COMPARISONS OF MASSETER EVOKED MYOGENIC POTENTIAL (MVEMP) BETWEEN 500 HZ TONE BURST AND NARROWBAND CE-CHIRP (CENTERED AT 500 HZ STIMULI) IN HEALTHY ADULTS

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by

NURUL ANIS NABILA BINTI ROSJI

Thesis submitted in fulfilment of the requirements
for the degree of
Bachelor of Health Sciences Honour (Audiology)

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CERTIFICATION

This is to certify that dissertation entitled 'Comparison of Masseter Evoked Myogenic Potential (mVEMP) Between 500 Hz Tone Burst and Narrowband CE-Chirp (Centered at 500 Hz Stimuli) in healthy adults' is the project done by NURUL ANIS NABILA BINTI ROSJI from September 2024 to July 2025 under my supervision. We have read this dissertation and, in our opinion, it fulfils the acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment of the degree of Bachelor of Health Sciences (Honours) (Audiology). Research work and collection of data belong to the Universiti Sains Malaysia**.**

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DECLARATION

I hereby declare that the work has been done by myself, all the results are of my own investigation and any ideas or quotation from others' work are fully acknowledged according to the standard referring practices of the discipline. I also declare that it has not been submitted as a whole in previous or concurrently for any other degress in any institutions. I acknowledge that that the research work and collection of data belong to Universiti Sains Malaysia (USM).

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LIST OF SYMBOLS

μV	Microvolt
ms	Milliseconds
<	Greater than
>	Less than
%	Percentage
r_a	Effect Size

LIST OF ABBREVIATIONS

VEMP	Vestibular Evoked Mygogenic Potential
mVEMP	Masseter Vestibular Evoked Mygogenic Potential
cVEMP	Cervical Vestibular Evoked Mygogenic Potential
oVEMP	Ocular Vestibular Evoked Mygogenic Potential
BPPV	Benign Paroxysmal Positional Vertigo
SCM	Sternocleidomastoid
NB	Narrowband
VOR	Vestibulo-ocular reflex
VSR	Vestibulo spinal reflex
VCR	Vestibulo colic reflex
VMR	Vestibulomasseteric reflex
ABR	Auditory Brainstem Response
MS	Multiple Sclerosis
iRBD	REM sleep Behavior Disorder
PTA	Pure Tone Audiometry
MVVSS	Malay Version of the Vertigo Symptom Scale
SD	Standard Deviation
IQR	Interquartile Range

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COMPARISONS OF MASSETER VESTIBULAR EVOKED MYOGENIC POTENTIAL (MVEMP) BETWEEN 500 HZ TONE BURST AND NARROWBAND CE-CHIRP (CENTERED AT 500 HZ) STIMULI IN HEALTHY ADULTS

ABSTRAK

'Masseter vestibular evoked myogenic potentials' (mVEMP) ialah pendekatan baharu dalam penilaian vestibular yang semakin mendapat perhatian dalam kalangan penyelidik. Respons biphasik berlatensi pendek ini berfungsi untuk mengesan fungsi vestibular, khususnya yang melibatkan sakul dan saraf vestibular inferior. Walaupun mempunyai potensi klinikal, faktor penting yang mempengaruhi respons mVEMP seperti jenis rangsangan yang digunakan masih kurang diterokai. Kajian ini bertujuan untuk membandingkan respons mVEMP yang dijana oleh rangsangan bunyi 500 Hz tone burst dan narrowband CE-Chirp dalam kalangan dewasa sihat. Kajian keratan rentas ini merekrut 23 orang dewasa sihat yang mempunyai pendengaran dan fungsi vestibular yang normal. Respons mVEMP direkodkan menggunakan rangsangan 500 Hz TB dan NB CE-Chirp (berpusat pada 500 Hz) pada intensiti 120 dB peSPL. Setiap rangsangan dipersembahkan sebanyak dua kali dan rakaman dilakukan dari otot masseter untuk menentukan amplitud P1-N1 serta komponen latensi P1 dan N1. Rrangsangan NB CE-Chirp menghasilkan purata amplitud P1-N1 yang jauh lebih besar (115.05 μV) berbanding 500 Hz TB (100.45 μV) ($p = 0.003$). Purata latensi P1 (9.13 ms) dan purata latensi N1 (15.20 ms) adalah lebih pendek secara statistik untuk rangsangan NB CE-Chirp berbanding 500 Hz TB (15.29 ms dan 20.80 ms masing-masing untuk latensi P1 dan N1) ($p < 0.05$). Kesimpulannya, NB CE-Chirp kelihatan sebagai rangsangan yang lebih berkesan untuk menjana respons mVEMP yang kukuh.

COMPARISONS OF MASSETER VESTIBULAR EVOKED MYOGENIC POTENTIAL (MVEMP) BETWEEN 500 HZ TONE BURST AND NARROWBAND CE-CHIRP (CENTERED AT 500 HZ) STIMULI IN HEALTHY ADULTS

ABSTRACT

The masseter vestibular evoked myogenic potentials (mVEMP) are a novel approach in vestibular assessment that has gained growing interest among researchers. This short-latency biphasic response helps to detect vestibular dysfunctions, involving the saccule and inferior vestibular nerve. Despite its potential, factors like stimulus type in mVEMP, remain insufficiently explored. This study aimed to compare mVEMP responses elicited by 500 Hz tone burst and narrowband CE-Chirp stimuli in healthy adults. This cross-sectional study recruited 23 healthy adults, with normal hearing and vestibular functions. The mVEMP responses were recorded using 500 Hz TB and NB CE-Chirp stimuli at an intensity level of 120 dB peSPL. Each stimulus was presented twice to obtain an averaged response, and recordings were made from the masseter muscle to determine P1-N1 amplitude and P1 and N1 latency components. The NB CE-Chirp produced a significantly larger mean P1-N1 amplitude (115.05 μV) than that of the 500 Hz TB (100.45 μV) ($p = 0.003$). The mean P1 latency (9.13 ms) and mean N1 latency (15.20 ms) were statistically shorter for the NB CE-Chirp stimulus compared to those of the 500 Hz TB (15.29 ms and 20.80 ms for P1 and N1 latencies, respectively) ($p < 0.05$). These results demonstrate a statistically significant effect of the stimulus type on mVEMP responses. In conclusion, compared to the 500 Hz TB, the NB CE-Chirp appears to be a more effective stimulus for eliciting robust mVEMP responses.

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The balance system is crucial for all physical activities, enabling us to perform tasks like climbing, cycling, driving, and much more. Without proper balance, even simple movements would become challenging. While many people include strength training and walking in their routines, exercises that enhance balance are often neglected, even though they are important (System, 2023). Maintaining a healthy balance becomes even more essential as we get older since it not only helps decrease the risk of accidents and falls, but it also makes it much simpler to carry out the activities of daily living.

In order to stay balanced, our bodies rely on a number of sensory systems working in tandem. These include our eyes (visual system), which let us see our surroundings, our bodies' inherent spatial awareness (proprioception), and our inner ear (vestibular system), which helps us stay oriented in space (Casale et al., 2023). Maintaining balance is a sophisticated task that requires seamless coordination among muscles, tendons, bones, eyes, ears, and the brain. If any of these systems are weakened, the others may overcompensate, leading to a disruption in our balance.

1.2 Overview of the Vestibular System

The vestibular system is broadly categorized into both peripheral and central components (Thompson, 2009). When it comes to maintaining our sense of balance, the vestibular system is a complicated network of structures and brain connections that plays a critical part in the process. The central vestibular system is made up of neuronal pathways in the brain that are responsible for receiving sensory information from the

peripheral vestibular system in the inner ear and then sending out signals that promote reflexive reactions maintains our sense of balance and position (Casale et al., 2023).

The vestibular sensory organs are located inside the thick petrous part of the temporal bone, in proximity to the cochlea, the auditory sensory structure (Varacallo., 2024). The vestibular system comprises two types of sensory receptors: the three semicircular canals, which sense angular acceleration in three-dimensional planes, and the two otolith organs, the saccule and utricle, which respond to linear acceleration, including gravitational effects and translational movements (Rosengren et al., 2010).

1.3 Clinical Significance

Dysfunction of the vestibular system may result in symptoms like vertigo, nausea, vomiting, visual abnormalities, auditory alterations, and other cognitive deficits (Casale et al., 2023). The relationship between the vestibular system and cognitive abilities is not well comprehended, yet, numerous people with vestibular disorders encounter challenges in spatial navigation, learning, memory, and object recognition. The pathophysiology of vertigo can be categorized as either peripheral or central. Peripheral vertigo is more prevalent than central vertigo, with three of the most common causes being benign paroxysmal positional vertigo (BPPV), Meniere's disease, and viral labyrinthitis (Nagarajan & Sinha, 2024)

1.4 Clinical Assessments of the Vestibular System

To unravel the intricate functions of the otolithic structures, including the inferior and superior branches of the vestibular nerve (Casale et al.,2023), the powerful electrophysiological technique known as vestibular evoked myogenic potential (VEMP) is employed. VEMP responses are meticulously captured from the otolithic

organs via the vestibulo-ocular reflex and vestibulo-collic reflex, offering a clear insight into their complex interactions (Curthoys et al., 2021). VEMP is defined as a rapid-onset muscular response triggered by short bursts of air-conducted sound, bone-conducted vibrations, or electrical stimulation (Curthoys et al., 2021). In clinical settings, air-conducted clicks or tone burst stimuli are frequently used to capture VEMP responses (Nagarajan & Sinha, 2024). While the vestibular system is typically unresponsive to sound, intense acoustic stimuli can successfully activate it. Notably, VEMPs can still be detected in individuals with severe hearing loss, but they are absent in those with both cochlear and vestibular deficits (Choi, 2020). This response is recorded using surface electrodes placed over the targeted muscles including the neck extensor muscles, masseter, soleus, gastrocnemius, triceps, and the inferior oblique muscle.

1.5 Vestibular Evoked Myogenic Potential (VEMP) Testing

Vestibular Evoked Myogenic Potential (VEMP) testing is an advanced, non-invasive diagnostic method used to evaluate the functioning of the vestibular system. It facilitates the identification and diagnosis of various vestibular disorders by assessing muscle responses to auditory and vibrational stimulation. Initially, the VEMP was obtained from the sternocleidomastoid (SCM) muscle, a technique referred to as cervical VEMP (cVEMP). Subsequently, an alternate methodology was established to capture myogenic reaction potentials from the inferior oblique muscle, known as ocular VEMP (oVEMP). Since that time, both cVEMP and oVEMP have

been extensively used vestibular assessments to examine the integrity of the sacculo-collic and utriculo-ocular pathways, respectively (Nagarajan & Sinha, 2024).

More recently, a new electromyogenic test called the masseter VEMP (mVEMP) has gained significant research and clinical interest. In mVEMP recordings, surface electrodes are placed on the tonically tensed masseter muscles to elicit a short-latency inhibitory EMG response bilaterally in reaction to galvanic or auditory stimuli (Nagarajan & Sinha, 2024). This method provides valuable insights into the functional status of the vestibulo-trigeminal pathway.

1.6 Problem Statement

Masseter VEMP (Mvemp) serves as a complementary test to cVEMP, assessing the same peripheral structures but targeting a different central pathway which is the vestibulo-trigeminal pathway. Numerous studies have explored factors that influence mVEMP responses, including variations in electrode placement (comparing zygomatic and mandibular configurations), differences in stimulation rates, filter settings, and the types of stimuli used to trigger mVEMP (Ozgur et al., 2024). The latency and amplitude of mVEMP waveforms are crucial parameters that distinguish between healthy individuals and those with clinical conditions. In conjunction with cVEMPs and oVEMPs, mVEMP holds promise in diagnosing brainstem lesions associated with REM Sleep Behavior Disorders, multiple sclerosis, and Parkinson's disease (Ozgur et al., 2024).

In clinical settings, various stimuli are used to record VEMP and stimulate the vestibular system. These stimuli include tone bursts, clicks, and chirp stimuli. Research indicates that tone burst stimulation has a longer latency than click stimulation. This is believed to be due to the comparatively extended rise and fall times

associated with tone bursts, resulting in a delayed peak in the response wave (Ozgur et al., 2015). Conversely, click stimulation, with its shorter rise and fall times, elicits a VEMP response more rapidly, often occurring before the stapes reflex is activated (Rosengren et al., 2010).

However, research from Bas et al. (2020) has shown that wide-band chirp stimuli result in oVEMP responses with shorter latencies, higher amplitudes, and more distinct waveform morphology, along with a higher response ratio, compared to click and tone burst stimuli. Given these advantages, chirp stimuli are considered a reliable and suitable choice for oVEMP analysis. Research conducted by Walther and Cebulla in 2016 on the topic of band-limited chirp stimulation in VEMP concluded that the designed CW-VEMP-chirp, spanning a frequency range of 250-1000 Hz (upward chirp), is an effective stimulus for use in VEMP diagnostic testing compared to click and tone burst stimulation as it showed a high stability in cVEMP and oVEMP testing. Despite the existence of various types of chirp stimuli, a narrowband (NB) CE-Chirp stimulus ranging from 360 to 720 Hz and centered at 500 Hz has been frequently utilized in cVEMP studies. A study by Mat et al. (2022) has shown that NB CE-Chirps presented by air conduction elicited larger PI-N1 amplitudes in oVEMP than TBs at 500 Hz along with the shorter latencies. However, it is unknown whether other type of chirps will also perform similarly to the NB CE-Chirps.

A study by Zakaria et al. (2015) found that the custom (downward) chirp stimulus showed that the amplitudes of VEMP peaks were significantly lower compared to the 500Hz tone burst stimulus but require further validation. However, the study by Rasmi (2023) shown that the custom build with wideband frequencies (100Hz-100Hz) also have the potential to elicit larger VEMP yielding shorter latencies and generally larger amplitudes compared to a traditional 500 Hz tone burst. So, it is

unknown whether this wider bandwidth chirp can also elicit the good response in mVEMP. Besides, research utilizing downward chirp stimuli for VEMP recordings remains limited.

Therefore, the purpose of this research is to compare the outcomes from the conventional 500 Hz tone burst with NB CE-Chirp in terms of the amplitudes and latencies of mVEMP responses. While the 500 Hz tone burst remains the gold standard in clinical settings due to its consistent and robust response characteristics, the NB-CE Chirp stimulus has emerged as a promising alternative. Furthermore, the research intends to determine which stimulus is the most reliable and suitable in mVEMP analysis for the clinical applications.

1.7 Research Question

This study aimed to provide answers for questions such as “Are there significant differences between the amplitude and latency of P1 and N1 of Masseter Vestibular Evoked Myogenic Potential (mVEMP) tested with 500 Hz tone burst and NB CE-Chirp (centered at 500 Hz) stimuli in healthy adults”?.

1.8 Study Objective

1.8.1 General Objective

To compare the masseter Vestibular Evoked Myogenic Potential (mVEMP) elicited by 500 Hz tone burst and NB CE-Chirp (centered at 500 Hz) stimuli in healthy adults.

1.8.2 Specific Objective

1. To determine the amplitude and latency of P1 and N1 of the masseter Vestibular Evoked Myogenic Potential (mVEMP) tested using 500 Hz tone burst stimulus in healthy adults.

2. To determine the amplitude and latency of P1 and N1 of the masseter Vestibular Evoked Myogenic Potential (mVEMP) tested using NB CE-Chirp (centered at 500 Hz) stimulus in healthy adults.

3. To compare the masseter Vestibular Evoked Myogenic Potential (mVEMP) results in amplitude and latency of P1 and N1 between 500 Hz tone burst and NB CE-Chirp (centered at 500 Hz) stimuli in healthy adults.

1.9 Research Hypothesis

1.9.1 Null Hypothesis, H0

There are no significant differences in amplitude and latency of P1 and N1 of the masseter Vestibular Evoked Myogenic Potential (mVEMP) between 500 Hz tone burst and NB CE-Chirp (centered at 500 Hz) stimuli in healthy adults.

1.9.2 Alternative Hypothesis, H1

There are significant differences in amplitude and latency of P1 and N1 of the masseter Vestibular Evoked Myogenic Potential (mVEMP) between 500 Hz tone burst and NB CE-Chirp (centered at 500 Hz) stimuli in healthy adults.

CHAPTER 2
LITERATURE REVIEW

2.1 Anatomy and Physiology of Ear

The human ear serves as the organ for auditory perception and balance. The human ear is a basic shell-shaped organ located on the lateral side of the head. It detects and analyses sound by the mechanism of transduction, which is the process of converting sound waves into electrochemical impulses.

In the context of physiological research, the ear can be categorised into three primary components; the external ear, the middle ear, and the inner ear. The outer ear, known as the auricle, consists of cartilage and is the segment that interacts most with the external environment. The physical features include the helix, antihelix, tragus, and antitragus, which culminate in a depression known as the acoustic meatus which ends at the tympanic membrane (Nava & Lasrado, 2023).

The middle ear is a cavity filled with air. It is made up of three ossicles: the malleus, incus, and stapes, as well as the eustachian tube, which connects the middle ear to the back of the nose. The eustachian tube helps equalise the middle ear's pressure. Pressure equality is a necessary condition for the proper transmission of sound vibrations (Nava & Lasrado, 2023).

The inner ear resides within the petrous temporal bone. It is composed of two primary components: the bony labyrinth, filled with perilymph fluid, and the membranous labyrinth, which is endolymph-filled and situated in the middle of the bony labyrinth, mimicking the shape of its small cavities (Zabolotnyi & Mischanchuk, 2020). It is worth mentioning that the inner ear comprises two distinct systems: the hearing system and the balance system.

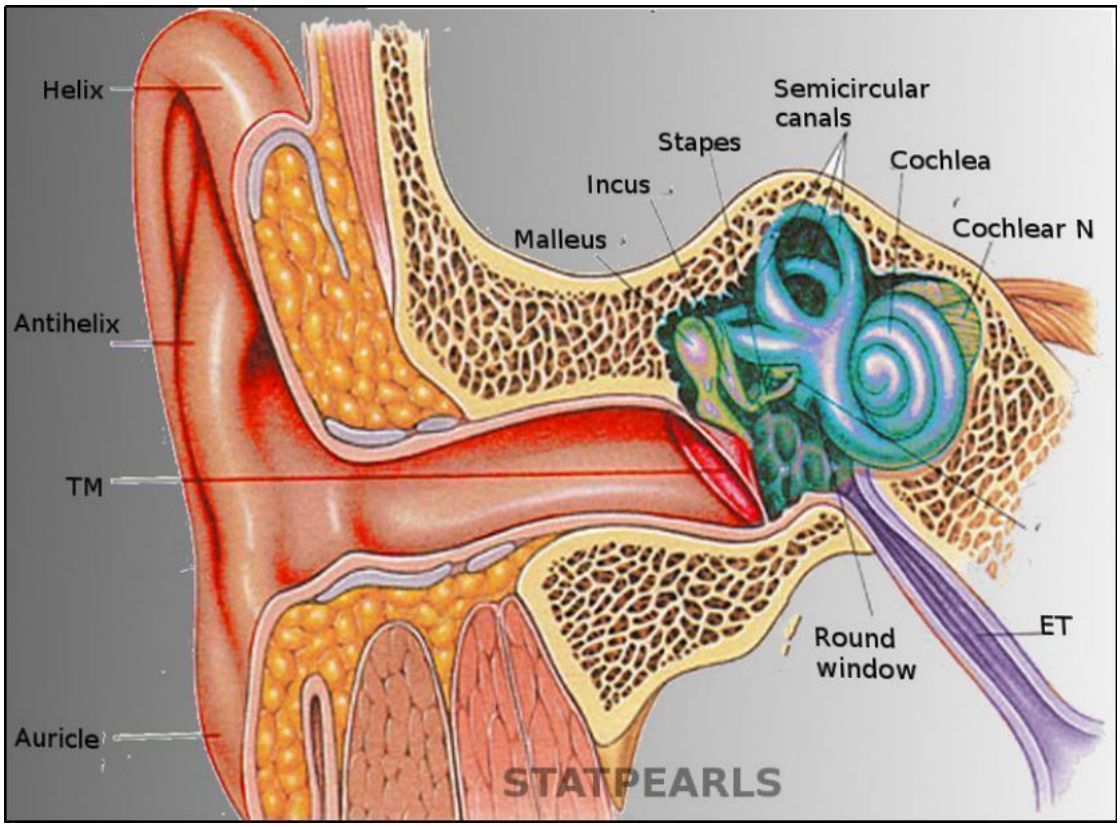

Figure 2.1 1 Anatomy of Ear

The ear is able to discriminate between numerous characteristics of sound, including pitch and loudness, which refers to the frequency of sound waves and the perception of the intensity of sound, respectively. Hearing initiates when the outer ear collects sound vibrations from the environment, directing them through the external auditory canal to the eardrum (tympanic membrane) (Encyclopedia, 2024). The vibrations cause the eardrum to move, which then transfers these vibrations through the tiny bones of the middle ear, known as the ossicles. The ossicles amplify the sound and pass it to the cochlea in the inner ear. Within the cochlea, the sound waves are converted into electrical impulses, which travel through the auditory nerve to the brain, where they are interpreted as sound (Nava & Lasrado, 2023).

2.2 The Vestibular System

The vestibular system is crucial for maintaining balance, keeping your sense of direction, and stabilizing vision, especially when you're in motion. It works by detecting changes in head position through specialized sensory organs that measure both rotational (angular) and straight-line (linear) movements. These organs convert these physical movements into electrochemical signals, which are then processed by the central nervous system. The brain uses this information to keep your vision steady as your head moves through the vestibulo-ocular reflex (VOR) and to adjust muscle activity for balance through vestibulocollic and vestibulospinal reflexes (Fife, 2010).

The vestibular and auditory systems not only manage hearing and balance but also play a role in complex brain functions like posture control, emotional regulation, and even creative thinking. Because of these extensive connections, it's crucial to conduct in-depth clinical assessments of disorders in these systems. A better understanding can enhance the effectiveness of prevention, treatment, rehabilitation, and even inform decisions regarding someone's fitness for particular jobs or work performance, highlighting the importance of a holistic approach in these areas (Zabolotnyi & Mischanchuk, 2020).

2.3 Mechanism of the Vestibular System

The semicircular canals detect rotational movements by sensing changes in the fluid that moves when the head rotates. This triggers hair cells, which send signals to the brain for angular motion detection. The vestibular system's role in balance and stability is primarily achieved through three reflex mechanisms that involve constant communication between the inner ear, muscles, and eyes (Renga, 2019). The main

integrated reflex systems are the Vestibulo-ocular reflex (VOR), the vestibulo spinal reflex (VSR), and the vestibulo colic reflex (VCR).

Vestibulo-ocular reflex, VOR is crucial for maintaining clear vision during head movement. By detecting head motion through the semicircular canals and otolith organs, the VOR activates a counter- movement in the eyes, directing them opposite to the head's motion. This adjustment keeps visual targets steady, preventing blurring that would otherwise occur if the eyes moved with the head (Coto et al., 2021). For example, when a person turns the head to the right, the VOR prompts the eyes to shift leftward at the same speed, preserving a focused gaze on the object of attention (Renga, 2019). look.

2.4 Overview of mVEMP

Similar to cVEMPs, VEMPs are also elicited at the level of the masseter muscle, also known as masseter VEMP (mVEMP). The mVEMP are short-latency biphasic responses that assess the integrity of vestibulotrigeminal pathways. These reflexes help stabilize the jaw and control precise motor functions during quick head movements, maintaining posture and coordination (Deriu et al., 2003). Unlike cVEMP and oVEMP, normative data for mVEMP is lacking, and this limits their potential use in clinical settings (Ravichandran, 2020).

The mVEMP is an inhibitory reflex in the jaw muscles that is influenced by the underlying level of muscle activation, measured by tonic EMG activity (Deriu et al., 2005). To achieve this baseline, subjects are seated upright and asked to clench their jaws, engaging the masseter muscles on both sides. A high-intensity sound is then delivered monaurally through insert earphones which is believed to produce stimulus-evoked fluid displacement in the saccule, which activates the vestibulomasseteric

reflex (VMR). This reflex temporarily reduces EMG activity in the masseter muscle, creating the mVEMP response.

Studies have shown that when masseter muscles are tonically activated in healthy individuals, they produce a short-latency inhibitory EMG response on both sides in reaction to galvanic or acoustic stimuli (Meier-Ewert, 1974; Deriu et al., 2005). To capture these signals (i.e., mVEMP), electrodes are positioned on the lower third of the masseter muscle's superficial layer, allowing for precise recording of this vestibular response.

In a preliminary study, Meier-Ewert et al. (1974) found that the acoustic jaw reflex only appeared in individuals with normal hearing and functional auditory nerves. Hearing-impaired patients with intact vestibular systems showed no jaw reflex in response to intense sounds (90-100 dB). This led researchers to suggest that the reflex is likely triggered by cochlear receptors rather than the vestibular organs, possibly as a protective or startle response to loud sounds.

The typical mVEMP appears as a biphasic waveform with an initial positive peak (P1) at about 11-12 ms followed by a negative peak (N1) around 21 ms. The mVEMP has several unique characteristics that are not observed in the cVEMP or oVEMP. Notably, mVEMP is a bilateral, symmetrical response, detectable from either masseter muscle, regardless of which ear receives the sound stimulus (Deriu et al., 2007; Vignesh et al, 2021). Conversely, those obtained from the SCM muscle are ipsilateral (Colebatch et al., 1994, Deriu et al., 2003). This difference is likely due to muscle function which is masseter muscles coordinate to position the jaw, allowing simultaneous bilateral contractions, which produces bilateral inhibitory responses. Thirusangu & Sinha (2023) reported that the amplitude of the mVEMP to bilateral

sound stimulations is larger compared to the ipsilateral and contralateral sound stimulations.

Wang & Young (2003) found that cVEMP amplitude remains consistent whether stimulated in both ears or one, suggesting a unilateral pathway. Additionally, the cVEMP response (p13) shows about a 30% greater amplitude than mVEMP, likely due to stronger vestibular signals to the larger sternocleidomastoid muscle compared to the masseter (Deriu et al., 2005). This difference may also result from the sternocleidomastoid's thicker muscle tissue and its significant role in postural control, which attracts stronger vestibular connections than those to the masseter muscle.

2.5 Vestibulo-Masseteric and Acoustic-Masseteric Reflex Pathways

The masseter muscles play a crucial role in the chewing process by lifting the lower jaw (mandible) and ensuring the teeth come together properly, which helps keep the jaw stable against gravity. These muscles are essential for various functions, including chewing, speaking, and maintaining jaw position in both resting and moving states (Lund & Olsson, 1983; Manns, Chan & Miralles, 1987). The acoustic jaw reflex is a brainstem reflex activated by sound when the head muscles, specifically the jaw muscles, are engaged voluntarily masseters (Meier-Ewert et al., 1974). Besides, research conducted by Deriu et al. (2003) concluded that transmastoid electrical stimulation could successfully trigger vestibulomasseteric reflexes in healthy individuals. Therefore, the auditory and vestibular stimulations are said to provoke responses from the masseters.

Deriu et al. (2005) reported that the vestibulo-masseteric reflex primarily functions to stabilize the head's position during unexpected movements. Specifically, when the head suddenly tilts forward (drops downward), the masseter muscles are

inhibited, reducing muscle activity. Conversely, when the head pitches upward, these muscles are excited, increasing their activation. This fine-tuned response, directed by the vestibular system, ensures that the head remains properly oriented in space by providing appropriate adjustments to the masseter muscles during sudden shifts.

In addition, sound can also elicit reflex responses in the masseter muscles, visible as inhibitory reactions. When a sound stimulates the cochlea, auditory nerve fibers carry the information to the dorsal cochlear nucleus (DCN) on the same side of the brain. From there, signals are sent to both the left and right trigeminal motor nuclei in the brainstem. This bilateral pathway explains why stimulating just one ear can trigger responses in both masseter muscles. The signals then travel through the mandibular branch of the trigeminal nerve, affecting the masseter muscles. This reflex, called the acoustic-jaw reflex, may function as a protective mechanism or a startled reaction to loud sounds (Meier-Ewert et al., 1974; Deriu et al., 2005).

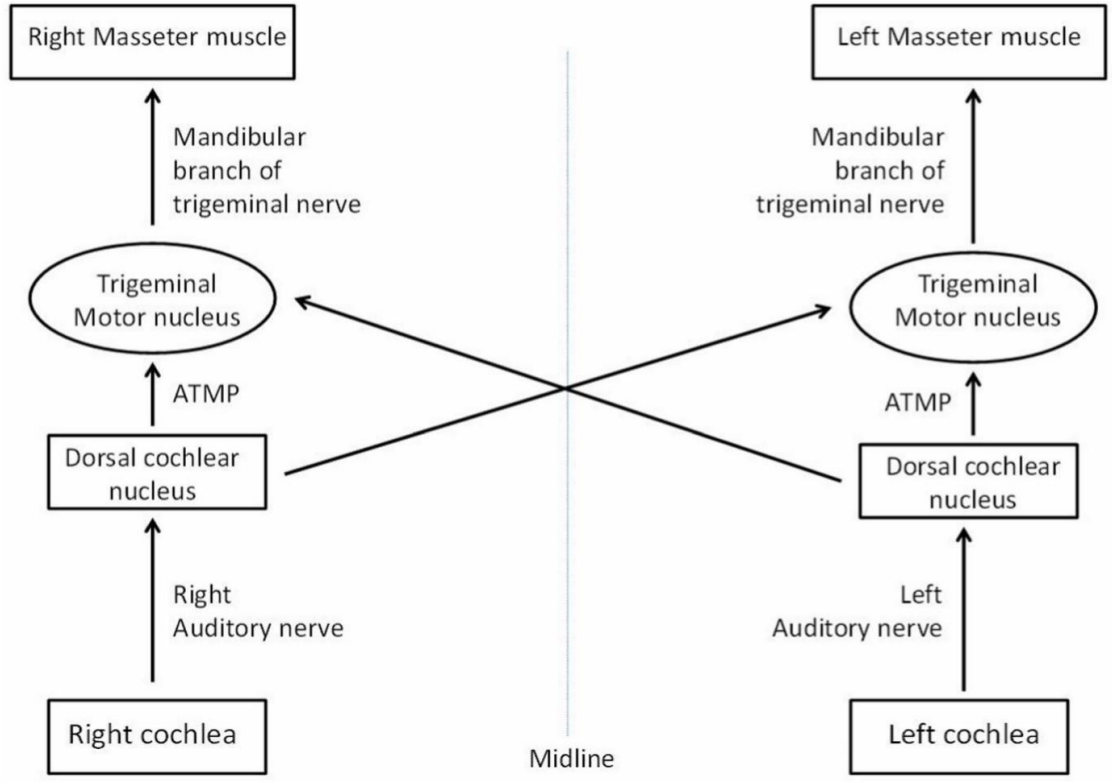

Figure 2.1 2 Acoustic-jaw Reflex (AMR) pathway

2.6 Electrode Placement to Record mVEMP

Consistent with previous research on VEMPs, it is demonstrated that electrode configuration influences the characteristics of the vestibulomasseteric reflex (VMR) (Ravichandran, 2020). Two main electrode placements, or belly-tendon montages, are used to record the mVEMP. In the first method, called the mandibular reference, the inverting electrode is positioned at the mandibular angle. The second method, zygomatic reference, the inverting electrode is placed on the middle of the zygomatic arch (Deriu et al., 2005). The active (non-inverting) electrode is placed on the lower third of the masseter muscle, while the ground electrode is positioned on the lower forehead. Most researchers prefer the zygomatic reference for mVEMP recordings (De Natale et al., 2018, Romero, Jacobson & Roberts, 2022, Vignesh, Singh & Rajalakshmi, 2021).

For both reflexes, the zygomatic electrode configuration produced higher rates of elicitation and greater corrected amplitudes. Additionally, bilateral stimulation resulted in more larger responses. This finding aligns with Loi et al. (2020), who reported that the zygomatic electrode montage demonstrated superior reliability compared to the mandibular montage for all reflex responses. This increased reliability is likely because the zygomatic placement reduces "reference contamination," which refers to unwanted interference in the signal. Such contamination occurs when the reference electrode is affected by electrical noise or activity from nearby muscles, distorting the measurements. By using the zygomatic configuration, this interference is minimized, resulting in clearer and more consistent reflex readings (Loi et al., 2020). However, a study by Thirusangu & Sinha (2023) found no significant differences in latencies or the amplitude between the zygomatic and mandibular montages when using a 500-Hz tone burst stimulus in young adults

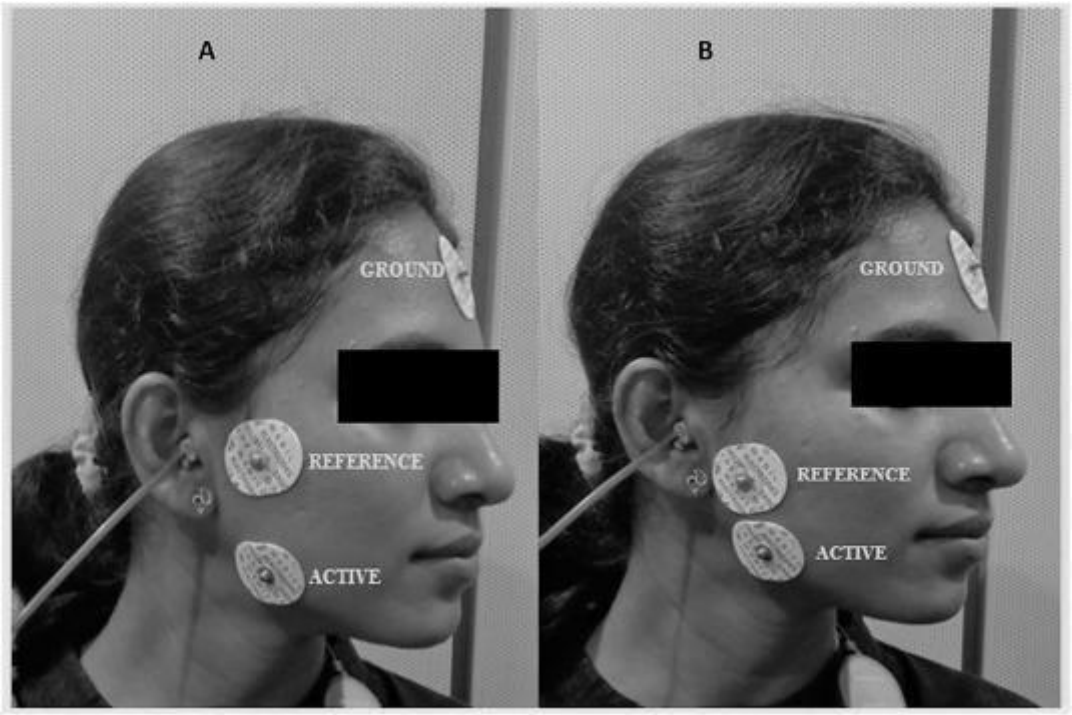

Figure 2.1 3 Electrode montages used to record mVEMP (A) Zygomatic electrode montage and (B) Mandibular electrode montage

2.7 Stimulus Used for Recording

Clicks, chirp and 500 Hz tone-burst stimuli have been primarily used to record mVEMP. The 500 Hz tone burst remains the preferred clinical standard for VEMP recordings due to its reliable, high-amplitude responses. Tone bursts at various frequencies, such as 250 Hz, 1 kHz, or 2 kHz, can be used to record VEMP, however, their amplitudes are significantly smaller compared to the 500 Hz tone burst (Cebulla & Walther, 2019). This supports previous findings indicating the 500 Hz tone burst's effectiveness for VEMP recordings (Ozgur et al., 2015; Zakaria et al., 2015; Sandhu et al., 2012). The 500 Hz tone burst has a specific design with defined rise, plateau,

and fall times, which enhances its ability to generate strong and reliable vestibular responses (Moinudeen, Varshini & Wesley, 2020).

Compared to the 500 Hz tone burst, a click stimulus generates notably smaller VEMP amplitudes (Viciana & Lopez-Escamez, 2012), but results in shorter latencies (Cheng, Huang & Young, 2003; Bo- Chen et al., 2014). This is due to the characteristics of the click stimulus, which has a rapid onset and a wide frequency range. These features allow for quicker activation of the vestibular response but do not produce as strong or sustained amplitudes as the 500 Hz tone burst, which focuses on a specific frequency for a more robust output.

However, studies suggest that chirp stimuli may yield even larger amplitudes and shorter latencies for VEMP, though findings are mixed, highlighting the need for further research to optimize chirp stimulus. The chirp stimulus was originally developed to enhance waveform clarity in auditory brainstem response (ABR) testing.

Besides, a study by Bo-Chen et al. (2014) noted that amplitudes produced by the chirp stimulus in auditory brainstem response (ABR) testing are significantly larger and nearly double compared to those generated by the traditional click stimulus. The chirp's flexibility lies in its design, allowing modifications in both frequency spectrum and time domain. For example, the CE-chirp covers a wide frequency range from 500 to 8000 Hz, while octave-band chirps, known as narrowband (NB) chirps, are designed for more specific frequencies (500, 1000, 2000, and 4000 Hz).

Consequently, narrowband chirps may also provide more robust myogenic reflex responses than tone bursts, leveraging their frequency-targeted advantage (Mat et al., 2022). Besides, Zakaria et al. (2015) reported that the custom downward chirp stimulus produced significantly lower VEMP amplitudes compared to the 500 Hz tone burst stimulus. In contrast, Rasmi (2023) demonstrated that a custom-designed chirp

with wideband frequencies (100-1000 Hz) has the potential to elicit larger VEMP responses, characterized by shorter latencies and generally higher amplitudes than the 500 Hz tone burst. Comprehensive studies are still needed to fully understand their efficacy and potential benefits in clinical and diagnostic settings.

2.8 Clinical Application of mVEMP Response

In the study conducted by Kılınç et al. (2023), it is proposed that utilizing a combination of cVEMP, oVEMP, and masseter VEMP (mVEMP) could significantly enhance the assessment of brainstem physiology. The mVEMP test, in particular, plays a crucial role in evaluating brainstem dysfunctions in patients with conditions such as multiple sclerosis, Parkinson's disease, and idiopathic REM-sleep behavior disorder. This assessment can serve as a valuable supplement to clinical evaluations and radiological imaging, providing deeper insights into the underlying neurological issues.

2.8.1 Parkinson's Disease

Parkinson's disease is characterized by the degeneration of specific nuclei in the brainstem, leading to various neurophysiological abnormalities Grinberg et al. (2010) and one notable symptom of this condition is the disruption of neurophysiological responses. Research indicates that all forms of VEMP like mVEMP, cVEMP, and oVEMP exhibit abnormal results in patients with Parkinson's disease, suggesting a significant impact of the disease on vestibular function (Natale et al., 2015). Patients with Parkinson's disease exhibit significantly reduced amplitudes of mVEMP compared to healthy individuals. The abnormality of mVEMP increases with the severity of Parkinson's disease However, no significant differences were observed in latency parameters between the two groups. Additionally, the study found

that the rate of abnormalities was higher in mVEMP (66.7%) than in cVEMP (41.7%) and oVEMP (45.8%), highlighting the effectiveness and sensitivity of masseteric VEMP in detecting brainstem pathologies, such as Parkinson's disease (Natale et al., 2015).

2.8.2 Multiple Sclerosis (MS)

For about 20% of people with multiple sclerosis (MS), causing symptoms like dizziness, the sensation of spinning and feeling off balance often causes dizziness and vertigo (Pula, Newman-Toker & Kattah, 2013). Magnano et al. (2014) investigated mVEMP in sixty patients diagnosed with MS, correlating their findings with MRI results. They discovered that patients with MS exhibited significantly prolonged peak latencies of p11 and N21 compared to healthy individuals. The authors suggested that mVEMP could enhance standard MRI assessments, aiding in the early detection of MS. Furthermore, Srinivasan et al. (2023) studied cVEMP, oVEMP, and mVEMP in forty-five MS patients. Their research found that mVEMP had the highest detection rate of abnormalities at 82.22%, outperforming the other VEMPs. Importantly, they noted that mVEMP could identify abnormalities even when there were no clinical or radiological indicators of brainstem dysfunction present in the patients. Together, these studies emphasize the potential of mVEMP as a valuable diagnostic tool for early identification and monitoring of MS progression, supporting its use alongside traditional imaging techniques.

2.8.3 REM Sleep Behaviour Disorder (iRBD)

Although there is a known link between sleep disturbances such as sleep apnea or insomnia and vestibular issues like dizziness and increased fall risk, the exact sleep-related factors that influence vestibular dysfunction are still not fully understood. Moreover, daytime symptoms associated with poor sleep, such as fatigue, anxiety, and

depression, may also play a role. Further research is essential to pinpoint which specific characteristics of sleep disturbances are most closely associated with these vestibular problems, which could be crucial for better treatment and prevention strategies (Altena et al., 2023). Besides, Natale et al. (2018) conducted a study comparing cVEMP, oVEMP, and mVEMP responses in twenty individuals with idiopathic REM sleep behavior disorder (iRBD) and twenty-two healthy controls. Their findings revealed significant and extensive brainstem abnormalities in the iRBD group. Specifically, the rate of abnormalities was 45% for cVEMP, 50% for oVEMP, and 65% for mVEMP. Additionally, amplitudes across all three VEMPs were notably reduced in patients with iRBD. These results align with the findings of Puligheddu et al., (2019) who also reported abnormal amplitude asymmetry ratios in individuals with idiopathic REM sleep behavior disorder. Together, these studies highlight the value of VEMP testing in detecting brainstem dysfunctions associated with sleep disorders.

CHAPTER 3
METHODOLOGY

3.1 Research Design

This study employed a cross-sectional research design. The eligible participants were tested using two types of auditory stimuli: a 500 Hz tone burst and a NB CE-Chirp (centered at 500 Hz). The purpose of this study was to compare the mVEMP responses elicited by each stimulus in terms of amplitude, latency, and other relevant metrics. By employing this approach, the study seeks to determine which stimulus is more effective in generating robust vestibular responses, thereby contributing to the optimization of vestibular testing protocols.

3.2 Study Area

This study was carried out in the Audiology Clinic of Pusat Pengajian Sains Kesihatan (PPSK), Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan.

3.3 Study Population

The target population in this study consisted of healthy young adults with normal hearing and vestibular functions in Universiti Sains Malaysia (USM), Health Campus, Kubang Kerian, Kelantan.

3.4 Subject Criteria

3.4.1 Inclusion Criteria

I. Young adults aged 18 to 30 years old.

II. Healthy persons with no history of head and neck injury and vestibular problem.

III. Individuals with no history of hearing and middle ear problems.

3.4.2 Exclusion Criteria

I. Abnormal PTA result.

II. Abnormal tympanometry result.

III. The presence of pathology in the masseter region.

3.5 Sample Size Estimation

The sample size was calculated using the MedCalc Statistical Software and based on the study conducted by Nagarajan & Sinha (2024). By taking an alpha value of 0.05, power of study of 0.9, mean difference of 0.23 and standard deviation of differences of 0.37, the sample size required was 30 subjects. In addition, by considering the 10% drop out, this study would recruit 33 participants.

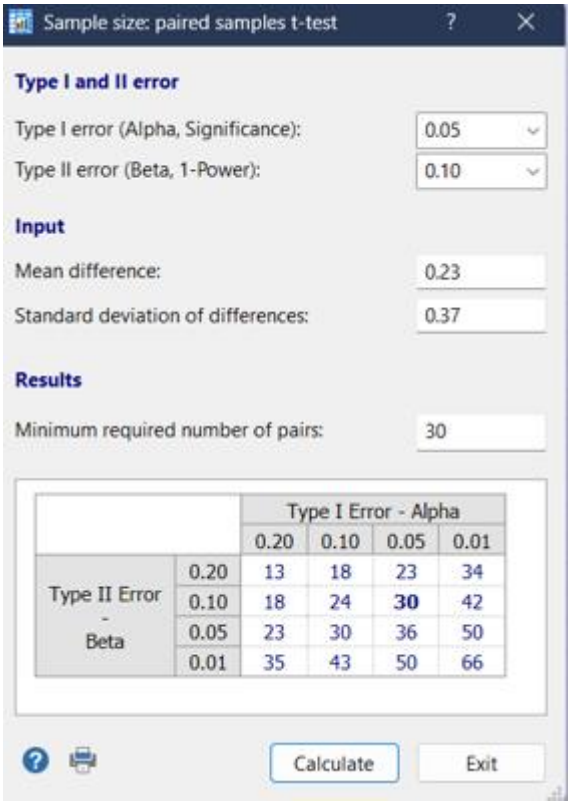

Figure 2.1 4 Sample size calculation using MedCalc statistical software

3.6 Sampling Method

This study used a random sampling method where the participants would be selected randomly among healthy adults regardless the race and gender in Universiti Sains Malaysia (USM) Kubang Kerian, Kelantan. The posters were advertised and distributed via social media to recruit the participants. Those interested in the study would contact the person in charge, and hearing screening was conducted at the PPSK Audiology Clinic. The participants were selected based on the stated inclusion and exclusion criteria.

3.7 Research Tools and Data Collection Method

3.7.1 Research Tools

I. Otoscope and speculum

II. Tympanometry (GSI Tympstar Pro or AT 235) and Probe

III. Pure Tone Audiometry (GSI 61 or GSI Audio Star Pro)

III. Pure Tone Audiometry (GSI 61 or GSI Audio Star Pro)

IV. Headphone

V. Bio-logic AEP System

VI. Conductive gel (NuPrep)

VII. Non-disposible Electrode

3.7.2 Data Collection Method

Before participating in this study, each participant was thoroughly informed about the research details and given a consent form, confirming their voluntary agreement to take part. To ensure participants were in good health and free from any hearing or balance disorders, routine hearing assessments were performed. The researcher explained each testing procedure and instructed participants to immediately report any pain or discomfort they might experience during the tests. The evaluation process would include history taking, performing an otoscopy examination, tympanometry and pure tone audiometry.

I. History taking

The researcher conducted a brief history to ensure participants met the inclusion criteria. An adult history form was used as a guide to gather comprehensive details about each participant's hearing status and medical background. This included