability than the left ear. The p1 latency of the left ear is found to have moderate to good reliability. In contrast, n1 latency has good reliability in both ears. It can be observed that the rectified amplitude of P1 – N1 in 500 Hz and 750 Hz in the right ear has moderate and good reliability, respectively, while the 1000 Hz is observed to be poor. In the left ear, the 500 Hz and 1000 Hz reliability were poor, but 750 Hz had good reliability.

Summary of Results

In summary, the results of the statistical analyses revealed that the P1 latency did not differ across the three frequencies in both females and males. It was also seen that P1 latency did not differ between males and females. The N1 latency also had no differences

across the three frequencies in both females and males. However, there was a difference between females and males; the N1 latency was shorter for females. The analysis of the rectified amplitude of P1 – N1 showed that the amplitude of 1000 Hz was significantly different from that of 750 Hz and 500 Hz in both females and males. However, the 500 Hz amplitude was not different from the 750 Hz response. There was no difference observed in amplitude between females and males. The test-retest reliability analysis of BC mVEMP showed poor reliability for P1 latency except for moderate reliability at 500 Hz in the right ear but moderate to good reliability in the left ear and good reliability of N1 latency in both ears. It was observed that the P1 – N1 amplitude reliability in the right ear for 1000 Hz was poor, and in the left ear, the 500 Hz and 1000 Hz were found to have poor reliability. Thus, the test-retest reliability of mVEMP using the B71 bone vibrator is poor. The test-retest reliability of all the latency and amplitude parameters needs to show an excellent test-retest reliability. If it is unreliable in an average healthy population, the BC mVEMP cannot be utilized reliably using the B71 bone vibrator in the clinical population.

CHAPTER – V

DISCUSSION

The objective of the current research was to determine the amplitude and latency of masseter VEMP using bone conduction stimulation mode in healthy adults. The latency and amplitude measures were then statistically compared between males and females. The study also aimed to assess the test-retest reliability of the mVEMP using the bone vibrator.

5.1 Latency and amplitude of mVEMP using bone conduction stimulation mode

Masseter VEMP was present at 500 Hz, 750 Hz and 1000 Hz in all the participants included in the study. The statistical analysis of latency showed that P1 and N1 were not different across all three frequencies. The rectified P1-N1 amplitude was more at 500 Hz and 750 Hz compared to 1000 Hz.

This is the first study characterizing the bone conduction masseter VEMP. Previously, the cVEMP and oVEMP have been recorded using a bone vibrator. Studies utilizing B71 & B81 transducers have reported a prevalence of 100% at 500 Hz, 750 Hz and 1000 Hz (Welgampola et al., 2003; Wiener-Vacher et al., 2023; Zhang et al., 2012) Previous studies have also reported a better amplitude at 500 Hz and 750 Hz than at other frequencies.

The tuning properties of vestibular evoked myogenic potentials are related to the physiological aspects of the otolith organs rather than the stimulus properties (Wei et al., 2013) The tuning properties of VEMP have been utilized to study the change in characteristics of the otolith organs in various pathologies. (Todd et al., 2000) modelled the vestibular evoked myogenic potentials as a single mass-spring system and reported the resonance of the otolith organs around 300 Hz. However, some of the studies also showed the resonant frequency of otolith organs to be around 400 Hz to 800 Hz (Akin et al., 2003; Janky & Shepard, 2009; Murofushi et al., 1999; Rauch et al., 2004; Timmer et al., 2006;

Todd et al., 2009; Wei et al., 2013). (Wei et al., 2013) reported that the responses generated from saccule have two components: one has a resonance around 300 Hz and the other at 1000 Hz. However, for tones below 500 Hz, the low-frequency components account for over 75 per cent of the whole response, and for tones above 1000 Hz, the high-frequency accounts for more than 75 per cent of the total response. This could be a reason for the highest amplitude of the masseter VEMPs at 500 and 750 Hz compared to other frequencies.

The latency differences for the peaks of mVEMP may not be seen as in the end organs of the vestibular system, and there is no resonator-like basilar membrane. Due to the basilar membrane, there could be a latency difference across the frequency. However, in the utricle and saccule, the entire hair cell moves together due to the sound stimulation. Hence, for vestibular evoked myogenic potentials, the amplitude may be a more significant parameter than the latency.

5.2 Comparison of latency and amplitude measures between males and females

In the study, the latencies and amplitude were compared for all three frequencies according to gender. The P1 latency obtained in this study showed no difference between females and males, but a difference was observed between females and males for N1 latency at 500 Hz, 750 Hz and 1000 Hz. The N1 latency was shorter for females comparatively at all frequencies. Also, comparing the rectified amplitude of P1-N1 between males and females found no difference across the three frequencies in this study.

The vestibular-evoked myogenic potentials, specifically cVEMP and oVEMP, have reported no significant differences in latency parameters (Carnaúba et al., 2011; Sung et al., 2011). However, there are reports that confirm a better amplitude of oVEMP in males compared to females (Sung et al., 2011). The differences in amplitude of oVEMP have been attributed to the differences in muscle bulk between males and females. The males

have more bulk IO muscles than females (Sung et al., 2011). In the literature, various studies reported the mVEMP evoked using air conduction stimulation mode compared between P1 and N1 latencies and found that the latencies were earlier in females compared to males (De Natale et al., 2019; Kılınç et al., 2023). This was explained by the inner ear in females compared to males (De Natale et al., 2019). This was similar to the study using click stimulation, which showed no difference in the corrected amplitudes (De Natale et al., 2019).

5.3 Test-Retest reliability

The present study showed that the reliability of P1 latency was poor in the right ear but had moderate to good reliability in the left ear. There was good reliability for N1 latency. However, the rectified amplitude analysis revealed a haphazard finding with poor reliability for only 1000 Hz in the right ear and moderate reliability only for 750 Hz in the left ear.

The latency of the P11 peak of mVEMP evoked by air conduction tone burst stimuli has outstanding test-retest reliability (Vignesh et al., 2021). Earlier investigations also revealed a distinct and definite P1 in click-evoked mVEMP responses. However, later negative peak N1 was found to have fair test-retest reliability, which (Deriu et al., 2007) refer to as a varying response in click-evoked mVEMP. The previous study found excellent reliability for the P1-N1 rectified amplitude (Vignesh et al., 2021). However, test-retest reliability in the present study ranges from poor to good across various mVEMP parameters, suggesting that the B-71 is unreliable in eliciting mVEMP.

Compared to reflex hammer and Mini-shaker stimuli, the B-71 bone oscillator has the least reliability and generates weaker responses in adults (Iwasaki et al., 2007). The reason is assumed that the otolith organ's resonant frequency is between 250 – 750 Hz, and VEMP tuning properties are also seen at these frequencies (Janky & Shepard, 2009; Park

et al., 2010). The B-71 device can deliver a wideband stimulus between 250 and 750 Hz (PCB Piezotronics, Inc., 2007). According to some of the earlier investigations, electromechanical vibrators (Iwasaki et al., 2007) or tone burst stimulation with a B-71 bone conductor (Sheykholeslami et al., 2000; Welgampola et al., 2003) are efficient stimuli. Implementing BC stimulation has proven to be more difficult due to the need to modify existing evoked potential systems to produce the stimulus (Rosengren et al., 2019). Typically, BC tone bursts need larger amplification from an additional external amplifier. Without an amplifier, the BC mVEMP recorded with a B-71 bone vibrator may not be an ideal tool to record the mVEMP.

CHAPTER – VI

SUMMARY AND CONCLUSION

Masseter vestibular evoked myogenic potential is a new clinical tool for assessing the integrity of the sacculomassetric reflex pathway. It is considered valuable for detecting pathology in the brainstem. Although there is various research in mVEMP, bone conduction evoked masseter VEMP has yet to be determined. It is seen from the literature that bone vibration is more effective than air conduction in eliciting cervical and ocular VEMP responses (Chou et al., 2012; Curthoys et al., 2011; Wackym et al., 2012; Wang et al., 2010; Welgampola et al., 2003). There are multiple needs for bone conduction-evoked VEMP, such as in cases of middle ear pathology, for eliciting responses at a lower intensity and for evoking bilateral responses concurrently and nearly equally. Clinical reliability is a requirement for a clinical tool to be effective. Therefore, the present study aimed to give experimental evidence on bone conduction evoked masseter VEMP responses and the parameters' reliability.

To achieve the aim, 30 healthy subjects (15 females and 15 males) aged 18 to 30 participated in the study. All the individuals had normal hearing sensitivity with intact middle ear. Retrocochlear pathology was ruled out using auditory brainstem responses. All these participants then underwent mVEMP recording with a Radio ear B-71 bone vibrator using the Neuro–Audio instrument of the Neurosoft system. The recording was accomplished with a zygomatic electrode montage, keeping the maximum voluntary muscle contraction between 30 and 50 %. There was a break period of two minutes between recordings to prevent masseter muscle fatigue. The BC transducer was mounted on the mastoid, and recording was done ipsilaterally. The mVEMP was then elicited with an intensity of 115 dB FL at 500 Hz, 750 Hz and 1000 Hz. The corrected amplitudes were

then obtained by EMG scaling. Fifteen of the participants then underwent a second mVEMP within one month of the first test.

The individual waveforms were then analyzed for absolute latency values of P1 and N1, peak-to-peak amplitude for all three frequencies. Test-retest reliability was then determined. Appropriate statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS) software version 20. The following analysis was done:

- Descriptive statistics were determined to obtain the mean and standard deviation for the absolute latency of P1 and N1 peaks and the peak–to–peak amplitude of the P1-N1 complex.
- The Shapiro-Wilk test of normality was done for all the parameters to determine if the data had a normal distribution.
- A paired sample t-test was performed to see for any individual ear differences at each frequency.
- Descriptive statistics was carried out to obtain mean and standard deviation for the combined ear data.
- Repeated measures ANOVA was done with gender as the between-group factor for P1 and N1 latency measures. Post hoc tests could not be performed for gender as fewer than three groups exist.
- An Independent t-test was done for the N1 latency measure to find the difference between males and females.
- Repeated measures ANOVA with gender as a between-group factor was done for amplitude measure.
- Repeated measure ANOVA was performed for within female group and within male group.

- The Bonferroni test was then determined to find the individual frequency difference between gender P1 – N1 amplitude measure.
- The intraclass correlation coefficient (ICC) was used to assess the test-retest reliability of bone conduction mVEMP.

The results of the study are as follows:

- The mVEMP elicited by bone conduction is present in all the young, healthy participants (100 % response rates) at 500 Hz, 750 Hz and 1000 Hz.
- The P1 and N1 latency measurements did not show any differences between frequencies.
- Although there was no difference in P1 latency between males and females, females had a shorter N1 latency.
- The rectified amplitude measures revealed that 500 Hz and 750 Hz had better responses than 1000 Hz. Further, no gender difference was observed for P1-N1 amplitude.
- N1 latency was found to have good reliability in both ears, whereas discrepancy was seen for the P1 latency measure. The rectified P1 – N1 amplitude reliability was poor at 1000 Hz in the right ear. In the left ear, the reliability of 500 Hz and 1000 Hz were poor.
- Considering the varied reliability across parameters, the reliability of the mVEMP evoked using the B-71 bone vibrator is poor.

Conclusion

Bone conduction mode can elicit the masseter VEMP with excellent response at all three frequencies. Since clinical interpretations primarily focus on VEMP amplitude measures, the present study's results indicated that the 500 Hz and 750 Hz amplitudes were significantly greater than 1000 Hz, suggesting that it is preferable to determine mVEMP

using 500 Hz and 750 Hz rather than 1000 Hz. The test-retest reliability of the mVEMP recorded with B-71 was very poor across all the frequencies. Only specific parameters showed a good response. Thus, the mVEMP with B-71 bone vibrator is not a reliable tool.

Implication of the study

This study demonstrates the viability of recording masseter vestibular evoked myogenic potential using bone conduction stimulation, which is advantageous when air conduction cannot be employed. The study offers normative values for the mVEMP generated by bone conduction concerning latency and amplitude. However, the reliability of BC mVEMP using a B-71 bone vibrator was poor, and thus, there is a need to study the mVEMP with other bone conduction devices.

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