TONE BURST VERSUS CHIRP IN CERVICAL VESTIBULAR EVOKED MYOGENIC POTENTIAL (CVEMP): COMPARISON BETWEEN NORMAL AND MILD TO MODERATE SENSORINEURAL HEARING LOSS

DR MOHAMAD NAJIB BIN SALLEH

Dissertation Submitted in Partial Fulfilment of the Requirement for the Degree of Master of Medicine (Otorhinolaryngology-Head and Neck Surgery)

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SUPERVISOR: ASSOC. PROF. DR. ROSDAN SALIM

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Ultimately, I dedicate this thesis to my lovely wife, Nik Noramalina Rozik. Three of my kids, Nik Nu'man Al-Basyir, Nik Nadeem Al-Afeef, and Nik Amna Sufiyya, have continuously supported me throughout my research—also not forgetting my deepest gratitude to my family, especially my parent, Salleh Bin Jasin and Rohani Bt Ismail for the endless patience, understanding and moral support from the beginning until the end of this journey.

Finally, I owe gratitude to all those who helped me directly or indirectly throughout completing this dissertation. No word can suffice to say how much I appreciate all the help I have received, and only Allah S.W.T will reward their good deeds.

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LIST OF ABBREVIATIONS AND SYMBOLS

≥	More or equal
>	More than
<	Less than
≤	Less or equal
@	At
%	Percent
μV	Microvolts
AC	Air-conduction
APC	Article processing charge
ABR	Auditory brainstem response
AEP	Auditory evoked potential
AMLR	Auditory middle latency response
ALR	Auditory late response
BPPV	Benign paroxysmal positional vertigo
BC	Bone-conduction
CVEMP	Cervical vestibular evoked myogenic potential
CHL	Conductive hearing loss
CE	Clause Elberling
CTA	Copyright transfer agreement
DC	Downward chirp
dB	Decibel
EMG	Electromyographic
E.g	Example given
HL	Hearing loss
Hz	Hertz
kHz	Kilohertz
ICMJE	International Committee of Medical Journal Editors
MMSNHL	Mild to moderate sensorineural hearing loss
Ms	Millisecond
Mm3	Cubic millimeter
NB	Narrowband
ORL	Otorhinolaryngology
oVEMPs	Ocular vestibular evoked myogenic potentials
PTA	Pure tone audiometry
SNHL	Sensorineural hearing loss
SCM	Sternocleidomastoid
SCC	Semi-circular canals
TB	Tone burst
UC	Upward chirp
USM	Universiti Sains Malaysia
VEMP	Vestibular Evoked Myogenic Potential
VHIT	Video Head Impulse Test
VCR	Vestibulo-colic reflex
VOR	Vestibulo-ocular reflex
VSR	Vestibulo-spinal reflex

ABSTRAK

Pengenalan: Telinga adalah penting untuk pendengaran dan keseimbangan, mengesan serta menganalisis bunyi, dan mengekalkan keseimbangan. Fungsi-fungsi ini dicapai dengan tindakan organ koklea dan vestibular telinga dalam. Cervical Vestibular evoked myogenic potential (cVEMP) ialah modaliti elektrofisiologi untuk menilai organ otolith dengan menentukan fungsi saccule dan sambungan sarafnya kepada rangsangan pendengaran yang kuat dengan memantau aktiviti otot sternokleidomastoid. Kajian ini bertujuan untuk membandingkan kesan rangsangan tone burst (TB), upward chirp (UC), dan downward chirp (DC) yang digunakan dalam cVEMP terhadap kependaman dan amplitud potensi miogenik dalam kehilangan pendengaran sensorineural normal dan ringan hingga sederhana (MMSNHL).

Objektif: Untuk mengesahkan teori penjanaan vestibular evoked myogenic potential (VEMP) dengan menyiasat peranan koklea menggunakan rangsangan pendengaran novel dalam pendengaran normal dan kehilangan pendengaran sensorineural ringan hingga sederhana

Kaedah: Dalam kajian perbandingan ini, keputusan VEMP peserta yang mengalami kerosakan koklea (tetapi fungsi vestibular normal) dibandingkan dengan orang dewasa dengan pendengaran dan fungsi vestibular yang normal. Kajian ini melibatkan 43 telinga normal dan 43 telinga dengan kehilangan pendengaran sensorineural ringan hingga sederhana, dengan umur peserta antara 18 hingga 59 tahun dan menggunakan kaedah persampelan rawak. Penilaian pendengaran dilakukan menggunakan pemeriksaan otoskopi, timpanometri, pure tone audiometry (PTA) dan tone decay. Penilaian vestibular dilakukan menggunakan ujian Romberg, ujian Dix-Hallpike, Ujian video Head Impulse (vHIT) dan Skala Gejala Vertigo Versi Bahasa Melayu (MVVSS). Rakaman VEMP dilakukan menggunakan tiga rangsangan berbeza: 500 Hz tone burst, upward chirp dan downward chirp.

Keputusan: Terdapat keputusan yang signifikasi di mana latensi P1 dan latensi N1 didapati berbeza secara statistik diantara stimulus (p<0.001) dalam kumpulan normal dan kumpulan kehilangan pendengaran sensorineural ringan hingga sederhana. Walau bagaimanapun, tidak terdapat perbezaan yang ketara dalam latensi dan amplitud P1 dan N1 diantara stimulus jika dibandingkan antara kumpulan kumpulan normal dan kumpulan kehilangan pendengaran sensorineural ringan hingga sederhana menggunakan stimulus yang berbeza (p>0.05). Sebaliknya, amplitud P1 dan N1 adalah tidak signifikasi menggunakan stimulus yang berbeza bagi setiap kumpulan normal dan kumpulan kehilangan pendengaran sensorineural ringan hingga sederhana dan antara perbandingan diantara kumpulan normal dan kumpulan kehilangan pendengaran sensorineural ringan hingga sederhana.

Kesimpulan: Stimulus "downward chirp" adalah yang paling pendek di antara ketiga-tiga stimulus. Walau bagaimanapun, tiada perbezaan yang signifikan dalam amplitud antara setiap rangsangan dalam kumpulan normal dan kumpulan kehilangan pendengaran sensorineural ringan hingga sederhana. Secara tidak langsung, koklea tidak menyumbang dengan ketara kepada penjanaan vemp bersama saccule dan sambungan

ABSTRACT

Introduction: The ear is essential for hearing and equilibrium, detecting and analyzing sound, and maintaining balance. These functions are achieved by the action of the cochlear and vestibular organs of the inner ear. Cervical Vestibular evoked myogenic potential (cVEMP) is an electrophysiological modality to assess otolith organs by determining the function of the saccule and its neural connection to a loud auditory stimulus by monitoring the activity of sternocleidomastoid muscle. This study aims to compare the effects of tone burst (TB), upward chirp (UC), and downward chirp (DC) stimulation used in cVEMP on the latency and amplitude of myogenic potentials in normal and mild to moderate sensorineural hearing loss (MMSNHL)

Objective: To verify the theory of vestibular evoked myogenic potential (VEMP) generation by investigating the role of cochlear using novel auditory stimuli in normal hearing and mild to moderate (MMSNHL)

Methods: In this comparative study, VEMP results of participants with cochlea damage (but normal vestibular function) were compared to that of adults with normal hearing and vestibular function. This study was conducted involving 43 normal ears and 43 ears with mild to moderate SNHL, with participants' ages ranging between 18 and 59 years old by using a random sampling method. The hearing assessment was done using otoscopy examination, tympanometry, conventional pure tone audiometry (PTA), and tone decay. The vestibular assessment was done using the Romberg test, Dix-Hallpike test, video Head Impulse Test (vHIT), and Malay Version of Vertigo Symptom Scale (MVVSS). VEMP recording was done using three different stimuli: 500 Hz tone burst, upward chirp, and downward chirp.

Results: There were significant results where the P1 latency and N1 latency were found to be statistically different between the stimuli (*p*<0.001) in each normal group and the MMSNHL group. However, there were no significant differences in the P1 and N1 latency compared to the normal group and MMSNHL using different stimuli (*p*>0.05). The P1 and N1 and amplitude were found to be not statistically different between the TB, UP, and DC in each group and between the comparison group of normal and MMSNHL (*p*>0.05).

Conclusion: Downward chirp stimuli was the shortest latency among the three stimuli. However, no significant difference in amplitude between each stimulus in the normal group and MMSNHL. It seems that the cochlear does not significantly contribute to the generation of vemp along with saccule and its central connection compared to normal and MMSNHL

CHAPTER 1 INTRODUCTION

The ear is essential for hearing and equilibrium, which detects and analyzes the sound and maintains a sense of balance. Anatomically, an ear can be divided into three parts, outer ear, middle ear, and inner ear. The inner ear consists of two crucial portions with distinct functions; the cochlea and vestibular organs which consist of semicircular canals, saccule, and utricle(Schultz *et al.,* 2017) Humans have an inner ear that is about 150 mm3 in size. Despite their diminutive size, the inner ear organs are biologically very potent. Incredibly, such tiny objects can result in many issues, including tinnitus, motion sickness, and a generalized lack of coordination. As a result of this phenomenon, the ear region is one of the most thoroughly researched systems of vertebrate anatomy and physiology (Ekdale, 2016). If the outer or middle ear is affected, conductive hearing loss (CHL) is said to occur. On the other hand, if the damage occurs on the cochlea or neural portions, the condition is known as sensorineural hearing loss (SNHL)(Lee & Bance, 2019)

In cross-section, the cochlea has three compartments. Perilymph is present in the upper chamber (scala vestibule) and lower chamber (scala tympani); endolymph is present in the scala media, which is separated from the scala tympani by the basilar membrane. The basilar membrane is traversed by the organ of Corti, which is the main sensory structure of the inner ear. Cochlea plays a significant role in analyzing the acoustic characteristic of sounds. To respond to variable frequencies of sound, the cochlea has a tonotopic representation, where the basilar membrane responds at each point to a characteristic frequency—the highest frequencies at the basal end nearest the oval window and progressively lower frequencies towards the apical end(Hudspeth, 2014; Lee & Bance, 2019)

Pure tone audiometry (PTA) is the gold standard for determining hearing sensitivity (Corry *et al*., 2017). Patients are asked to click a button when they hear sound stimuli to indicate their responses during this test. The audiometry results must be precise and reliable.

Besides that, the vestibular system optimizes visual acuity during head motion, enhances balance control, and detects self-motion and orientation relative to gravity (Kingma & van de Berg, 2016). The vestibulo-ocular reflex (VOR) ensures vision during head motion by moving the eyes contrary to the head to stabilize the line of sight in space; vestibulo-spinal reflexes (VSR) keep the head and body upright and vestibulo-collic reflex (VCR) help maintain stability of the head during movement of the torso. The semicircular canals (SCCs) sense angular acceleration to detect head rotation; the otolith organs sense linear acceleration to detect both head translation and the position of the head relative to the pull of gravity. The SCCs are arranged in a push-pull fashion with two canals on each side working together: the right and left lateral, the right anterior and left posterior, and the left anterior and right posterior SCC (Fetter, 2000). Symptoms of vestibular dysfunction include a variety of complaints: vertigo, nausea and vomiting, intolerance to head motion, spontaneous nystagmus, unsteady gait, and postural instability (Strupp & Brandt, 2013).

For bedside or office examination of vestibular status, the Romberg, Fukuda, and heel-toe test can be used for the vestibulo spinal test while head shake, head impulse, and dix- hall pike test can be used for the VOR test (Huh *et al*, 2013). For diagnosing vestibular disorders, various clinical tests are utilized to precisely determine the status of the semicircular canals, otolith organs (saccule and utricle), and central pathways such as caloric test and video head impulse test to evaluate SCC and VOR, while oVEMP and cVEMP to evaluate the status of utricle and saccule respectively. (Curthoys, 2012; Renga, 2019) .

The VEMP is a helpful clinical diagnostic for determining the functionality of the vestibular organs. The electrical responses produced by particular vestibular organs in response to sound stimulus are represented by VEMP. It has two distinct peaks: a positive peak, P1, with a latency of 13 ms, and followed by a negative peak, N1, with a latency of about 23 ms Using a standard auditory evoked potential device, VEMP is routinely recorded with loud sounds (≥ 90 dB n HL). VEMP is typically recorded using stimuli, including clicks and tone bursts (Noij & Rauch, 2020; Ozgur *et al*., 2015)

A new stimulus known as "chirp" has recently been created, verified, and made accessible for clinical usage. As a result, waveforms generated by chirp stimulations are substantially more robust and consistent with shorter testing times than waveforms produced by traditional stimuli (Dau *et al*., 2000; Elberling & Don, 2010; Jamal *et al*., 2020). The chirp stimulus might be band-limited (with a narrow frequency range between 250 and 700Hz) or wideband (with a wide frequency range between 0.1 and 1.4kHz) (Cebulla & Walther, 2019a; Dau et al., 2000). It can have "upward (UC)" or "downward (DC)" patterns, where "upward" patterns have low frequencies at the start and high frequencies towards the end of the stimulus, respectively.

In more recent studies, there is considerable percentages of abnormal VEMP results were found in patients with SNHL due to cochlear damage. A cross-sectional observational study was done by Akin *et al*. in 2012 recorded the effects of noise exposure on the cervical vestibular evoked myogenic potential (cVEMP) in individuals with asymmetric noise-induced sensorineural hearing loss (NIHL). They found that about 33% of SNHL patients had abnormal VEMP results, and a significant association was found between the severity of hearing loss and VEMP outcomes. In this study, they suggested that the sacculocollic pathway may be susceptible to noise-related damage.

Another study done by Wang *et al.* in 2007, they investigated the effect of chronic noise exposure on vestibular evoked myogenic potential in 20 patients with chronic NIHL. In this prospective study revealed abnormal VEMP responses in about 50% subjects. Furthermore, hearing thresholds at 4kHz were significantly correlated with VEMP results. However, the author concluded that the vestibular part, especially the sacculocollic reflex pathway has been damaged.

Taken together, based on more recent findings on adults with SNHL, there is a need to reconsider the current theory of VEMP generation, which is the focus of the present study. Recently, there has been an increased interest to study VEMP evoked by band-limited chirp stimuli (Syahirah & Mohd Normani, 2016; Walther & Cebulla; 2016). As revealed in this study, the chirp stimuli were found to produce more robust VEMP waveforms than the conventional low frequency tone bursts.

Based on the available evidence, two emerging patterns have been identified. First, VEMP has been associated with hearing loss, raising concerns about cochlear involvement in VEMP generation. Second, the latency findings with chirp stimuli show that the VEMP generator (i.e., saccule) is highly sensitive to sound timing, a condition similar to cochlea. Given that the saccule is part of the vestibular system, which is primarily responsible for body balance, and that the temporal aspect of the saccule has not been thoroughly studied, it appears plausible that the cochlea may also contribute to the generation of VEMPs.

The effect of hearing loss on cVEMP is still debatable. As such, there is a need to gather more evidence on the relation between hearing loss and cVEMP. In this study, TB, UC, and DC were used to compare the waveform of cVEMP generation in normal and mild to moderate SNHL to look for any significant differences between all these types of stimuli and their correlation with cochlear.

CHAPTER 2 OBJECTIVE OF STUDY

2.1 General objective

To verify the theory of cVEMP generation by investigating the role of cochlear using novel auditory stimuli in normal hearing and MMSNHL.

2.2 Specific objective

1. To compare cVEMP latency and amplitude between 500Hz tone burst, upward chirp, and downward chirp stimuli in normal hearing adults.

(Within-group comparison)

2. To compare cVEMP latency and amplitude between 500Hz tone burst, upward chirp, and downward chirp stimuli in mild to moderate SNHL adults.

(Within-group comparison)

3. To compare latency and amplitude of cVEMP between normal and mild to moderate SNHL

(Between group comparison)

4. 4. To compare latency differences of cVEMP between normal and mild to moderate SNHL

(Between group comparison)

CHAPTER 3 MANUSCRIPT

3.1 Title page

Tone Burst Versus Chirp in Cervical Vestibular Evoked Myogenic Potential (cVemp): Comparison Between Normal and Mild To Moderate Sensorineural Hearing Loss

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3.2 Abstract

Introduction: The ear is essential for hearing and equilibrium, detecting and analyzing sound, and maintaining balance. These functions are achieved by the action of the cochlear and vestibular organs of the inner ear. Cervical Vestibular evoked myogenic potential (cVEMP) is an electrophysiological modality to assess otolith organs by determining the function of the saccule and its neural connection to a loud auditory stimulus by monitoring the activity of sternocleidomastoid muscle. This study aims to compare the effects of tone burst (TB), upward chirp (UC), and downward chirp (DC) stimulation used in cVEMP on the latency and amplitude of myogenic potentials in normal and mild to moderate sensorineural hearing loss (MMSNHL)

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Keywords: *cVEMP, chirp stimuli, cochlea damage, mild to moderate SNHL*

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3.4 Methodology

This study was a comparative study done at Hospital Universiti Sains Malaysia, Health Campus, Kubang Kerian, Kelantan, from February 2022 until July 2022. This study was approved by the university Human Research Ethics Committee with code FRGS/1/2020/SKK06/USM/02/7. The analysis was performed according to Helsinki Declaration, and written consent was obtained from each subject.

Based on the study by Akin et al. (2012) that compared VEMP results between normal and hearing-impaired adults, and by using MedCalc for Windows version 19.6.1 (MedCalc Software, Ostend, Belgium), the calculated sample size was 43; a total of 86 participants for two groups (43 participants for normal, and 43 patients for MMSNHL). Normal participants were selected by systematic random sampling method, while for MMSNHL, they were chosen by convenience sampling and screened for inclusion and exclusion criteria.

The inclusion criteria for normal participants included patients aged 18 and 59 years old with no history of hearing and vestibular problems and good general health. Inclusion criteria for MMSNHL included patients aged between 18 and 59 years old, diagnosed with MMSNHL due to cochlea damage in one or both ears (no significant air-bone gaps and both air conduction and bone conduction thresholds exceed 20dB HL at 250, 500, 1000, 2000, 4000, and 8000 Hz frequencies, as well as normal in tympanometry and tone decay), no history of the vestibular problem (normal results in vestibular assessment) and good general health. Mild to moderate hearing loss is defined as an audiometric pure-tone average between 20-70 dB HL. Patients with neck pain or neck problems and those with

SNHL due to labyrinthitis, acoustic neuroma, and Meniere's disease were excluded from the study.

Patients who consented were interviewed to complete a proforma comprising their demographic information, medical history, surgical history, and medication history. The status of the external ear canal and the tympanic membrane was then examined using otoscopy. After that, the patient underwent a conventional PTA and tympanometry test. Patients with normal hearing underwent the following vestibular tests: the Romberg test, the Dix-Hallpike test, the VHIT, and the MVVSS to exclude vestibular problems. Tone decay tests, Romberg tests, Dix-Hallpike tests, VHIT, and the Malay version of the vertigo symptom scale (MVVSS) were performed on patients with MMSNHL. All participants in the normal group and MMSNHL group of the tests undergo a VEMP test.

In this study, A two-channel Biologic Navigator Pro AEP system (Natus Medical Inc., Mundelein, USA) device was used to record the cVEMP responses. The electrical responses produced by saccule in response to sound stimulus are represented by cVEMP. s. The cVEMP response was recorded ipsilaterally during the acoustic stimulation. The tone burst of 500Hz and chirp stimuli using upward and downward chirp was delivered repetitively at 90dB HL with a stimulus rate of 5/s. The duration of the tone burst is 7ms. Both chirps are band-limited and contain frequencies between 200 and 1000 Hz with a 10ms period (upward chirp, 200- 1000 Hz and downward chirp, 1000 – 200 Hz). The comprehensive examination and tests were done in one clinic visit and took about 2 hours to complete for each patient.

3.5 Result

All 86 candidates for normal hearing and MMSNHL were examined, and VEMP data was successfully obtained. For normal subjects, the mean age was 29.11 years, with a standard deviation of 6.45 years. Malay comprised 88.6% of the population, while Chinese and Indian comprised 5.7% and 5.7%, respectively. 57.1% of them were females, and 42.9% were males. As for the MMSNHL group, the age was 41 with a standard deviation of 10.74 years (range 18-59 years). Most were Malay, 96.3%, and 51.9 % were female.

Figure 3.1 shows VEMP waveforms for all three stimuli from a representative subject. The VEMP responses for representative MMSNHL participants are illustrated in Figure 3.2.

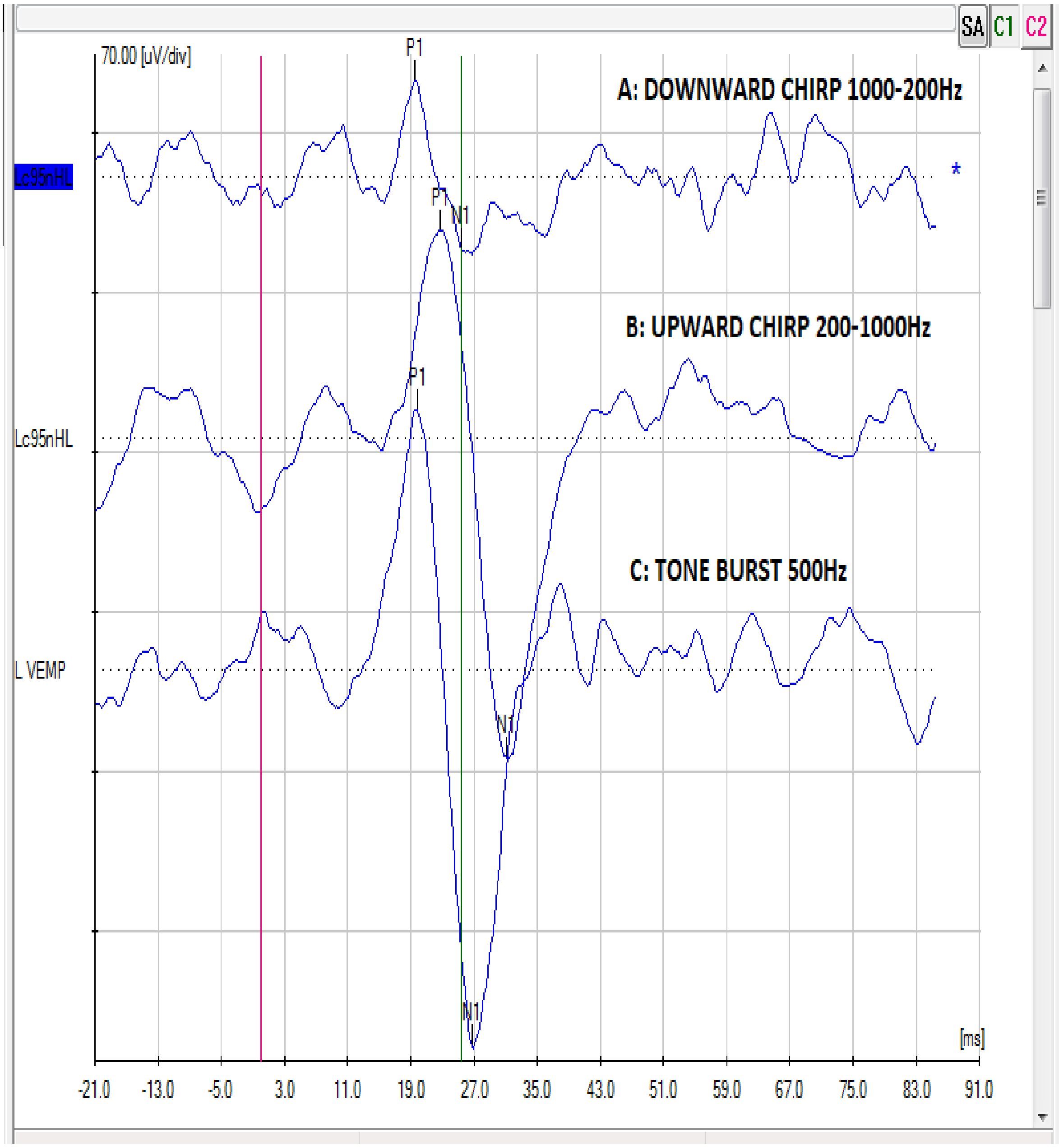

Figure 3.1 shows the VEMP waveforms for a tone burst at 500 Hz, an upward chirp at 200–1000 Hz, and a downward chirp at 1000–200 Hz in a healthy subject.

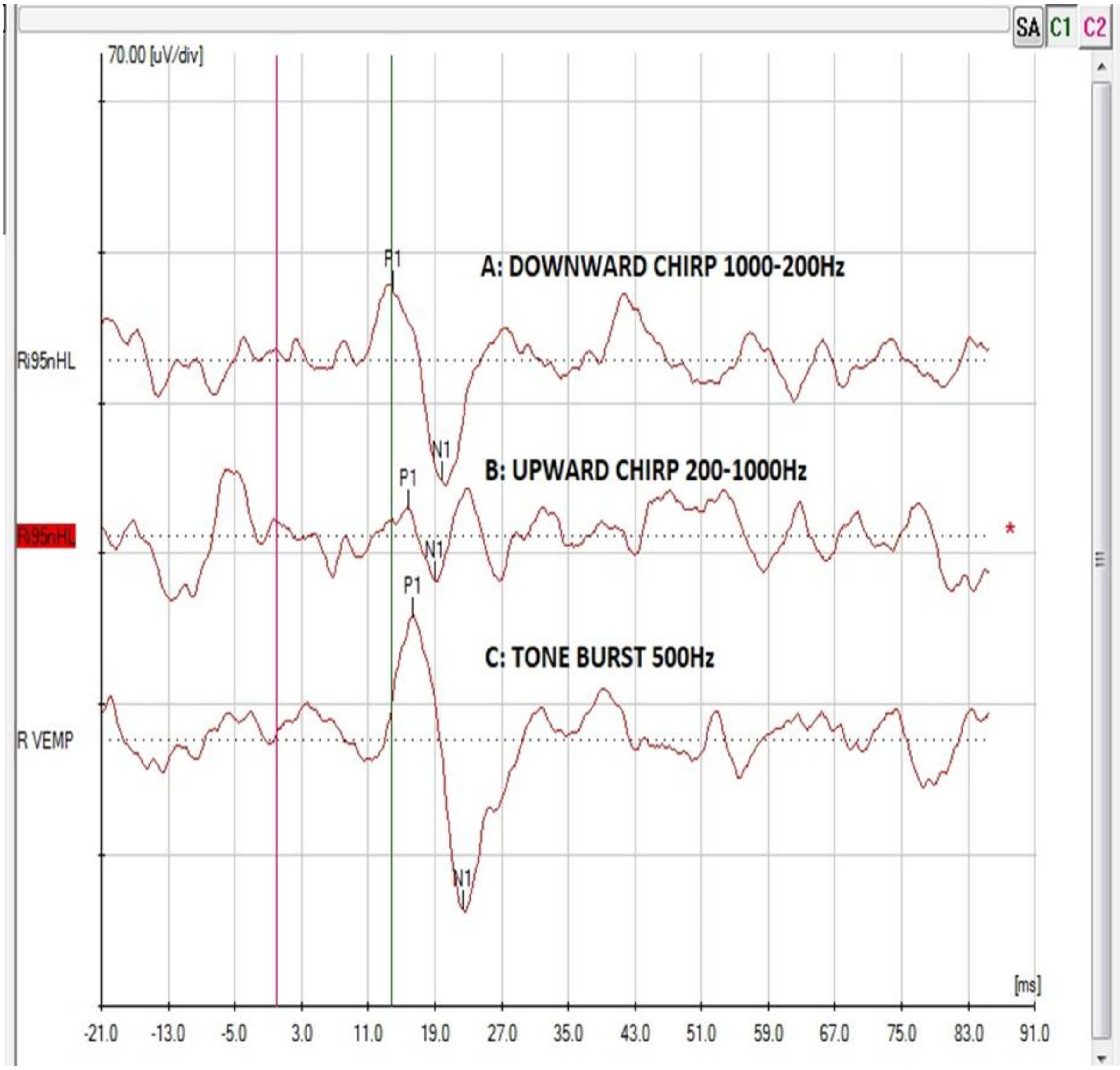

Figure 3.2 illustrates the VEMP waveforms for tone bursts of 500 Hz, upward chirps of 200-1000 Hz, and downward chirps of 1000-200 Hz in a subject with mild to moderate SNHL.

The mean and standard deviation for cVEMP parameters (P1 latency, N1 latency, P1 amplitude, and N1 amplitude) for normal subjects are shown in Table 3.1. As shown, the P1 and N1 latency was found to be statistically different between the stimuli ($p = 0.01$). Using the pairwise comparisons with Bonferroni correction, it was found that only a significant result was obtained when DC with UC and DC with TB stimuli were compared ($p = 0.002$, $p = 0.01$).

Table 3.1 Mean, standard deviation, and *p*-value for each VEMP parameter when the three stimuli (500 Hz TB, UC stimulus, and DC stimulus) are compared in normal subjects

VEMP Parameter	500 Hz tone burst	Upward chirp	Downward chirp	*p*-value
P1 latency (ms)	17.82 ± 2.41	18.44 ± 2.38	16.08 ± 2.27	<0.001
N1 latency (ms)	21.82 ± 2.88	22.11 ± 3.34	19.77 ± 2.89	<0.001
P1 amplitude (μV)	13.93 ± 12.61	11.80 ± 6.25	16.10 ± 2.38	0.088
N1 amplitude (μV)	15.70 ± 11.39	12.65 ± 8.05	15.28 ± 11.64	0.278

The Post Hoc Test with Bonferroni correction results revealed that P1 latency (ms) did not significantly differ between TB and UC with a *p*-value of 0.654 but significantly between TB and DC with a *p*-value of 0.002 and between UC and DC with a *p*-value of 0.001.

The results of the Post Hoc Test with Bonferroni correction showed that N1 latency (ms) did not differ significantly between TB and UC with a *p*-value of 1.000 but did differ significantly between TB and DC with a p-value of 0.002 and between UC and DC with a *p*-value of 0.001. In a conclusion, downward chirp stimuli are the shortest among the three stimuli.

The mean and standard deviation for cVEMP parameters (P1 latency, N1 latency, P1 amplitude, and N1 amplitude) for MMSNHL are shown in Table 3.2. As shown, the P1 latency was found to be statistically different between the stimuli (p = 0.01). Using the pairwise comparisons with Bonferroni correction, it was found that only a significant result was obtained when DC with UC and DC with TB stimuli were compared *(p* = 0.002, p = 0.01).

Table 3.2 Mean, standard deviation, and *p*-value for each cVEMP parameter when the three stimuli (500 Hz TB, UC stimulus, and DC stimulus) are compared in MMSNHL

VEMP parameter	500 Hz tone burst	Upward chirp	Downward chirp	*p*-value
P1 latency (ms)	17.93 ± 2.10	18.88 ± 2.55	16.14 ± 2.353	<0.001
N1 latency (ms)	21.15 ± 2.68	21.95 ± 3.57	19.83 ± 3.03	<0.001
P1 amplitude (μV)	14.31 ± 10.77	13.80 ± 8.68	14.04 ± 10.22	0.913
N1 amplitude (μV)	13.98 ± 12.96	13.99 ± 17.91	12.03 ± 11.26	0.810

The Post Hoc Test with Bonferroni correction results revealed that P1 latency (ms) did not significantly differ between TB and UC with a p-value of 0.147 but did differ significantly between TB and DC with a *p*-value of 0.001 and between UC and DC with a *p*-value of <0.001.

The results of the Post Hoc Test with Bonferroni correction showed that N1 latency (ms) did not differ significantly between TB and UC with a p-value of 0.383 but did differ significantly between TB and DC with a *p*-value of 0.041, and between UC and DC with a *p*-value of <0.001. In a conclusion, downward chirp stimuli are the early latency among the three stimuli.

The mean and standard deviation for VEMP parameters (P1 latency, N1 latency, P1 amplitude, and N1 amplitude) for 500 Hz tone burst when normal and MMSNHL subjects were compared are shown in Table 3.3. There was no significant P1 latency and N1 latency between the normal and mild to moderate SNHL.

Table 3.3 Mean, standard deviation, and *p*-value for each cVEMP parameter for 500 Hz TB when normal and MMSNHL subjects are compared

VEMP parameter	Normal	SNHL	*p*-value
P1 latency (ms)	17.82 ± 2.41	17.93 ± 2.10	0.615
N1 latency (ms)	21.82 ± 2.88	21.15 ± 2.68	0.713
P1 amplitude (µV)	13.93 ± 12.61	14.31 ± 10.77	0.511
N1 amplitude (µV)	15.69 ± 11.39	13.98 ± 12.96	0.956

Table 3.4 shows the mean and standard deviation for VEMP parameters (P1 latency, N1 latency, P1 amplitude, and N1 amplitude) for the upward chirp when normal subjects and MMSNHL subjects were compared. There was no significant difference between the P1 and N1 latencies, as shown in the table.

Table 3.4 Mean, standard deviation, and *p*-value for each cVEMP parameter for UC stimulus when normal and MMSNHL subjects are compared

VEMP parameter	Normal	SNHL	*p*-value
P1 latency (ms)	18.44 ± 2.38	18.88 ± 2.55	0.605
N1 latency (ms)	22.11 ± 3.34	21.95 ± 3.57	0.916
P1 amplitude (µV)	11.80 ± 6.25	13.80 ± 8.69	0.164
N1 amplitude (µV)	12.65 ± 8.05	13.99 ± 17.91	0.867

The mean and standard deviation for VEMP parameters (P1 latency, N1 latency, P1 amplitude, and N1 amplitude) for downward chirp when normal and mild to moderate SNHL subjects were compared and are shown in Table 3.5. As shown in the table, there was no significant difference between P1 latency or N1 latency and P1 and N1 amplitude. As a conclusion, cochlea damage in patients with mild to moderate SNHL does not affect cVEMP results using three different stimuli.

Table 3.5 Mean, standard deviation, and *p*-value for each cVEMP parameter for DC stimulus when normal and MMSNHL subjects are compared

VEMP parameter	Normal	SNHL	*p*-value
P1 latency (ms)	16.08 ± 2.27	16.14 ± 2.35	0.517
N1 latency (ms)	19.77 ± 2.89	19.83 ± 3.03	0.897
P1 amplitude (μV)	16.10 ± 2.38	14.40 ± 10.22	0.779
N1 amplitude (μV)	15.28 ± 11.64	12.03 ± 11.26	0.993

Table 3.6 displays the mean, standard deviation, and p-value for the latency difference between P1 and N1 for chirp stimuli in normal and mild to moderate SNHL subjects. No significant difference was found between normal and mild to moderate SNHL In addition, we conclude that the onset effect of saccule activity is similar in the normal and mild to moderate SNHL groups.

Table 3.6 Mean, standard deviation, and *p*-value for latency difference of P1 and N1 for chirp stimuli when normal and MMSNHL subjects are compared

VEMP parameter	Normal	SNHL	*p*-value
Latency difference of P1 (ms)	2.15 ± 2.70	2.33 ± 2.47	0.771
Latency difference of N1 (ms)	2,14 ± 2.77	2.37 ± 2.97	0.614

3.6 Discussion

(VEMP) is a short latency myogenic response that is evoked by brief pulses of air-conducted (AC) sound, bone-conducted (BC) vibration, or electrical stimulation and recorded using surface electrodes placed over muscles. There are two types of VEMP which are cVEMP and ocular vestibular evoked myogenic potentials (oVEMPs). cVEMP which are a manifestation of the vestibular-colic reflex, predominantly the sacculocollic reflex, are assessed by measuring electromyographic (EMG) activity from surface electrodes placed over the tonically activated sternocleidomastoid (SCM) muscles that reflect saccular functions while oVEMPs are produced by synchronous activity in the extraocular muscles in response to stimulation, including the sound that predominantly reflects utricular functions (Curthoys *et al.,* 2011; Murofushi *et al.,* 2011; Xu *et al*., 2016)

The main sensitivity range, in terms of evoking VEMPs, is around 500 Hz in normal young and middle-aged individuals (Rosengren et al., 2010). Air-conducted VEMPs can be elicited by various low-frequency and intense sound stimuli, mainly by clicks, TB, or chirps. TB is especially commonly used in clinical practice (Cebulla & Walther, 2019b; Rosengren *et al.,* 2010). Recently, chirp stimuli are increasingly used in audiological diagnostic work and evaluations as clinically proven to be very effective in clinical practice (Cebulla & Walther, 2019). Chirps represent acoustic stimuli in which the frequency varies over time and either increases (UC) or decreases (DC).

Tone burst stimuli showed a longer latency than click and chirp stimuli, according to research by Ozgür *et al.* (2015). They suggested that this might be because of the tone burst stimulation response wave's late peak and considerably longer rise/fall time. The stapes reflex is stimulated by the click stimulation response wave, which has a shorter rise/fall time and generates a VEMP response first. On the other hand, (Syahirah and Mohd Normani, 2016) found that downward chirp latency is the earliest, followed by 500Hz tone burst and upward chirp. They discovered that the chirp appears to be a good stimulus for recording cVEMP responses because the amplitude recorded is much larger and clearer than that of the 500Hz tone burst. Based on their findings, they conclude that the upward and downward chirp are comparable to the tone burst stimulus-response, and thus chirp can be used as an alternative stimulus instead of tone burst only.

The upward chirp has the largest amplitude, followed by the 500 Hz tone burst and click sound, according to (Walther and Cebulla, 2016). They also noted that the chirp, tone burst, and click stimuli had slightly different latencies. They cited the characteristics of the various stimuli as the reason for this. Differences in delay may also result from the time-shifted presentation of the stimulus frequency components in all three stimuli used.

As mentioned earlier, cVEMP was invented to assess the manifestation of the vestibular-colic reflex, predominantly the sacculocollic reflex. In this study, cVEMP was done using different stimuli which are TB, UC, and DC to test saccular activity in a normal hearing patient without vestibular problem with the comparison with a patient that had mild to moderate SNHL also without vestibular problem, thus we evaluated the relation of cochlear in VEMP generation without interaction of vestibular disorder.

Some studies mentioned that VEMP generation will be affected in the present sensorineural component with normal vestibular function. The results are consistent with previous studies in animals and humans that suggest the saccule may be particularly susceptible to noise-related damage (El-Salam *et al*., 2017). Besides that, some studies found that VEMP generation is not affected by the presence of SNHL in healthy vestibular function (Ozeki *et al*., 1998).

In the present study, we found that there were significant differences in P1 and N1 latencies between all three stimuli, with the downward chirp being the shortest and early latency, followed by the tone burst, and the upward chirp being the longest. According to (Wang *et al*., 2014), chirp stimuli have shorter latencies as well as increased speed and reliability. This is consistent with our findings, which showed that DC stimulation resulted