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Test-retest reliability of vestibular evoked myogenic potentials with a B81 bone conductor

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In partial fulfilment of the requirements for the degree BA Audiology in the Department of Speech-Language Pathology and Audiology, Faculty of Humanities, University of Pretoria.

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Plagiarism Declaration

We (Kaylee Boyens, Marli Coetzee, Aakifah Saban, and Anome Victor) hereby declare that this research report is our original work. Where secondary material is used, this has been carefully acknowledged and referenced in accordance with university requirements.

We understand what plagiarism is and are aware of the University of Pretoria's policy in the regard.

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Abbreviations

AR (Acoustic Reflex); AC (Air Conduction); BC (Bone Conduction); cVEMP (Cervical Vestibular Evoked Myogenic Potential); oVEMP (Ocular Vestibular Evoked Myogenic Potential); dB (Decibel); dB HL (Decibel Hearing Level); EMG (Electromyography); mCTSIB (Modified Clinical Test of Sensory Interaction on Balance); NB (Narrowband); SCM (Sternocleidomastoid); SSCD (Superior Semicircular Canal Dehiscence); SVV (Subjective Visual Vertical test); VOR (Vestibulo-ocular reflex); VCR (Vestibulo-collic reflex); VEMP (Vestibular Evoked Myogenic Potential)

Abstract

Objective: To determine the test-retest reliability of cervical and ocular vestibular myogenic potentials (VEMPs) evoked by a 500 Hz narrowband (NB) CE-Chirp conducted through a B81 Bone Conductor.

Design: This study employed a quantitative, exploratory research design. A within-participant, within-session, and between-session reliability analysis was conducted. Twenty participants (10 female, 10 male) were recruited using convenience and snowball sampling methods, with screening processes ensuring normal middle ear, hearing, and vestibular function. Data collection involved repeated testing sessions, with statistical analyses applied to assess the reliability of the recorded VEMP responses. The latency, amplitude and asymmetry of the VEMPs elicited at 55 dB nHL bone conduction (BC) CE-Chirp.

Study Sample: The study population consisted of participants aged 18 to 60, with normal middle ear, hearing, and vestibular system functioning were recruited from the researchers' network of family and friends.

Results: The Shapiro-Wilk test confirmed the use of non-parametric statistics. No significant differences were observed in P1 latency, N1 latency, or P1-N1 amplitude between ears or genders for both cVEMP and oVEMP parameters, allowing data to be pooled. The Friedman test revealed significant differences across variables ($p<0.001$) particularly between Test 1 and Test 3, with the Wilcoxon Signed Rank Test identifying significant differences ($p<0.05$) in P1-N1 amplitude, asymmetry ratio, and P1/N1 latencies. Spearman's correlation coefficients showed moderate within-session reliability but very poor between-session reliability for both cVEMP and oVEMP parameters.

Conclusions: The B81 bone conducted CE-Chirp c- and oVEMPs proved to be reliable in within- and between-session testing regarding P1-N1 amplitudes and asymmetry ratio.

Key Words: Vestibular Evoked Myogenic Potential (VEMP), Re-test, CE Chirp, Bone conduction, Narrowband, Reliability, B81

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1. Introduction

The otolith organs of the peripheral vestibular systems can be measured through Vestibular Evoked Myogenic Potentials (VEMPs) which serve as a fundamental tool in the assessment of the systems' functioning (Colebatch & Halmagyi, 1992; Halmagyi et al., 1994; Romero et al., 2021). VEMPs are characterised as short-latency electromyographic potentials in neurophysiological and vestibular assessments for the purpose of identifying various types of vestibular dysfunction (Colebatch & Halmagyi, 1992; Halmagyi et al., 1994; Romero et al., 2021). Clinical practice predominantly employs two types of VEMP tests: ocular vestibular myogenic potentials (oVEMPs) and cervical vestibular evoked myogenic potentials (cVEMPs), each response characterised by their respective vestibular end organ, allowing for site of lesion testing for vestibular dysfunction (Rosengren et al., 2019).

cVEMPs are ipsilateral inhibited potentials, which record the sternocleidomastoid muscle's reaction through a carefully placed electrode. The stimulus activates the following structures in this order: saccular macula, inferior vestibular nerve, vestibular nucleus, the medial vestibulo-spinal tract, accessory nucleus and nerve, and the ipsilateral sternocleidomastoid muscle, all which is associated with the vestibulocollic reflex (VCR) (Akin et al. 2003; Colebatch et al. 1994; Rosengren et al. 2010). It is used in clinical practice to assess saccular functioning and the integrity of the inferior vestibular nerve (Colebatch et al., 1994). In contrast, oVEMPs are the synchronous extraocular EMG activity recorded from the contralateral inferior oblique extraocular muscle in response to a stimulus. This results in the activation of the utricle, superior vestibular nerve, the corresponding vestibular nucleus, and the oculomotor nuclei which is associated with the vestibular ocular reflex (VOR) (Rosengren et al., 2009, 2010). oVEMPs reflect utricular and superior vestibular nerve functioning in test findings (Rosengren et al., 2009; Curthoys et al., 2009).

The integration of both cVEMP and oVEMP responses proves beneficial in the diagnosis of various vestibular disorders, in particular, superior semicircular canal dehiscence syndrome (SSCD), Ménière's disease, benign paroxysmal positional vertigo, vestibular neuritis, vestibular schwannomas and specific brainstem lesions. This is achieved by the acquisition of either decreased, increased, or absent VEMP response amplitudes (Herdman & Clendaniel, 2014).

The two vestibular evoked myogenic potentials differ visually in their corresponding electromyogenic response waveform morphology (Li et al., 2014). cVEMP waveforms consist of a positive peak occurring first, labelled P1, followed by a negative peak, labelled N1. oVEMP waveforms are reversed in the sense that the waveform consists of a negative peak occurring first, labelled N1, followed by the positive waveform, labelled P1 thereafter. Latencies differ between cVEMPs and oVEMPs due to differences of the respective response elicitation pathways, consequently resulting in two distinctly different waveforms, as well as the type of transducer and stimuli used during testing (Li et al., 2014).

VEMPs are conventionally elicited using air conduction (AC) in vestibular audiological testing, likely due to the abundance of research indicating good reliability in vestibular testing making use thereof (Curthoys, 2010). However, alternative methods such as bone conduction (BC) offer some distinct advantages over AC (Curthoys, 2010; Papathanasiou et al., 2014). One significant advantage is BC's ability to bypass middle ear abnormalities that may inhibit AC testing, ensuring the stimulation of otolith structures necessary to produce cVEMP and oVEMP responses necessary for interpreting test results. Consequently, BC VEMPs can reflect normal otolith functioning in the presence of middle ear abnormalities, where AC VEMPs might otherwise show absent results. Although both AC and BC VEMPs share an otolith origin, the optimal frequency for eliciting VEMP responses varies, with BC stimuli exhibiting lower thresholds and enhanced specificity at frequencies below 500 Hz (Clinard et al., 2020; Herdman & Clendaniel, 2014).

Physiological evidence indicates that both saccular and utricular neurons respond to 500 Hz BC and 500 Hz AC stimulation (Herdman & Clendaniel, 2014). Frequency has a significant effect on the latency and amplitude of the VEMPs for BC stimulation (Cai et al., 2011). The frequencies that elicit the largest peak-to-peak amplitude for a BC cVEMP are below 500 Hz, allowing for easier interpretation and identification of responses (Clinard et al., 2020). A maximum BC cVEMP amplitude is observed with stimuli of 200 to 250 Hz, whereas a maximum BC oVEMP amplitude is observed with stimuli of 100 Hz (Sheykholeslami et al., 2001; Todd et al., 2008; Welgampola et al., 2003; Zhang et al., 2012). This low frequency tuning unfortunately restricts the clinical use BC VEMPs, as most commercially available transducers produce insufficient low frequency output regarding transient tone bursts, which are typically used for VEMP

application (Clinard et al., 2020). The B81 bone conductor was designed as a means to address the low frequency tuning limits of previously available transducers, such as the conventionally used B71. It has greater output in the lower frequencies and was designed to decrease harmonic distortion at higher output levels (Eichenauer et al., 2014; Håkansson, 2003; Jansson et al., 2014). Therefore the B81 bone conductor is the ideal transducer due to the beneficial low distortion and high output combination it can provide compared to the B71. Thus, unlike AC stimulation, BC stimulation using the B81 bone conductor that may obtain results at a lower thresholds and is compatible with conductive hearing loss, though limited by the low frequency output in commercially available B71 transducers (Mahdi et al., 2013; McNerney & Burkard, 2011). Various BC stimuli may be used to elicit VEMP responses, this includes tone bursts, clicks, and CE-Chirps (Piker et al., 2013). The B81 BC transducer was employed in the current study making use of a CE-Chirp stimulus.

The CE-Chirp stimulus represents a significant advancement in VEMP testing, designed to synchronise neural responses across the basilar membrane for larger responses and shorter latencies compared to conventional stimuli (Maslin, 2017; Çoban et al., 2021; Mat et al., 2021; Wang et al., 2014). Its application in BC VEMPs improves reliability for monitoring vestibular disorders and intervention effectiveness over time (Sheykholeslami et al., 2019). Compared with conventional stimuli such as clicks or tone bursts, CE-chirp can evoke cVEMP with shorter latencies and produce a more stable response (Wang et al., 2014). oVEMP stimulated by wideband chirp stimuli has shorter latencies, higher amplitudes, and clearer waveform morphology, with a higher ratio of present responses (Bas et al., 2020). CE-Chirps, when used in conjunction with the B81 bone conductor, are considered more reliable and capable of producing consistent responses. This enhanced reliability is due to the engineering of CE-Chirps to deliver more effective cochlear stimulation, yielding response amplitudes that are, on average, 2 times larger than those generated by traditional stimuli such as clicks and tone bursts (Nuber, 2016). Literature indicates that the B81 bone conductor designed to address the limitations of its predecessor (the B71), should enhance response consistency and reliability, particularly at lower frequencies where traditional bone conductors fall short. Combined with the use of the CE-Chirp stimulus, which synchronises neural responses across the basilar membrane, B81 should theoretically

result in larger, more stable VEMP responses (Eichenauer et al., 2014; Maslin, 2017; Wang et al., 2014).

Instruments used such as the B81 bone conductor alongside the CE-Chirp have to produce consistent results over time or when used by two researchers simultaneously to be deemed reliable (Brink et al, 2018). The test-retest reliability of AC VEMPs has been evaluated in the past. Fuemmeler et al. (2020) found both cVEMPs and oVEMPs are reliable using AC and BC stimuli when testing children. Similarly, two other studies found reliable cVEMP and oVEMP results using an AC 500 Hz tone burst stimulus (Anupriya & Kumar, 2019; Maes et al., 2009). Reddy et al. found that narrowband (NB) CE-Chirps are reliable during VEMP testing to estimate the function of the vestibular system. While AC VEMPs using CE-Chirps have been shown to be reliable compared to other stimuli, more research is needed to confirm the test-retest reliability of BC CE-Chirps for clinical use (Anupriya & Kumar, 2019; Fuemmeler et al., 2020; Maes et ald., 2009). Thus, more testing regarding the reliability of BC CE-Chirps on participants who have normal vestibular function using VEMPS needs to be conducted.

In conclusion, VEMPs are crucial for diagnosing vestibular disorders, with BC VEMPs and CE-Chirp stimuli offering advantages over AC VEMPs. The combination of the B81 bone conductor and CE-Chirp stimulus in VEMP testing, could potentially improve diagnostic accuracy and reliability. However, more research is needed to establish the test-retest reliability of BC CE-Chirps, especially in clinical settings, to solidify their role in vestibular assessment and intervention monitoring over time. The current study therefore aimed to investigate the test-retest reliability of B81 BC VEMPs using 500 Hz narrowband (NB) CE-Chirps in adults with normal hearing sensitivity.

2. Method

To determine test-retest reliability, a quantitative study with a correlational design was conducted (Brink et al., 2018). Within-participant, within-session and between-session testing was used to determine the test-retest reliability of the B81 bone conductor in the measurement of c- and oVEMPs. Prior to data collection, ethical clearance (Appendix A) was obtained from the Research Committee of the Department of Speech-Language Pathology and Audiology, Faculty of Humanities with reference number SLPA2024/09.

2.1. Participants and sampling

Participants were recruited using convenience and thereafter snowball sampling methods (Brink et al., 2018). Initially, the researchers contacted family and friends through word of mouth (Golzar et al., 2022). The study population consisted of 20 participants (10 female, 10 male) aged 18 to 50, to reduce the possibility of any participants with hearing and vestibular system dysfunction that may be attributed to age.

Before the commencement of any testing, informed consent was obtained from all participants (Appendix B). Only participants demonstrating normal results across all audiological and vestibular assessments, indicative of normal audiological and vestibular function, were included in the study cohort. This would include normal behavioural hearing sensitivity determined by screening audiometry and defined as a PTA lower than 15 dB HL alongside normal middle ear functioning as confirmed with otoscopy, tympanometry and screening acoustic reflex thresholds at 1000 Hz (ASHA, 2023). A vestibular screening battery included mCTSIB, bedside Head Impulse Test and Subjective Visual Vertical Test. These tests were included into the screening battery to confirm normal peripheral and central vestibular function in all participants. If any prospective participant presented with abnormal results, they were excluded from the study and referred to relevant medical professionals for further evaluation.

2.2. Material and Apparatus

A range of calibrated equipment and measurement tools were utilised for both participant selection and vestibular assessment to ensure the accuracy and reliability of data collection. The selection process involved rigorous screening using specific tools to determine participant eligibility according to the study's inclusion and exclusion criteria. Prior to testing, all equipment underwent calibration to guarantee the precision of the measurements and the consistency of results throughout the study.

During audiometric screening for participant selection, a Welch Allyn otoscope was first used to examine the tympanic membrane and external auditory canal (Falkson & Prasanna, 2021). Following this, tympanometry and acoustic reflex testing were conducted using the MAICO Diagnostic Touch Tymp MI 34 (Interacoustics, 2022) to assess middle ear function. To evaluate hearing thresholds, pure tone audiometry was

performed using an Interacoustics Diagnostic Audiometer, calibrated to ISO 389-1 (1998) and 389-2 (1994) standards, allowing for accurate testing at frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Supra-aural headphones with 40 dB interaural attenuation were used for AC threshold estimation. All audiometric assessments were conducted in an ISO 6189-compliant soundproof booth, providing a quiet and controlled environment to ensure reliable results. The audiological evaluation (Appendix D) required participants to present with bilaterally normal otoscopic examinations, Type A tympanograms, acoustic reflexes (AR) at 1000 Hz, and pure tone averages (PTA) below 29 dB HL across the frequency range of 500 to 4000 Hz.

For vestibular participant selection, a medium-density foam mat was used to deprive participants of somatosensory input, thereby influencing their balance (Khatter & Hathiram, 2012). To further assess vestibular function, infrared video goggles were employed to record and analyse eye movements under both fixation and eyes-covered conditions (Interacoustics, 2023a). Additionally, a low-tech setup, consisting of a bucket with a fixed protractor, was utilised to perform the SVV test, aiding in the identification and exclusion of any vestibular dysfunction. A battery of tests was utilised to assess participants' vestibular function (Appendix E) to ensure the absence of vestibular dysfunction. These included the modified Clinical Test of Sensory Interaction on Balance (mCTSIB), the subjective visual vertical (SVV) test, the spontaneous nystagmus assessment, the bedside head impulse test (HIT), and smooth pursuit tracking. This combination of tests provided a comprehensive assessment of postural control, utricular function, and overall vestibular integrity.

The vestibular assessment equipment utilised a B81 bone conductor as the transducer, chosen for its ability to improve low-frequency output and reduce harmonic distortion at higher output levels, addressing the limitations of the older B71 model (Eichenauer et al., 2014; Håkansson, 2003). Left, Right, Ground, and Vertex electrodes were placed on the skin to record electrical signals generated from VEMPs to assess vestibular function (Cabral et al., 2008). A Lenovo Thinkpad Laptop equipped with Otoaccess software acted as the central hub, managing vestibular testing by controlling stimuli, recording responses, and storing data, while allowing for real-time signal monitoring and precise stimulus timing (Interacoustics, 2022c). The Interacoustics Eclipse system, equipped with a VEMP module, elicited VEMP responses through auditory stimuli, which were visually represented as graphs. This

enabled researchers to calculate electromyographic scaling for further analysis (Interacoustics, 2022c). Signal quality and accuracy were further optimised with the use of an EPA pre-amplifier, enhancing the signal-to-noise ratio during VEMP testing (Interacoustics, 2022a; NF Corporation, 2020).

2.3. Participant selection and data collection procedures

VEMP testing, or data collection, was initiated following the completion of comprehensive case history (Appendix C), as well as audiological and vestibular screenings. Following the screening process, participants were given a 15-minute break before VEMP testing commenced.

To obtain cVEMP results, participants were seated in a chair and prepared for EMG electrode placement by scrubbing the skin at designated sites (Appendix F) — sternocleidomastoid (SCM) midpoint, forehead, and sternum—with gauze swabs and NuPrep skin gel. This step was essential to ensure optimal adhesion and conductivity of the electrodes (Crumley, 2011). A thin layer of Ten20 conductive gel was applied to the scrubbed areas to enhance electrical signal transmission and to ensure low-impedance results (Yang et. al, 2018). To maintain electrode stability throughout testing, adhesive tape was applied over the electrode montage, ensuring the electrodes remained securely in place for the duration of the session. This step was critical in obtaining reliable and stable responses. Furthermore, all consumables were used individually for each participant to adhere to infection control protocols.

Electrodes (non-inverting, ground, and inverting) were strategically positioned on both sternocleidomastoid muscle belly's, middle forehead and clavicle to measure myogenic responses to BC CE-Chirp sound stimuli. Participants were instructed to maintain sustained contraction of the SCM muscle while turning their heads 45° away from the tested side (Hain, 2021). The intensity of the muscle contraction was monitored using an electromyography (EMG) monitor, with an optimal target range set between 50 to 150 µV to ensure the reliability of the results (Bogle et al., 2013). A B81 bone conductor was utilised to deliver a 500 Hz narrowband CE-Chirp stimulus to elicit cVEMP responses. To guarantee the accuracy of the electrode function, impedance levels were measured, with a cutoff threshold of less than 5 kOhms deemed acceptable (Interacoustics, 2016; Interacoustics, 2022c). The Interacoustics Eclipse system was employed and configured for 200 sweeps with a sweep time of 100 ms (Isaradisaikul

et al., 2012). Following the cVEMP testing, the peaks P1 and N1 were identified for subsequent waveform analysis (Interacoustics, 2022c). To mitigate potential tester bias, both c- and oVEMP result interpretation and waveform marking were performed by multiple skilled vestibular experts, reducing subjectivity and enhancing result reliability.

To obtain oVEMP results, participants were seated in an upright position in a quiet room. The facial areas below the eyes and chin were cleansed with gauze swabs and NuPrep skin gel, ensuring stable myogenic responses throughout the testing process. A montage of three surface EMG electrodes were placed to capture the oVEMP response (Curthoys et al. 2009; Iwasaki et al. 2009; Manzari et al. 2010c): the non-inverting electrode was positioned 1 cm below the lower eyelid of the eye opposite the sound stimulus; the inverting electrode was placed on the participant's chin and the ground electrode was placed on the participant's forehead. Participants were instructed to direct their gaze upwards, ideally at a 30-degree angle, to facilitate the elicitation of larger responses (Chihara et al., 2007; Rosengren et al., 2006). A 500 Hz NB CE-chirp stimulus was randomly presented via the B81 bone conductor. This frequency was chosen for its ability to elicit robust VEMP responses with minimal variability (Coban et al., 2020; Colebatch et al., 2016; Clinard et al., 2020). Responses were recorded for P1 and N1 latency, P1-N1 amplitude, left-right asymmetry ratio, and threshold, with results recorded on a data collection sheet (Appendix C). Amplitudes were measured from baseline to peak, and peak-to-peak amplitudes, as well as N1 and P1 latencies, were assessed at maximal stimulation intensity.

The initial test session (T1) involved recording CE-Chirp-evoked VEMPs for both c- and o-VEMPs using the B81 bone conductor, with the session lasting approximately one hour. T1 was initiated by conducting either c- or oVEMP testing, depending on the randomised order of electrode montage assigned to each participant. For half of the study population, cVEMP testing was performed first, while the other half began with oVEMPs. To enhance the reliability and consistency of the VEMP results, all test results were repeated.

Following the completion of the initial testing session (T1), participants were given a 30-minute break to minimise the effects of potential muscle fatigue. Subsequently,

participants engaged in a second session (T2) on the same day, during which the same electrode montage was maintained, and tests were performed with identical duration and protocols as in T1. For within-session reliability, the same researcher conducted both T1 and T2, ensuring consistency in the administration of the tests. A third session (T3) was scheduled one week later, mirroring the procedures established in T1. cVEMP and oVEMP testing were done in varying sequences during each instance, occasionally commencing with cVEMPS and at other times with oVEMPS.

Bias can arise during the manual identification of waveforms, as subjective judgement is often required, particularly when signal amplitudes are low or waveforms are unclear. To mitigate this potential bias, the current study employed researcher triangulation (Brink et al., 2018), where multiple experienced vestibular researchers independently marked and interpreted the waveforms. This method reduced subjective influence and enhanced the reliability of waveform identification (Pannucci & Wilkins, 2011).

VEMP parameters are mostly similar for both cVEMPs and oVEMPs. Both require the following: an impedance of less than 5 k Ω, a stimulus intensity of 50/55 dB HL and a stimulus rate of 5.1/s. Both are recorded with a rarefaction polarity in a 100 ms time window with low pass filters being set at 1000 Hz and high pass filters being set at 10 Hz. cVEMPs require an artefact rejection of 800µV where oVEMPs require it at 400 µV. cVEMPs require gain of 2000 and oVEMPs require gain of 20 000. cVEMPs are recorded between 150-200 sweeps where oVEMPs require 300 sweeps. Regarding each VEMPs required muscle contraction, cVEMPs require the SCM to be between 50-150 V and oVEMPs do not require a specific EMG monitored muscle contraction for results to be recorded.

2.4. Data analysis

Data from one participant was excluded as the participant did not return for testing at T3. In total, data from 20 participants was analysed. Descriptive and inferential statistical analyses were employed to evaluate the collected data, utilising IBM SPSS Statistics for Windows (version 29). The normality of the data distribution was assessed through several methods, including the investigation of skewness, visual examination of Q–Q plots, and the Shapiro-Wilk test regarding all variables for each stimulus, bilaterally. Results from these analyses indicated that the collected data was not normally distributed for both c- and oVEMPs. cVEMP parameters with no significant

differences (or T1, T2 and T3 N1 latencies, P1-N1 amplitudes and AR) (*W*= 0.91 to 0.975; p>0.05), as well as parameters with significant differences (or T1, T2 and T3 P1 latencies as well as T2 P1-N1 amplitude) (*W*= 0.795 to 0.884; p<0.05), confirm not normally distributed data. oVEMP parameters with no significant differences (or T1 and T2 P1 latencies, N1 latencies and P1N1 amplitude and T3 N1 latencies, N1P1 amplitude) (*W*=0.914 to 0.922; p>0.05), as well as parameters with significant differences (or T3 P1 latencies, N1-P1 amplitudes and AR) (*W*= 0.632 to 0.877; p<0.05), additionally confirm not normally distributed data. Consequently, nonparametric statistical methods were applied. In addition, the median and standard error were used to determine statistically significant differences between ears and gender for each test.

The Wilcoxon Signed Rank Test for independent samples revealed no statistically significant differences for P1 latency (W= -0.876 to -0.256; p>0.05), N1 latency (W=-1.709 to -0.829; p>0.05), and P1-N1 amplitude (W=-0.501 to -0.109; p>0.05) parameters between ears for cVEMP and oVEMP N1 latency (W= -1.258 to -1672; p>0.05, P1 latency (W= -378 to -943; p>0.05), and N1-P1 amplitude (W= -628 to -1.664; p>0.05).

Further data analysis using the Mann-Whitney U test showed no statistically significant differences between genders for cVEMP variables, including P1-N1 amplitude (U= -0.653 to 0; p>0.05), P1 latency (U= -3.041 to -0.943; p>0.05) and N1 latency (U= -2.616 to -1.022; p>0.05). Furthermore, similar analysis confirmed no statistically significant differences between genders for oVEMP variables P1-N1 amplitude (U= -1.006 to -0.096; p>0.05), P1 latency (U= -1.054 to -0.532; p>0.05) and N1 latency (U= -1.595 to 0; p>0.05) as well.

Due to the lack of statistical independence between the ears, data from both ears were pooled to facilitate a more efficient and simplified analysis (Colegrave & Ruxton, 2017). Since no statistically significant differences were observed between the left and right ear responses, pooling the data eliminated the need to account for inter-ear variability, thereby streamlining the analysis process. This method also enhanced the statistical power by increasing the sample size, allowing for a more robust and comprehensive interpretation of the results without the confounding influence of redundant comparisons. The pooled c- and oVEMP data were confirmed to be non-normally

distributed, supporting the continued use of nonparametric tests for further statistical evaluations.

The Friedman test and Wilcoxon Signed Rank Test were utilised to investigate potential differences across the three test sessions for both c- and oVEMPs. Spearman's Correlation Coefficient (Spearman's rho) was employed to evaluate the absolute reliability of the measurements by assessing the strength and direction of the relationships between variables (Xiao et al., 2015). A value of $p<0.05$ was accepted as statistically significant.

3. Results

cVEMPs

Data from 20 right ears and 20 left ears were analysed. Table 1 shows the median and Standard Error (SE) for P1 latencies, N1 latencies, P1-N1 amplitude, and asymmetry ratio for right and left ears for T1, T2, and T3.

Table 1: Mean and standard error (SE) for Cervical Vestibular Evoked Myogenic Potentials (n=40)

		Test 1			Test 2			Test 3		
		Right ear	**Left ear**	**Both**	**Right ear**	**Left ear**	**Both**	**Right ear**	**Left ear**	**Both**
P1 latencies (ms)	Median	12.00	12.00	12.00	11.33	12.00	11.67	12.00	12.33	12.00
	SE	0.38	0.43	1.71	0.37	0.46	1.80	0.59	0.62	2.59
N1 latencies (ms)	Median	20.67	21.33	20.84	20.83	21.33	21.00	20.67	20.33	18.00
	SE	0.42	0.46	1.87	0.46	0.55	2.20	0.51	0.49	4.55
P1-N1 amplitude (µV)	Median	84.22	88.51	88.5	108.82	85.76	88.47	91.8	99.37	94.10
	SE	10.74	14.36	53.25	10.36	11.95	48.01	8.82	12.25	45.33
AR (%)	Median	0.18			0.19			0.175		
	SE	0.02			0.04			0.03		

ms = milliseconds; µV = microvolt; AR = asymmetry ratio, SE= Standard Error

P1 latencies had similar median values for T1, T2 and T3, which were also found to be similar when considering pooled data for left and right ears. SE values were observed higher in T3 than T1 and T2. N1 latencies had median values close to one another for T1, T2 and T3 with higher SE values for T3. The median values for the P1-N1 amplitude had a wide range and variable SE values. The asymmetry ratios for T1, T2 and T3 were close to each other in value, as well as the corresponding SE values.

The Friedman test indicated a significant difference between variables (χ^2= 239.717; p<0.001), although it did not clarify which specific variables or sessions (within or between sessions) were involved in this difference. A repeated Wilcoxon Signed Rank Test further identified no significant within-session differences (T1 and T2) for P1 latencies (p= 0.980), N1 latencies (p= 0.665), or P1-N1 amplitudes (p=0.267). Between sessions, no significant differences regarding T1 and T3 for P1 latency (p= 0.068) and P1-N1 amplitude (p= 0.683). N1 latencies showed a significant difference between sessions but not regarding within-session testing, specifically between T1 and T3 (p<0.001). Significant differences were identified comparing between-session testing sessions T2 and T3 for P1 (p= 0.045) and N1 latencies (p<0.001), but not for P1-N1 amplitude (p= 0.845).

Spearman's correlation coefficient analysis revealed good correlation between P1 latencies (r= 0.829; p<0.001), N1 latencies (r= 0.707; p<0.001) and P1-N1 amplitudes (r= 0.706; p=<0.001) and weak correlation for asymmetry ratios (r= 0.329; p= 0.251) regarding within session testing sessions T1 and T2. A moderate correlation (r = 0.413, p=0.012) between P1 latencies in between-session testing sessions T1 and T3, while poor correlations were observed for N1 latencies (r= 0.180, p= 0.293) and P1-N1 amplitudes (r= 0.253, p= 0.136) in the same between-session tests. A good correlation was also revealed between within-session tests T1 and T2 for P1 latencies (r= 0.829; p<0.001), N1 latencies (r= 0.707; p<0.001) and P1-N1 amplitude (r= 0.706; p<0.001). A moderate correlation was found for between-session tests T2 and T3 P1 latencies (r= 0.466; p= 0.004), and P1-N1 amplitude (r= 0.465; p= 0.004), while a poor correlation was found between the corresponding N1 latencies (r= 0.112; p= 0.508).

Additionally, the asymmetry ratio of T1 vs T2 illustrated a poor correlation (r= 0.329, p= 0.251) and T1 compared to T3 demonstrated a good correlation (r= 0.788; p= 0.007) when assessed using Spearman's rho.

oVEMPs

Data from 20 right ears and 20 left ears were analysed. Table 2 shows the median and Standard Error (SE) for P1 latencies, N1 latencies, P1-N1 amplitude and Asymmetry Ratio for right and left ears for T1, T2, and T3.

Table 2: Mean and standard error (SE) statistics for Ocular Vestibular Evoked Myogenic Potentials (n=40)

		Test 1			Test 2			Test 3		
		Right ear	**Left ear**	**Both**	**Right ear**	**Left ear**	**Both**	**Right ear**	**Left ear**	**Both**
P1 latencies (ms)	Median	11.67	12.34	11.67	11.33	12.67	12.00	11.00	11.67	11.67
	SE	1.16	1.13	4.20	1.02	0.98	4.13	0.94	0.28	2.03
N1 latencies (ms)	Median	7.00	7.50	7.33	7.00	7.67	7.50	7.00	7.33	7.33
	SE	1.16	1.13	4.36	1.00	1.03	4.09	0.64	0.28	1.88
P1-N1 amplitude (µV)	Median	16.60	12.660	15.66	17.30	9.7	13.90	18.86	19.40	18.92
	SE	3.94	3.255	13.83	3.88	3.63	15.33	3.53	3.80	12.95
AR (%)	Median	0.16			0.19			0.20		
	SE	0.06			0.06			0.04		

ms = milliseconds; µV = microvolt; AR = asymmetry ratio, SE= Standard Error

P1 median values were overall larger for the right ear compared to the left, but similar in value regarding SE measurements. N1 latencies were all between 7.00 and 8.00 for all tests with lower T3 SE values compared to T1 and T2. The P1-N1 amplitudes were larger in the right ear compared to the left for T1 and T2, but similar in T3. The corresponding P1-N1 SE values were all similar and ranged from 3.00 to 3.88 for all the values and tests. The asymmetry ratios grew larger from T1 to T3, with SE values being very similar.

The Friedman test revealed a p-value of <0.001 (χ^2= 85.333), indicating a significant difference across all tested variables. However, it was unclear which specific variables (P1 latencies, N1 latencies or P1-N1 amplitude) or sessions (within-session or between-session) contributed to this difference. A repeated Wilcoxon Signed Rank

Test identified no significant differences were found between within-session tests T1 and T2's P1 latencies (p= 0.757), N1 latencies (p= 0.275) or P1-N1 amplitudes (p= 0.689). Significant differences (p<0.05) were found for between-session tests T1 and T3 for several parameters, including P1 latencies (p= 0.013) and N1 latencies (p= 0.021), suggesting significant between-session variability. The P1-N1 amplitude (p= 0.689) and asymmetry ratio (p= 0.875) indicated no significant differences when these between-session testings were compared.

Spearman's correlation coefficient for within-session comparisons of T1 compared to T2 indicated a moderate correlation for P1 latencies (r= 0.594; p= 0.001), but a good correlation for N1 latencies (r= 0.870; p<0.001) and P1-N1 amplitude (r= 0.791; p<0.001). A moderate correlation was indicated when comparing between-session tests T1 and T3 parameters namely P1 latency (r= 0.581; p= 0.002), N1 latency (r= 0.613; p= 0.001) and P1-N1 amplitude (r= 0.677; p<0.001). A poor correlation was identified for between-session tests T2 and T3 P1 latencies (r= 0.371; p= 0.074) while a moderate correlation was revealed between both N1 latencies (r= 0.584; p= 0.002) and P1-N1 amplitude (r= 0.533; p= 0.007).

The asymmetry ratio of T1 vs T2 illustrated a weak correlation (r= 0.329; p= 0.251) and no significant difference indicative of good reliability, while asymmetry ratios compared for between-session tests T1 and T3 displayed good correlation (r= 0.788; p= 0.007) and a significant difference indicative of poor reliability.

4. Discussion

The current study aimed to evaluate the test-retest reliability of c- and o-VEMPs elicited by a 500 Hz narrowband CE-Chirp using the B81 bone conductor both within- and between-sessions. The current study demonstrated strong within-session correlation for cVEMP measurements, but noted moderate to poor correlation for between-session testing. The present study found moderate to good correlation for within session oVEMP measurements and moderate correlation regarding between session oVEMP measurements.

The current study identified no significant differences and strong within-session correlations for all cVEMP parameters including P1 latencies, N1 latencies, P1-N1 amplitudes, and asymmetry ratios. No significant differences (p= 0.012) and moderate

correlation were found for between-session testing regarding P1 latencies. Although no significant differences were identified for N1 latencies (p= 0.293) and P1-N1 amplitudes (p= 0.136) and asymmetry ratios (p= 0.007), correlations were poor.

For oVEMP testing, moderate correlation and significant differences were measured for within-sessions regarding P1 latencies (p= 0.001), while good correlations and significant differences were identified for N1 latencies (p<0.001) as well as N1-P1 amplitudes (p<0.001). A poor correlation was identified for asymmetry ratios with no significant difference (p= 0.251). Results obtained for between session testing indicated a moderate correlation and significant difference for N1 latencies (p= 0.001), P1 latencies (p= 0.002), N1-P1 amplitudes (p<0.001) and a good correlation and no significant difference was identified for asymmetry ratios (p= 0.007).

cVEMPS

The current study demonstrated strong within-session correlation for cVEMP measurements, but noted moderate to poor correlation for between-session testing. Good within-session correlation was measured in all the variables measured namely P1 latency (r= 0.829; p<0.001), N1 latency (r= 0.707; p<0.001) and P1-N1 amplitude (r= 0.706; p<0.001). Moderate correlation was identified for between-session P1 latencies (r= 0.413, p= 0.012) and poor correlation was identified for between-session N1 latencies (r= 0.253, p= 0.136) and P1-N1 amplitudes (r= 0.180, p= 0.293). This finding aligns with studies by Anupriya and Kumar (2019), which reported that cVEMP with an AC stimulus demonstrated high reliability for within-session recordings but vary in between-session reliability depending on if the VEMPS were measured sequentially or simultaneously.

The present investigation indicates that cVEMP P1 latencies serve as an effective metric for assessing reliability, but N1 latencies are variable and not a reliable measurement. Variability in latency measurements can arise from numerous external influences. Kumar et al. (2018) identified several potential factors impacting latency reliability, including the methods of stimulus presentation— specifically, the distinctions between AC and BC, as well as the effects of forehead taps or vibrations during testing. Additional considerations, such as participant seating and the type of stimulus utilised, have also been implicated in previous studies (Isaradisaikul et al. 2008; Nguyen et al. 2010; Behtani et al. 2018). The current study aimed to mitigate these previously

reported influences to enhance the reliability of cVEMP measurements. This was accomplished by utilising bone conduction CE-Chirps delivered via a B81 bone conductor, which is anticipated to provide a more consistent stimulus and reduce variability associated with external factors. Literature suggests N1 latencies are more reliable and robust (Maes, 2009; Murofushi et al., 2001), however it was found to have poor reliability during the current study. This finding may be due to any of the discussed influences that may have differed in between session testing, for example participant seating. P1 latencies are recognised for their diagnostic sensitivity to abnormalities within the auditory pathway, however in the present study P1 latencies' reliability across sessions appears less reliable than suggested in previous literature.

The present study also assessed the reliability of cVEMP P1-N1 amplitudes, revealing robust within-session reliability but demonstrating poorer reliability in between-session comparisons. The study's results indicate a consistent pattern of high reliability when patients are retested within the same session, a finding that echoes the conclusions of Isaradisaikul et al. (2008) and Anupriya and Kumar (2019), who similarly reported strong intra-session reliability for cVEMP measurements in normal hearing adults. However, the present investigation did not compute similar high reliability results regarding between-session reliability as poor correlations were found in this study after a one-week interval regarding P1-N1 amplitudes. This discrepancy suggests that while cVEMP measurements may be stable within a single session, they are susceptible to variability when tested over longer periods as found in studies done by Reddy et al. (2020) and Anupriya and Kumar (2019). The variability in between-session P1-N1 amplitude comparisons may be attributed to several factors, notably the inconsistencies in SCM muscle contraction levels that can occur intra-subject. This phenomenon has been extensively discussed in the literature, with authors pointing out the influence of muscle activation on cVEMP outcomes (Rosengren et al, 2009). Many external factors may play significant roles in modulating results at the time of re-testing participants, including health status and electrode placement.

Electrode placement is a critical factor influencing the reliability of cVEMP recordings. Present investigation included electrodes placed at the midpoint of the SCM muscle, forehead, and sternum, following the standardised placement protocols to ensure consistent myogenic responses (Interacoustics, 2022c). This approach is consistent with methodologies employed by Maes et al. (2009), who emphasised the importance

of standardised electrode positioning to enhance the reliability of cVEMP measurements. Variable electrode placement may influence the reliability of between session testing as a wrong or too low electrode placement may result in a point referred to as the nulls point where no response from the corresponding muscle will be recorded in the session (Interacoustics, 2022a).

Muscle contraction methods varied across studies, with some using self-sustained contractions similar to the current study, while others employed external aids like manometers to ensure stable muscle activity (Maes et al., 2009). Maes et al. (2009) found that utilising a blood pressure manometer to sustain SCM muscle contraction led to strong test-retest reliability, demonstrating the significance of maintaining consistent muscle activation throughout testing. Thus, inconsistent muscle contraction may thus be considered as an external influence that will alter the reliability of between session testing.

oVEMPS

The present study found moderate correlation for the oVEMP parameters namely N1 latencies ($r= 0.870$; $p<0.001$), P1 latencies ($r= 0.594$; $p= 0.001$) and strong correlation was found for N1-P1 amplitude ($r= 0.791$; $p<0.001$) for within-session measurements. Moderate correlation was found for between session testing regarding N1 latencies ($r= 0.613$; $p= 0.001$), P1 latencies ($r= 0.581$; $p= 0.002$) as well as N1-P1 amplitudes ($r= 0.677$; $p<0.001$). This moderate correlation identified alongside a significant difference between variables may suggest a larger sample size is needed for the correlation and significance to align in deductions. The correlation identified between variables are independent of the sample size, therefore oVEMP N1 latencies, P1 latencies and N1-P1 amplitudes may still be considered to have moderate reliability.

VEMP testing has been reported to be reliable in the adult population when using AC and BC stimulation via various methods such as clicks with headphones, taps with a mini shaker, and clicks with a B71 bone conductor (Nguyen et al., 2010, Versino et al, 2001); however, there is limited information on test retest reliability when using the B81 bone conductor in conjunction with a CE chirp stimulus to elicit oVEMPs.

When considering between-session test-retest reliability, poor between-session correlation was observed in the current study, as observed similarly by Reddy et al

(2022) for 500 Hz AC NB CE-Chirp oVEMP N1 and P1 latencies. Significant differences regarding N1 and P1 latencies of between-session testing were identified. Coban et al (2020) investigated the effect of a 500 Hz BC CE-Chirp stimulus on oVEMP response latencies, stating that a chirp stimulus compensates for temporal dispersion in the cochlea by synchronising the arrival of each frequency component with its point of maximum excitation along the basilar membrane, resulting in shorter N1 and P1 latencies. Latency parameters are suggested to not be reliable and it is recommended that amplitude parameters rather than latency parameters be used to monitor changes over time.

The use of 500 Hz NB CE-Chirps conducted through a B81 Bone Conductor in the current study, to elicit oVEMP amplitude responses, proved to be reliable for within- and between-session testing. This suggests that while oVEMP testing generally exhibits amplitude reliability across multiple studies, factors such as testing methods, including different types of transducers and stimuli, may influence the consistency of outcomes, warranting further investigation into the specific conditions that impact oVEMP amplitude reliability. A study by Piker et al. (2011) states that the oVEMP amplitude is reliable, as it is not an inhibitory potential which is the case with cVEMP repossess, but rather an excitatory response (Piker et al., 2011). This statement has been supported by the current study as good reliability and non-significantly different amplitude parameters were found in regards to within- and between-session reliability. Nguyen et al. (2010) investigated a larger pool of participants with a variety of stimuli where they found good to excellent within-session reliability for N1-P1 amplitude parameters. Piker et al. (2011) found excellent between-session reliability when measuring oVEMP amplitudes, on average being ten weeks apart. In contrast Reddy et al. (2022) found poor between-session test-retest reliability for oVEMP amplitude responses when using 500 Hz AC NB CE-Chirp, similar to this study.

The current study measured oVEMP asymmetry ratios of moderate to strong correlation for within-session testing. These results play a part in establishing test-retest reliability of oVEMPs when using a 500 Hz NB CE-Chirp with a B81 Bone Conductor. This is in agreement with Reddy et al. (2022) who observed overall poor between-session reliability with the only difference to the current study being AC stimulation. Contrary to the aforementioned study, Nguyen et al. (2010) found excellent

reliability for oVEMP asymmetry ratios. This is in agreement with the current study's findings which yielded asymmetry ratios

Regarding cVEMP and oVEMP testing, the present study followed a structured protocol with testing conducted within the same session and one week later for between-session reliability assessment. Testing intervals were similar to those used in Maes et al. (2009), where participants underwent repeated testing within a single session and again between sessions to evaluate VEMP reliability. The current study implemented a 30-minute resting period between tests within the same session, while Maes et al. (2009) used longer rest intervals to minimise muscle fatigue effects. The results show that the present study's within-session correlation was moderate to strong, matching findings from Maes et al. (2009). Between-session correlation was found to not be as reliable as the previously obtained within-session moderate to strong correlation, reflecting similar patterns in other research such as Reddy et al. (2020).

Clinical implications

cVEMP parameters that illustrated good reliability are P1 latencies, P1-N1 amplitudes and asymmetry ratios for within and between session testing. Monitoring of changes in specific pathologies that have influenced or may influence vestibular function of the saccule and inferior vestibular nerve may be used through analysing the P1 latencies, P1-N1 amplitudes and asymmetry ratios of cVEMPs. N1 latencies cannot be considered part of this analysis as it has demonstrated poor reliability for between session testing which will be essential in monitoring the progression of a pathology over time. The identification of anatomical anomalies or current vestibular dysfunctions may also be obtained through the analysis of P1 latencies, P1-N1 amplitudes and asymmetry ratios.

oVEMP parameters that illustrate good reliability are asymmetry ratios for within and between session testing. Specific pathologies that influenced or may influence the utricle and superior vestibular nerve may be used by analysing the asymmetry ratios of oVEMPs. P1 latencies and N1 latencies alongside N1-P1 amplitudes were demonstrated not to be reliable and can thus not be used to monitor a pathology over time. Current anatomical anomalies or vestibular dysfunction may be identified through the analysis of asymmetry ratios as they have been shown to demonstrate reliable results for within and between session testing.

These findings suggested that while the current protocol is effective for identifying vestibular dysfunctions or anatomical anomalies, caution should be exercised in interpreting latency measures for monitoring of vestibular function over time as latencies are not a reliable source of information regarding vestibular function.

Limitations and recommendations

The current study was careful to consider measurement error to ensure the accuracy and reliability of the results. The conduction of multiple sessions (T1, T2, and T3) with scheduled breaks allowed for a comprehensive evaluation of both within-session and between-session reliability. This approach mitigated systematic biases, such as participant or muscle fatigue to the test, ensuring that any observed variability was due to true test-retest differences rather than random errors or procedural inconsistencies.

Variation of electrode placements may have played a possible role in the significant difference observed between oVEMP N1 latencies and P1 latencies compared between T1 and T3, or between-session testing (Isaradisaikul et al. 2008). Due to researcher variability for between session recordings, inconsistent electrode placements may be dismissed in playing a role in the differences regarding within- and between session latencies.

VEMP recordings, when elicited by the advantageous B81 bone conductor which produces less distortion when stimulus intensity is increased, compared to the B71, had the potential to deliver increased responses. The use of the B81 in conjunction with the CE-Chirp stimulus increased the potential VEMP responses further (Bas et al., 2020; Mat et al., 2021). The researchers recommend more research be conducted to investigate the test-retest reliability of eliciting VEMPs via the B81 bone conductor using a CE-Chirp stimulus as limited data regarding BC stimuli exist at this time. Larger sample sizes across different populations or testing where specific pathologies affect the vestibular system functioning, for example SSCD, Ménière's disease and vestibular neuritis, may be considered for future studies. As VEMPs are considered an example of monitoring methods for the progression of vestibular pathologies, it may be useful to test the reliability of VEMPs when regarding a specific pathology.

5. Conclusion

The current literature lacks substantial evidence on the test-retest reliability of BC cVEMPs and oVEMPs, particularly when using a CE-Chirp stimulus. This study aimed to investigate reliability of the P1 and N1 latencies, P1-N1 amplitude, and asymmetry ratio evoked by a 500 Hz CE-Chirp delivered through a B81 bone conductor. Within-session testing yielded reliable outcomes for most cVEMP parameters, with the exception of N1 latencies. The asymmetry ratios for oVEMP testing was deemed reliable as the N1 latencies, P1 latencies and N1-P1 amplitude cannot be considered reliable during re-testing. Thus, the B81 bone conductor combined with the CE-Chirp shows potential for reliable within session evaluation of vestibular function, particularly through P1-N1 amplitudes and asymmetry ratios.

However, between-session latencies exhibited significant variability, limiting their reliability across multiple testing sessions. These findings suggest that while the current protocol is effective for identifying vestibular dysfunctions or anatomical anomalies, caution should be exercised in interpreting latency measures for monitoring of vestibular function over time. Future research should explore alternative stimuli and electrode montages to improve between-session reliability and further refine bone-conducted VEMP testing methods for broader clinical application.

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Appendices

Appendix A: Ethical Clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100. Since 1919

Department of Speech- Language Pathology and Audiology

7 March 2024

Dear Researchers,

Project:	Test-retest reliability of CE-Chirps using the B81 bone conductor for cervical and ocular vestibular evoked myogenic potentials.
Researchers:	Kaylee Boyens (19036869), Marli Coetzee (21446068), Aakifah Saban (17009032), Anome Victor (21640336)
Supervisors:	Prof L. Biagio de Jager, Ms T. Reddy
Department:	Department of Speech-Language Pathology and Audiology
Reference Number:	SLPA2024/09

Thank you for the application submitted to the Research Committee of the Department of Speech-Language Pathology and Audiology, Faculty of Humanities. We have the pleasure of informing you that the above application was approved on 7 March 2024.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal.

We wish you success with the project.

Sincerely

Prof Lidia Pottas
Chair: Departmental Research Committee

Prof J van der Linde
HEAD: DEPARTMENT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY

Room 7.22, Level 7, Humanities Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Email makone.maja@up.ac.za | www.up.ac.za

Appendix B: Informed Consent Form

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Test-retest reliability of bone conducted CE-Chirps using the B81 bone conductor to record cervical and ocular vestibular evoked myogenic potentials

Please complete the following:

I, _____, hereby acknowledge that I have received and read the information letter pertaining to the research study titled: Test-retest reliability of bone conducted CE-Chirps using the B81 bone conductor to record cervical and ocular vestibular evoked myogenic potentials.

I confirm that I understand the information provided therein regarding the nature and purpose of the study, as well as the procedures involved.

I acknowledge that I had the opportunity to ask any questions I deemed necessary regarding the study, and that satisfactory answers were provided to me by the researcher(s) or their designated representatives.

I hereby consent to voluntarily participate in the aforementioned research study. I understand that my participation is entirely voluntary, and I reserve the right to withdraw from the study at any time without any adverse consequences or penalties.

I understand that any data collected from me during the course of this study will be used solely for research purposes in accordance with the terms outlined in the information letter. I acknowledge that appropriate measures will be taken to ensure the confidentiality and anonymity of my data.

I agree to comply with all study procedures and instructions provided by the researcher(s) or their designated representatives to the best of my ability.

_____ _____

Signature of participant Contact Number

_____ _____

Date Alphanumeric Code

(completed by researcher)

Appendix C: Case History

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Case history

Alphanumeric code:_____

Please fill in the following as accurately as possible.

Circle where applicable e.g.,	Yes	No

English Competence: How well do you understand spoken English?

Excellent	
Good	
Poor	
Not at all	

Afrikaans Competence: How well do you understand spoken Afrikaans?

Excellent	
Good	

Poor	
Not at all	

General information				
Birthdate	Year /month /day		/ /	
Male, female, non-binary, other	Male	Female	Non-binary	Other
Preferred contact method	SMS	WhatsApp	Call	Email
Please provide contact information: e.g., cell phone number or email address				

Hearing					
Have you noticed a decrease in your hearing?	Yes	No	Right	Left	Both
Do you feel your hearing is the same in both ears or do you have a better ear?	Right	Left	Both		
	Yes	No	Right	Left	Both

Do you ever hear a ringing or buzzing noise in your ears? **Describe:**			
Family history of hearing loss?	Yes	No	
Do you struggle to understand people when they are talking and ask for repetition?	Yes	No	
Do you struggle to follow a conversation when it is noisy around you?	Yes	No	
Do you experience any dizziness, imbalance or falls?	Yes	No	

Ears					
Have you noticed any problems with your ears? Pain?	Yes	No	Right	Left	Both
Do you experience aural fullness?	Yes	No	Right	Left	Both
Have you had/ do you get ear infections	Yes	No	Right	Left	Both

Do you have any discharge from your ears? (last 3 months)	Yes	No	Right	Left	Both
Have you had any head injuries?	Yes	No			
Have you had any neck, ear or head surgeries? **If yes, what surgeries?**	Yes	No			

	Medication and health			
Are you currently sick, or have you been sick recently?	Yes	No		
Do you have any medical diagnosis? (e.g., hypertension, diabetes)	Yes	No		
Speech and/or language difficulties	Yes	No		
Arthritis	Yes	No		
Heart conditions	Yes	No		
	Yes	No	Chronic	

Are you currently taking any medication?				

Balance		
Do you ever feel off balance?	Yes	No
If yes when does this happen		
Does it ever feel like the room you are in is spinning?	Yes	No
If yes, when does this happen?		
Have you ever been diagnosed with a balance disorder?	Yes	No
If yes, please elaborate.		

Appendix D: Audiological Screening Form

UNIVERSITEIT VAN PRETORIA
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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

AUDIOLOGICAL SCREENING DATA COLLECTION FORM

Patient number: _____ Audiology student: _____

Patient DOB, age: _____ Date: _____

Gender: _____ Alphanumeric code:_____

Otoscopy

Right ear	Left ear

Pure tone testing

Frequency	Right ear threshold	Left ear threshold
500 Hz		
1000 Hz		
2000 Hz		
4000 Hz		
PTA		

Tympanometry

Screening tymp (226 Hz)	**Right ear tympanogram type**	**Left ear tympanogram type**
Acoustic reflex (1000 Hz)	**Right ear threshold**	**Left ear threshold**

Patient meets all audiological study requirements	
Yes	No

_____ _____

Patient signature Student signature

Appendix E: Vestibular Screening Form

UNIVERSITEIT VAN PRETORIA
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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

VESTIBULAR SCREENING DATA COLLECTION FORM

Patient number: _____ Audiology student: _____

Patient DOB, age: _____ Date: _____

Gender: _____ Alphanumeric code:_____

Spontaneous nystagmus

	Present/absent:
With vision/light	
With vision denied	

Smooth pursuit

Able to follow movements smoothly	Unable to follow movements smoothly

Head impulse test

Able to maintain fixated gaze	Overshoots/ undershoots/ unable to maintain fixated gain

Bucket test

Degrees of deviation	**Interpretation**	
	Normal deviation	Abnormal deviation

Hyperventilation induced nystagmus

Present nystagmus:	Absent nystagmus

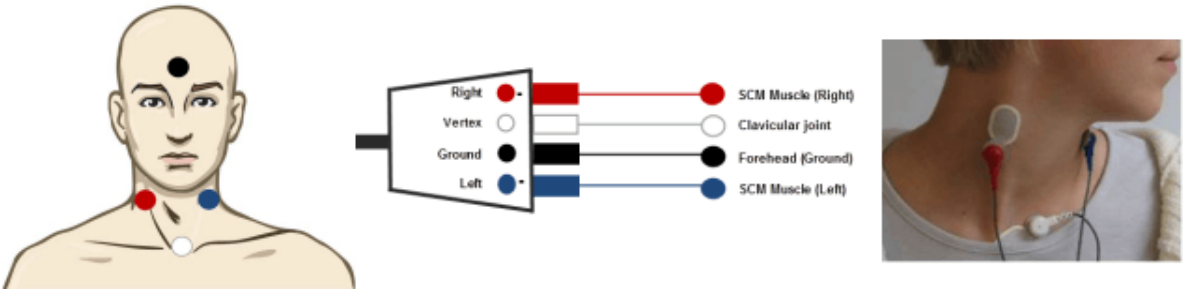
Patient meets all vestibular study requirements	
Yes	No

_____ _____

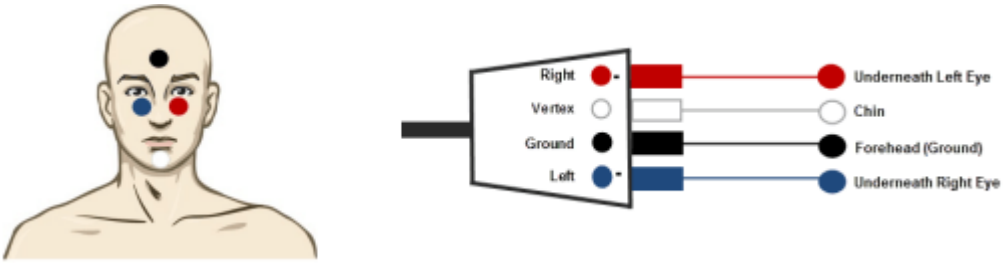
Patient signature Student signature

Appendix F: Electrode Placement

cVEMP (Interacoustics, 2022b)



oVEMP (Interacoustics, 2022d)



Appendix G: Data Collection Form

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Data collection form

Patient number: _____ Audiology student: _____

Patient DOB, age: _____ Date: _____

Gender: _____ Alphanumeric code:_____

cVEMP results:

Ear	**P1 latency (ms)**	**N1 latency (ms)**	**Inter-peak amplitude (µV)**	**Asymmetry ratio (%)**	**Normal (N) Abnormal (A)**
Left					
Right					

oVEMP results:

Ear	**P1 latency (ms)**	**N1 latency (ms)**	**Inter-peak amplitude (µV)**	**Asymmetry ratio (%)**	**Normal (N) Abnormal (A)**
Left					
Right					

_____ _____

Patient signature Student signature

Appendix H: Participant Information Letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Test-retest reliability of bone conducted CE-Chirps using the B81 bone conductor for cervical and ocular vestibular myogenic potentials in adults with normal hearing.

Principal Investigator

Anomé Victor

Department of Audiology

083 287 5151

u21640336@tuks.co.za

INVITATION TO PARTICIPATE IN A RESEARCH STUDY

Dear invitee

We are pleased to invite you to participate in a research study. Our team comprises fourth-year Audiology students enrolled at the University of Pretoria. The focus of this study is to assess the test-retest reliability of bone-conducted CE-Chirps using the B81 bone conductor for eliciting cervical and ocular vestibular myogenic potentials in adults with normal hearing. This research initiative is motivated by the requirements of our KMP 481 module, an integral component of the BA Audiology degree program at the University of Pretoria. The study is conducted under the guidance and supervision of Professor Leigh Biagio de Jager and Miss Tarryn Reddy. The primary aim of this study is to ascertain the reliability of the B81 bone conductor when evaluating a balance-related neural response across multiple testing sessions.

Purpose of study

It is imperative that you fully understand the objectives and scope of the research before deciding to participate. We kindly ask you to thoroughly review the following information. Should you have any inquiries or need further details, please do not hesitate to contact the Principal Investigator.

Participation in research study

We extend a warm invitation for your participation in this study, which entails two days of testing over a two-week period. Participants have the option to withdraw from the study at any point as it is entirely voluntary, and the study guarantees complete anonymity.

Information regarding the research study

Please take note of the following information concerning this study:

a) Participant candidacy

The participants for this study must possess the following characteristics:

- Aged between 18 and 60 years.
- No history of vestibular or balance disorders.
- No hearing related pathologies on the day of testing
- Verbal proficiency in English and/or Afrikaans

Participants will undergo a series of tests on the first day of testing to confirm normal hearing and the absence of balance disorders. Participants will be required to provide/disclose information regarding any recent health issues.

b) Requirements from the participant

Participation in this study necessitates attendance for testing on two separate days within a two-week timeframe. The initial day of testing will involve two testing sessions, while the second day will entail a single test of similar complexity.

On the first day, participants will undergo a hearing screening to assess normal hearing. Subsequently, they will engage in four bedside assessments as part of the vestibular screening process. Two Vestibular Evoked Myogenic Potential (VEMP) tests will be administered, involving the placement of electrodes around the face and neck area to measure neural stimulation elicited by the bone conductor's stimulus. A 15-minute break will be provided between each VEMP test.

The second day's test session, scheduled one week after the initial day of testing, will involve VEMP testing once again in order to compare results with those from the previous week.

c) Test venue

Testing will be conducted at the Department of Communication Pathology on the Hatfield campus of the University of Pretoria.

d) Possible risks and benefits associated with this study

Participating in this study poses no known risks, as the testing procedures are considered objective and only necessitate passive cooperation from the participant.

This study offers potential benefits to participants by providing insights into balance and hearing-related information, both in a general sense and on a personal level.

Participants have the autonomy to decline answering any or all questions and may choose to terminate their involvement at any time.

What will I need to do if I agree to participate?

All tests conducted as part of this study will be non-invasive and provided free of charge, with the results made available to participants. If you choose to participate, the following procedures will be followed:

Otoscopy:

- During this test, you will be seated upright while your ear canal is visually inspected using an otoscope (ear-light).

Middle ear test:

- For this test, you will remain seated upright while a soft plastic probe is gently inserted into your ear canal to assess middle ear pressure, volume and movement.

Hearing test:

- This test involves wearing earphones and responding to soft sounds of varying pitches by pressing a button. Additionally, you will be asked to repeat a list of words heard through headphones. These tests will be performed in order to establish your hearing sensitivity.

Vestibular screening:

- For this screening procedure you will be expected to participate in four vestibular assessments. These assessments include: standing in different positions with eyes open and closed, aligning a line vertically, wearing vision-denying goggles to measure eye movement recorded in darkness, as well as experiencing small head-jerk movements while wearing goggles.

Data collection:

- Vestibular Evoked Myogenic Potential (VEMP) testing will be conducted by scrubbing areas of your skin (forehead, under eyes, chin, sides of neck, bottom of neck) and the placement of electrodes with medical tape. The electrodes will be positioned for approximately 30 minutes, including rest periods. You will be instructed to look over your left and right shoulder at various times and maintain a gaze 30 degrees upwards. This testing will occur twice on the first day of testing and once again one week later.

Sharing of results

Results retrieved from this study will be used in ways sensitive to the personal information provided by the participants. Results will guide and determine test-retest reliability of the B81 bone conductor with specific parameters like the CE Chirp stimulus.

Contact information

If you have any inquiries regarding this study or encounter any adverse effects as a consequence of your participation, you are encouraged to reach out to the Principal investigator. Additionally, if you have questions concerning your rights as a research participant, please feel free to contact the Principal Investigator of the research team for further assistance. Their contact number is provided on the first page of this document.

Voluntary Participation

Participation in this study is entirely voluntary, and the decision to take part is entirely yours. Should you choose to participate, you will be required to sign a consent form. However, you retain the freedom to withdraw from the study at any point without providing a reason. Withdrawal from the study will not impact any existing relationship you may have with the researchers involved. You have the right to decline participation or discontinue testing at any stage without affecting any ongoing services or treatments you receive at the Audiology practice or the Department of Speech-Language Pathology and Audiology at the University of Pretoria. If you opt to withdraw before the completion of data collection, your data will either be returned to you or destroyed.

Confidentiality

All information obtained from your participation will be treated with strict confidentiality. Once the data sheet is completed by me, your data will be assigned a unique identifier, and your

name will not be linked to any document. Furthermore, research articles published in scientific journals will not contain any details that could potentially identify you.

The data collection sheets from this study will be securely stored for a period of 15 years, both in hard copy and scanned electronic formats. These files will be stored on a CD and/or USB stick at the Department of Speech-Language Pathology and Audiology for potential future research by other investigators. However, any future research utilising this data will require the submission of a proposal to the Research Ethics Committee of the Faculty of Humanities at the University of Pretoria.

Conclusion

Before you agree to take part, you should fully understand what is involved. If you have any questions that this letter does not fully explain, please do not hesitate to ask me either in person or by telephone on 083 287 5151.

Should you decide to participate in this study, please complete the attached document to your fullest ability.

Thank you for your consideration of this request.

Kind regards

Principal Investigator
Anomé Victor