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Faculty of Humanities
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Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss

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A dissertation submitted in fulfilment of the requirements for the degree MA (Audiology) at the Department of Speech-Language Pathology and Audiology.

Faculty of Humanities,

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November 2019

Plagiarism declaration

I, (Mieke Kritzinger) hereby declare that this dissertation is my own work. Where secondary material is used, it has been carefully acknowledged and referenced in accordance with the University of Pretoria Department of Speech-Language Pathology and Audiology's requirements.

I understand what plagiarism is and am aware of the University of Pretoria's policy regarding this matter.

2019-11-19

Mieke Kritzinger

Date of declaration

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Acknowledgements

I would like to thank the following:

- To my Heavenly Father, for Blessing me throughout the whole process.
- Dr Leigh Biagio de Jager, for her insight and knowledge of the topic, for always making time to guide and encourage me and for being enthusiastic throughout the whole process. I really appreciate your assistance and expert advice.
- My parents and sister who were always willing to assist me with anything, for continuously believing in me and for their never-ending love, support and motivation.
- The rest of my family for their love and support it has been appreciated enormously.
- Dr Michael Maslin, for his expert advice on the topic and his insight with regards to the finer detail.
- My friends and fellow masters' students who were always willing to lend a helping hand.
- Andani Madzivhandila and Mauritz Blignaut for helping me with data collection.
- All the staff and management of Aerosud and Transoranje School for the Deaf for their support.
- All the individuals that were willing to participate in my study.

Table of Contents

List of Appendices

List of tables

List of figures

List of abbreviations

AEP	Auditory Evoked Potentials
AM	Amplitude-Modulated
ASSR	Auditory Steady State Response
CAEP	Cortical Auditory Evoked Potentials
daPa	Dekapascal
dB	Decibel
dB HL	Decibel Hearing Level
dB nHL	Decibel normal Hearing Level
dB SPL	Decibel Sound Pressure Level
EEG	Electroencephalogram
FM	Frequency- Modulated
Hz	Frequency
kΩ	Kiloohm
ml	millilitres
ms	millisecond
n	number of ears
nHL	normal Hearing Level
nV	nanovolt
peSPL	peak equivalent Sound Pressure Level
PTA	Pure Tone Average
Sec	Second
SNHL	Sensorineural Hearing Loss
SNR	Signal to Noise Ratio
SD	Standard Deviation
µV	microvolt

Abstract

Purpose: To compare the frequency specific Cortical Auditory Evoked Potential (CAEP) and the chirp-evoked 40 Hz Auditory Steady State Response (ASSR) with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

Method: The study tested 23 adults with normal hearing and 20 adults with SNHL. The participants were aged between 18–65 years. A repeated measures within-participant descriptive design was used to collect the quantitative data. The participants underwent behavioural pure tone, CAEP and ASSR testing on the same day.

Results: Similar CAEP difference scores across frequencies for the participants with normal hearing (mean=12.32-14.40 dB) and with SNHL (mean=10.00-16.47 dB) were measured. However, for the ASSR difference scores across frequencies slightly smaller difference scores were measured for the participants with SNHL (mean=10.17-17.30 dB) than for the participants with normal hearing (mean=11.74-17.14 dB). CAEP thresholds were significantly closer to the behavioural pure tone thresholds at 500 ($p=0.028$; mean absolute difference 14.40 dB) and 2000 ($p=0.016$; mean absolute difference 12.56 dB) Hz for participants with normal hearing. In participants with sensorineural hearing loss, CAEP and ASSR thresholds were measured at similar sensation levels and were not statistically different ($p>0.05$).

Conclusion: For the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex the CAEP was closer to the behavioural hearing thresholds than the 40 Hz ASSR at all frequencies except at 4000 Hz, regardless of the hearing sensitivity.

Keywords: Auditory steady state response (ASSR), Cortical auditory evoked potential (CAEP), Auditory evoked potential (AEP), Residual noise, Signal to noise ratio (SNR), objective threshold estimation, awake adults.

Chapter 1: Introduction

Objective measures for hearing estimation in populations who cannot accurately provide behavioural results are necessary (Hall III & Swanepoel, 2010). Populations include children; people who falsify their hearing thresholds (malingerers); and people with physical or mental disabilities. One such method includes auditory evoked potentials (AEP) (Hone, Norman, Keogh, & Kelly, 2003). The AEP's that are used for threshold estimation include Auditory Steady State Response (ASSR) and Cortical Auditory Evoked Potential (CAEP). These ASSRs are periodic brain potentials evoked by repeating stimuli such as chirps, clicks, amplitude-modulated (AM) or frequency-modulated (FM) tones (Katz, Chasin, English, Hood, & Tillery, 2015; B. B. A. Stach, 2002). On the other hand, CAEPs are scalp-recorded potentials that are evoked by frequency specific transient stimuli, such as tone bursts (Biagio, Swanepoel, & Soer, 2009; Katz et al., 2015; Lightfoot, 2016; Yeung & Wong, 2007)

Several studies comparing how accurately ASSR and CAEP tests determine behavioural thresholds have been done (Biagio et al., 2009; Tomlin, Rance, Graydon, & Tsialios, 2006; Van Maanen & Stapells, 2005; Yeung & Wong, 2007). Two of the studies concluded that CAEP more accurately estimated hearing thresholds in adults with hearing losses (Biagio et al., 2009; Tomlin et al., 2006), while one concluded that multiple frequency 40 Hz ASSR yielded more accurate results in the same population (Van Maanen & Stapells, 2005). The final study reported that both these tests equally predicted behavioural thresholds and that the accuracy with which they predicted the behavioural thresholds improved as the degree of hearing loss and the test frequency were increased (Yeung & Wong, 2007).

Van Maanen and Stapells (2005) compared the multiple 80 Hz and 40 Hz ASSR and CAEP for behavioural threshold estimation in adults with hearing loss. A multiple-ASSR method which averaged for eight minutes was used. When comparing the 40 Hz multiple-ASSR to the 80 Hz multiple-ASSR, these authors indicated that the 40 Hz multiple-ASSR stimulus was more accurate than the 80 Hz multiple-ASSR when the tests were used to determine the behavioural hearing thresholds in adults with normal

hearing or with sensorineural hearing loss (SNHL). This statement is based on the finding that the 40 Hz multiple-ASSR, across all frequencies, but at 4000 Hz specifically, were notably more accurate in the prediction of behavioural threshold than the 80 Hz multiple-ASSR. When comparing the multiple 40 Hz ASSR and CAEP, the multiple 40 Hz ASSR was found to better predict hearing thresholds in awake adults with both normal hearing or with SNHL. This study concluded that the 40 Hz multiple-ASSR was the most accurate method of threshold estimation in adults with normal hearing or SNHL (Van Maanen & Stapells, 2005).

Yeung and Wong (2007) compared CAEP audiometry with ASSR to see which one best predicted behavioural hearing thresholds in adults with normal hearing or with mild to profound SNHL. This study used a single-frequency 40 Hz ASSR protocol, with an epoch of 89 seconds. When comparing the CAEP and the ASSR results to the behavioural hearing thresholds, results indicated that both of these tests equally predicted behavioural hearing thresholds in adults whose hearing thresholds were normal or when they had a hearing loss. However, the more severe the degree of hearing loss, especially for the profound thresholds, the more accurately both the CAEP and the ASSR predicted the behavioural thresholds (Yeung & Wong, 2007).

Biagio, Swanepoel and Soer (2009) compared the CAEP and ASSR in adults exposed to occupational noise. A single-frequency 40 Hz AM/FM ASSR protocol, with an epoch of 89 seconds was used to evaluate adults with normal hearing or who presented with a mild to severe SNHL. The degree of hearing loss was overestimated by up to 20 dB at 500 Hz using the ASSR, presumably due to the short averaging time. However, the CAEP predicted the behavioural hearing thresholds more accurately than the ASSR across all frequencies, especially for the adults with hearing loss (Biagio et al., 2009).

Tomlin, Rance, Graydon and Tsialios, (2006) compared the single frequency 40 Hz ASSR and CAEP in awake adult participants. The behavioural hearing thresholds for this study ranged from within normal limits, to severe-to-profound degrees of SNHL. The study also made use of an ASSR protocol that averaged for 89 seconds. When comparing the ASSR results to the behavioural hearing thresholds, it indicated that the

greater the degree of hearing loss, the better the accuracy of the ASSR at 500 and 4000 Hz (Tomlin et al., 2006). The CAEP results were relatively constant regardless of the adult's hearing thresholds at both frequencies. The CAEP thus shows less variability than the ASSR when predicting hearing thresholds concerning the frequencies and the degree of hearing loss. This study, therefore, concluded that the CAEP more accurately predicted behavioural hearing thresholds than the 40 Hz ASSR (Tomlin et al., 2006).

The comparison between CAEP and ASSR to determine which one best predicts behavioural hearing thresholds has already been studied. However, there are indications that the averaging time, stimuli used and controlled residual noise criteria may influence the outcomes of these tests. The studies that identified CAEPs as the more accurate AEP for estimation of hearing thresholds all used the single-frequency ASSR system with an epoch of 89 seconds. In contrast, the multiple-frequency 40 Hz ASSR system used by van Maanen and Stapells (2005) made use of a mean recording time of 21 minutes, and the outcome indicated that the ASSR more accurately predicted behavioural thresholds than the CAEP. Residual noise levels are reduced when the recording time increased, which could lead to more accurate behavioural threshold prediction. The length of the recording time resulted in different outcomes and it seems possible that the difference in residual noise may have led to the different conclusions drawn rather than the AEP itself. Equitable residual noise levels, thus longer recording times, in the ASSR and CAEP being compared may result in a different conclusion.

The earlier studies comparing ASSR and CAEP threshold prediction have all made use of AM/FM stimuli. A next-generation multiple-frequency ASSR system has introduced the use of chirp stimuli. Chirp stimuli were shown to compensate for the basilar membrane travelling wave and the cochlear delay (Lee et al., 2016). This could lead to more accurate ASSR thresholds and larger response amplitudes and ASSR thresholds closer to behavioural hearing thresholds (Elberling, Don, Cebulla, & Stürzebecher, 2007; Lee et al., 2016). No previous studies were comparing the chirp ASSR and the CAEP using frequency specific stimuli to determine which one more

accurately predicted the hearing thresholds in adults with SNHL (Lee et al., 2016; Mühler, Mentzel, & Verhey, 2012; Rodrigues & Lewis, 2014). The current study, therefore, proposes to compare the frequency specific tone burst CAEP and chirp-evoked 40 Hz ASSR with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

1. Chapter 2: Methodology

2.1 Research aim

The main aim of this study was to compare the frequency specific tone burst CAEP and chirp-evoked 40 Hz ASSR with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

2.2 Research design and setting

Repeated measures within-participant descriptive design was used in this study. The research was cross-sectional, comparing several age groups' data, and took place within a controlled environment (Leedy & Ormrod, 2014). The data collected was quantitative, meaning that the collected data were converted into numerical indices (Leedy & Ormrod, 2014).

This study primarily took place in two settings. The first setting was at the Department of Speech-Language pathology and Audiology at the University of Pretoria. This is where the participants with normal hearing were tested. The participants with SNHL were sourced and tested at an industry with an established hearing conservation program.

2.3 Ethical considerations

2.3.1 Permission

- Ethical clearance was obtained from the Research Ethics Committee of the Faculty of Humanities at the University of Pretoria.
- Permission to access the participants' annual hearing screening records of the industry were obtained (Appendix A and B).
- Permission to test the participants at the industry was obtained.

2.3.2 Voluntary and informed consent

An informed consent letter (Appendix D, E and F) was given to each participant in the normal hearing group and within the group with SNHL before testing started. The participants were informed verbally and in writing about the procedures that were performed and what was expected of them. The ethical information that were provided

included the following sections: Background information regarding the study, the rationale and aim for the research project, the requirements for the participating individuals, what participation requires of them, confidentiality and anonymity, an explanation of the rights of the participants, the benefits and risks involved in participation and assurance that participation in the study was voluntary and that the participant could withdraw at any moment. All the participants had to give written consent before they could partake in the study (Leedy & Ormrod, 2014).

2.3.3 Protection from harm

Researchers should attempt not to physically or psychologically harm their research participants (Leedy et al., 2019). In this study, no participant was caused harm on any level. They were handled respectfully, given clear instructions on what the study entailed and on what we expected of them. We also communicated that the study was completely voluntary and that they may withdraw at any stage.

2.3.4 Right to privacy

Participants' data were kept confidential by referring to each participant using an alphanumeric code after the data had been collected. The participant's name was not used on any form. The only people involved during the assessment were the researcher and the participant. Only the researcher was aware of each participant's identity and results. However, all information was kept confidential.

2.3.5 Plagiarism

This study adhered to the University of Pretoria plagiarism policy. The written report and research study was the researchers' unique work. A declaration of originality was included on page one.

2.3.6 Research storage

The University of Pretoria's policy stated that all data must be stored for a minimum of 15 years. The data was stored electronically on a computer and an external hard drive.

All hard copies and paperwork were stored in the supervisor's office at the Department of Speech-Language pathology and Audiology, at the University of Pretoria.

2.4 Participants and selection

Participants of the normal hearing group were friends and family of the researcher. Potential participants of the group with SNHL had been recruited from an industry where there were previous records of hearing tests. The previous records were used to identify possible participants for the research study.

2.4.1 Selection criteria

The study tested 23 adults with normal hearing and 20 adults with SNHL. The participants were aged 18 – 61 years (Hall, 2007). The participants with normal hearing were recruited from the friends and family of the researcher. Normal hearing was taken as any hearing threshold <15 dB HL (American Speech-Language-Hearing Association (ASHA), 2015). The group with SNHL was recruited from an industry that required annual hearing testing as part of a hearing conservation programme for their employees. A hearing loss was defined as sensorineural when the participant's air conduction and bone conduction results were affected in the same way and were <15 dB HL apart (American Speech-Language-Hearing Association (ASHA), 2015; B. A. Stach, 2010). Previous hearing test results were used in order to identify employees with a hearing loss. To eliminate confounding variables, additional criteria for participant selection were added: All participants had to present with normal middle ear and outer ear status, which was determined by Type A tympanograms and otoscopic examinations respectively (Katz et al., 2015). Furthermore, no central disorders or head injuries had to be present, seeing as this can cause elevation of the ASSR and CAEP thresholds. To determine whether or not a central disorder is present, the participant had to complete Appendix C (Case history). When there was any indication of a central disorder or head injury; the participant was excluded from the study. It was simpler that the majority of the participants was fluent in English or Afrikaans, to rule out any communication barriers during the case history and instruction of the tests. However, a participant was not excluded based only on

language. When a language barrier occurred, a translator was provided. The participants were not exposed to any noise 24 hours prior to testing, as this could have lead to a temporary threshold shift (Katz et al., 2015). Non-probability purposive sampling was used (Leedy et al., 2019).

2.4.2 Equipment for participant selection

The apparatus and equipment discussed in Table 2.1 were used for participant selection:

Table 2.1: Equipment for participant selection

Equipment	Description
Welch Allyn Pocketscope™ otoscope with reusable specula	This apparatus was used to visually inspect the outer ear canal and the tympanic membrane for any otitis externa, otitis media and occluding cerumen, that might influence the test results of the hearing test, the ASSR and the CAEP (B. A. Stach, 2010).
GSI TympStar: Middle-Ear Analyzer, that was calibrated annually, immediately prior to data collection according to the SANS 10154-1 protocol.	Immittance measurements, which consist of tympanometry and acoustic reflexes, was used to objectively measure the middle ear functioning of all participants (B. A. Stach, 2010).
GSI 61 Clinical Audiometer that was calibrated annually, immediately prior to data collection according to the SANS 10154-1 protocol.	Behavioural pure tone audiometry was done to determine the hearing thresholds of the participants. This was done through air conduction and bone conduction audiometry by using the Hughson-Westlake procedure (Poling, Kunnel, & Dhar, 2016). This testing was conducted by presenting tones at

	various intensities at 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. Results were recorded at the lowest intensity a participant responds to 50% of the time (B. A. Stach, 2010).

2.4.3 Procedure for participant selection

2.4.3.1 Informed consent

An informed consent letter and participant information letter (Appendix D, E and F) were given to each participant in the normal hearing group and in the group with SNHL before testing. All test procedures and the rationale of the study were comprehensively explained to each participant. Data collection did only commence once informed consent was provided. Each participant's identity was kept confidential, as is their results, which was reported on anonymously.

2.4.3.2 Diagnostic test battery

The diagnostic test battery was conducted on each participant by a certified audiologist at the University of Pretoria. This test battery included:

1 An otoscopic examination to ensure that there were no outer ear problems such as excessive cerumen or foreign bodies that could have influenced the study's test results.

2 Immittance measurements, including tympanometry and acoustic reflexes, were conducted following the otoscopic examination to determine the functioning of the middle ear and the presence or absence of acoustic reflexes (B. A. Stach, 2010). Normal tympanometry results were determined by Type A tympanograms, which was characterised by a compliance of 0.3 to 1.75 ml and a middle ear pressure of -50 daPa to +50 daPa (Jerger, 1970). For ipsilateral acoustic reflexes to be normal, it should be present at 1000 Hz. Any abnormal results were indicative of abnormal middle ear pathology and had excluded the participant from the study.

3 Pure tone audiometry was performed in a soundproof booth at the University of Pretoria's Department of Speech-language Pathology and Audiology, using the Hughson-Westlake procedure (Poling et al., 2016) to determine normal hearing thresholds. Normal hearing thresholds were defined as any threshold <15 dB HL (American Speech-Language-Hearing Association (ASHA), 2015). For participants with SNHL, the pure tone results were obtained at the industry. Sensory neural hearing loss was defined as any threshold >15 dB HL, where the air conduction and bone conduction were affected to the same degree (American Speech-Language-Hearing Association (ASHA), 2015; B. A. Stach, 2010). Air conduction pure tone audiometry was tested at frequencies 125, 250, 500,1000, 2000, 4000 and 8000 Hz in a descending method using supra-aural headphones. Bone conduction pure tone audiometry was tested at frequencies 250, 500, 1000, 2000 and 4000 Hz using the A24895 bone conduction vibrator.

2.5 Equipment for data collection

Calibration was an essential part before testing procedures could commence ensuring accurate testing. The Interacoustics Eclipse was calibrated once a year. For AEP testing, two types of calibration were used, peSPL (peak equivalent Sound Pressure Level) and nHL (normal Hearing Level). For a given peSPL dB value, the maximum acoustical or vibration level was calibrated to match the level of continuous tones used to obtain the same dB SPL reading on a sound level meter (Interacoustics, 2017a). Whereas, nHL is a correction, which compensated for the variance in perceived loudness of the very brief stimuli like tone bursts and Clicks. There, therefore, was a direct similarity between the indicated level in HL and the nHL levels well known from standard audiometry (Interacoustics, 2017a). The equipment was calibrated in accordance with ISO 389-6-2007. The equipment described in Table 2.2 was used for data collection.

Table 2.2: Equipment for data collection

Equipment	Description
Interacoustics Eclipse EP 25 auditory evoked (AEP) response system, using the ASSR and ABR software, calibrated in accordance with ISO389-1. The calibration of the ASSR was done in dB HL and for the ABR was done in dB nHL. ER-3A insert earphones were used (Interacoustics, 2017b)	This equipment was used for frequency specific estimation of the behavioural hearing thresholds of each participant.

2.6 Procedure for data collection

2.6.1 CAEP testing

The CAEP testing was the initial AEP test; however, were counterbalanced with the ASSR test throughout data collection. The test environment where testing did occur had to be quiet, the ambient noise should not exceed 35 dB A, as this could alter the test results (British Society of Audiology, 2015). Before this test was conducted, the participant's skin was prepared for electrode placement. An abrasive gel or paste, NuPrep, was used to clean the skin of any debris that can influence the connectivity that the electrode might have with the skin's surface. The electrodes were placed, as stated in table 2.3. The participants were asked to sit in a reclining chair with their eyes open but downcast. They were asked to read a passage or watch a closed caption movie to ensure an awake state. The reusable silver chloride cup electrodes were placed on the skin by using a conductive paste. The electrodes were then secured using micropore plaster. An impedance measurement followed to ensure proper connectivity between the electrodes and the skin. Impedances had to be five kΩ or less (BSA, 2015). The insert earphone was inserted into the test ear. The CAEP test, for threshold estimation, began at 50 dB nHL and was tested at 500, 1000, 2000 and 4000 Hz (Interacoustics, 2015). A response was seen as present when, the waveform morphology, latency and amplitude were appropriate. The response had to be

repeatable, and at lower stimulus levels, the morphology, amplitudes and latencies had to correlate with higher stimulus levels (BSA, 2015). The response was absent when, the waveform was not repeatable, and there were no morphology, amplitude and latencies within the appropriate range. A clear response is defined in (BSA, 2015) as an N1 P2 with a Signal to Noise ratio (SNR) of ≥2.5, and residual noise of ≤2 μV. When a response was present, the stimulus level was reduced in 20 dB steps, then 10 dB steps were used to determine the threshold. (BSA, 2015) When there was no response at 50 dB nHL, the stimulus level was increased by 20 dB and was decreased in 10 dB steps until a response was present (BSA, 2015). Participants were asked to read a passage silently while this test continues, as active participation was shown to enhance the amplitudes of the waveforms (Katz et al., 2015). The CAEP test had been recorded using the stimulus and recording parameters in tables 2.3 and 2.4. Residual noise levels were monitored throughout the testing procedure, seeing that high residual noise levels had an impact on the precision of the waveforms (BSA, 2015). Residual noise levels had to be reduced by increasing the recording time and by repeating the waveforms.

Table 2.3: Stimulus parameters of the CAEP

Type	Tone burst
Stimulus Duration	Up to 780 ms
Rate	0.7 Hz
Frequency	500, 1000, 2000 and 4000 Hz
Polarity	Alternating
Level	20 – 100 dB nHL, (-10 – 100 dB nHL) in 10 dB steps
Presentation (Mode; Ear)	Air conduction; Monaural
Calibration	dB nHL
Transducer	ER-3A insert earphones
Electrode placement	Vertex - High forehead (Fz) Ground – Either Right temple (F 8) or Left temple (F 7)

	Right - Right mastoid bone (M2) Left – Left mastoid bone (M1)

(Interacoustics, 2015)

Table 2.4: Recording parameters for the CAEP

Analysis time	-150 ms – 1050 ms
Dots trace	450 displayed
Low Pass Filter	1500 Hz
High Pass Filter	3.3 Hz
Rejection levels	80 µV

(Interacoustics, 2015, 2017b)

2.6.2 ASSR testing

ASSR testing was the second AEP test to be conducted; the CAEP and ASSR testing were counterbalanced throughout the data collection procedure. The test environment was the same as for CAEP testing. The preparing of the skin and electrode placement was the same as for CAEP testing. The insert earphones were, however, placed in two ears simultaneously. An impedance measurement did follow to ensure good connectivity between the electrodes and the skin. Impedances were five kΩ or less (Interacoustics, 2017b). The electrodes were placed, as stated in table 2.5. The participant was asked to sit in a reclining chair with their eyes open but downcast and to read a passage or watch a closed caption movie to remain alert during the testing procedure. An ASSR is more sensitive to electrical or Electroencephalogram (EEG) noise than the CAEP. The testing did start at an intensity of 50 dB HL for all participants and took place at 500, 1000, 2000 and 4000 Hz. For threshold determination, the intensity was decreased in 20 dB steps and increased in 10 dB steps. The response was seen as present when a green detection curve appeared on the test frequency graph and absent or timed out when a red detection curve appeared (Interacoustics, 2017b). When a threshold was present, the threshold was repeated, to ensure

reliability. The ASSR testing did continue by using the stimulus and recording parameters in Tables 2.5 and 2.6.

Table 2.5: Stimulus parameters for the ASSR

Type	CE-Chirp
Duration	Continuous: 6 minutes
Rate (awake)	40 Hz
Frequency	500, 1000, 2000 and 4000 Hz
Polarity	N/A
Level	0-100 dB nHL in 10 dB steps
Bandwidth	1-octave ± ½ octave – 3 dB
Masking	0-100 dB SPL White noise
Calibration	dB nHL
Presentation (Mode; Ear)	Air conduction; Monaural
Transducer	Insert earphones
Electrode placement	Vertex - High forehead (Fz) Ground – Either Right temple (FT 10) or Left temporal lobe (FT 9) Right - Right mastoid bone (M2) Left – Left mastoid bone (M1)

(Interacoustics, 2015)

Table 2.6: Recording parameters using the ASSR

Sampling frequency	30 kHz
Artefacts reject system	Standard voltage-based system
Gain	74 – 110 dB
Channels	2
Algorithmic sensitivity	95% false pass probability
Rejection levels	80 µV

(Interacoustics, 2015)

2.7 Data processing procedure and analysis

CAEP's waveform analysis process required two markers. The markers had to reach consensus on the threshold and waveform markings before the analysis did continue. Threshold had to adhere to the minimum criteria as set out by the British Society of Audiology (BSA, 2015). To do so, the SNR had to be determined. The signal was determined by measuring the N1-P2 amplitude. The trough of the N1 to the peak of the P2 was used to calculate the N1-P2 amplitude. We analysed the residual noise levels in each threshold level trace. The analysis entailed the following: the A-B button was selected in order to display the A and B bins of the target threshold trace. The amplitude of gap between the A and B traces displayed was then averaged at five specific latency points on the wave (viz. -30 ms; 150 ms; 330 ms; 510 ms; 690 ms) while being careful not to move either the A or B curves. The averaged value provided the estimate of the residual noise level of each trace. The signal (N1-P2 amplitude) was required to be 2.5 times larger than the residual noise level, with residual noise being less than 2 μV for the threshold response to be accepted as present. In the event of an SNR of less than 2.5, the CAEP waveform to the stimulus 10 dB greater was evaluated to determine if that trace adhered to minimum threshold criteria.

The raw data was initially captured in Microsoft Excel spreadsheets before it was transferred to SPSS version 24 for statistical analysis. Mean, standard deviation, bubble plots and bar graphs were used to describe the data. Difference scores and absolute difference scores were also calculated by subtracting the behavioural hearing thresholds at 500 to 4000 Hz from the ASSR or CAEP threshold. The use of only difference scores between behavioural pure tone and AEP threshold is likely to underestimate the true proximity of AEP thresholds if both positive and negative values were measured then averaged across participants. It was, therefore, necessary to calculate absolute difference scores in addition to the unprocessed difference scores.

Normality of distribution was assessed by using the Shapiro-Wilk tests. Shapiro-Wilk indicated that the CAEP difference scores were normally distributed (W=1.89-439, p>0.05); however, the ASSR difference scores, ASSR absolute difference scores and CAEP absolute difference scores were not normally distributed (W=0.001-0.035,

$p<0.05$). A Wilcoxon signed-rank test was therefore conducted to determine the relationship between the group data of the participants with normal hearing and the participants with SNHL. The difference scores were assessed by a histogram with a superimposed normal curve between the ASSR and CAEP thresholds at all the frequencies. Absolute difference scores and difference scores were assessed with and without outliers.

An analysis of variance (ANOVA) using the absolute difference scores and difference scores was run to determine the interaction between the AEP and hearing sensitivity A multiple regression analysis was performed to predict the difference scores, as well as the absolute difference scores between AEP, hearing sensitivity and frequency. Linearity was confirmed as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Independence of residuals was established. A visual inspection of a plot of studentized residuals versus unstandardized predicted values indicated that there was homoscedasticity. There was no evidence of multicollinearity, as tolerance values greater than 0.1. There were no studentized deleted residuals greater than ±3 standard deviations, no leverage values greater than 0.2, and values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot. The level of significance was set as $p<0.05$.

2.8 Reliability, validity and trustworthiness

Reliability, the consistency with which this study yields a certain result when the entity being measured hasn't changed, validity, to ensure the tests measure what it is supposed to measure, and trustworthiness will be obtained using the following measures (Leedy et al., 2019):

- The same calibrated equipment was used to test each participant. The equipment was calibrated according to the SANS 10154-1 protocol.
- The CAEP was interpreted separately, by two experienced audiologists, to minimise the bias effect.
- The waves of the CAEP and the threshold responses for the ASSR was repeated to ensure reliability.
- The same procedure were followed for each participant.
- Individual differences will be controlled for by using within-participant design.
- All the tests were conducted on the same day to ensure that no variables such as level of awareness, especially for the CAEP affected the study.
- Identical normative data was used for each participant.
- Signal averaging did continue until residual noise levels for threshold ASSR and threshold CAEP were equivalent.
- Next-generation technology, which uses Bayesian Weighting, was used. This, in turn, did lead to lower residual noise levels and did result in more accurate results.

3. Chapter 3: Article

Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss

Authors: Mieke Kritzinger, Leigh Biagio de Jager

3.1 Abstract

Purpose: To compare the frequency specific tone burst Cortical Auditory Evoked Potential (CAEP) and the chirp-evoked 40 Hz Auditory Steady State Response (ASSR) with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

Method: The study tested 23 adults with normal hearing and 20 adults with SNHL. The participants were aged between 18–65 years. A repeated measures within-participant descriptive design was used to collect the quantitative data. The participants underwent behavioural pure tone, CAEP and ASSR testing on the same day.

Results: Similar CAEP difference scores across frequencies for the participants with normal hearing (mean=12.32-14.40 dB) and with SNHL (mean=10.00-16.47 dB) were measured. However, for the ASSR difference scores across frequencies slightly smaller difference scores were measured for the participants with SNHL (mean=10.17-17.30 dB) than for the participants with normal hearing (mean=11.74-17.14 dB) CAEP thresholds were significantly closer to the behavioural pure tone thresholds at 500 ($p=0.028$; mean absolute difference 14.40 dB) and 2000 ($p=0.016$; mean absolute difference 12.56 dB) Hz for participants with normal hearing. In participants with sensorineural hearing loss, CAEP and ASSR thresholds were measured at similar sensation levels and were not statistically different ($p>0.05$).

Conclusion: For the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex the CAEP was closer to the behavioural hearing thresholds than the 40 Hz ASSR at all frequencies except at 4000 Hz, regardless of the hearing sensitivity.

Keywords: Auditory steady state response (ASSR), Cortical auditory evoked potential (CAEP), Auditory evoked potential (AEP), Residual noise, Signal to noise ratio (SNR), objective threshold estimation, awake adults

3.2 Introduction

Objective measures for hearing estimation in populations that include children, malingerers and or people with physical and mental disabilities, who cannot accurately provide behavioural results are necessary (Hall III & Swanepoel, 2010). One such method includes auditory evoked potentials (AEP) (Hone, Norman, Keogh, & Kelly, 2003). The AEP's that are used for threshold estimation include Auditory Steady State Response (ASSR) and Cortical Auditory Evoked Potential (CAEP). These ASSRs are periodic brain potentials evoked by repeating stimuli such as chirps, clicks, amplitude-modulated (AM) or frequency-modulated (FM) tones (Katz et al., 2015; B. B. A. Stach, 2002) On the other hand, CAEPs are scalp recorded potentials that are evoked by frequency specific transient stimuli, such as tone bursts (Biagio et al., 2009; Katz et al., 2015; Yeung & Wong, 2007).

Several studies comparing how accurately ASSR and CAEP tests determine behavioural thresholds have been done (Biagio et al., 2009; Tomlin et al., 2006; Van Maanen & Stapells, 2005; Yeung & Wong, 2007). Two of the studies concluded that CAEP more accurately estimated hearing thresholds in adults with hearing losses (Biagio et al., 2009; Tomlin et al., 2006), while one concluded that multiple frequency 40 Hz ASSR yielded more accurate results in the same population (Van Maanen & Stapells, 2005). The final study reported that both these tests equally predicted behavioural thresholds and that the accuracy with which they predicted the behavioural thresholds improved as the degree of hearing loss and the test frequency were increased (Yeung & Wong, 2007).

These studies indicated that the averaging time, stimuli used and controlled residual noise criteria might influence the outcomes of these tests. The studies that identified CAEPs as the more accurate AEP for estimation of hearing thresholds all used the single-frequency ASSR system with an epoch of 89 seconds. In contrast, the multiple-

frequency 40 Hz ASSR system used by van Maanen and Stapells (2005) made use of a mean recording time of 21 minutes, and the outcome indicated that the ASSR more accurately predicted behavioural thresholds than the CAEP. Residual noise levels are reduced when the recording time increased, which could lead to more accurate behavioural threshold prediction. The length of the recording time resulted in different outcomes, and it seems possible that the difference in residual noise may have led to the different conclusions drawn rather than the AEP itself. Equitable residual noise levels, thus longer recording times, in the ASSR and CAEP being compared may result in a different conclusion.

The earlier studies comparing ASSR and CAEP threshold estimation have all made use of AM/FM stimuli. A next-generation multiple-frequency ASSR system has introduced the use of chirp stimuli. Chirp stimuli have been shown to compensate for the basilar membrane travelling wave and the cochlear delay (Lee et al., 2016). This could lead to more accurate ASSR thresholds and larger response amplitudes and ASSR thresholds closer to behavioural hearing thresholds (Lee et al., 2016). There were no studies comparing the chirp ASSR and the CAEP to determine which one more accurately predicted the hearing thresholds in adults with SNHL (Lee et al., 2016; Mühler et al., 2012; Rodrigues & Lewis, 2014). The current study, therefore, proposed to compare the frequency specific tone burst CAEP and chirp-evoked 40 Hz ASSR with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

3.3 Method

Ethical clearance was obtained from the Research Ethics Committee of the Faculty of Humanities, University of Pretoria.

Repeated measures within-participant descriptive design was selected to collect the quantitative data. The research was cross-sectional and took place within a controlled environment (Leedy & Ormrod, 2014). Non-probability purposive sampling was used to collect the data.

Participants

The study tested 23 adults with normal hearing (hearing threshold <15 dB HL) and 20 adults with SNHL (hearing threshold >15 dB HL). The participants were aged between 18 – 65 years (Hall, 2007). The participants with normal hearing, recruited from family and friends, and the participants with SNHL, recruited from an industry with an established hearing conservation program.

An experienced audiologist performed otoscopy, tympanometry, behavioural threshold testing (500 to 4000 Hz), CAEP and ASSR testing on the same day for each participant. Behavioural, CAEP and ASSR threshold estimation's minimum test intensity were recorded up to 0 dB nHL/ HL. In order for an individual to be considered for participation in the study they had to comply with the following results: Normal outer and middle ear functioning and no central disorders or head injuries had to be present seeing as this can cause elevation of the ASSR and CAEP thresholds.

Materials and Procedures

Evoked potential testing

The Interacoustics Eclipse EP 25 auditory evoked (AEP) response system, using the ASSR and ABR software, calibrated in accordance with ISO389-1 was used for data collection. The calibration of the ASSR and ABR was done in dB HL, and dB nHL respectively. ER-3A insert earphones were used (Interacoustics, 2017b). The same electrode placement was used for both ASSR and CAEP testing, namely: vertex on the high forehead (Fz); ground on the left temple (F 7) right on the right mastoid bone (M2) and left on the left mastoid bone (M1).

Threshold estimation for both ASSR and CAEP testing began at 50 dB HL and 50 dB nHL respectively and was tested at 500, 1000, 2000 and 4000 Hz. The same threshold-seeking method was used for both tests, with 10 dB intensity increments and 20 dB decrements.

Cortical Auditory Evoked Potential (CAEP) testing

The CAEP test, for threshold estimation, used a tone burst stimulus. Tone bursts were presented using an alternating polarity at a rate of 0.7 Hz. The participants were asked to sit in a reclining chair with their eyes open but downcast. They were asked to read a passage or watch a closed caption movie to ensure an awake state. The reusable silver chloride cup electrodes were placed on the skin by using a conductive paste. The electrodes were then secured using micropore plaster. An impedance measurement followed to ensure proper connectivity between the electrodes and the skin. Impedances had to be five kΩ or less (BSA, 2015). The low pass filter was 1500 Hz, and the high pass filter was 3.3 Hz. The artefact rejection levels were 80 µV. The stimulus duration was up to 780 ms per trace. The analysis time was -150 ms to 1050 ms A clear response is defined in (BSA, 2015) as an N1-P2 with a Signal to Noise ratio (SNR) of ≥2.5, and residual noise of ≤2 µV.

Auditory Steady State Response (ASSR) testing

The ASSR used a CE-Chirp stimulus at a rate of 40 Hz. The participant was asked to sit in a reclining chair with their eyes open but downcast and to read a passage or watch a closed caption movie to remain alert during the testing procedure The reusable silver chloride cup electrodes were placed on the skin by using a conductive paste. The electrodes were then secured using micropore plaster. An impedance measurement followed to ensure proper connectivity between the electrodes and the skin. Impedances had to be five kΩ or less (BSA, 2015). The artefact rejection level was 80 µV. The averaging time was set up to 6 minutes. The algorithmic sensitivity was set at 95% false pass probability. A response was seen as present when a green detection curve appeared on the test frequency graph and absent or timed out when a red detection curve appeared (Interacoustics, 2017b).

Data processing and analysis

CAEP's waveform analysis process required two markers which had consensus on the threshold and waveform markings before the analysis did continue. Threshold had to adhere to the minimum criteria as set out by the BSA (2015). To do so, the SNR had to be determined. The signal was determined by measuring the N1-P2 amplitude.

We analysed the residual noise levels in each threshold level trace. The analysis entailed the following: the A-B button was selected in order to display the A and B bins of the target threshold trace. The amplitude of gap between the A and B traces displayed was then averaged at five specific latency points on the wave (viz. -30; 150; 330; 510 and 690 ms) while being careful not to move either the A or B curves. The averaged value provided the estimate of the residual noise level of each trace. The signal (N1-P2 amplitude) was required to be 2.5 times larger than the residual noise level, with residual noise being less than 2 µV for the threshold response to be accepted as present. In the event of an SNR of less than 2.5, the CAEP waveform to the stimulus 10 dB greater was evaluated to determine if that trace adhered to minimum threshold criteria. The absolute difference scores and the difference scores were assessed with and without outliers.

The raw data was initially captured in Microsoft Excel spreadsheets, whereafter it was transferred to SPSS version 24 for statistical analysis. Mean, standard deviation, bubble plots and bar graphs were used to describe the data. Difference scores and absolute difference scores were also calculated by subtracting the behavioural hearing thresholds at 500 to 4000 Hz from the ASSR or CAEP threshold. The use of only difference scores between behavioural pure tone and AEP threshold is likely to underestimate the true proximity of AEP thresholds if both positive and negative values were measured then averaged across participants. It was, therefore, necessary to calculate absolute difference scores in addition to the unprocessed difference scores.

Normality of distribution was assessed by using the Shapiro-Wilk tests. Shapiro-Wilk indicated that the CAEP difference scores were normally distributed ($W=1.89\text{-}439$, $p>0.05$); however, the ASSR difference scores, ASSR absolute difference scores and CAEP absolute difference scores were not normally distributed ($W=0.001\text{-}0.035$, $p<0.05$). A Wilcoxon signed-rank test was therefore conducted to determine the relationship between the group data of the participants with normal hearing and the participants with SNHL. The difference scores were assessed by a histogram with a superimposed normal curve between the ASSR and CAEP thresholds at all the frequencies.

An analysis of variance (ANOVA) using the absolute difference scores and difference scores was run to determine the interaction between the AEP and hearing sensitivity A multiple regression analysis was performed to predict the difference scores, as well as the absolute difference scores between AEP, hearing sensitivity and frequency. Linearity was confirmed as assessed by partial regression plots and a plot of studentized residuals against the predicted values. Independence of residuals was established. A visual inspection of a plot of studentized residuals versus unstandardized predicted values indicated that there was homoscedasticity. There was no evidence of multicollinearity, as tolerance values greater than 0.1. There were no studentized deleted residuals greater than ±3 standard deviations, no leverage values greater than 0.2, and values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot. The level of significance was set as $p<0.05$.

3.4 Results

The participant group with normal behavioural pure tone thresholds, presented with a mean age of 20.91 years (SD=1.05). The participants with SNHL were aged between 21 and 61 years of age, with a mean age of 41.32 years (SD=10.89). The mean and standard deviation of the pure tone behavioural thresholds of the participants with normal hearing and with SNHL is included in Table 3.1.

Table 3.1: Mean and standard deviation of the pure tone behavioural thresholds of the participants with normal hearing (n=44) and the participants with sensorineural hearing loss (n=37)

	Mean (dB HL)		SD	
Frequency (Hz)	**Normal hearing participants**	**SNHL**	**Normal hearing participants**	**SNHL**
500	6.36	39.59	5.01	27.24
1000	5.45	38.24	4.15	29.21
2000	3.86	41.62	4.43	29.65
4000	4.43	45.27	4.21	28.41
PTA 500, 1000, 2000	5.14	39.82	3.50	28.02
PTA 500, 1000, 2000, 4000	5.14	41.18	3.32	27.63

dB HL= Decibel Hearing Level n= number of ears PTA= Pure Tone Average SD= Standard Deviation SNHL= Sensorineural hearing loss

The three and four frequency PTA mean for the participants with normal hearing was 5.14 dB HL with the SD being 3.50 and 3.32 respectively. The PTA for the participants with SNHL indicated that the average degree of hearing loss for this population was mild to moderate hearing loss (American Speech-Language-Hearing Association (ASHA), 2015).

The CAEP findings for the participants with normal hearing, with regards to latency and amplitude, are included in Table 3.2.

Table 3.2: CAEP results for the participants with normal hearing

	Latency (ms)		Amplitude (peak to baseline) (µV)		Amplitude (peak to peak) (µV)	
Frequency (Hz)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
500 P1 (n=42)	84.14	34.90	0.88	0.93	2.24	1.22
N1	144.29	35.83	1.35	0.71	2.68	1.00
P2	210.67	39.60	1.34	0.89	1.99	1.35
1000 P1 (n=42)	79.95	31.35	0.81	0.77	2.14	1.13
N1	134.05	31.62	1.33	0.74	2.79	1.14
P2	196.71	37.09	1.45	0.83	1.99	1.21
2000 P1 (n=41)	76.83	35.05	0.86	0.94	2.47	1.41
N1	136.39	39.87	1.61	0.90	3.03	1.27
P2	200.63	39.87	1.47	0.82	2.11	1.24
4000 P1 (n=40)	72.20	41.67	0.91	0.73	2.39	1.19
N1	127.90	40.17	1.48	0.79	2.91	1.06
P2	195.00	46.78	1.33	0.86	1.90	1.12

µV= microvolts CAEP= Cortical auditory evoked potential ms= milliseconds n= number of ears SD= Standard Deviation

The SD was marginally larger for the latencies of the 4000 Hz CAEPs than for lower stimulus CAEPs. The SD for amplitudes was similar for waves at different stimulus frequencies.

The thresholds and residual noise level results of the CAEP for the participants with normal hearing are included in Table 3.3.

Table 3.3: CAEP thresholds and residual noise levels at threshold for the participants with normal hearing

	Threshold (dB nHL)	Residual noise levels (µV)
Frequency (Hz)	**Mean (SD)**	**Mean (SD)**
500 (n=42)	19.52 (12.49)	0.81 (1.04)
1000 (n=42)	20.00 (11.69)	0.72 (0.33)
2000 (n=41)	16.10 (8.63)	0.77 (0.32)
4000 (n=40)	17.50 (11.71)	0.77 (0.41)

µV= microvolts CAEP= Cortical auditory evoked potential dB nHL= decibel normal Hearing level n= number of ears SD= Standard Deviation

The mean threshold for the participants with normal hearing fell between 16.10 and 20.00 dB nHL with the highest mean threshold being 20 dB nHL at 1000 Hz (SD=11.69). The mean residual noise levels all were ≤2 µV at 500, 1000, 2000, and 4000 Hz. The residual noise levels complied with the noise criteria for CAEP responses to be present (BSA, 2015).

The CAEP findings for the participants with SNHL, with regards to latencies and amplitudes, are included in Table 3.4.

Table 3.4: CAEP results for the participants with SNHL

	Latency (ms)		Amplitude (peak to baseline) (µV)		Amplitude (peak to peak) (µV)	
Frequency (Hz)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
500 P1 (n=34)	76.12	31.49	0.85	0.56	1.99	0.99
N1	133.12	24.27	1.31	0.59	2.72	0.84
P2	196.53	33.37	1.41	0.87	1.94	1.41
1000 P1 (n=37)	72.00	27.56	0.74	0.56	2.13	0.83
N1	123.03	27.08	1.56	0.62	3.01	0.83
P2	196.00	32.35	1.48	0.63	1.99	1.22
2000 P1 (n=33)	57.82	25.35	0.86	0.62	2.01	1.02
N1	112.30	22.51	1.28	0.65	2.87	0.99
P2	181.21	24.86	1.59	0.82	1.82	1.02
4000 P1 (n=34)	70.94	22.19	0.65	0.53	1.66	0.77
N1	115.12	20.22	1.18	0.65	2.65	0.81
P2	176.35	25.76	1.48	0.72	1.99	0.93

µV= microvolts CAEP= Cortical auditory evoked potential ms= milliseconds n= number of ears SD= Standard Deviation SNHL= Sensorineural hearing loss

The SD was marginally larger for the latencies of the 500 Hz CAEPs than for higher stimulus CAEPs. The SD for amplitudes was similar for waves at different stimulus frequencies.

The thresholds and residual noise level results of the CAEP findings for the participants with SNHL are included in Table 3.5.

Table 3.5: CAEP thresholds and residual noise levels for the participants with SNHL

	Threshold (dB nHL)	Residual noise levels (µV)
Frequency (Hz)	**Mean (SD)**	**Mean (SD)**
500 (n=34)	54.41 (24.40)	0.83 (0.33)
1000 (n=37)	52.97 (27.58)	0.91 (0.44)
2000 (n=33)	47.88 (27.92)	0.94 (0.52)
4000 (n=34)	53.53 (26.84)	0.84 (0.47)

µV= microvolts CAEP= Cortical auditory evoked potential dB nHL= decibel normal Hearing level n= number of ears SD= Standard Deviation SNHL= Sensorineural hearing loss

The mean threshold for the participants with sensorineural hearing loss fell between 47.88 and 54.41 dB nHL with the highest mean threshold being 54.41 dB nHL at 500 Hz (SD=24.40) — the mean residual noise levels all ≤2 µV at 500, 1000, 2000, and 4000 Hz. The residual noise levels complied with the noise criteria for CAEP responses to be present (BSA, 2015).

ASSR findings for the participants with normal hearing, with regards to thresholds obtained and residual noise levels, are included in Table 3.6.

Table 3.6: ASSR thresholds and residual noise levels for the participants with normal hearing

	Threshold (dB HL)		Residual Noise (µV)	
Frequency (Hz)	**Mean**	**SD**	**Mean**	**SD**
500 Hz (n=44)	25.68	12.97	0.05	0.03
1000 Hz (n=44)	24.55	14.86	0.05	0.03
2000 Hz (n=44)	20.57	10.96	0.05	0.02
4000 Hz (n=44)	17.39	10.59	0.05	0.02

µV= microvolts ASSR= Auditory steady state response dB HL= decibel Hearing level n= number of ears SD= Standard Deviation

The mean thresholds obtained decreases as the frequency increased. Residual noise levels at all frequencies are very low, less than 0.06 µV.

ASSR findings for the participants with SNHL, with regards to thresholds obtained and residual noise levels, are included in table 3.7.

Table 3.7: ASSR thresholds and residual noise levels for the participants with SNHL

	Threshold (dB HL)		Residual Noise (µV)	
Frequency (Hz)	**Mean**	**SD**	**Mean**	**SD**
500 Hz (n=37)	56.89	25.26	0.07	0.05
1000 Hz (n=36)	54.17	28.47	0.06	0.03
2000 Hz (n=35)	51.57	31.10	0.07	0.05
4000 Hz (n=30)	47.00	24.27	0.09	0.15

µV=microvolts ASSR= Auditory steady state response dB HL= decibel Hearing level SD= Standard Deviation SNHL= Sensorineural hearing loss n= number of ears

The mean thresholds obtained decreases as the frequency increased. Residual noise levels at all frequencies are very low, less than 0.1 µV.

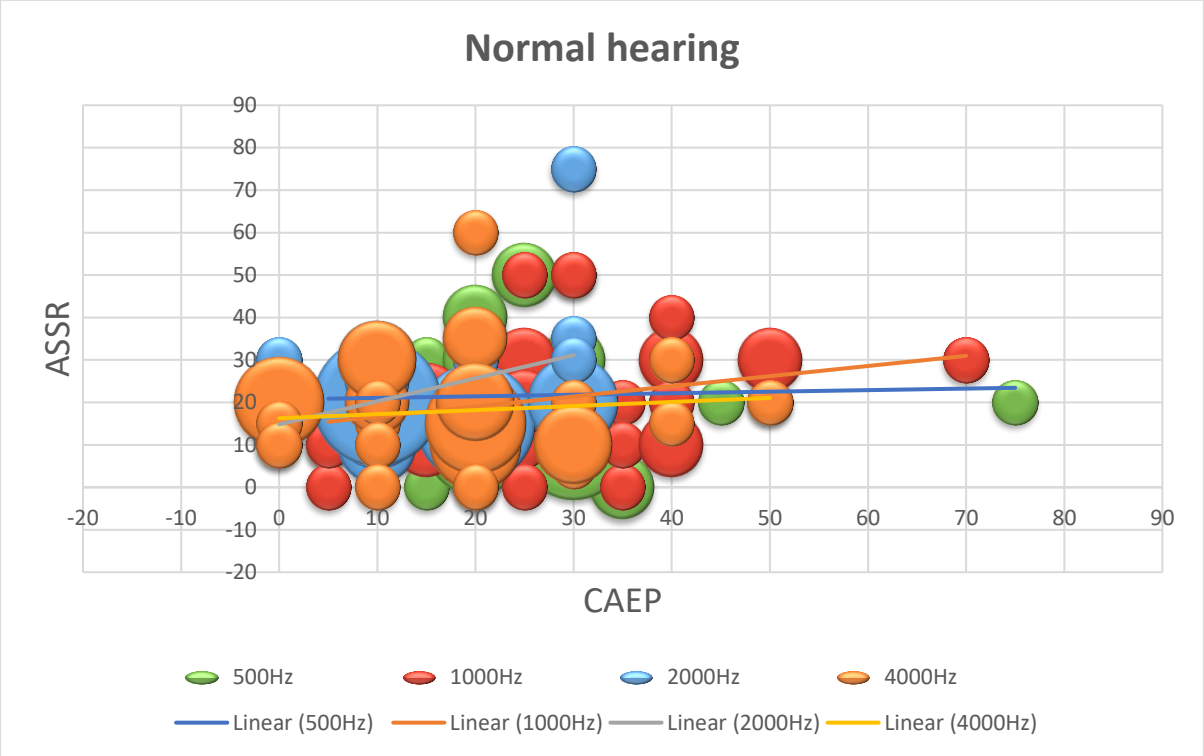

Figure 3.1: Cortical Auditory Evoked Potential (CAEP) and Auditory steady state response (ASSR) thresholds for participants with normal hearing across all the frequencies (500 to 4000 Hz)

At 500 and 4000 Hz, a poor correlation was measured between the ASSR and CAEP thresholds (R_2 =0.002 and 0.01, respectively; Cohen, 1988). The group with normal hearing had a clustered distribution between the thresholds of the ASSR and that of the CAEP at a 1000 Hz, except for one outlier, where the ASSR threshold (30 dB HL) was much lower than the CAEP threshold (70 dB nHL). At 2000 Hz ASSR and CAEP threshold estimation were quite similar, except for the one outlier, where the CAEP threshold was much higher than the ASSR threshold estimation.

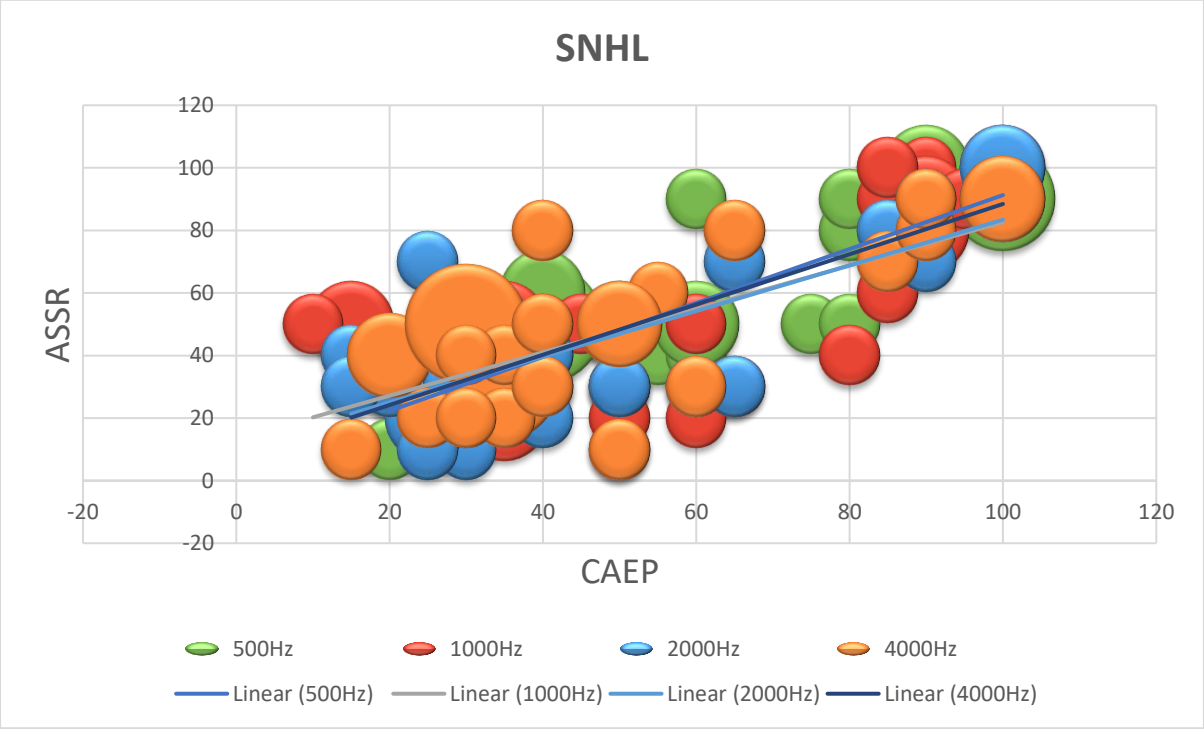

Figure 3.1: Cortical Auditory Evoked Potential (CAEP) and Auditory steady state response (ASSR) thresholds for participants with SNHL across all the frequencies (500 to 4000 Hz)

For the participants with SNHL a strong positive correlation between measures was evident at 500, 2000 and 4000 Hz (R_2= 0.658, 0.593 and 0.575 respectively; Cohen, 1988), however only a moderate positive correlation was evident between the ASSR and CAEP threshold estimation at 1000 Hz (R_2=0.484; Cohen, 1988).

A clustered bar graph of the absolute differences by frequency for CAEP and ASSR for both the participants with normal hearing and for the participants with SNHL is displayed in Figure 3.3.

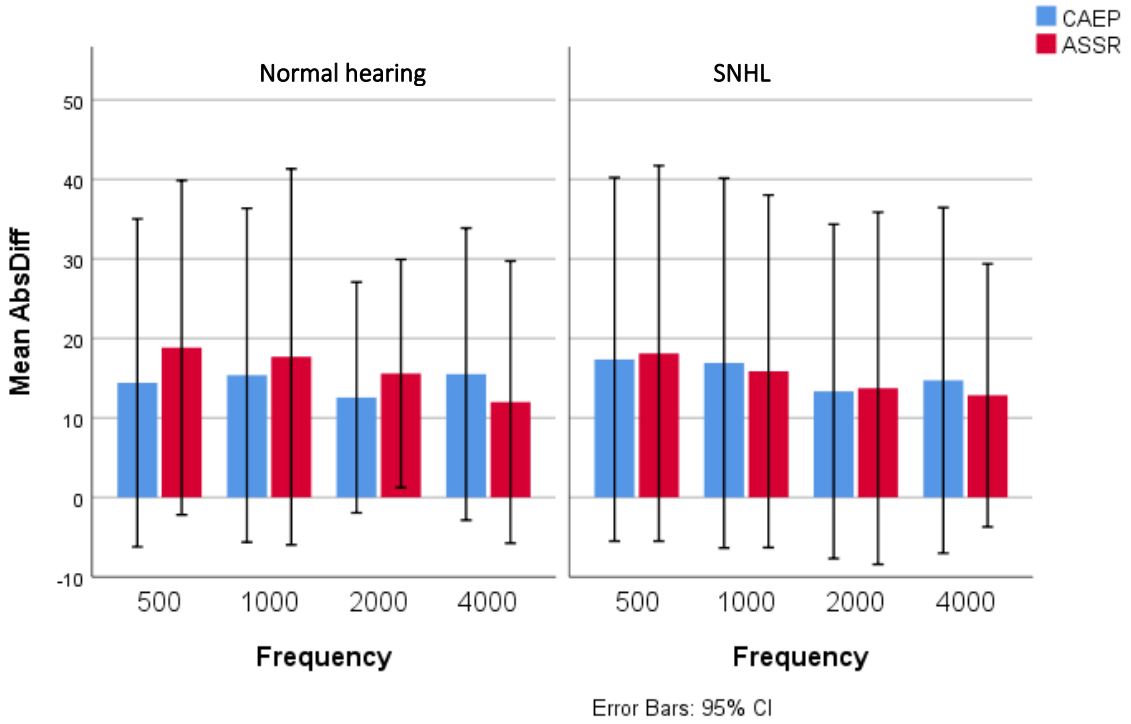

Figure 3.3: A clustered bar graph of the absolute differences by frequency for CAEP and ASSR for both the participants with normal hearing and with SNHL

A Wilcoxon signed-rank test was conducted to determine the absolute difference between ASSR and CAEP thresholds for the participants with normal hearing. The absolute difference between AEP and behavioural thresholds that were asymmetrically distributed between ASSR and CAEP at 1000 ($z=0.75$, $p>0.05$) and 4000 Hz ($z=1.73$, $p>0.05$), showing no statistical significance. However, the difference between AEP and behavioural thresholds at 500 Hz ($z=1.62$, $p=0.025$) and 2000 Hz ($z=1.66$, $p=0.023$) were statistically significant. The CAEP thresholds were closer to the behavioural thresholds than the ASSR at 500, 1000 and 2000 Hz. In contrast, however, the ASSR was closer to the behavioural thresholds at 4000 Hz.

A Wilcoxon signed-rank test was conducted to determine the absolute difference between ASSR and CAEP thresholds for the participants with SNHL. There was no statistical difference between the ASSR 500 Hz and CAEP 500 Hz (z=0.00, p>0.05), ASSR 1000 Hz and CAEP 1000 Hz (z=0.17, p>0.05) ASSR 2000 Hz and CAEP 2000 Hz (z=0.67, p>0.05) and ASSR 4000 Hz and CAEP 4000 Hz (z=0.52, p>0.05). The CAEP thresholds were marginally closer than the ASSR thresholds at 500 Hz, equivalent at 2000 Hz, while the ASSR was slightly better at 1000 and 4000 Hz in predicting the behavioural hearing thresholds.

A clustered bar graph of the differences by frequency for CAEP and ASSR for both the participants with normal hearing and for the participants with SNHL is displayed in figure 3.4.

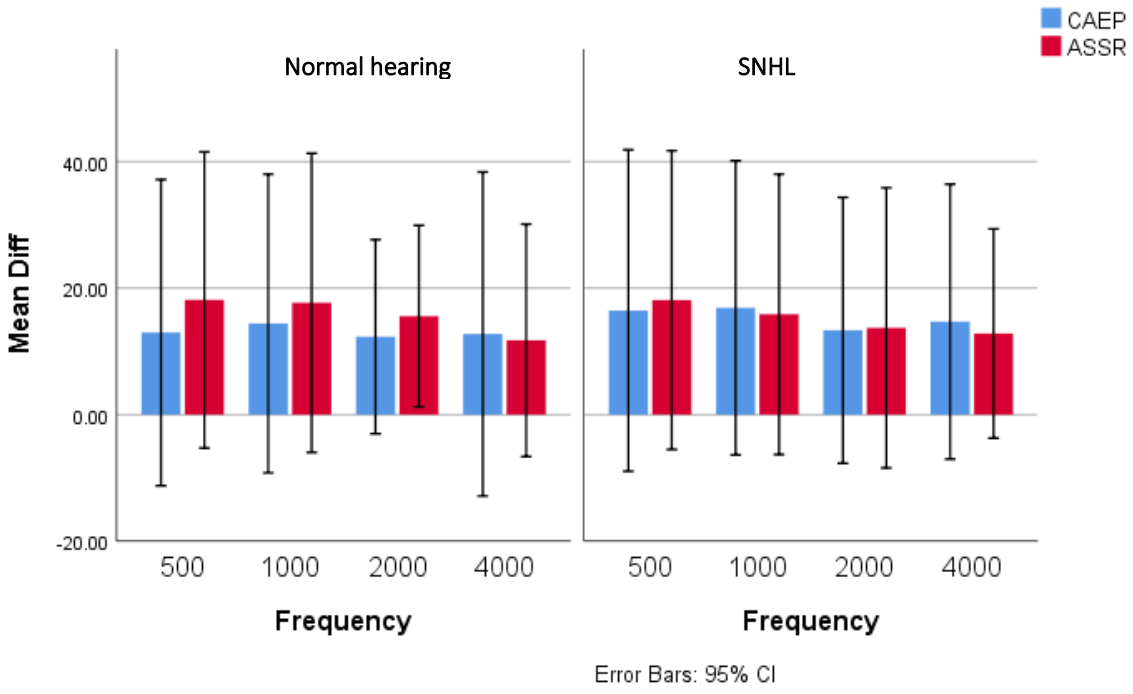

Figure 3.4: A clustered bar graph of the differences by frequency for CAEP and ASSR for both the participants with normal hearing and for the participants with SNHL

The largest mean difference was measured between the ASSR thresholds and the behavioural pure tone thresholds (mean=15.92 SD=11.22). Similar mean difference scores were detected between the CAEP thresholds and the behavioural pure tone thresholds. The mean differences between ASSR thresholds and both groups' hearing thresholds are higher than those of the CAEP thresholds.

A Wilcoxon signed-rank test was conducted to determine the difference between ASSR and CAEP thresholds for the participants with normal hearing. The difference between AEP and behavioural thresholds were asymmetrically distributed between the ASSR and CAEP at 1000 ($z=1.94$, $p>0.05$) and 4000 Hz ($z=0.13$, $p>0.05$), showing no statistical significance. However, the difference between AEP and behavioural thresholds at 500 ($z=2.19$, $p=0.028$) and 2000 Hz ($z=2.42$, $p=0.016$) were statistically significant. The CAEP thresholds were closer to the behavioural thresholds than the ASSR at 500, 1000 and 2000 Hz. In contrast, however, the ASSR was closer to the behavioural thresholds at 4000 Hz.

A Wilcoxon signed-rank test was conducted to determine the difference between ASSR and CAEP thresholds for the participants with SNHL. There was no significant difference between the ASSR 500 Hz and CAEP 500 Hz ($z=0.00$, $p>0.05$), ASSR 1000 Hz and CAEP 1000 Hz ($z=0.17$, $p>0.05$) ASSR 2000 Hz and CAEP 2000 Hz ($z=0.67$, $p>0.05$) and ASSR 4000 Hz and CAEP 4000 Hz ($z=0.52$, $p>0.05$). The CAEP was marginally closer than the ASSR to the behavioural hearing threshold at 500, 1000 and 2000 Hz with a similar difference between AEP and behavioural thresholds at 4000 Hz.

According to the general linear model, the absolute differences of CAEP thresholds at 500, 1000, 2000 and 4000 Hz showed no statistical significance $F(3,195)=2.047$, $p=0.109$. The absolute differences of ASSR thresholds at 500, 1000, 2000 and 4000 Hz showed statistical significance $F(3,213)=10.679$, $p<0.0005$.

An analysis of variance (ANOVA) using the absolute difference scores was run to determine the interaction between the AEP and hearing sensitivity. There was no significant interaction between the two variables, with and without outliers respectively, ($F1,594=1.858$; $p=0.173$, partial $n^2=0.003$) and ($F1,608=1.319$; $p=0.251$, partial $n^2=0.002$). Homogeneity of variance was confirmed ($p=0.228$, 0.385 respectively). Similarly, there was no significant interaction between the difference scores of the two variables, with and without outliers, respectively, ($F1,596=2.553$; $p=0.111$, partial $n^2=0.004$). and ($F1,608=2.490$; $p=0.115$, partial $n^2=0.004$). Homogeneity of variance was confirmed ($p=0.715$, 0.707 respectively).

A regression analysis was performed to predict the absolute differences scores and difference scores from the choice of AEPs, hearing sensitivity and frequency. For both scores the regression model was significant (absolute difference scores= $F(3, 608)=3.893$, $p =0.009$, adjusted $R^2=0.014$) and (difference scores= $F(3, 608)=4,274$, $p =0,005$, adjusted $R^2=0.016$) but only frequency contributed significantly to the model ($p<0.01$) while hearing sensitivity and the choice of AEP did not contribute significantly ($p>0.05$).

A regression analysis was repeated with outliers excluded from the model. The regression model again significantly predicted absolute difference and difference scores (absolute difference scores= $F(3, 594)=2.833$, $p =0,38$, adjusted $R^2=0.009$) and (difference scores= $F(3, 596)=3.618$, $p =0,12$, adjusted $R^2=0.013$), but with only frequency contributing significantly to the model ($p<0.01$).

3.5 Discussion

The main aim of the study was to compare the frequency specific CAEP and chirp-evoked 40 Hz ASSR with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL. The current study concluded that the CAEP threshold is generally closer to the behavioural hearing thresholds than the 40 Hz ASSR at all frequencies except at 4000 Hz. The study further found that the group with normal hearing participants presented with significantly smaller CAEP difference scores than ASSR difference scores at 500 and 2000 Hz. In participants with sensorineural hearing loss, no statistical difference was found between methods concerning the AEP sensation level.

CAEPs

The current study measured similar CAEP difference scores across frequencies for the participants with normal hearing (mean=12.32-14.40 dB) and with SNHL (mean=10.00-16.47 dB), with the largest difference scores measured at 500 and 1000 Hz respectively. Both Lightfoot and Kennedy (2006; 11 dB at 1000 Hz and 10 dB at 2000 Hz) and Tomlin et al. (2006; 11 dB at 500 Hz and 12 dB at 4000 Hz) reported similar CAEPs difference scores to the present study in adults with normal hearing and with sensorineural hearing loss. Larger differences scores of 20 dB at 500, 1000 and 2000 Hz were reported by Van Maanen and Stapells (2005) while Biagio et al. (2009; 0 dB at 500 Hz, 3 dB at 1000 Hz, 6 dB at 2000 Hz; 1 dB at 4000 Hz) and Yeung and Wong (2007; 6 dB at 500 Hz, 8 dB at 1000 and 2000 Hz; -2 dB at 4000 Hz) reported smaller difference scores in comparison to that of the current study. Both Biagio et al. (2009) and Yeung and Wong (2007) made use of similar length of stimulus averaging and both normal and elevated hearing thresholds as did the current study. The minimum SNR required for the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex in the current study may have resulted in higher CAEP thresholds than that of Biagio et al. (2009) and Yeung and Wong (2007). Van Maanen and Stapells (2005) used a lower number of stimuli per replication, which could have led to higher residual noise levels and consequently elevated threshold responses. As was the case in the present study, previous studies found no significant difference between the proximity of CAEP threshold to participants

with normal hearing versus those with sensorineural hearing loss (Biagio et al., 2009; Tomlin et al., 2006; Van Maanen & Stapells, 2005).

ASSR

The 40 Hz ASSR results of the current study demonstrated a decrease in mean thresholds relative to the behavioural pure tone threshold as the frequency was increased for both the participants with normal hearing and the participants with SNHL. The current study found the ASSR difference scores for participants with SNHL (17.30, 15.29, 11.71 and 10.17 dB at 500 to 4000 Hz respectively) to be slightly smaller than for the participants with normal hearing (18.14, 17.67, 15.58 and 11.74 dB at 500 to 4000 Hz respectively). Both Van Maanen and Stapells (2005; 14 dB at 500 Hz, 11 dB at 1000 Hz, 12 dB at 2000 Hz and 0 dB at 4000 Hz) and Yeung and Wong (2007; 11 dB at 500 Hz, 14 dB at 1000 Hz, 12 dB at 2000 Hz and 4 dB at 4000 Hz) had slightly smaller ASSR difference scored across all frequencies than the current study. The smaller difference scores may have been due to the longer averaging time (viz. eight minutes) employed compared to that of the current study (viz. six minutes). Biagio et al. (2009; 25, 22, 32 and 27 dB at 500 to 4000 Hz respectively) and Tomlin et al. (2006; 30 dB at 4000 Hz) showed larger difference scores than the current study but made use of a short maximum epoch of 89 seconds. It has been established that longer averaging times reduces ASSR thresholds (Israelsson, Bogo, & Berninger, 2015). The longer averaging time that was used by Van Maanen and Stapells (2005) and Yeung and Wong (2007) can be the result of their difference scores being closer to behavioural thresholds than the difference scores of the current study, and the difference scores of Biagio et al. (2009) and Tomlin et al. (2006) being larger than the difference scores of the current study.

Another explanation for the lower ASSR sensation levels than the studies of Biagio et al. (2009) and Tomlin et al. (2006) could be the stimuli and systems used. Both Biagio et al. (2009) and Tomlin et al. (2006) made use of AM/FM stimuli ASSR systems, whereas the current study used a ‘next generation’ ASSR system (Sininger, Hunter, Hayes, Roush, & Uhler, 2018) that employs chirp stimuli (Biagio, 2009; Tomlin et al., 2006). Chirp stimuli were shown to compensate for the basilar membrane travelling

wave and the cochlear delay (Lee et al., 2016). Lee et al. (2016) and Venail, Artaud, Blanchet, Uziel, and Mondain (2014) compared how accurate the narrowband CE-chirp ASSR predicts behavioural thresholds, and concluded that the CE-chirp ASSR allows for a fast and reliable assessment of behavioural hearing thresholds. The CE-chirp ASSR system used in the current study may have had resulted in ASSR thresholds being closer to the behavioural hearing thresholds.

Biagio et al. (2009) and Van Maanen and Stapells (2005) found no significant difference between the participants with normal hearing and the participants with SNHL. In contrast, however, Tomlin et al. (2007) found a significant difference between the participants with normal hearing and those with SNHL. All of the previous studies are in contrast with the current study, who concluded that the ASSR is slightly better in predicting the behavioural hearing thresholds of the participants with SNHL than in those with normal hearing. The next generation ASSR response detection paradigm used in the present study employs both phase and amplitude information of the fundamental frequency and 20+ harmonics thereof for the purpose of response detection. The advanced objective response detection strategy used has been shown to result in lower ASSR thresholds (Sininger et al., 2018).

CAEP compared to the 40 Hz ASSR

The CAEP thresholds in the current study were generally closer to the behavioural hearing thresholds of both participants with normal hearing and with SNHL than the 40 Hz ASSR at, 500, 1000, and 2000 Hz; however, the 40 Hz ASSR were closer to the behavioural thresholds at 4000 Hz than the CAEP. There appears to be a consensus between the current and previous literature on this pattern of findings. Biagio et al. (2009), and Tomlin et al. (2006) also concluded that CAEP thresholds were closer to behavioural hearing thresholds than ASSR thresholds were at 500, 1000 and 2000 Hz. Furthermore, both Van Maanen and Stapells (2005) and Yeung and Wong (2007) found that the ASSR thresholds were slightly closer to the behavioural pure tone thresholds than CAEP thresholds at 4000 Hz.

Despite the CAEP being closer to the behavioural hearing thresholds than the 40 Hz ASSR at all the frequencies except at 4000 Hz, there was no statistically significant interaction between the choice of AEP and hearing sensitivity ($p>0.05$). A multiple regression analysis was performed to predict the absolute differences scores between AEPs, hearing sensitivity and frequency. The model statistically significantly predicted the AEP absolute difference and difference scores ($p<0.01$). However, only frequency contributed statistically significantly to the model ($p<0.01$).

The lower CAEP than ASSR thresholds reported in the current study may be considered unexpected if one considers firstly, the lower 40 Hz ASSR thresholds in relation to behavioural thresholds compared to previous literature (Biagio, 2009; Tomlin et al., 2006); secondly, the use of a longer averaging time than in Biagio et al. (2009) and Tomlin et al. (2006); and finally, the use of next-generation ASSR system that uses CE chirp stimuli.

The current study did control for residual noise levels to achieve better SNR for CAEP threshold estimation. Van Maanen and Stapells (2005), controlled for residual noise levels in that they only recorded AEP responses as present when the signal was subjectively larger than the noise levels. None of the previous studies comparing CAEP and ASSR thresholds controlled for the residual noise levels (Biagio et al., 2009; Tomlin et al., 2006; Yeung & Wong, 2007). The present study adhered to best practice guidelines regarding maximum permissible residual noise levels (≤2 μV) and minimum SNR (≥2.5) requirements at CAEP threshold level (BSA, 2015). A previous study that was done by Billings, Tremblay, Stecker and Tolin (2009) showed the importance of good SNR when conducting CAEP testing. The study tested the CAEP of participants with normal hearing in twelve different conditions at intensity levels of 60 and 75 dB SPL. The first condition was quiet, followed by increments in noise over five conditions. The study concluded that the SNR significantly affected the amplitudes, and therefore also reduced the threshold levels at which the response can be measured (Billings, Tremblay, Stecker, & Tolin, 2009). Although ASSR SNR was not measured in the present study, maximum permissible residual noise levels were abided by. This, along with the long averaging time and use of CE chirp stimuli is likely to have led to better SNR in low amplitude ASSR responses. Making use of a structured method to estimate

residual noise and SNR, as was done in the current study, can consequently result in CAEP and ASSR thresholds closer to the behavioural hearing thresholds for both the participants with normal hearing and the participants with SNHL.

The CAEP system used in the current study did not provide a measure of residual noise or SNR. However, the use of the procedure advocated by BSA (2015) enabled the application of a strict noise criterion for CAEP threshold prediction, which has not previously been the case with comparisons between CAEP and 40 Hz ASSR measures. The minimum SNR required for the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex in the current study may have resulted in higher CAEP thresholds than mentioned in previous research.

Despite the significantly closer proximity of CAEP to behavioural pure tone threshold than ASSR at 500 and 2000 Hz in adults with normal hearing sensitivity, this is likely to have limited clinical implications. This is due to the advantage of the objective (as opposed to subjective response detection) that is offered by ASSR. Subjective response detection is required by the majority of commercially available CAEP systems. This requires considerable experience, particularly at low and threshold sensation levels. Clinicians are therefore likely to select ASSR over CAEP due to the response detection method.

The comparison of the clinical impact that both accuracy and time efficiency, as well as the automated CAEP system, will have on the CAEP and ASSR methods used for threshold estimation. The evaluation of time efficiency and inter-rater reliability would be a valuable addition to future comparative studies.

3.6 Conclusion

The current study found that the CAEP was closer to the behavioural hearing thresholds than the 40 Hz ASSR at all frequencies except at 4000 Hz. In participants with normal hearing, participants presented with significantly smaller CAEP than ASSR difference scores at 500 and 2000 Hz. In participants with sensorineural hearing loss, CAEP and ASSR thresholds were measured at similar sensation levels. Although the present study found the 40 Hz ASSR to be closer to the threshold at 4000 Hz, the threshold was not statistically closer to the behavioural threshold than CAEP thresholds. Therefore, for the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex, CAEP with strict maximum residual noise and minimum SNR at threshold, rather than the 40 Hz ASSR, is consequently advocated, regardless of the hearing sensitivity. Despite this, the objective response detection offered by ASSR may remain the most influential consideration for clinicians.

4. Chapter 4: Summary and Conclusion

Objective threshold estimation for populations that include children, malingerers and or people with physical and mental disabilities, who cannot accurately provide behavioural results exists (Hall III & Swanepoel, 2010). One such method includes auditory evoked potentials (AEP) (Hone et al., 2003). The AEP's that are used for threshold estimation include Auditory Steady State Response (ASSR) and Cortical Auditory Evoked Potential (CAEP).

Previous studies indicated that the averaging time, stimuli used and controlled residual noise criteria might influence the outcomes of these tests (Biagio et al., 2009; Tomlin et al., 2006; Van Maanen & Stapells, 2005). The studies that identified CAEPs as the more accurate AEP for estimation of hearing thresholds all used the single-frequency ASSR system with an epoch of 89 seconds. In contrast, the multiple-frequency 40 Hz ASSR system used by van Maanen and Stapells (2005) made use of a mean recording time of 21 minutes, and the outcome indicated that the ASSR more accurately predicted behavioural thresholds than the CAEP. Residual noise levels are reduced when the recording time increased, which could lead to more accurate behavioural threshold prediction. The length of the recording time resulted in different outcomes, and it seems possible that the difference in residual noise may have led to the different conclusions drawn rather than the AEP itself.

The earlier studies comparing ASSR and CAEP threshold estimation have all made use of AM/FM stimuli. A next-generation multiple-frequency ASSR system has introduced the use of chirp stimuli. There were no studies comparing the chirp ASSR and the CAEP to determine which one more accurately predicted the hearing thresholds in adults with SNHL (Lee et al., 2016; Mühler et al., 2012; Rodrigues & Lewis, 2014) The current study, therefore, proposed to compare the CAEP and chirp-evoked ASSR with equivalent residual noise levels for behavioural threshold prediction in adults with normal hearing and with SNHL.

4.1 **Summary of results**

The current study measured similar mean CAEP difference scores across frequencies for the participants with normal hearing and with SNHL, with the largest difference scores measured at 500 and 1000 Hz, respectively. The ASSR difference scores for participants with SNHL were found to be slightly smaller than for the participants with normal hearing.

The CAEP thresholds in the current study were generally closer to the behavioural hearing thresholds of both participants with normal hearing and with SNHL than the 40 Hz ASSR at, 500, 1000, and 2000 Hz; however, the 40 Hz ASSR were closer to the behavioural thresholds at 4000 Hz than the CAEP.

Previous studies made use of AM/FM stimuli ASSR systems, whereas the current study used a 'next generation' ASSR system (Sininger et al., 2018) that employs chirp stimuli (Biagio, 2009; Tomlin et al., 2006). The CE-chirp ASSR system used in the current study may have had resulted in ASSR thresholds being closer to the behavioural hearing thresholds. The researchers hypothesised that the next-generation ASSR might have yielded better results; however, results indicated that the CAEP is closer to behaviour thresholds than the 40 Hz ASSR.

Although ASSR SNR was not measured in the present study, maximum permissible residual noise levels were abided by. This, along with the long averaging time and use of CE chirp stimuli is likely to have led to better SNR in low amplitude ASSR responses. Making use of a structured method to estimate residual noise and SNR, as was done in the current study, can consequently result in CAEP and ASSR thresholds closer to the behavioural hearing thresholds for both the participants with normal hearing and the participants with SNHL.

4.2 **Clinical implications**

- For the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex, CAEP with strict maximum residual noise and minimum SNR at threshold, rather than 40 Hz ASSR, is advocated for use for threshold estimation in adult, regardless of hearing sensitivity. Although the present study found the 40 Hz ASSR to be closer to the behavioural threshold at 4000 Hz than the CAEP threshold, the threshold was not significantly closer to the behavioural threshold.
- Interpretation of CAEP threshold estimation does, however, require clinical experience. In the participants with hearing loss, no significant differences were obtained; therefore, the ASSR can be used for threshold estimation, which requires no subjective response detection.
- Despite CAEP thresholds being significantly lower than ASSR thresholds in adults with normal hearing, it is worth noting that the next-generation ASSR thresholds were closer to the behavioural thresholds than were previously reported with first-generation ASSR systems.
- The residual noise levels of each CAEP response had to comply with the noise criteria of ≤2μV per BSA guidelines (BSA, 2015). Measuring the residual noise levels and ensuring 2.5:1 SNR provided some objectivity in determining the presence or absence of the CAEP response. This is fundamental to the accuracy of the clinical use of the measure and should be employed routinely.

4.3 **Critical evaluation**

Strengths

- The current study used a strict residual noise criterion, which has not been applied in previous research.
- There are currently no previous studies that compared CAEP and ASSR thresholds to the behavioural hearing thresholds that made use of the next-generation ASSR software with the Chirp stimuli.
- Within-participant comparisons were made to rule out any individual differences. The participants were tested on the same day to ensure that no variables such as level of awareness, especially for the CAEP affected the study.
- The 40 Hz ASSR and CAEP have the same neural generators located in the primary auditory cortex; therefore, the participants had to be awake throughout the tests. The participants were asked to read a passage or watch a closed caption movie and were given regular breaks to ensure an awake state
- A single AEP system, namely the Interacoustics' Eclipse AEP system was used for both ASSR and CAEP testing; this ruled out any possible extraneous variables such as calibration differences, that could have influenced the test results.
- Although inter-rater reliability was not compared, two independent evaluators were required to determine the CAEP thresholds.

Limitations

- The CAEP system that was used by the current study did not provide a measure of residual noise and SNR measurements. The clinicians, therefore, relied on a structured method for residual noise measurement. Although this enables estimates of residual noise and SNR at threshold, an objective measure hereof would have been preferable.
- Time efficiency between the CAEP and ASSR methods was not compared.
- Subjective response detection was required for CAEP interpretation. There is one system that is commercially available that provides objective response detection. Had this system been available to the researchers, this may have improved objectivity of response detection for CAEPs.
- The participants with normal hearing had an uneven distribution of male versus female participants. The majority of the participants with normal hearing were female who,

according to previous research does not have a significant impact on the 40 Hz ASSR outcomes (Melynyte, Pipinis, Genyte, Voicikas, Rihs, & Griskova-Bulanova, 2018). However, Hall (2007) mentioned the lack of research related to the effects that gender has on the SCAEP.

4.4 **Future research**

The current study has brought to light the need for additional research in the following areas:

- Comparison of the clinical impact that both accuracy and time efficiency will have on the CAEP and ASSR methods used for threshold estimation. Seeing that the ASSR system for threshold estimation has been reported to be clinically faster, however less accurate than the CAEP.
- The impact that the measure of the inter-rater reliability will have on the CAEP threshold estimation. To measure to what an extent the interpretation of the CAEP thresholds by two independent clinicians has on the test results.
- To compare the impact that the automated CAEP system, as opposed to the CAEP system used in the current study, has on the threshold estimation. To determine the accuracy with which the automated CAEP system determines the CAEP thresholds.

4.5 **Conclusion**

The current study found that the CAEP was closer to the behavioural thresholds than the 40 Hz ASSR at all frequencies except at 4000 Hz. In participants with sensorineural hearing loss, CAEP and ASSR thresholds were measured at similar sensation levels In participants with normal hearing; participants presented with significantly smaller CAEP than ASSR difference scores at 500 and 2000 Hz. Although the present study found the 40 Hz ASSR to be closer to the threshold at 4000 Hz, the threshold was not statistically closer to the behavioural hearing threshold. Therefore, for the purpose of threshold estimation, representing the auditory function to the level of the auditory cortex, CAEP with strict maximum residual noise and minimum SNR at threshold, rather than the 40 Hz ASSR, is consequently advocated, regardless of the hearing sensitivity. Despite this, the objective response detection offered by ASSR may remain the most influential consideration for clinicians.

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Appendices

APPENDIX A - INDUSTRIAL INFORMATION FORM

Department of Speech-Language Pathology and Audiology
Lynnwood Rd, Hatfield, Pretoria, 0002
Mieke Kritzinger, Researcher
P.O. Box 138, Montanapark, Pretoria, 0159
Tel. nr.: 082 044 4949

Dear Sir/Madam,

Re. Information form regarding providing participants and participant results in the research project

Thank you for considering letting your employees participate in this research project. The project is entitled 'Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss'. The study is being completed in fulfilment of the requirements of the degree Master of Arts (Audiology).

Background Information

The main aim of this study is to compare two objective tests of hearing. These tests of hearing are objective because the participant doesn't need to actively participate, other than to remain alert through one and relaxed for the duration of the other. Objective tests of hearing are required when a client cannot or will not co-operate for the normal behavioural hearing assessment. An objective test of hearing is useful to determine the client's true thresholds of hearing.

Rationale for the research project

The reason it has become necessary to compare the performance of these two tests is that there is a newer objective test of hearing, called ASSR, which is potentially more accurate and faster than the CAEP which has been used to assess hearing loss. New equipment, technology and stimuli could also possibly influence the accuracy of the objective test's results.

Who would participate in this study?

Participation in this study is completely voluntary, and participation can be withdrawn at any point. Certain participants in this study must be individuals who already have sensorineural hearing loss (SNHL). For the objective tests to be accurate, the participants must respond consistently and co-operate well during the behavioural assessment. Participants must also be able to understand English or Afrikaans so that they can follow the instructions given during the assessment.

What would participation involve?

The researcher will need access to previous hearing assessments of all employees. The results will be fine-combed to determine which participants meet the criteria for the study. Participation in this study involves a single assessment session lasting approximately two and a half hours. The session will involve the traditional behavioural hearing assessment as well as a quick test to ensure the middle ear is healthy. This will be followed by the two objective tests. The behavioural assessment involves placing earphones on the participant, who will be asked to respond by pressing a button to indicate whenever a pure tone or beep is heard. The objective tests will be performed by putting four electrodes on the participant's forehead and ear lobes. Insert earphones will be put in both ears, through which sounds of different volumes will be presented. The participant will be asked to remain still but alert during the CAEP, and will be encouraged to relax, or even sleep, during the ASSR. It will also be necessary to ask each participant their age, whether or not they have a history of neurological problems, and what medication they use.

Confidentiality and anonymity

The assessment will take place at the industry. Only the participant and the researcher will be present during the assessment. Once the assessment is completed, the results of the CAEP will be shown to another audiologist who will assist in the interpretation thereof. The results of the assessment will be completely confidential and will not be given to the employer or any other party. Participants' information will be kept confidential by referring to each participant using the alphanumeric code. The participant's name will not be used in any form. Each participant will verbally receive the tests results directly after the assessment is completed. The health and safety department of the industry will also receive a written report of the findings for each of their employees that take part in the research project. All data will be stored for a minimum of 15 years at the University of Pretoria for research and archiving purposes.

Why should the industry participate in the research project?

There is no direct benefit to the participant in the research project, but the results will give audiologists information on the comparative accuracy of the two objective tests of hearing. The results will guide audiologists in choosing the most accurate and quickest objective method of hearing assessment to be used at clinics.

There is no risk involved in the assessment and no discomfort on the part of the participant. The assessment is lengthy and may result in fatigue. However, as mentioned previously, during part of the assessment, the participant is encouraged to relax or sleep.

The industry will have more in-depth information regarding the hearing of their employees.

The industry is entitled to contact me at any point in the event of any further queries regarding the research project. The participant and the industry will also have access to the results of the study on request from the researcher. An article summarizing the study will also be published in an audiological journal.

Please feel free to contact me on 082 044 4949 if you need to clarify any of the above information. I would be most grateful if you would agree to participate in this research project.

With thanks and kind regards Mieke Kritzinger: . . Researcher / Audiologist

Mr Henry Weissensee _____

Production and Training Manager Place of signing

_____

Researcher

Dr Leigh Biagio de Jager _____

Supervisor Place of signing

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

APPENDIX B- INDUSTRIAL CONSENT FORM

Department of Speech-Language Pathology and Audiology
Lynnwood Rd, Hatfield, Pretoria, 0002
Mieke Kritzinger, Researcher
P.O. Box 138, Montanapark, Pretoria, 0159
Tel. nr.: 082 044 4949

Date: 09/11/2018 consent form regarding participation in the research project.

We, AEROSUD, hereby consent to participate in and provide previous audiological data of our employees to the research project entitled 'Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss', undertaken by Mieke Kritzinger in fulfilment of the requirements of MA (Audiology). We have read and understood the information form detailing the aims and assessment procedure of the research project. We have been given the opportunity to ask the researcher questions in order to obtain clarification of any aspect of the study.

We understand that involvement in the research project is voluntary and that we may withdraw from participation in the study at any point without any negative consequences.

Mr Henry Weissensee
Production and Training Manager

Place of signing

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Researcher

Dr Leigh Biagio de Jager
Supervisor

Place of signing

APPENDIX C - QUESTIONNAIRE – CASE HISTORY FORM

Name: _____ Age: _____

Do you have any family history of hearing loss?: _____
_____
_____

Did you have any surgeries done in your head and neck area: If yes, where and how long ago?: _____
_____
_____

Do you have a history of middle ear infections?: _____
_____
_____

Do you have any history of neurological problems? If yes please name and describe the problem:_____
_____
_____

What medications are you currently taking?:_____
_____
_____

APPENDIX D - NORMAL HEARING PARTICIPANT INFORMATION FORM

Department of Speech-Language Pathology and Audiology
Lynnwood Rd, Hatfield, Pretoria, 0002
Mieke Kritzinger, Researcher
P.O. Box 138, Montanapark, Pretoria, 0159
Tel. nr.: 082 044 4949

Dear Sir/Madam,

Re. Information form regarding participation in the research project

Thank you for considering participating in this research project. The project is entitled 'Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss'. The study is being completed in fulfilment of the requirements of the degree Master of Arts (Audiology).

Background Information

The main aim of this study is to compare two objective tests of hearing. These tests of hearing are objective because the participant doesn't need to co-operate, other than to remain alert through one and relaxed for the duration of the other. Objective tests of hearing are required when a client cannot or will not co-operate for the normal behavioural hearing assessment. An objective test of hearing is useful in order to determine the client's true thresholds of hearing.

Rationale for the research project

The reason it has become necessary to compare the performance of these two tests is that there is a newer objective test of hearing, called ASSR, which is potentially more accurate and faster than the CAEP which has been used to assess hearing loss. New equipment and technology could also possibly influence the accuracy of the objective test's results.

Who would participate in this study?

Participation in this study is completely voluntary, and participation can be withdrawn at any point. Participants must have normal hearing. For the objective tests to be accurate, the participants must respond consistently and co-operate well during the behavioural assessment. Participants must also be able to understand English or Afrikaans so that they can follow the instructions given during the assessment.

What would participation involve?

Participation in this study involves a single assessment session lasting approximately two and a half hours. The session will involve the traditional behavioural hearing assessment as well as a quick test to ensure the middle ear is healthy. This will be followed by the two objective tests. The behavioural assessment involves placing earphones on the participant, who will be asked to respond by pressing a button to indicate whenever a pure tone or beep is heard. The objective tests will be performed by putting four electrodes on the participant's forehead and ear lobes. Soft sponge earphones will be put in each ear canal, through which sounds of different volumes will be presented. The participant will be asked to remain still but alert during the CAEP, and will be encouraged to relax, or even sleep, during the ASSR. It will also be necessary to ask each participant their age, whether or not they have a history of neurological problems, and what medication they use.

Confidentiality and anonymity

The assessment will take place at the University of Pretoria or at the industry. Only the participant and the researcher will be present during the assessment. Once the assessment is completed, the results of the CAEP will be shown to another audiologist who will assist in the interpretation thereof. The results of the assessment will be completely confidential; it will only be given to the employer and the participant. Participants' information will be kept confidential by referring to each participant using the alphanumeric code. The participant's name will not be used in any form. Each

participant will verbally receive the tests results directly after the assessment is completed. The health and safety department of the industry will also receive a written report of the findings for each of their employees that take part in the research project. All data will be stored for a minimum of 15 years at the University of Pretoria for research and archiving purposes.

Why should I participate in the research project?

There is no direct benefit to the participant in the research project, but the results will give audiologists information on the comparative accuracy of the two objective tests of hearing. The results will guide audiologists in choosing the most accurate and quickest objective method of hearing assessment to be used at clinics.

There is no risk involved in the assessment and no discomfort on the part of the participant. The assessment is lengthy and may result in fatigue. However, as mentioned previously, during part of the assessment, the participant is encouraged to relax or sleep.

The participant is entitled to contact me at any point in the event of any further queries regarding the research project. The participant will also have access to the results of the study on request from the researcher. An article summarizing the study will also be published in an audiological journal. The results will be stored for archiving and future research purposes.

Please feel free to contact me on 082 044 4949 if you need to clarify any of the above information. I would be most grateful if you would agree to participate in this research project.

With thanks and kind regards Mieke Kritzinger: Researcher / Audiologist

Participant	Date
Mieke Kritzinger	
Researcher	Place of signing
Dr Leigh Biagio de Jager	
Supervisor	Place of signing
Dr Jeannie van der Linde	
Head of Department	Place of signing

APPENDIX E - HEARING IMPAIRED PARTICIPANT INFORMATION FORM

Department of Speech-Language Pathology and Audiology
Lynnwood Rd, Hatfield, Pretoria, 0002
Mieke Kritzinger, Researcher
P.O. Box 138, Montanapark, Pretoria, 0159
Tel. nr.: 082 044 4949

Dear Sir/Madam,

Re. Information form regarding participation in the research project

Thank you for considering participating in this research project. The project is entitled 'Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss'. The study is being completed in fulfilment of the requirements of MA (Audiology). The industry has granted access to your previous hearing test results, and you have been identified as a possible participant in this study.

Background Information

The main aim of this study is to compare two objective tests of hearing. These tests of hearing are objective because the participant doesn't need to co-operate, other than to remain alert through one and relaxed for the duration of the other. Objective tests of hearing are required when a client cannot or will not co-operate for the normal behavioural hearing assessment. An objective test of hearing is useful in order to determine the client's true thresholds of hearing.

Rationale for the research project

The reason it has become necessary to compare the performance of these two tests is that there is a newer objective test of hearing, called ASSR, which is potentially more accurate and faster than the CAEP which has been used to assess hearing loss.

New equipment and technology could also possibly influence the accuracy of the objective test's results.

Who would participate in this study?

Participation in this study is completely voluntary, and participation can be withdrawn at any point. The participants in this study must be individuals who already have a hearing loss. For the objective tests to be accurate, the participants must respond consistently and co-operate well during the behavioural assessment. Participants must also be able to understand English or Afrikaans so that they can follow the instructions given during the assessment.

What would participation involve?

Participation in this study involves a single assessment session lasting approximately two and a half hours. The session will involve the traditional behavioural hearing assessment as well as a quick test to ensure the middle ear is healthy. This will be followed by the two objective tests. The behavioural assessment involves placing earphones on the participant, who will be asked to respond by pressing a button to indicate whenever a pure tone or beep is heard. The objective tests will be performed by putting four disks on the participant's forehead and ear lobes. Soft sponge earphones will be put in each ear canal, through which sounds of different volumes will be presented. The participant will be asked to remain still but alert during the CAEP, and will be encouraged to relax, or even sleep, during the ASSR. It will also be necessary to ask each participant their age, whether or not they have a history of neurological problems, and what medication they use.

Confidentiality and anonymity

The assessment will take place at the industry. Only the participant and the researcher will be present during the assessment. Once the assessment is completed, the results of the CAEP will be shown to another audiologist who will assist in the interpretation thereof. The results of the assessment will be completely confidential; it will only be given to the employer and the participant. Participants' information will be kept confidential by referring to each participant using the alphanumeric code. The participant's name will not be used in any form. Each participant will verbally receive the tests results directly after the assessment is completed. The health and safety department of the industry will also receive a written report of the findings for each of their employees that take part in the research project. All data will be stored for a minimum of 15 years at the University of Pretoria for research and archiving purposes.

Why should I participate in the research project?

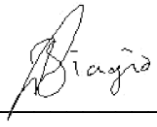
There is no direct benefit to the participant in the research project, but the results will give audiologists information on the comparative accuracy of the two objective tests of hearing. The results will guide audiologists in choosing the most accurate and quickest objective method of hearing assessment to be used at clinics.

There is no risk involved in the assessment and no discomfort on the part of the participant. The assessment is lengthy and may result in fatigue. However, as mentioned previously, during part of the assessment, the participant is encouraged to relax or sleep.

The participant is entitled to contact me at any point in the event of any further queries regarding the research project. The participant will also have access to the results of the study on request from the researcher. An article summarizing the study will also be published in an audiological journal. The results will be stored for archiving and future research purposes.

Please feel free to contact me on 082 044 4949 if you need to clarify any of the above information. I would be most grateful if you would agree to participate in this research project.

With thanks and kind regards Mieke Kritzinger: Researcher / Audiologist

Participant	Date
Mieke Kritzinger	
Researcher	Place of signing
Dr Leigh Biagio de Jager	
Supervisor	Place of signing
Dr Jeannie van der Linde	
Head of Department	Place of signing

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

APPENDIX F - PARTICIPANT CONSENT FORM

Department of Speech-Language Pathology and Audiology
Lynnwood Rd, Hatfield, Pretoria, 0002
Mieke Kritzinger, Researcher
P.O. Box 138, Montanapark, Pretoria, 0159
Tel. nr.: 082 044 4949

Date: _____consent form regarding participation in the research project

I, _____, hereby consent to participate in the research project entitled 'Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss', undertaken by Mieke Kritzinger in fulfilment of the requirements of MA (Audiology). I have read and understood the information form detailing the aims and assessment procedure of the research project. I have been given the opportunity to ask the researcher questions in order to obtain clarification of any aspect of the study.

I understand that involvement in the research project is voluntary and that I may withdraw from participation in the study at any point without any negative consequences.

_____ _____

Participant Date

Kritzinger

Researcher

Dr Leigh Biagio de Jager

Supervisor

Biagio

Place of signing

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YUNIBESITHI YA PRETORIA

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

APPENDIX G – DECLARATION FOR THE STORAGE OF RESEARCH DATA

Declaration for the storage of research data and/or documents

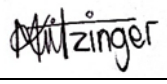
I/ We, the principal researcher(s), Mieke Kritzinger, and supervisor(s), Dr Leigh Biagio de Jager, of the following study, titled: Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss, will be storing all the research data and/or documents referring to the above-mentioned study in the following department: Department of Speech-language pathology and audiology at the University of Pretoria.

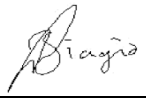
We understand that the storage of the mentioned data and/or documents must be maintained for a minimum of 15 years from the commencement of this study.

Start date of study: 14-01-2019

Anticipated end date of study: 30-11-2019

Year until which data will be stored: 2034

Name of Principal Researcher(s)	Signature	Date
Mieke Kritzinger		10/11/18

Name of Supervisor(s)	Signature	Date
Dr Leigh Biagio de Jager		10/11/18

Name of Head of Department	Signature	Date
Dr Jeannie van der Linde		10/11/18

University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 2816
Fax +27 (0)12 420 3517
www.up.ac.za

Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

APPENDIX H – MEMORANDUM OF AGREEMENT FOR ACADEMIC SUPERVISION OF POSTGRADUATE STUDENTS

Memorandum of Agreement

for Academic Supervision of Postgraduate Students

This document should be read in conjunction with the following University of Pretoria policy documents:

This document should be read in conjunction with the following University of Pretoria (UP) policy documents:

- the **University of Pretoria General Regulations** applicable to postgraduate study (G.16 to G.61),
- the **University Code of Ethics for Research**,
- the **University Plagiarism Policy**,
- the **Policy for the Preservation and Retention of Research Data**,
- the **Intellectual Property Policy**,
- the **Guidelines for Postgraduate** Supervision and
- the **UP Declaration of Originality form**.

IMPORTANT:

- These documents are all available on the university of Pretoria web site (http://www.up.ac.za) and on request from the Registrar's Division.
- Students are expected to read them and to ensure that they understand the content.
- Clear mediation mechanisms are available to deal with any grievances, personal problems or disagreements that may arise between a postgraduate candidate and the supervisor.
- (Refer to the General Regulations and Information of the University of Pretoria pertaining to the Student Communication Channel, Section B.15).

Memorandum of Agreement between Postgraduate Student and Supervisor

Name of student: Mieke Kritzinger

Student number: 15014012

Email address: mieke15k@gmail.com

Degree: MA (Audiology)

Department: Speech-Language Pathology and Audiology

School:

Faculty: Humanities

Name of supervisor: Dr Leigh Biagio de Jager

Email address: leigh.biagio@up.ac.za

Department: Speech-Language Pathology and Audiology

School:

Faculty: Humanities

THE STUDENT: Mieke Kritzinger accepts and undertakes the following roles and responsibilities:

1. Reading, understanding and abiding by the relevant rules and regulations of the University (in particular, those in the policies listed above).
2. Working independently under the guidance of the supervisor and ensuring that she or he stays abreast of the latest developments in the field of study.
3. Developing, with the advice of the supervisor, and abiding by, a time schedule which outlines the expected completion dates of various stages of the research work and dissertation or thesis (See Supervisor section, #4 below).
4. Attending pre-scheduled meetings with the supervisor and being adequately prepared for these consultation sessions (See Supervisor section, #5 below).
5. Submitting proposals, reports and written work at times agreed upon with the supervisor.

6. Taking account of the feedback provided by the supervisor before subsequent submission of written work.
7. Undertaking to submit the dissertation or thesis within the prescribed time for the completion of the degree unless exceptional circumstances arise, and to plan accordingly.
8. Accepting responsibility for the overall coherent structure of the final dissertation or thesis and, as far as possible, submitting written work that is free of spelling mistakes, grammatical errors and incorrect punctuation.
9. Undertaking to submit draft papers for publication, taking into account advice provided by the supervisor.
10. Informing the supervisor of any absence or circumstances that may affect the student's progress and schedule for completion.

THE SUPERVISOR: Dr Leigh Biagio de Jager accepts and undertakes the following roles and responsibilities:

1. Abiding by the relevant rules and regulations of the University.
2. Assisting the student in building knowledge and research skills in the specific area of postgraduate study and relevant to the level of the degree.
3. Ensuring that the proposed research project is feasible, of an appropriate level for the degree under consideration, and that the necessary resources and facilities will be available to enable the student to complete the research timeously.
4. Providing information on the conditions to be met in order to achieve satisfactory progress/performance and assisting with the construction of a written time schedule which outlines the expected completion dates of various stages of the research work.
5. Being accessible to the student by attending meetings in line with a schedule agreed upon in advance by the supervisor and the student and being prepared for the meetings.
6. Implementing an arrangement for student supervision in cases where the supervisor is away from the University e.g. sick leave, sabbatical leave, or leaves the employ of the University, and communicating these arrangements to the student timeously.

7. Accepting submission of written work at intervals agreed on by the student and supervisor, providing constructive comment and criticism within a time frame jointly agreed on at the start of the research, and informing the student, in writing, of any inadequacy relating to progress or work, in relation to the expectations previously agreed on by the student and supervisor. (In general, feedback should be provided within one month).
8. Assisting the student with the production of the dissertation or thesis, including providing guidance on technical aspects of writing and discipline-specific requirements.
9. Assisting with the publication of research articles as appropriate and ensuring understanding regarding the ownership of research results in accordance with the University's policy on intellectual property.
10. Contributing to the student's academic development by introducing her or him to relevant academic and professional networks through conferences, seminars and other events where possible.

THE STUDENT and THE SUPERVISOR:

1. Confirm that we have read and understood this Memorandum of Agreement;
2. Confirm that we have discussed and agreed on authorship of publications emanating from the project and understand that this must be agreed before any articles are submitted for publication;
3. Confirm that we have discussed and agreed on matters related to intellectual property and how it will be dealt with in future;
4. Understand that in the event that the student fails to maintain satisfactory progress, consultation between supervisor and student will take place and a warning letter from the Dean, and/or probation may result;
5. Understand that if satisfactory performance is not achieved after a probation period of three months, the supervisor may recommend to the Dean that the registration is terminated;
6. Understand that the student may appeal (in writing) the termination via a process of appeal to the Vice-Principal responsible for Research and Postgraduate Education;
7. Agree to accept the content of the Memorandum of Agreement for the duration of the period of study, in respect of the degree as specified below.

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

RECORD OF AGREEMENT ON PLACES AND DATES OF MEETINGS, MILESTONES AND DEADLINES

(to be completed at the time when the Agreement is signed)

AGREED MILESTONES (AND RELEVANT NOTES)	PLANNED DATE FOR COMPLETION	DEADLINE FOR COMPLETION
Proposal writing and ethical clearance	December 2018	January 2019
Data collection	March 2019	May 2019
Data analysis	June 2019	July 2019
Article writing	July 2019	August 2019
Dissertation writing	August 2019	September 2019
Final dissertation submission	September 2019	November 2019

Name of student: Mieke Kritzinger

Student number: 15014012

Degree: MA Audiology

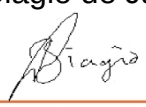
Department: Speech-Language Pathology and Audiology

Faculty: Humanities

Signed at 12:32 **on** 10/11/18

Student's signature: 

Name of supervisor: Leigh Biagio de Jager

Supervisor's signature: 

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Fakulteit Geesteswetenskappe
Departement Spraak-Taalpatologie en Oudiologie
Lefapha la Bomotho
Kgoro ya Phatholotši ya Polelo-Maleme le Go kwa

Name of co-supervisor:

Co-supervisor's signature:

Provisional date for thesis / dissertation submission: October 2019

Date Forwarded to the Head of Department:

Signature of receipt by Head of Department:

Signature of receipt in Dean's Office*

ATTACHMENTS REQUIRED:

1. Plagiarism Policy Agreement
2. Declaration of Originality

UNIVERSITY OF PRETORIA

PLAGIARISM POLICY AGREEMENT

The University of Pretoria places great emphasis upon integrity and ethical conduct in the preparation of all written work submitted for academic evaluation.

While academic staff teaches you about referencing techniques and how to avoid plagiarism, you too have a responsibility in this regard. If you are at any stage uncertain as to what is required, you should speak to your lecturer before any written work is submitted.

You are guilty of plagiarism if you copy something from another author's work (e.g. a book, an article or a website) without acknowledging the source and pass it off as your own. In effect, you are stealing something that belongs to someone else. This is not only the case when you copy work word-for-word (verbatim), but also when you submit someone else's work in a slightly altered form (paraphrase) or use a line of argument without acknowledging it. You are not allowed to use work previously produced by another student. You are also not allowed to let anybody copy your work with the intention of passing it off as his/her work.

Students who commit plagiarism will not be given any credit for plagiarised work. The matter may also be referred to the Disciplinary Committee (Students) for a ruling. Plagiarism is regarded as a serious contravention of the University's rules and can lead to expulsion from the University.

The declaration which follows must accompany all written work submitted while you are a student of the University of Pretoria. No written work will be accepted unless the declaration has been completed and attached.

Full names of candidate: Mieke Kritzinger

Student number: 15014012

Date: 10/11/18

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.

SIGNATURE OF CANDIDATE: 

SIGNATURE OF SUPERVISOR: 

This document must be signed and submitted to the Head: Student Administration within two months of registering for the research component of the programme.

UNIVERSITY OF PRETORIA

DECLARATION OF ORIGINALITY

This document must be signed and submitted with every

essay, report, project, assignment, dissertation and/or thesis.

Full names of student: Mieke Kritzinger

Student number: 15014012

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.

2. I declare that this dissertation (e.g. essay, report, project, assignment, dissertation, thesis, etc.) is my own original work. Where other people's work has been used (either from a printed source, Internet or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.

3. I have not used work previously produced by another student or any other person to hand in as my own.

4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE OF STUDENT: 

SIGNATURE OF SUPERVISOR: 

APPENDIX I: ETHICAL APPROVAL LETTER

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

30 November 2018

Dear Ms Kritzinger

Project:	**Cortical Auditory Evoked Potential (CAEP) and the chirp Auditory Steady State Response (ASSR) in predicting behavioural hearing thresholds in adults with sensorineural hearing loss**
Researcher:	**M Kritzinger**
Supervisors:	**Dr L Biagio de Jager**
Department:	**Speech-Language Pathology and Audiology**
Reference number:	**15014012 (GW20181121HS)**

Thank you for the application that was submitted for ethical consideration.

I am pleased to inform you that the above application was **approved** by the **Research Ethics Committee** at a meeting held on 29 November 2018. Data collection may therefore commence.

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. Should the actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

We wish you success with the project.

Sincerely

Prof Maxi Schoeman
Deputy Dean: Postgraduate and Research Ethics
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: PGHumanities@up.ac.za

cc: Dr L Biagio de Jager (Supervisor) Dr J van der Linde (HoD)