Does one size fit all? Exploring the effect of hearing aid impulse noise reduction on isiXhosa click sounds: A pilot study

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Abstract

To advance audiology research in modern day South Africa we have to recognise the injustices of the past to create a better future. Historically, South African audiology research was focused on Afrikaans and English. Currently, no published data exists on how the language characteristics of African languages are processed by hearing amplification technology. Hearing aids are programmed using a fitting rationale that calculates the amount of amplification needed to make sounds audible. Additionally hearing aid features are applied to make non-speech sounds less bothersome while a hearing aid user is listening to speech. Impulse noise reduction was developed to reduce the amplitude of clicks and pops. Due to the acoustic similarities between isiXhosa click sounds and non-speech click sounds e.g., sudden onset and decay, high intensity and broad frequency spectrum - a potential gain limiting risk exists when amplifying isiXhosa click sounds through a hearing aid equipped with the impulse noise reduction feature.

This study investigated the interaction of isiXhosa click sounds and hearing aid signal processing. High quality, single female speaker, recordings were created of words containing the 18 types of isiXhosa click sounds. These recorded words were played in a controlled environment, and the output of one hearing aid, set to a flat 40dB hearing loss, was recorded while using one of two selected commercial fitting rationales (NAL-NL2 and DSL v5.0a) and switching impulse noise reduction on and off.

A factorial *ANOVA* detected no significant mean gain reduction ($p = .645$) of isiXhosa clicks with impulse noise reduction switched on or off, irrespective of the selected fitting formula. A significant finding was that DSL v5.0a's mean amplitude of isiXhosa click sounds was higher compared to NAL-NL2 ($p < .001$).

In practice this study's findings can be used during clinical decision making. Should more audibility of isiXhosa clicks be required the DSL v5.0a fitting rationale can be selected. In contrast, should more comfort of isiXhosa clicks be required, the NAL-NL2 fitting formula can be selected. The 2

intention of this study was not only to investigate the interaction of impulse noise reduction and isiXhosa click sounds, but to shed a glimmer of light on the diversity of languages spoken within South Africa and the boundless potential research opportunities that exist within the field of Audiology.

Keywords: Audiology research South Africa, isiXhosa click sounds, hearing aid signal processing, impulse noise reduction, fitting rationales (NAL-NL2, DSL v5.0a), language diversity in audiology.

List of abbreviations

ANOVA -Analysis of Variance

ANSI - American National Standards Institute

CD - Compact Disc

dB SPL - decibel sound pressure level

DSL-V - Desired Sensation Level version V

HREC - Human Research Ethics Committee

ICF - International Classification of Functioning, Disability and Health framework

IEC - International Electrotechnical Commission

INR - Impulse Noise Reduction

ISTS - International Speech Test Signal

iXC-WL - isiXhosa Click Word List

NAL - National Acoustics Laboratory

NAL-NL2 - National Acoustics Laboratory Non-linear version 2

NCA - Western University's National Centre for Audiology

NLFC - Non-Linear Frequency Compression

RECD - Real Ear to Coupler Difference

RITE - Receiver In The Ear

SD - Secure Digital memory card

SOV - Subject, Object and Verb

UCL - Uncomfortable Loudness Level

VU - Volume Unit

WHO - World Health Organization

XLR - External Line Return

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Oprah Winfrey said the following: “I believe luck is preparation meeting opportunity”. This statement rings true through my experience completing this research project. I am grateful for this opportunity and feel incredibly lucky to have been guided by my supervisors Lucretia Petersen and Vera Hlayisi. It has been a great privilege to learn from you.

A lot of life happened during this study and I am eternally grateful to my husband, Wessel Strydom for his unwavering support. You’re simply the best. With you I can take on the world.

I would also like to thank my parents for the example they have set for me. Your dedication to your professions and approach to life inspired me to further my education, to be curious about the world, and never stop learning.

I will choose to find joy in the journey.

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Chapter 1: Introduction

"If you talk to a man in a language he understands, that goes to his head. If you talk to him in his language, that goes to his heart." Nelson Mandela

The profession of audiology was established in South Africa in 1962 (Swanepoel, 2006). Since 1962 until present time the profession of audiology as well as the country of South Africa has gone through a continual process of change, adaptation, and modernisation. Since the origination of audiology in South Africa, the country has progressed from the Union of South Africa, the apartheid era to the post-apartheid era. This continual paradigm shift is evident in research and service delivery in the field of Audiology in South Africa. Historically training institutions in South Africa developed the audiology profession to address the needs of white Afrikaans- and English- speaking citizens. South Africa held its first democratic election in 1994 and the newly elected government created the new constitution of South Africa which was promulgated by President Nelson Mandela on 18 December 1996 (Sachs, 1996). The preamble of the constitution of the republic of South Africa summarises the vision of our country as follows: "We the people of South Africa recognise the injustices of our past; honour those who suffered for justice and freedom on our land; respect those who have worked to build and develop our country; and believe that South Africa belongs to all who live in it, united in our diversity. We therefore, through our freely elected representatives, adopt this Constitution as the supreme law of the Republic so as to – Heal the divisions of the past and establish a society based on democratic values, social justice and fundamental human rights; lay the foundations for a democratic and open society in which government is based on the will of the people and every citizen is equally protected by law; improve the quality of life of all citizens and free the potential of each person; and build a united and democratic South Africa able to take its rightful place as a sovereign state in the family of nations." (Constitution of South Africa, 1996).

This giant leap forward in the political landscape of South Africa led to training institutions enrolling student groups that are increasingly representative of the ethnic, linguistic, and cultural diversity of South Africa (Swanepoel, 2006). Due to the injustices in the history of South Africa – very little scientific research has been completed to fully represent South African citizens linguistic diversity. In the field of Audiology in South Africa there is a gap in the research as no prior studies have been completed to investigate how African language characteristics interacts with amplification technology. This study intends to contribute information to the audiology research base in South Africa and advocate for the recognition, inclusion, and further study to highlight the unique language characteristics of all South African citizens.

The following section will focus on orientating the reader to the research question and provide the context and motivation for the current study.

Chapter 2: Literature review

Hearing is a fundamental part of interpersonal communication. The sense of hearing enables a person to experience the rich sound environment of the world. Generally, hearing loss causes loss of sensitivity of sound as well as impaired frequency selectivity and deficits in temporal processing (Katz, 2009). Deterioration in hearing can affect a person's ability to communicate and their quality of life negatively (Yamada, Svejdikova & Kisvetrova, 2017).

The first chapter (McCarthy & Alpiner, 2021) of the book titled Adult Audiologic Rehabilitation by Montano & Spitzer (2021) sets the scene – that for researchers to shape the future they have to understand the past. A brief overview of the theoretical frameworks takes the reader from the classic medical model of treatment to the initial international classification of impairment, disability and handicap (WHO, 1980). More recently in 2019 Phonak convened a group of researchers at the Well-Hearing is Well-Being™, a conference where experts were invited to share their thoughts on the effect of hearing loss on well-being (Vercammen et al., 2020). The research presented at this conference resulted in the formulation of a position statement on how well-being can be defined in the healthcare context as well as to guide future research aimed at improving quality of life for people with living with hearing loss (Vercammen et al, 2020). The position statement defined three broad dimensions of well-being that is affected by hearing loss namely the socio-emotional dimension, the cognitive dimension, and the physical dimension. The three dimensions are founded on the World Health Organization (WHO)'s constitution, which since 1948 describes health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." In 1986, the Ottawa Charter for Health Promotion added that "To reach a state of complete physical, mental and social well-being, an individual or group must be able to identify and to realize aspirations, to satisfy needs, and to change or cope with the environment. The Well-Hearing is Wellbeing body of work adds additional viewpoints and depth to the International Classification of Functioning, Disability and Health framework (ICF) which takes into account an individual's bodily and personal functions and how it affects their ability to participate in activities in their environment. This development from the medical model to a patient centred, rehabilitation model provides a framework to better understand the complexities of hearing loss and how its effects extend far beyond a reduction of hearing sensitivity.

The rehabilitation of hearing loss is multifaceted, but an important part of the treatment of hearing loss is the engineering of assistive technology like hearing aids. Sound amplification in a hearing aid aims to improve audibility of sound for a patient with hearing loss (Kollmeier & Kiessling, 2018). Improved access to sound by amplifying sounds that an individual with hearing loss needs can assist the individual to decern spoken word for communication as well as to provide environmental awareness. On the other hand, amplification of sound can result in an increase in intensity of all sounds including noise (Ewert & Oetting, 2018). Hearing aid technology has improved extensively since the introduction of analogue hearing aids (Johnson, 2013). The development of the digital signal processor and the use thereof in hearing aids has made it possible to selectively amplify sound as well as reduce unwanted noise (Levitt, 2007). A digital hearing aid operates by converting an analogue sound signal into digital binary code. A hearing aid's digital signal processor then applies mathematical calculations to the binary code. The processed binary code is subsequently converted back to a sound signal and delivered in the hearing aid wearer's ear canal (McAllister, Black & Waterman, 1995). Modern hearing aids' digital signal processor can make millions of calculations per second (Grieder, 2016). Fast digital signal processing in hearing aids allows for advanced mathematical algorithms to be applied to the created binary code/input signal (Grieder, 2016).

Hearing aid manufacturers have developed algorithms that can be applied to the input signal to improve the comfort of the amplified sound for the hearing aid user. According to Launer, Zakis & Moore (2016) hearing aid signal processing can be classified into three broad classes – amplification, sound cleaning and environmental classification. Digital hearing aids amplify sound by applying acoustic gain to an input signal prescribed by a selected fitting formula (Keidser et al., 2011). A digital hearing aid processor also has sensors that actively monitor the environment and input signal and applies combinations of different algorithms to provide audibility while simultaneously providing listening comfort (Launer, Zakis & Moore, 2016). Hearing aid sound cleaning algorithms aim to partially remove static, non-speech ambient noises or sudden, loud impulse sounds. The selected fitting formula combined with comfort feature algorithms affects the level of sound that is delivered in a hearing aid user's ear canal. These calculations influence the way a hearing aid user experiences environmental sounds and speech produced around them regardless of their cultural, geographic and linguistic background.

Hearing aid technology research is mostly driven by the forecasted needs of consumers in developed nations (McPherson, 2011). Hearing aid research and development is concentrated in North America, Canada, Europe, and Australia. A literature review by Chasin (2008) regarding hearing aid fitting considerations indicated that languages with unique characteristics e.g., tonal languages can benefit from different amplification strategies compared to English. With a tonal language like Mandarin – meaning can be derived from tones, consonants and vowels (Hyman, 2011). English is considered a non-tonal language as it uses intonation to add linguistic information to consonants and vowels e.g., a rising tone at the end of a question phrase but meaning cannot be derived from tones by themselves. The National Acoustics Laboratory (NAL), the research division of Australian Hearing, a statutory authority under the commonwealth Department of Human Services has recently developed a fitting formula with gain calculations specifically for tonal languages (National Acoustics Laboratory Version 2 for tonal languages or NAL-NL2 Tonal) (Furuki et al., 2023). This prescriptive fitting formula optimises the tonal quality of sound for hearing impaired persons fitted with hearing aids who speak tonal languages i.e., Mandarin, Cantonese and Japanese etc. The majority of African languages are considered tonal – where there are a two-way contrasts between higher and lower pitch, but the tonal characteristics is vastly different compared to Chinese which has become the standard model for tonal languages in linguistic studies (Odden, 1995). Therefore, it is important that the sub-populations within the serviced hearing loss population's unique needs are researched, understood, and effectively managed.

In developing countries like South Africa, amplification and other hearing health needs may differ from those in industrialized nations, for cultural, health, or economic reasons (McPherson, 2011). Approximately two thirds of the world's population with hearing loss live in developing countries (McPherson, 2011). The spoken language of the indigenous people of Sub-Saharan Africa has unique features that are linked to the region (Gxilishe, 2004). South Africa has a rich cultural heritage, and the South African constitution recognizes eleven official languages (Deumert, 2010). IsiXhosa is the most widely distributed African language in South Africa and is the second most spoken language by South Africans after isiZulu (Nozewu, 2023). There are approximately 7.9 million first language isiXhosa speakers in South Africa (Peer, 2015). Hearing well enables people to live a more active and healthier lifestyle because hearing aids provides access to more environmental and speech sounds fostering feelings of security and confidence (Vercammen et al., 2020). Hearing well and the positive effects thereof on a person's socio-emotional, cognitive, and physical well-being is a driving factor for this study as this study aims to shed light on the unique language characteristics of South African citizens – specifically the isiXhosa language. In the post-colonial era in South Africa, researchers in communication sciences should support and participate in equitable research to recognise, investigate and thoroughly record scientific data on all of South Africa's eleven official languages, not only a select few (Pascoe et al. 2011).

Currently we are in an era where artificial intelligence is influencing the way scientific research. Through utilising the web page www.connectedpapers.com a visual representation of articles that are linked to each other through citations can be created. Please refer to the image in Appendix VIII. The connected paper's visualization was solely used to illustrate the geographic location of citations linked to articles authored by Marchall Chasin, who's research provided context for this study. The body of research created by Marshall Chasin which investigates setting hearing aids for different languages was part of the inspiration for the current study. In the image of the connected papers a cluster of papers are linked to Chasin (2011a) and Chasin (2011b) that investigated hearing aid processing in Asian countries and their unique language characteristics (on the left-hand side of the image). On the righthand side of the connected papers' image a small cluster of cited articles are shown with European languages and their interaction with hearing aids investigates. In contrast to the clusters of papers who cited Marshall Chasin's work in Asia and Europe – no connections exist linking research publications to the African continent. A unique difference between African languages (e.g., isiXhosa) and English is the use of consonant sounds in the form of click sounds. In some languages, clicks are used as interjections or non-linguistic gestures (e.g., expressing frustration), but in isiXhosa it forms part of the consonant inventory (Gxilishe, 2004). IsiXhosa is a tonal language that contains the most click sounds (18 in total) in the Nguni language family. The isiXhosa click sounds can be divided in 3 main categories – dental, palatal and lateral. Click sounds are produced in an implosive manner and can be distinctively heard compared to other speech sounds. IsiXhosa click sounds are salient consonant sounds that contain high levels of acoustic energy (high intensity and broad frequency spectrum) compared to their co-articulated consonants and vowels (Gxilishe, 2004). A digital hearing aid's output response when processing isiXhosa click sounds has not been documented and this represents a gap in current hearing aid research.

A digital hearing aid equipped with an impulse noise reduction algorithm's sound classification system actively analyzes incoming sounds for very sharp peaks in the input signal (Taylor & Mueller, 2016). When the signal envelope exceeds a certain slope, magnitude and sound pressure level the processing algorithm assumes that these peaks could possibly provide discomfort for the listener and subsequently impulse noise reduction is applied (Dyballa et al., 2016). An impulse noise reduction algorithm attempts to reduce sharp peaks of the input signal giving the suspected noise a duller sound (Taylor & Mueller, 2016) by applying broad band attenuation with a very fast onset and release time (Dyballa et al., 2016). Upon review of the literature on impulse noise and the characteristics of isiXhosa click sounds similarities between the two can be deduced e.g., both impulse noise and clicks are transient (sounds with sudden onset and decay), high intensity and they have broad frequency spectra.

To program hearing aids an audiologist needs to select a specific fitting formula to program the aids. The fitting formula prescribes the amount of acoustic gain that a hearing aid needs to provide to overcome a measured hearing loss. According to Johnson (2012) there are two main rationales that fitting formulas follow e.g., loudness normalization and loudness equalization. The loudness normalisation rationale intends to restore the loudness perception of the listener with hearing loss to the same loudness perceived by a listener with normal hearing. The loudness equalization rationale aims to equalize the perception of loudness over a range of frequencies instead of having lower frequencies dominate loudness as is the case for listeners with normal hearing. Two of the most popular universally available fitting formulas is the National Acoustics Laboratory Non-linear version 2 (NAL-NL2) and the Western University's Desired Sensation Level version V (DSL-V) (Fukuri et al., 2023).

The National Acoustics Laboratory' (NAL) – mission is "to lead the world in hearing research and evidence-based innovation to improve hearing health and transform the lives of people with hearing difficulties" (National Acoustics Laboratory, 2022). NAL utilised the loudness equalization rationale when they developed NAL-NL 1 and NAL-NL2 fitting formula.

The Desired Sensation Level version V (DSL-V) was developed based on research completed by Dr. Richard Seewald (Wolfe & Smith, 2022). Western University's National Centre for Audiology (NCA) is "dedicated to advancing research to support the diagnosis and treatment of hearing disorders. The National Centre for Audiology is Canada's largest research and teaching facility dedicated to hearing" (National Centre for Audiology, 2022a). During the development of the DSL-V at a collaborative approach was used by the researchers at the NCA – "Susan Scollie, Sheila Moodie, Marlene Baggato, Leonard Cornelisse, John Pumford as well as software engineer, Steve Beaulac" (National Centre for Audiology, 2022b) contributed to the development of the DSL-V family of fitting formulae in 2002 and its revisions in the years following that. In the development process of the DSL-V fitting formula the NCA followed the loudness normalization rationale.

The calculated gain in the recent versions of DSL-V and NAL-NL2 are becoming more and more similar in the amount of prescribed gain – the two fitting formulas can recommend differences in gain depending on the hearing aid user's age, gender, hearing loss and hearing aid experience level (Fukuri et al., 2023). The NAL NL2 and DSL-V fitting formulas were selected for this study as they are commercially available fitting rationales that can be used in most brands of hearing aids. The NAL-NL2 and DSL fitting formulae are generic prescriptive formulae based on explicit theory and empirical findings (Smeds et al., 2015). The NAL-NL2 and DSL-V can be objectively verified by probe microphone measurements in contrast to proprietary fitting formulae which are device specific (Narayanan et al., 2023).

The research hypothesis for the current study would therefore be that impulse noise reduction could have a potential gain limiting effect on isiXhosa click sounds. Gain limiting of a specific speech sound for a hearing-impaired person could mean the difference between understanding a spoken message or the message being unintelligible. Current hearing aid algorithms are developed in countries where the language does not contain click sounds. The possible effect of impulse noise reduction on speech containing click sounds has not been conducted to date. This research study's outcome could possibly provide insight into a specific population's hearing needs and how a hearing aid functions in a specific linguistic environment. The research conducted by the Australian National Acoustics Laboratory in relation to the NAL-NL2 for tonal language prescriptive hearing aid fitting formula has shown benefits of augmenting amplification strategies for speakers of East Asian languages (Chasin & Hockley, 2013). Asian language speakers can derive different meanings from low frequency pitch changes in words. Compared to English pitch or intonation can add additional meaning to words and phrases, but meaning cannot be derived from a change in pitch in isolation. Hearing-impaired persons speaking tonal languages therefore require more low-frequency gain in their hearing aids than English-speaking hearing-impaired persons would.

The article by Chasin & Hockley (2013), also states that the most salient, but least studied, issues in hearing health care is the clinical ramification for many clients who do not speak English. Clinical questions came up regarding whether a hearing aid programmed for English should be set the same or differently when fit to a client whose first language is not English.

Research by Chasin (2011a) investigated differences between English and non-English languages (e.g. Chinese, Arabic & Russian) and provided evidence that non-English speakers who uses hearing aids could benefit from specific programming strategies in hearing aids to improve speech intelligibility.

Another research study by Chasin (2011b) investigated the unique language characteristics of Arabic, Russian, Portuguese, Chinese and Japanese and specific recommendations on how to program a hearing aid for these non-English languages were made. Examples of programming recommendations by Chasin (2011) included amplifying 3000-3500Hz more for improved access to palatal sounds for Russian speaking individuals. Languages that have tonal consonants require more gain in the low and mid frequencies (125Hz-2000Hz). Languages with a subject, object and verb (SOV) structure which typically contained postpositions required more gain for softer level inputs resulting in higher levels of compression on the amplification circuitry. The research by Chasin (2011b) highlighted that not only does unique sound characteristics of different languages require different levels of amplification – morphological structure also needs to be taken into account when making amplification and compression decisions when fitting a hearing aid.

Currently no published research exists to confirm or refute whether different amplification strategies in modern hearing aids influences the listening experience of hearing-impaired African language speakers. This research can also assist South African audiologists who are faced with a multi-lingual patient load with diverse hearing needs (Kiyaga & Moores, 2003) to consider the feature algorithms they activate for their isiXhosa speaking patients. Further research into the development of population specific algorithms for South Africa could be motivated by the findings of this research study.

Research in the field of audiology specifically taking into account the multi-lingual setting in South Africa is timely and relevant - as the knowledge generated is valuable for equitable audiologic service delivery for the all the people of South Africa (Ramkissoon & Khan, 2003). Hearing well enables people to live a more active and healthier lifestyle because hearing aids provides access to more environmental and speech sounds fostering feelings of security and confidence (Vercammen et al., 2020). Hearing well and the positive effects thereof on a person's socio-emotional, cognitive, and physical well-being is a driving factor for this study as this study aims to shed light on the unique language characteristics of South African citizens – specifically the isiXhosa language

Chapter 3: Methodology

Introduction: This chapter will provide a detailed description of the methodology that was utilised in this study. Upon the commencement of this study a data collection tool was created. Subsequently the data collection tool was used to gather numerical data for quantitative, descriptive statistical analysis. This section will conclude with the ethical considerations which was considered when completing this research project.

Aim & Objective

Aim: To investigate if hearing aid impulse noise reduction, in conjunction with a selected prescriptive amplification formula, has any gain limiting effects on the isiXhosa click sound.

Objective: Compare the electro-acoustic effect of hearing aid impulse noise reduction on isiXhosa click sounds using the DSL-V vs. the NAL-NL2 prescriptive fitting formulae.

Research design

A 2x2 factorial experimental research design was chosen for this study. Factorial designs are used when we wish to gather information about the effects of different kinds or intensities of treatments at the same time (Sytsma, 2009). With a single 2x2 factorial design information can be gained about the effects of each of the two treatments and the effect of the two levels within each treatment, and the interaction of the treatments (Kitsche & Schaarschmidt, 2015). A factorial design is a more economical option than running separate experiments (Wu & Hamada, 2011). Historically factorial research designs have been used to evaluate the effectiveness of hearing aid features (Collins et al., 2009). The above-mentioned references support the usefulness of a 2X2 factorial design as it is an effective and efficient method used in audiological research.

This study's factorial study design was constructed to investigate the selected dependent variable (click amplitude) in response to exposure to two different independent variables, each with two levels [prescriptive fitting formula (DSL-V vs. the NAL-NL2) and impulse noise reduction (on versus off)].

Data collection instrumentation

Due to limited research in the relating to African languages and how they interact with hearing aid technology - this study required a data collection tool to be created. The motivation for the creation of this data collection tool is that there are no commercially available high-quality recordings of isiXhosa speech for research purposes – specifically relating to the click sounds. The recordings will be used to measure the electro-acoustic effect of hearing aid impulse noise reduction on isiXhosa click sounds.

Prior to the data collection high quality voice recordings were created using the Zoom H4n Pro digital audio recorder device. The audio recorder was connected to a RØde NT3 condenser microphone via an *External Line Return* (XLR). The RØde NT3 microphone can record the full audio spectrum of human hearing (RØDE n.d) – 20-20KHz. It has a very low equivalent input noise level of 16dBA (A-weighted). The equivalent input noise level of a microphone is the self-noise that a microphone produces even when no sound is present. Due to the low equivalent noise level, there is very low risk of input noise interference when producing the voice recordings. Similarly, the equivalent input noise of the *Phonak* hearing aid used in this study is less than 18dB (see appendix VI) as specified in the manufacturer's product specifications. Ideally the equivalent input noise of a hearing aid needs to be below the hearing thresholds of the hearing aid user to be inaudible. The recordings were made of an adult, female isiXhosa mother tongue speaker. A list of isiXhosa words adapted from Gxilishe (2004) containing two examples of all 18 types click sounds (see Appendix I). A female's voice was selected based on the research by Holube, et al., 2010) in the development of the *International Speech Test Signal* (ISTS). The ISTS was developed to obtain a standard speech test signal that can be used to analyse the processing of speech by a hearing instrument (Holube, 2015). The authors recommended a female test signal as most parameters (range of fundamental frequency, average spectral shape) for female speech are in the middle between male and children's voices. The adult female will not partake in the study. The adult female who was chosen for the study is a first language isiXhosa speaker and she is also a qualified audiologist with three years of experience post-graduation. She is currently employed in the public health sector in the Western Cape and perform daily diagnostic hearing tests including live speech audiometry testing. Audiologists are trained to perform live speech audiometry testing. During this procedure they must regulate the level of their voice to a *Volume Unit* (VU) meter and pronounce words with sufficient elocution and consistent volume for listeners to understand them. Thirty-six words were recorded in total (two examples of words containing each click type). The described instrumentation (Zoom H4N digital recorder and RØde NT3 microphone connected with an XLR cable) was used for the recording of the words in a soundproof booth.

A *Phonak Audeo V90* hearing aid with a power receiver will be used for the processing of the sound. The hearing aid will be set to omnidirectional. The fitting formula and impulse noise reduction will be manipulated for the purpose of the study and all other features will be deactivated. A custom-made recording microphone will be used to record the output from the hearing aids. The voice recordings as well as the output recordings from the hearing aids will be completed in higher than compact disc (CD) quality (Srinivasan & Jamieson, 1998) - uncompressed WAV format at 24-bit depth and a sampling rate of 96 kHz. Open-source sound processing software – Audacity – will be used to separate the recordings into single words and their respective click category. Audacity software was selected on the basis that it is open source, free to the public – see Figure 1 for an example of continuous recording using the aforementioned software. Figure 2 provides and example of how recordings were stored.

The phonemic and acoustic analysis toolkit (*Praat™*) software was used for the click intensity measurements in the four different hearing aid setting configurations (as shown in table i). *Praat™* is a free to download software program dedicated to those studying linguistics. The *Praat™* software is capable of analysing, synthesising and manipulating speech recordings. *Praat™* was created by Paul

Boersma and David Weenink of the Institute of Phonetics Sciences of the University of Amsterdam (Boersma, Paul & Weenink, 2025).

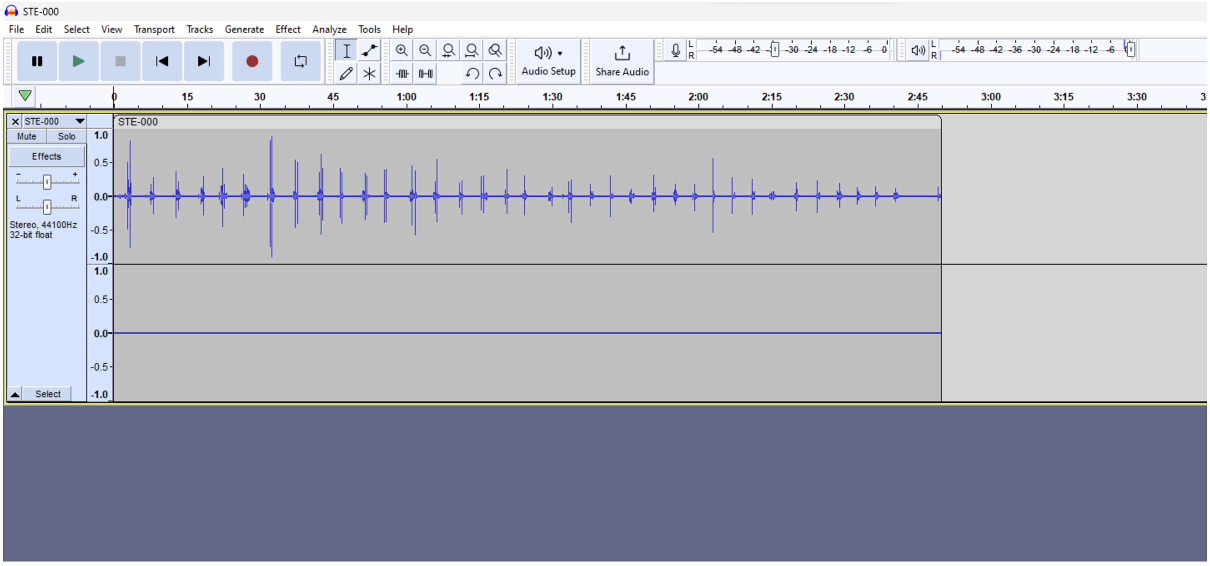

FIGURE 1. CONTINUOUS RECORDING IN AUDACITY SOFTWARE

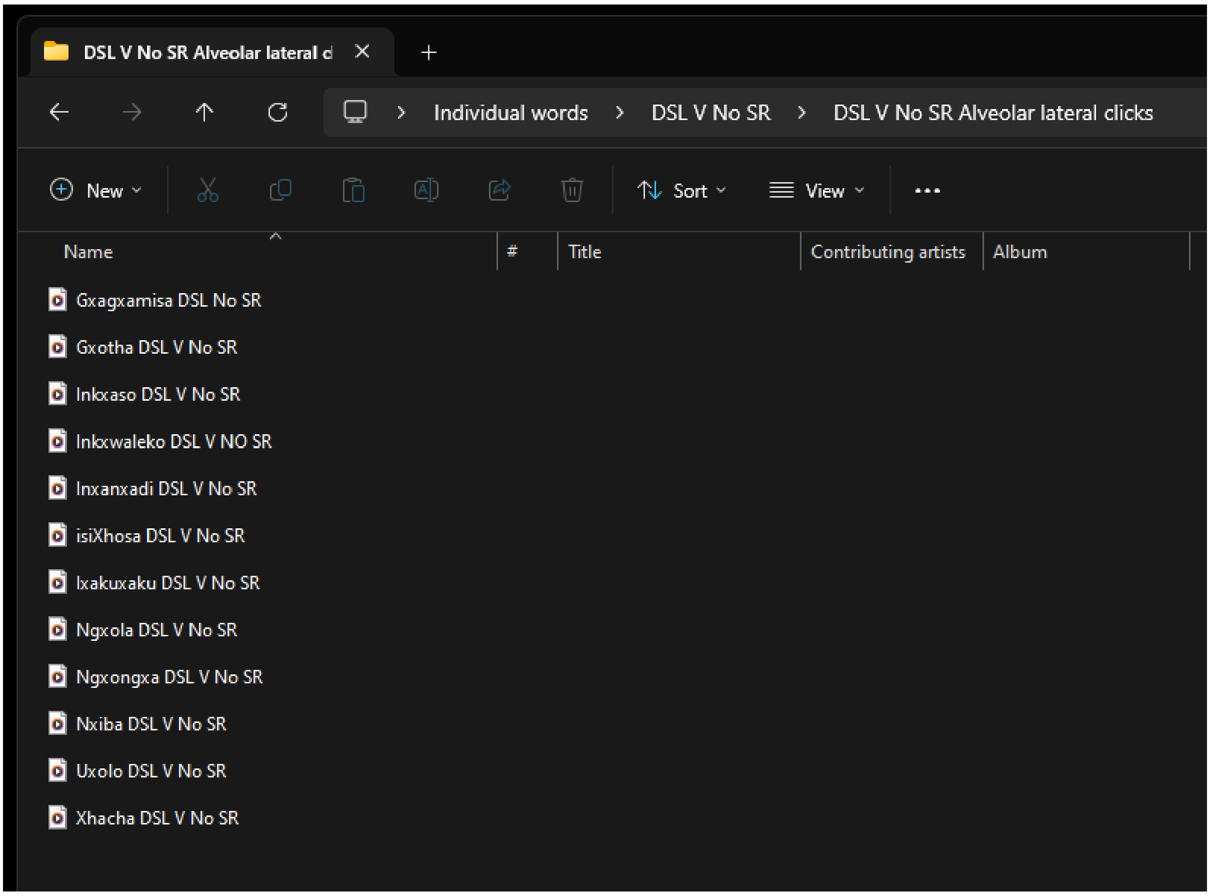

Figure 2. Example of recorded folder with words saved as individual files

Data collection procedure

The data collection procedure summary will be provided initially in this section. Following the summary the detailed step by step procedure will be described.

The data collection tool (in the form of high-quality recordings) will be used as described in the data collection instrumentation. The output of a *Phonak Audeo V90* hearing aid will be recorded while the recorded isiXhosa words containing click sounds is played in the free field in a soundproof booth. The fitting formula and feature combinations will be recorded to obtain the information relating to the dependent variable (isiXhosa click sound intensity). Spectral sound analysis will be conducted on the 36 pre-recorded words containing all types of isiXhosa click sounds using *Praat™* software. The peak spectral amplitude (dependent variable) will be measured in response to changing the selected fitting formula (independent variable) and turning impulse noise reduction on or off (independent variable). Spectral analysis of the click sounds will be completed and the collected data will be processed via a factorial *ANOVA* (factorial analysis of variance).

The words will be categorised as follows:

- Setting 1 – recordings processed with the DSL-V prescriptive formula and impulse noise reduction feature switched off.
- Setting 2 – recordings processed with the DSL-V prescriptive formula and impulse noise reduction feature switched on.
- Setting 3 – recorded words processed with the NAL-NL2 prescriptive formula and impulse noise reduction switched on.
- Setting 4 – recorded words processed with the NAL-NL2 prescriptive formula and impulse noise reduction switched off.

Table 1 presents a summary of the used data measurements.

Table 1. Data measurements

	Unprocessed recorded words containing click sounds	Independent variables		Dependent variable after measurement
Setting 1	Peak amplitude of isiXhosa click sounds	Amplified with DSL-V	Impulse noise reduction OFF	Peak amplitude of isiXhosa click sound
Setting 2	Peak amplitude of isiXhosa click sounds	Amplified with DSL-V	Impulse noise reduction ON	Peak amplitude of isiXhosa click sound
Setting 3	Peak amplitude of isiXhosa click sounds	Amplified with NAL-NL2	Impulse noise reduction OFF	Peak amplitude of isiXhosa click sound
Setting 4	Peak amplitude of isiXhosa click sounds	Amplified with NAL-NL2	Impulse noise reduction ON	Peak amplitude of isiXhosa click sound

The data collection took place at Bellville Ear Institute. *The Phonak V90* hearing aids were connected to the *Phonak Target* software with programming cables connected to the *HI-pro* hearing aid programming interface. The hearing aids were set to a flat 40dB hearing loss. Programming the hearing aid to a 40dB flat audiogram is a standard practice in audiology research specifically when evaluating hearing aid features (Bisgaard, Vlaming & Dahlquist, 2010). According to the research by Bisgaard, Vlaming & Dahlquist (2010) the International Electrotechnical Commission (IEC) has defined standard audiograms, including flat, moderate, audiograms to limit variability when testing hearing aid features. Dörfler et al. (2020) further highlighted the utility of using a flat 40dB audiogram when assessing hearing aid features - “A flat frequency response allows for the straightforward evaluation of a hearing aid’s amplification capabilities without the confounding effects of varying audiometric profiles”.

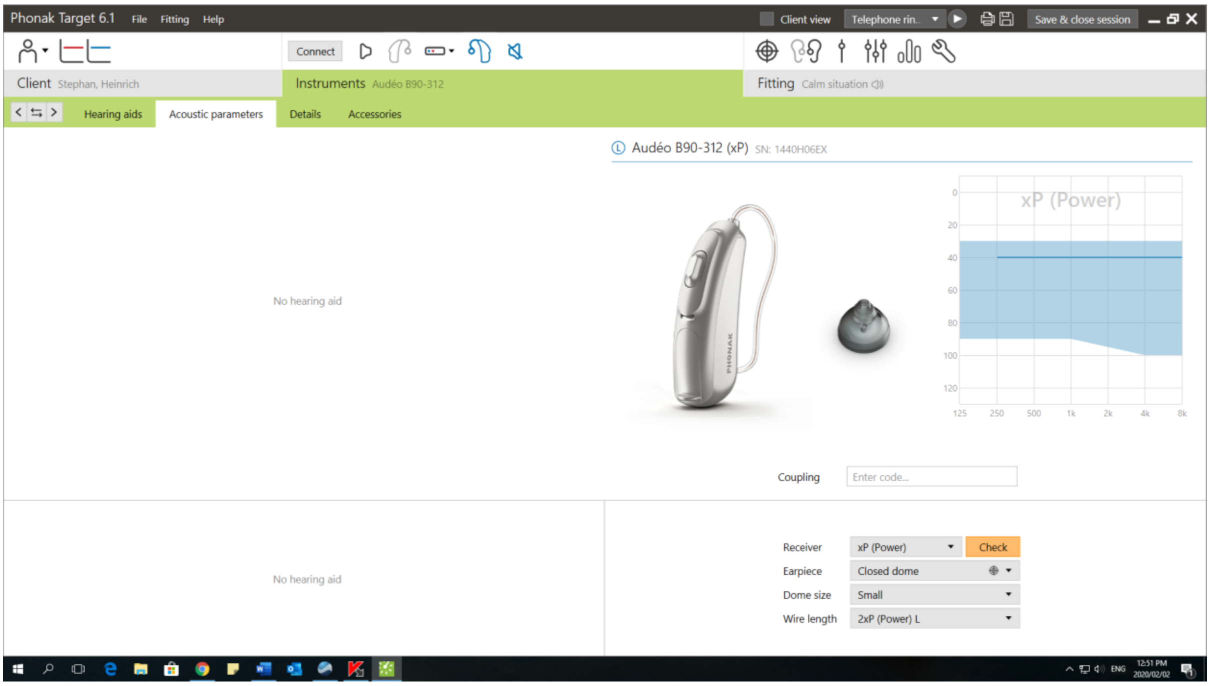

FIGURE 3. BASIC SET UP 40DB FLAT AUDIOGRAM

The first fitting formula that was selected in the global tuning screen was the *DSL V5a* adult fitting formula. A separate calm program was created as the startup program of the hearing aid. In the program options screen of the calm program – the microphone was set to omni-directional. The *NoiseBlock* (*Phonak*'s digital noise reduction) feature was set to 0 (off). The *WhistleBlock* (*Phonak*'s digital feedback reduction) feature was set to 0 (off). The *WindBlock* (*Phonak*'s digital wind noise reduction) feature was set to 0 (off). The *SoundRelax* (*Phonak*'s impulse noise reduction) feature was set of 0 (off). Fitting reports for each of the four settings appears in appendix II (setting 1), appendix III (setting 2), appendix IV (setting 3) and appendix V (setting 4). The fitting reports confirm what was saved on the hearing aid in each setting.

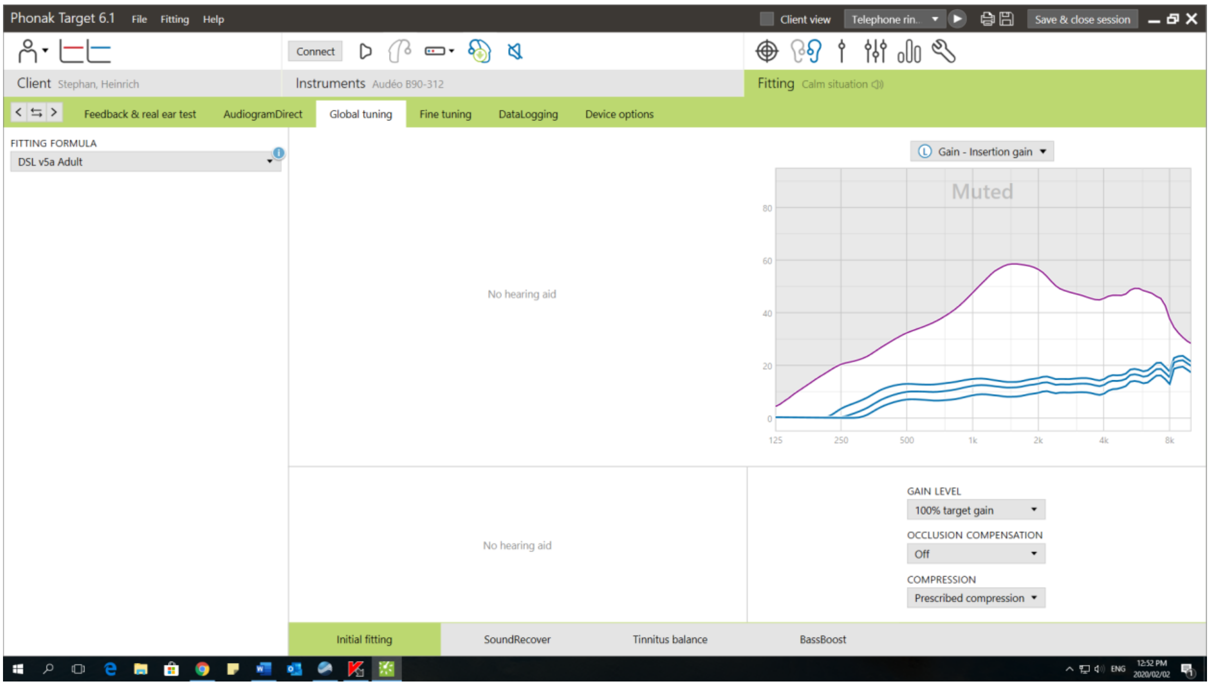

FIGURE 4. FITTING FORMULA SELECTION

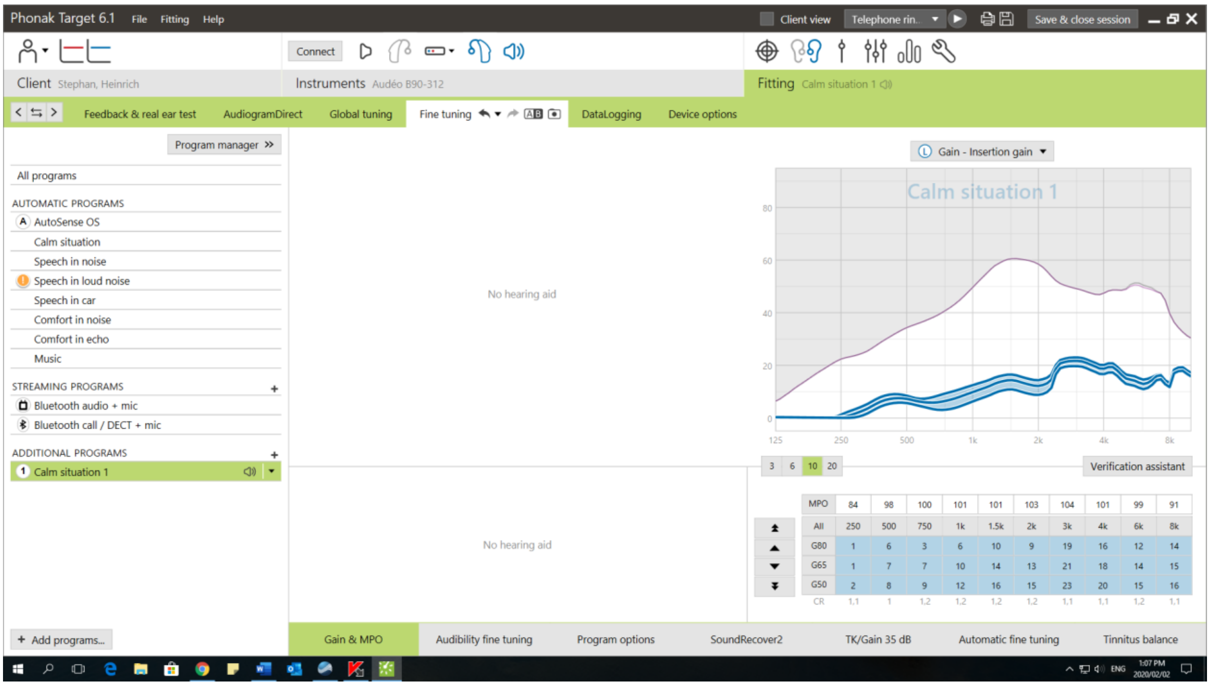

FIGURE 5. ADDITIONAL PROGRAM CALM SITUATION

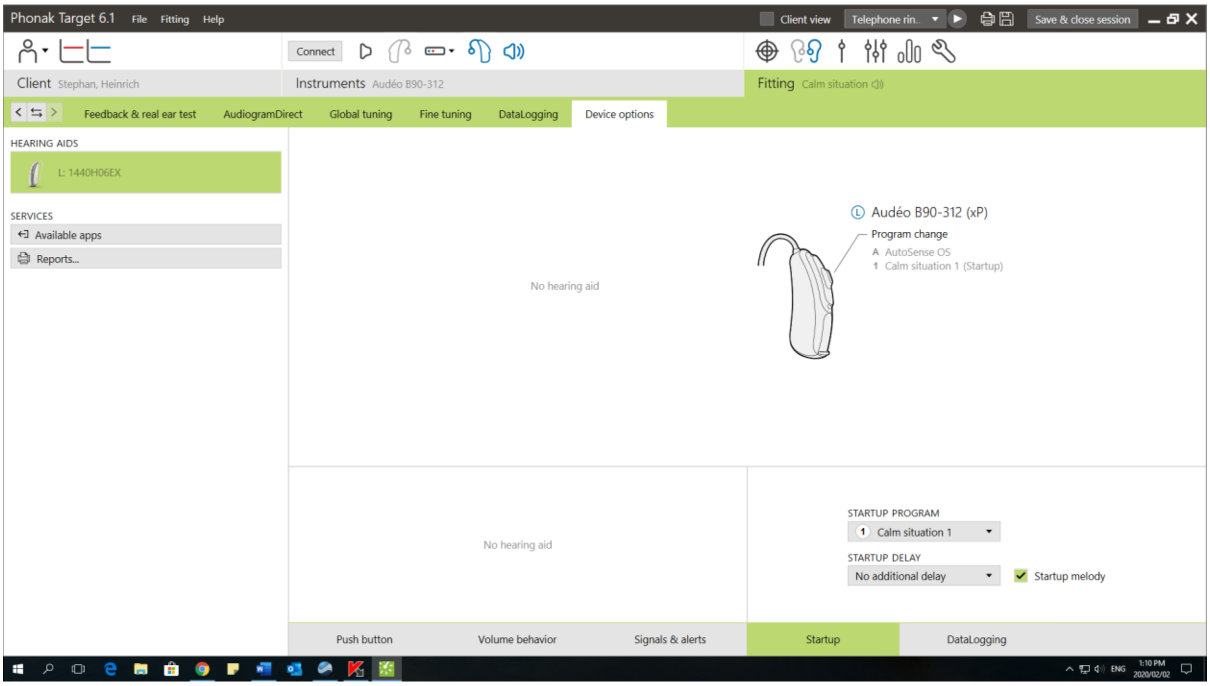

FIGURE 6. SET TO STARTUP IN CALM PROGRAM

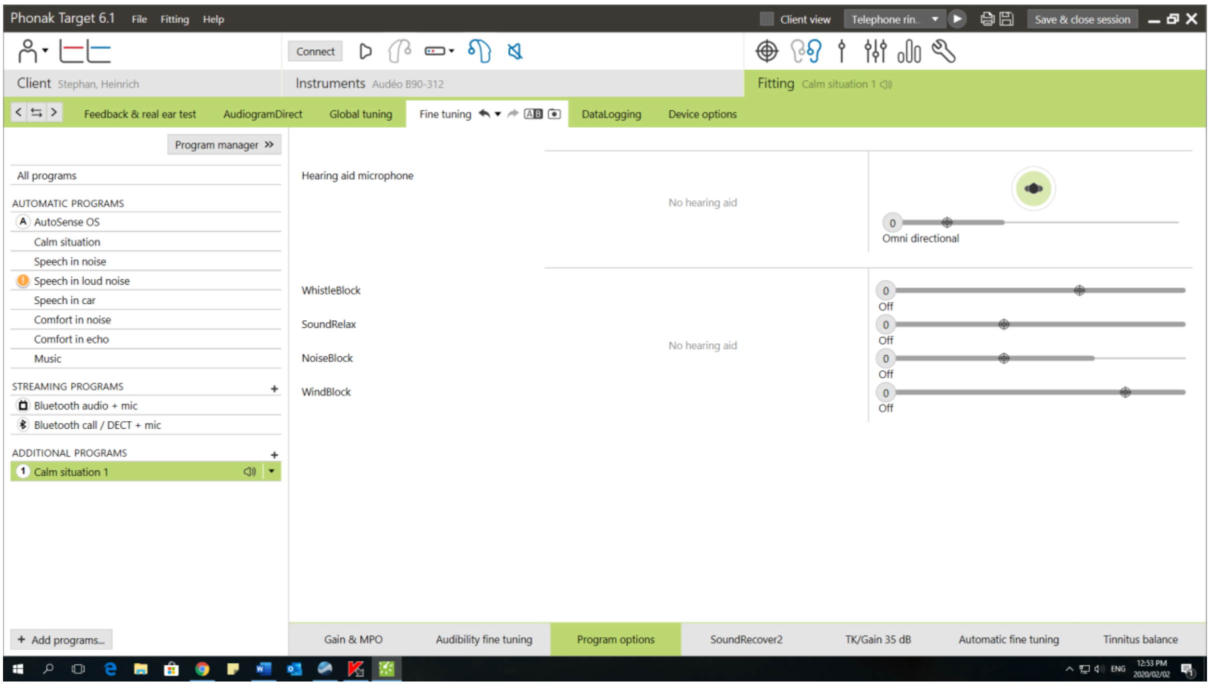

FIGURE 7. ALL ADAPTIVE FEATURES SWITCHED OFF

The hearing aid output was verified in the test box of an *Audioscan Axiom* hearing aid verification system. The test box coupler microphone was calibrated according to the manufacturer's instructions. The coupler microphone's calibration record is shown below – the calibration was within the manufacturer's specification – confirming that the equipment is in good working order.

FIGURE 8. COUPLER MICROPHONE CALIBRATION SET UP

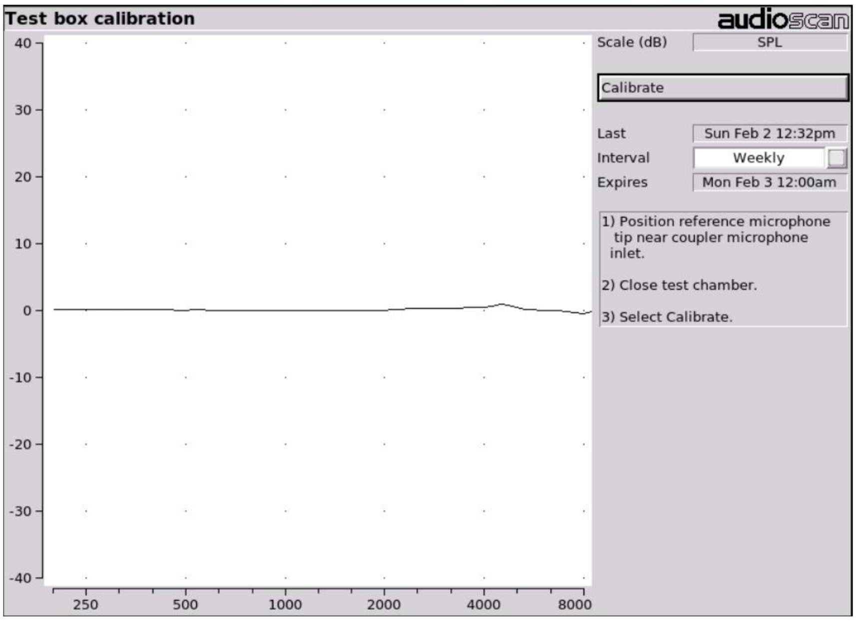

FIGURE 9. COUPLER MICROPHONE CALIBRATION RECORDING

The *Axiom* test box setting test box was set up to measure the output of a *receiver in the ear* (RITE) hearing aid in comparison to the *DSL V5a* adult hearing aid fitting targets. Monaural targets were selected as only one hearing aid was being used for the recordings. The venting was selected as occluded because the hearing aid recording microphone fully occluded the receiver. The average UCL (uncomfortable loudness level) and RECD (real ear to coupler difference) values were chosen as all the measurements were completed in the *HA-1* hearing aid coupler in the test box of the verification system. No bone conduction values were entered into the hearing aid software or into the verification system.

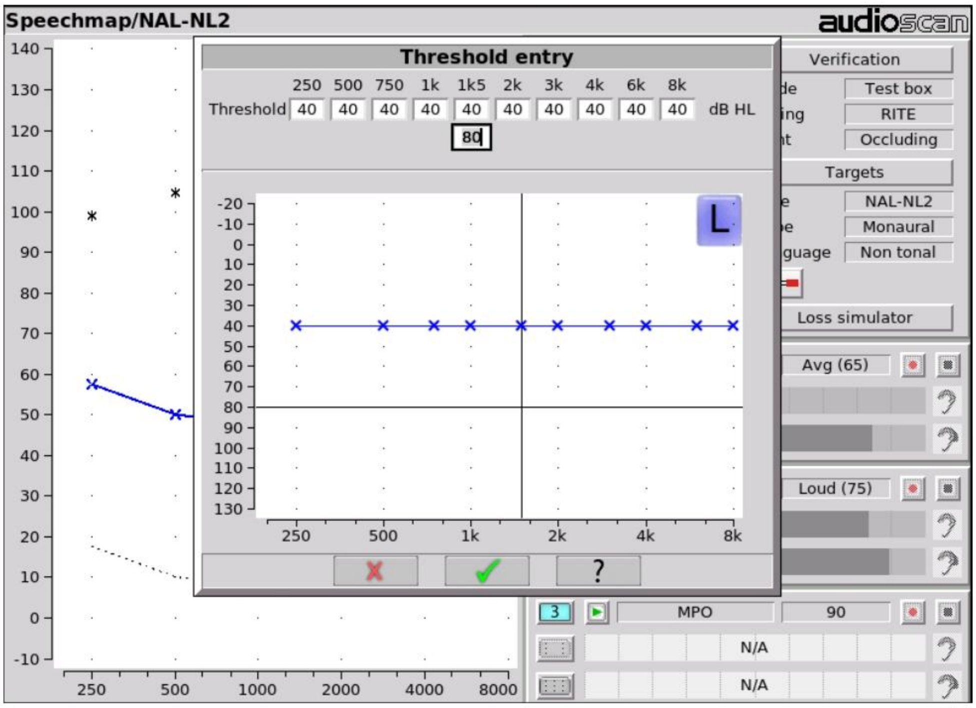

FIGURE 10. THRESHOLD ENTRY

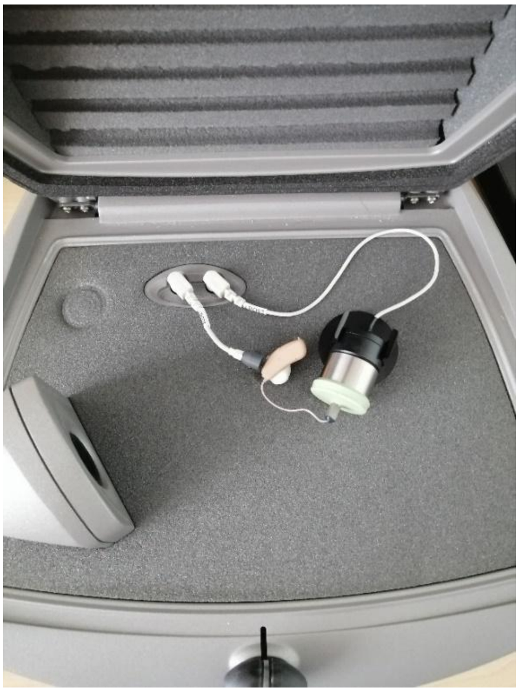

FIGURE 11. TEXT BOX SET UP WITH HEARING AID

The *SpeechMap™* procedure was used to measure the output from the hearing aid. The *DSL V5.0a* adult fitting formula was selected on the verification machine and the output was adjusted to match the fitting targets at 55dB, 65dB and 75dB. Similarly, the measurements were completed for the *NAL-NL2* fitting formula.

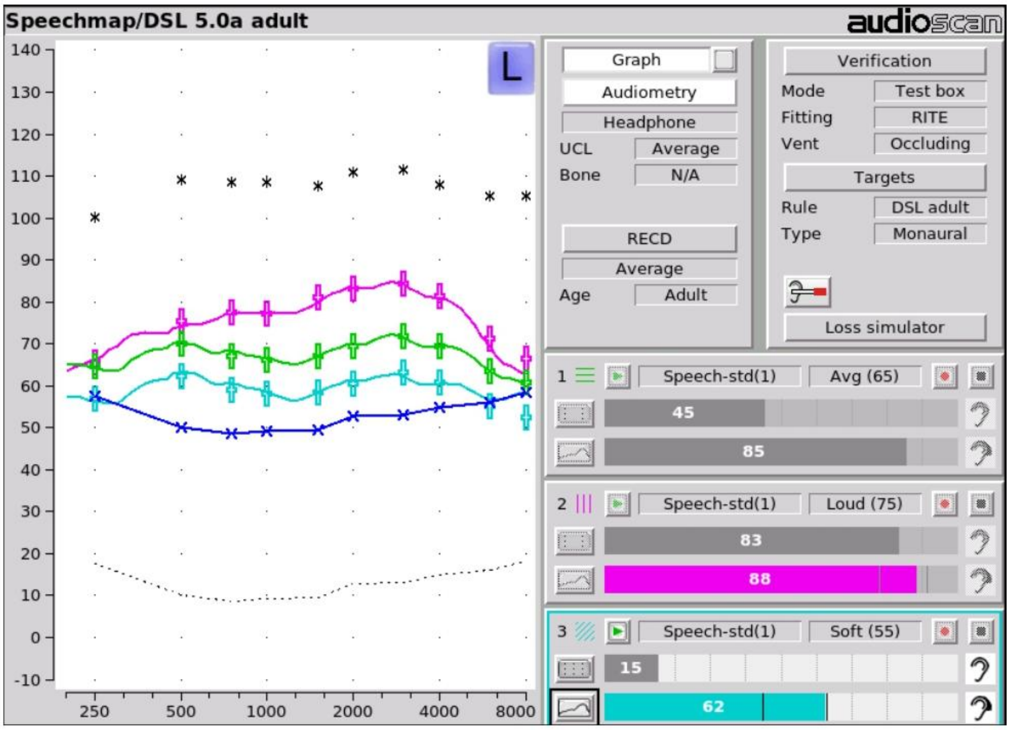

FIGURE 12. DSL 5.0A ADULT OUTPUT MEASUREMENT IN SPEECHMAP

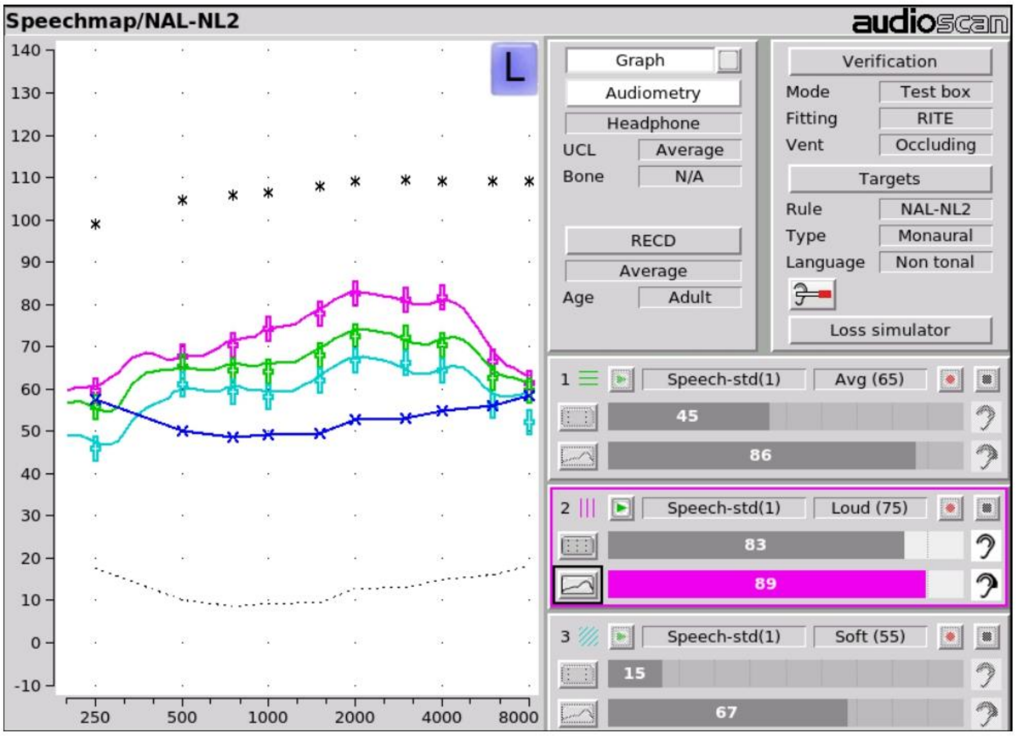

FIGURE 13. NAL NL 2 OUTPUT MEASUREMENT IN SPEECHMAP

The four setting combinations in accordance with the research design was programmed on the hearing aids (independent variables).

- Setting 1 – the hearing aid was programmed and verified using the *DSL 5.0a* adult fitting formula with all the adaptive features turned off (see Figure 14).
- Setting 2 – only the *SoundRelax* feature (impulse noise reduction setting) was switched on while using the *DSL 5.0a* adult fitting formula (see Figure 15).
- Setting 3 – the hearing aid was programmed using the *NAL-NL2* fitting formula with all the adaptive features turned off (see Figure 16).
- Setting 4 – only the *SoundRelax* feature (impulse noise reduction setting) was switched on while using the *NAL-NL2* fitting formula (see Figure 17).

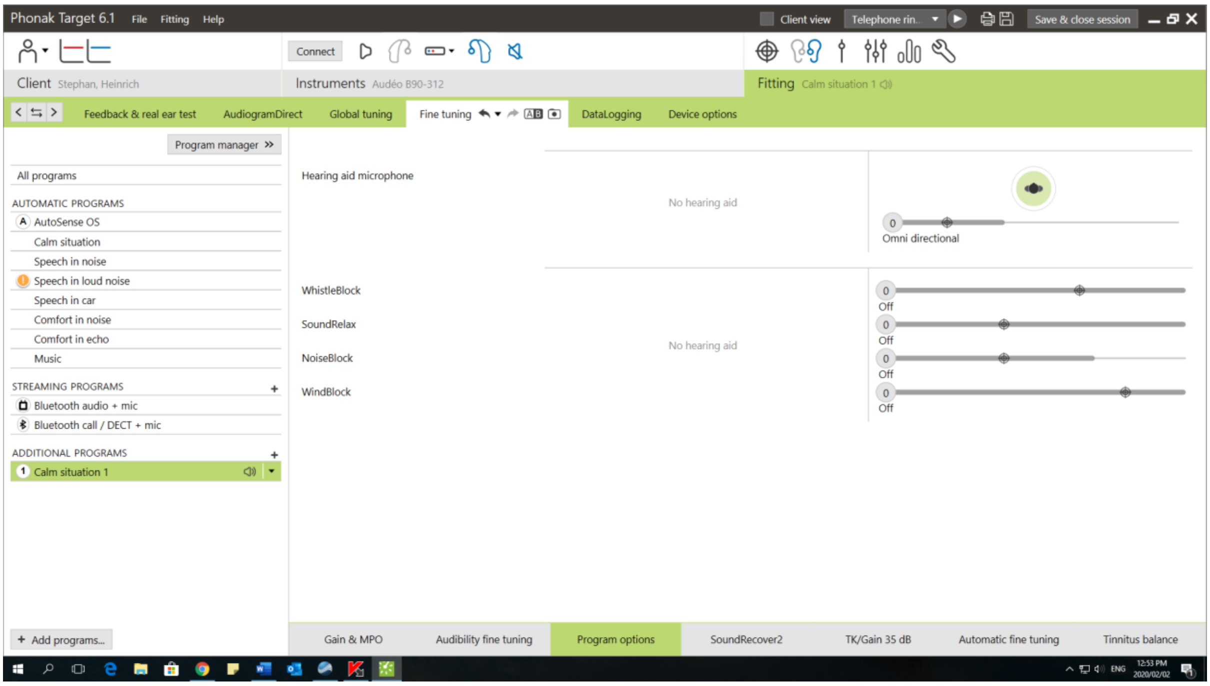

FIGURE 14. SETTING 1

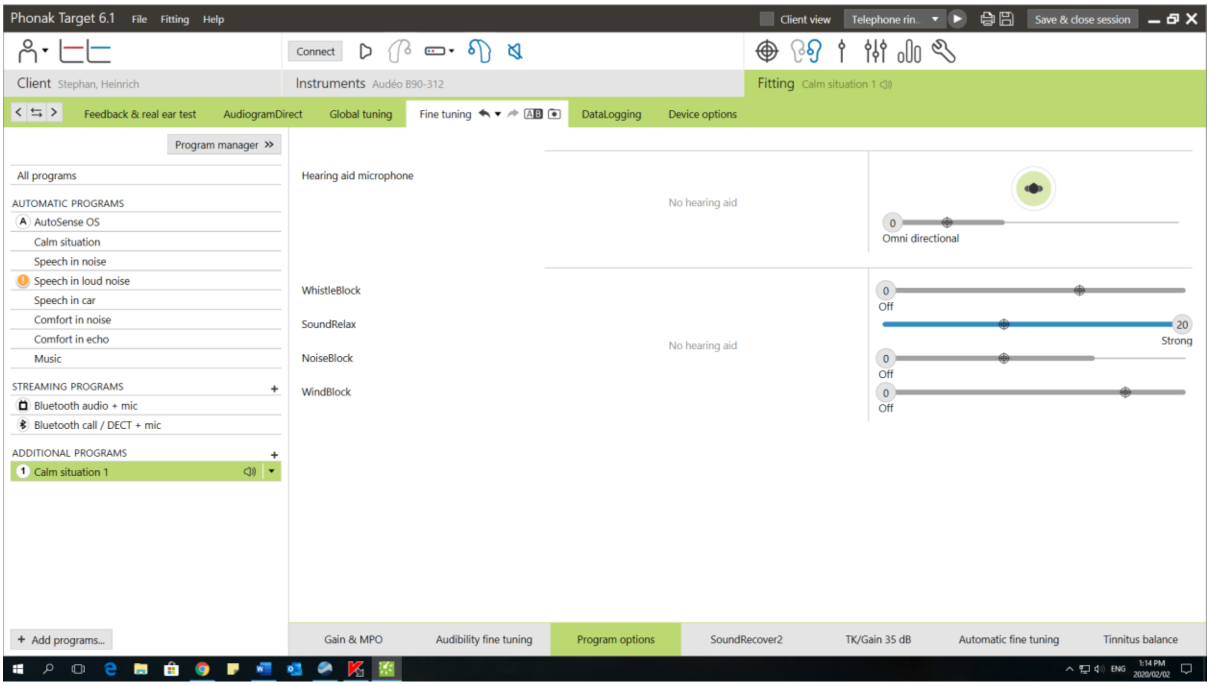

FIGURE 15. SETTING 2

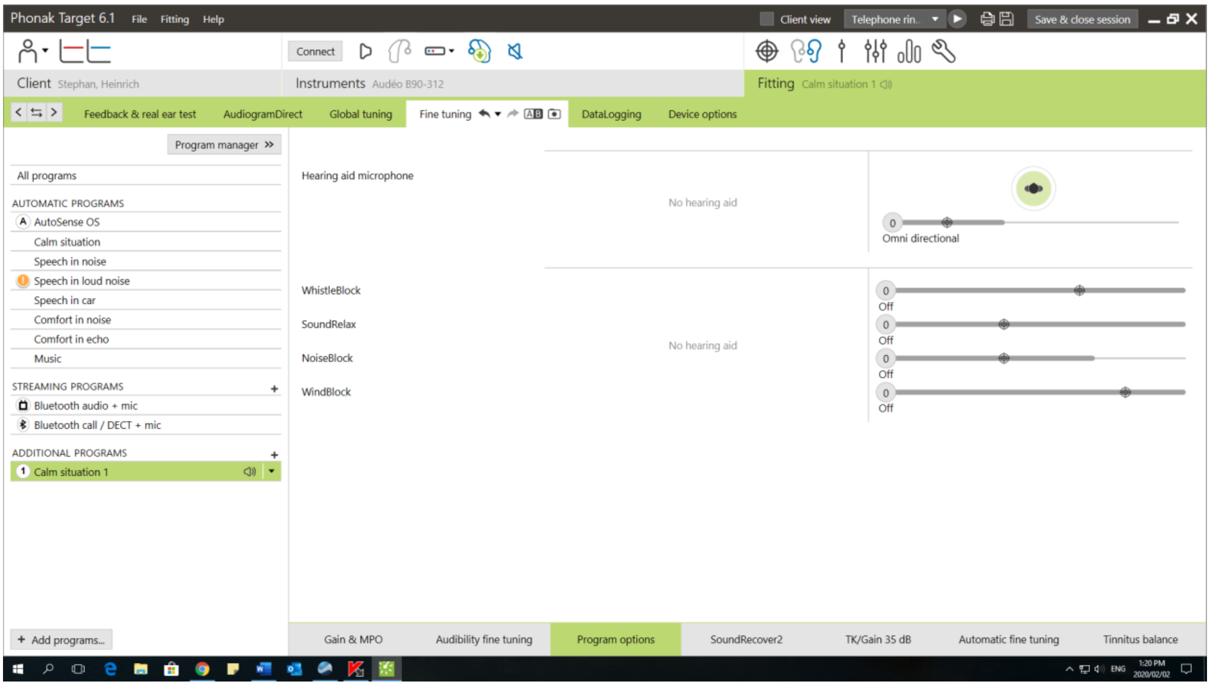

FIGURE 16. SETTING 3

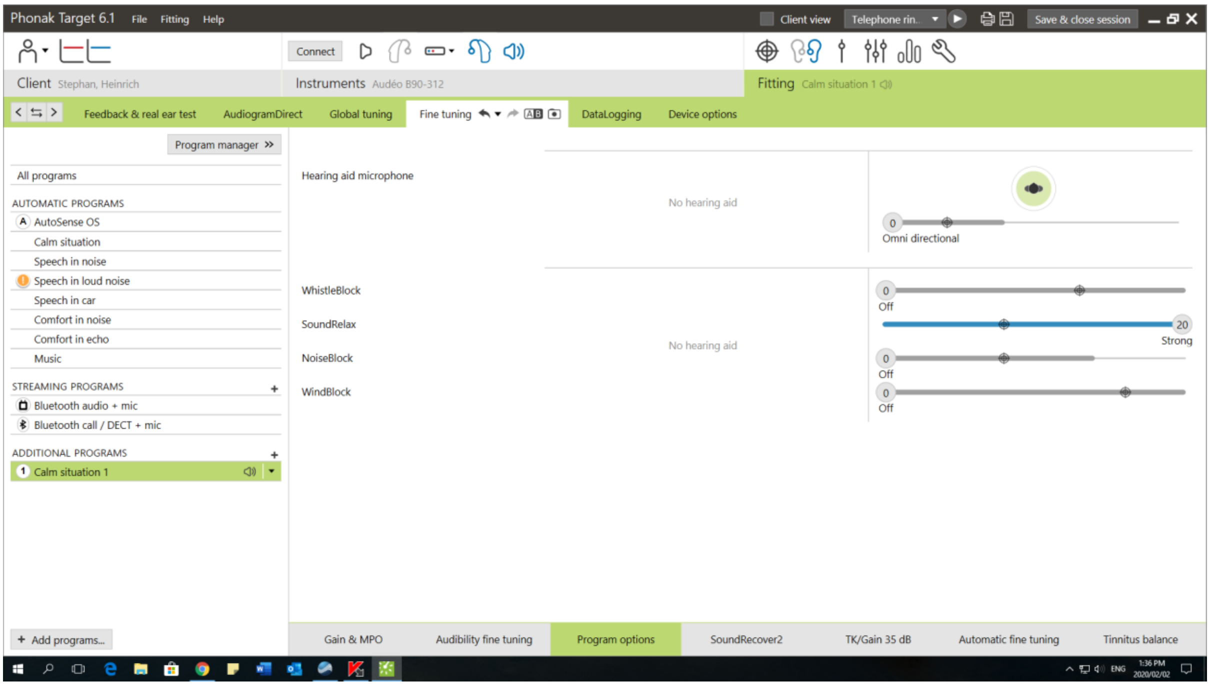

FIGURE 17. SETTING 4

Following the hearing aid programming and verification in the test box – the hearing aid's output was measured in a soundproof booth using a recording microphone and a custom-made coupler provided by *Phonak*. The hearing aid was positioned one meter away from the free field speaker in the soundproof booth. A tripod was used to keep the hearing aid in the same position with the device orientated towards the free field speaker.

FIGURE 18. SET UP IN SOUND PROOF BOOTH

The audiometer was set to free field, 65dB (conversational level speech) with the auxiliary input selected as external A. The laptop (Lenovo ThinkPad running Windows 11) containing the isiXhosa recordings was connected to the external A port via a 3.5-inch audio connector cable. The laptop's volume was set on 100%.

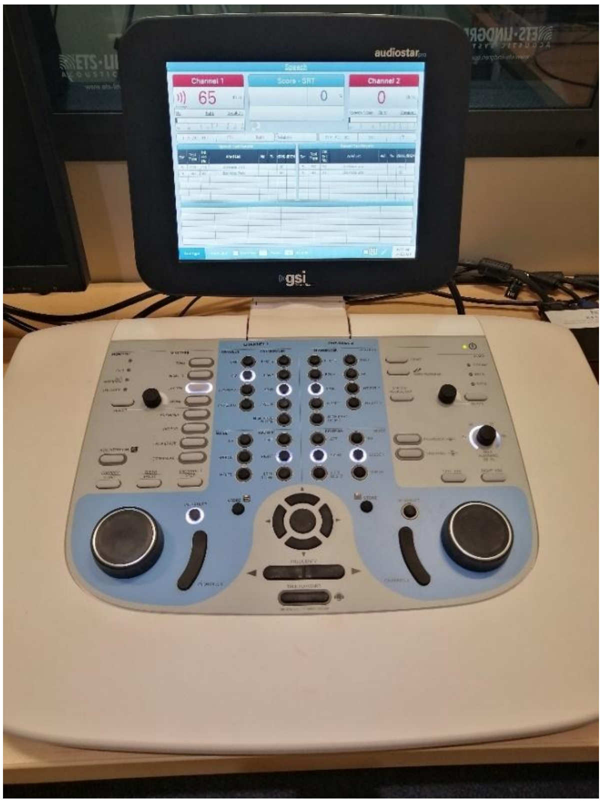

FIGURE 19. AUDIOMETER SET UP

The recorded words were played through the audiometer (see Figure 19) and recorded by a *Zoom H1N* digital recorder to the microphone and hearing aid set up. The recordings were stored in the corresponding folders (four folders) according to the parameter settings as set out in the research design (see Figure 20).

Following the recordings the *Praat™* software was used to quantify the intensity of the isiXhosa click sounds. The steps followed to complete the measurement started by opening and reading the sound file from the stored folder on the computer. An individual word was selected and the analyse spectrum function was selected. The *Praat™* software then generated the spectrogram of the individual word. The highlight function was used to isolate the click sound in the first syllable and when necessary, in the second and third syllable as well. In the *intensity* drop down menu the *get maximum intensity* option was selected. This provided a measurement in decibel of the maximum intensity of the selected sound.

The measurements were recorded in a table format (appendix VII). Tables were used to organise the information according to the word, fitting formula and feature activation, click type and intensity of the click in the first, second and/or third syllable.

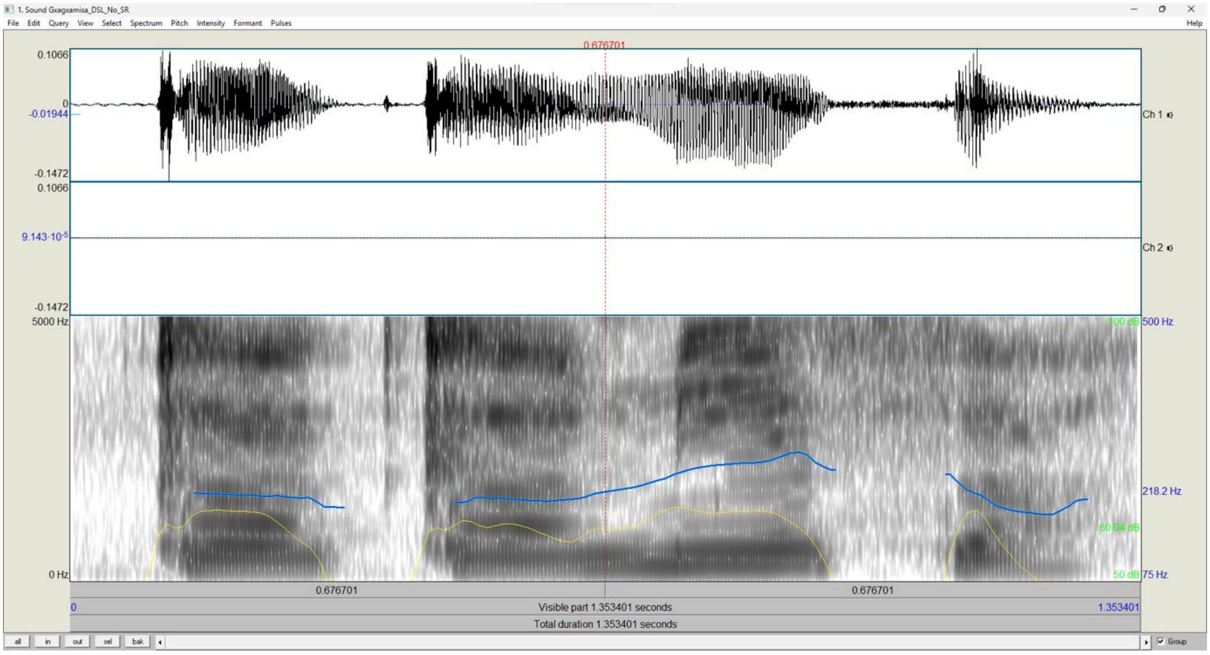

FIGURE 200. EXAMPLE OF SPECTRAL ANALYSIS VIEW

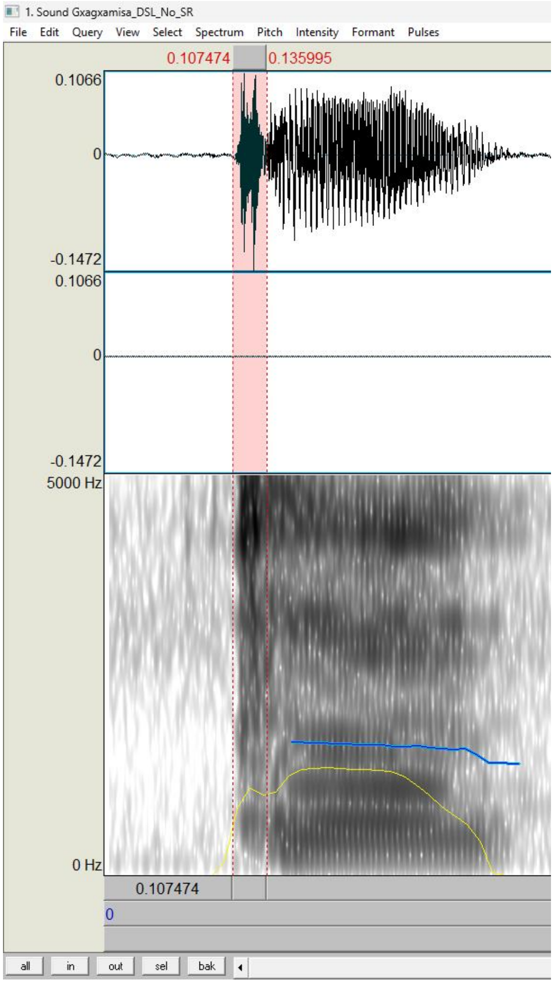

FIGURE 212. ISOLATION OF CLICK SOUND

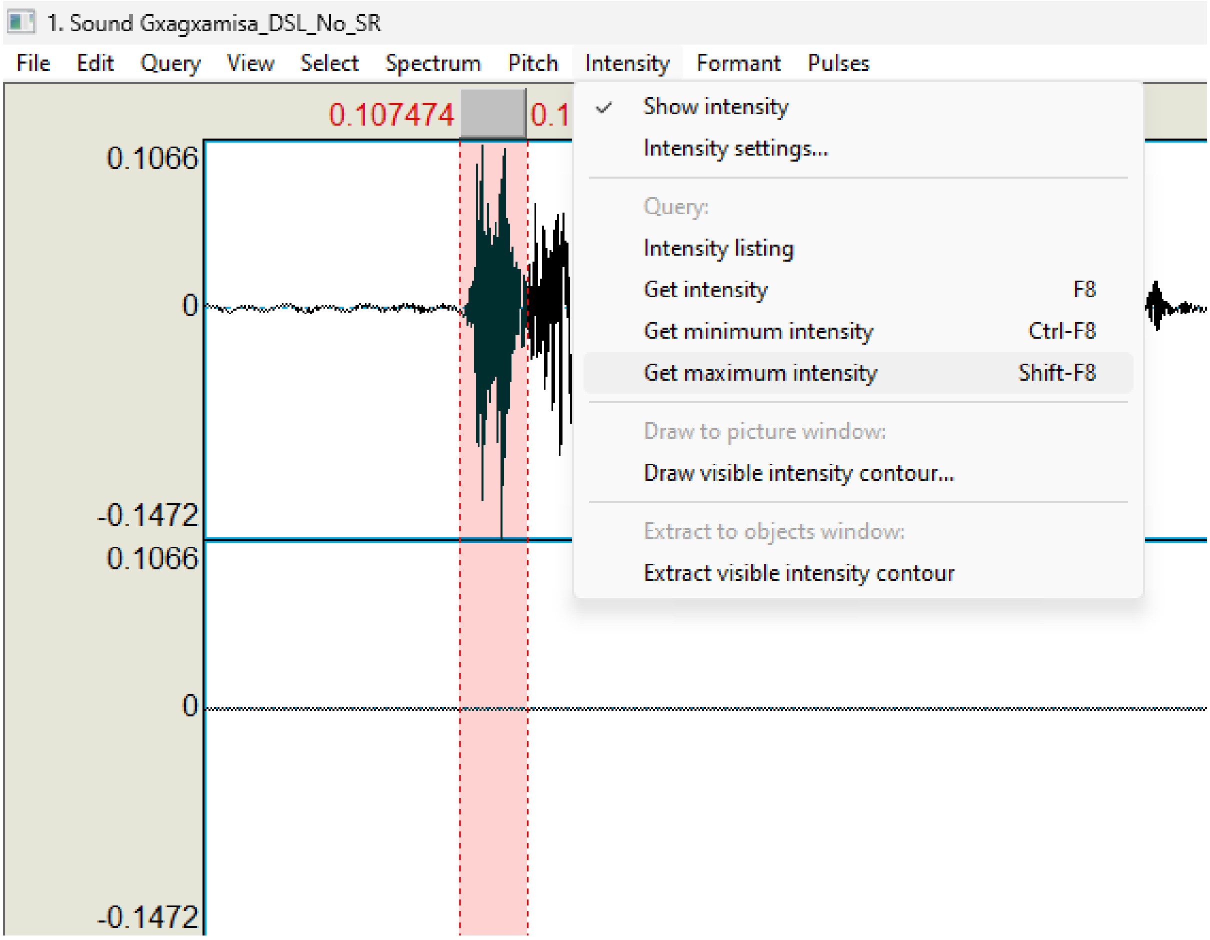

FIGURE 23. OBTAIN MAXIMUM INTENSITY OF SELECTED CLICK SOUND

Data management

The collected data will be copied from the *Secure Digital* (SD) memory card used in the *Zoom H1N* recording device and saved on the researcher's personal laptop. To ensure that the recordings are not lost to equipment malfunction or loss – a copy will be saved on the researcher's *OneDrive* as provided by University of Cape Town. The data collected during the peak amplitude measurements were saved in a table formal on *Microsoft Word*.

Data analysis

A factorial analysis of variance (*ANOVA*) was utilised to analyse the collected data. A factorial *ANOVA* will quantitatively measure the main effect of the selected fitting formula as well as the main effect of the impulse noise reduction. Post-hoc pairwise comparisons will also be made to compare if the selected fitting formula or the impulse noise reduction feature had an effect on the amplitude of the click sound.

Validity & reliability

The internal validity of this study relating to aim one is strengthened by the measurements obtained e.g. the dampening effect of impulse noise reduction will be quantified into an internationally recognised format – decibel sound pressure level (dB SPL). A threat to external validity relating to aim one is that a specific brand of hearing aid will be used – therefore the data cannot be generalised to all hearing aids – as different manufacturers may approach impulse noise with different mathematical algorithms. Internal validity relating to aim two is strengthened by using counter balanced sample words containing all 18 types of isiXhosa click sounds. Content validity in this study is reinforced as two examples containing all types of isiXhosa clicks are used for data collection. The words are recorded by a female voice whose characteristics generally fall between male and paediatric voices, and it follows the example of the creation of the *International Speech Test Signal (ISTS)*.

External reliability of this study is strengthened by using proven statistical tests 2x2 factorial analysis. Threats to the internal reliability is variation in the measuring equipment used as the material and equipment used for the study has been purposefully created to measure a specific phenomenon. As this is a pilot study, the collected data will provide information on a phenomenon that has not been documented before and therefore provide information for future studies to be conducted to further investigate African language speaker's experience of amplification devices.

Ethical Considerations

The study will abide by the ethical principles as set out by the declaration of Helsinki (World Medical Association, 2013). Prior to the commencement of this study ethical clearance from the *Human Research Ethics Committee* (HREC) was sought. The research proposal and synopsis were provided to the HREC and approval for the study to be conducted was granted (please see appendix IX).

The research methodology was described in as much detail as possible to transparently describe the research process and how the data was collected and handled by the researcher.

Non maleficence

The data collection tool was created prior to the *COVID 19 pandemic*. Thereafter the study was designed to be as low risk as possible. This was due to the data collection taking place during the *COVID 19 pandemic* in 2020 and 2021. Therefore, no human participants were recruited and only desktop measurements were completed in respect of the social distancing regulations that were in place at the time.

The study utilised open-source software that is free to use by the general public (*Praat™* and *Audacity*) to create and process the quantitative data. Credit to the creators of the software were provided and the copyright restrictions and intentions for the created software was respected. In order to use the software, the creator's terms and conditions were accepted by the researcher.

Beneficence and justice

The data created in this study will be used to add to the research base of Audiology specifically related to isiXhosa. Due to the history of South Africa – very limited published research studies exist exploring the interaction of South African languages and its interaction with hearing technology (Kathard, et al., 2007). The information created by this study can be utilised in the future to inform further studies with regards to isiXhosa and hearing aid technology. The isiXhosa community who requires hearing health care can therefore benefit from researched clinical applications when programming hearing aids to respect their language's unique characteristics.

Confidentiality

The voice recordings will not be linked to the speaker's identity. The recordings for the creation of the data collection wool will be recorded on a password protected SD card. The processing of the data will be completed on the researcher's laptop which is password protected. All data including the word processing, *Microsoft Excel* spreadsheets and audio recordings will be backed up on an external hard drive that will be kept in a safe place as well as in password protected cloud storage (*OneDrive*). Only the researcher and his two supervisors will have access to the collected data.

Chapter 4: Results

In this study it was investigated if hearing aid impulse noise reduction, in conjunction with the selected prescriptive fitting formula, has any gain limiting effects on the isiXhosa click speech sounds.

The *DSL-V* and *NAL-NL2* prescriptive fitting formulas were compared in this study when isiXhosa click sounds were processed by a hearing aid. Four setting combinations were used:

- The DSL-V fitting formula with the impulse noise reduction feature switched off;
- DSL-V fitting formula with the impulse noise reduction feature switched on:
- NAL-NL2 fitting formula with the impulse noise reduction feature switched off; and
- NAL-NL2 fitting formula with the impulse noise reduction feature turned on.

The volume of the output from the hearing aid when amplifying isiXhosa click sounds were measured in decibels (dB). The mean was derived from the average of all the words measured click sound intensity. The Statistica program by TIBCO was used for the statistical calculations.

TABLE 2. DESCRIPTIVE STATISTICS FOR FITTING FORMULAE WITH IMPULSE ON/OFF

Fitting Formula	Impulse	Mean	SD	N
DSL-V	Off	62.54	2.96	36
	On	63.19	3.01	36
	Total	62.86	2.98	72
NAL-NL2	Off	61.16	3.36	36
	On	59.85	6.44	36
	Total	60.50	5.14	72

A factorial *ANOVA* detected a main effect of fitting formula, but no main effect of Impulse nor a significant fitting formula by Impulse interaction (see Table 3). The mean amplitude was significantly higher with the *DSL-V* fitting formula (62.9 vs 60.5; $p < 0.001$). However, there was no main effect of the Impulse being Off or On (mean amplitude = 61.85 and 61.52 respectively; $p = .645$).

Table 3. Factorial ANOVA results

Source	Type III Sum of Squares	*df*	Mean Square	F	*p*-value	Partial Eta Squared	Observed Power
Fitting Formula	200.34	1	200.34	11.36	**< .001*** **	.075	.92
Impulse	3.75	1	3.75	.21	.645	.002	.07
Fitting Formula * Impulse	34.45	1	34.45	1.95	.164	.014	.28

Post-hoc pairwise comparisons (see Table 4) showed that amplitude was only significantly different between *DSL-V* and *NAL-NL2* when the impulse was On. No such difference was observed when the impulse was Off. Within each of the fitting formulas, there was no significant difference in amplitude when the Impulse was Off or On.

Table 4. Post-hoc pairwise comparisons

Comparison	*p*-value
DSL-V: Off vs On	.509
NAL-NL2: Off vs On	.191
Off: DSL-V vs NAL-NL2	.165
On: DSL-V vs NAL-NL2	**< .001*** **

Chapter 5: Discussion

The primary purpose of this study was to investigate if there is a gain limiting effect of *impulse noise reduction* (INR) on isiXhosa click speech sounds. No gain limiting effect was observed when INR was on vs. off when a hearing aid was processing isiXhosa click sounds. However, the mean amplitude of the peak volume of isiXhosa click sounds were significantly higher with the *DSL v5.0a* adult fitting formula vs. *NAL-NL2*.

As limited published research exists regarding African languages and how it is processed by hearing aids (Kathard, 2007) – this study aimed to add data to the research base by investigating a unique language characteristic e.g., isiXhosa click sounds and how modern hearing aid technology handles these speech sounds. Impulse noise reduction can be achieved by spectral subtraction, adaptive filtering or by using directional microphones (Chabries & Bray, 2018). All three of these methods to reduce impulse noise reduction could potentially affect the way isiXhosa click sounds are processed by a hearing aid.

Firstly, with spectral subtraction in hearing aid processing the input signal is monitored by sensors in the hearing aid's microprocessor and when a sudden impulse noise occurs it is subtracted from the audio signal. Spectral subtraction can pose a risk to speech understanding as useful speech components could be removed from amplified speech (Lakshmi, Rout & O'Donoghue, 2021). This potential removal of speech sounds was one of the motivations to undertake the current study.

Secondly, adaptive filtering can by utilised to reduce impulse sounds. Adaptive filtering involves the input signal of a hearing aid to be monitored and subtracting sudden sounds from the output signal in real time. Adaptive filtering requires fast computational power as any processing delay can introduce a delay in the processed signal. A future study of isiXhosa click sounds processed by a hearing aid with INR can be completed where isiXhosa mother tongue speaker's perception is measured to investigate if the INR feature has an effect on the isiXhosa click sounds. The processing of isiXhosa click sounds could potentially be affected by processing delay as described above.

Thirdly, directional microphones can be used to reduce the impact of impulse noises coming from besides or behind of a hearing aid user as the microphone will focus on sounds coming from the front. In the present study the hearing aids were programmed to use omni-directional microphones and the speech was presented at a 0° azimuth. The use of an omni-directional microphone was selected to isolate the INR feature. The effect of a directional microphone on isiXhosa click-sounds being presented from different directions could be a further recommendation for future studies.

As described in the above paragraphs - these three methods of impulse noise reduction (spectral subtraction, adaptive filtering and directional microphones) could potentially attenuate isiXhosa click sounds. This study's findings did not show significant attenuation of isiXhosa click sounds in hearing aids when the impulse noise reduction feature was activated - indicating that the hearing aid used in this study’s micro processing sensors did not identify the isiXhosa click sound as a non-speech impulse sound and therefore did not attenuate the isiXhosa click sounds.

A second possible reason that isiXhosa click sounds were not attenuated by the INR feature is that the input signal was presented in a quiet environment at approximately 70dB. Research by Santurette et al. (2023), indicated that sudden sounds are usually louder than the average surrounding sound. An example that Santurette et al. (2023), used was the clicking of typing on a keyboard. In a quiet environment the keyboard clicks will create sudden peaks that can possibly be annoying, but not loud enough to be painful or uncomfortable. Conversely in a louder than average environment clicking on a keyboard will not be louder than the average surrounding sound. Santurette et al. (2023) indicated that sudden sounds in loud environments will be attenuated more compared to sudden sounds in quiet environments as sudden sounds could potentially become uncomfortably loud in loud environments.

Due to the abovementioned reasons why a hearing aid’s processor does not attenuate isiXhosa click sounds - this study confirmed that the INR (*SoundRelax™*) technology used in the *Phonak Audeo*

V90 hearing aid caused no measurable gain reduction when isiXhosa click sounds were processed in the hearing aid when the INR feature was active. A possible explanation for the absence of gain limiting when using INR is that the hearing aid processor did not detect a large enough, sudden peak with rapid onset while isiXhosa speech was presented. The measured peak volumes of the isiXhosa click sounds ranged from 55dB to 67dB – which is comparable to conversational volume. Unfortunately, *Phonak* does not publish their threshold volume peak that would trigger the INR feature to be activated. What can be deduced from this study is that a peak volume of an isiXhosa click sound of 67dB did not cause the hearing aid to apply gain limiting to the output signal of the hearing aid.

In contrast to the current study - a previous study by Zaar et al. (2017) generated evidence that consonant perception can be affected spectral characteristics (e.g. frequency lowering technology) as well as by temporal signal modifications [e.g. impulse noise reduction (INR)]. The study by Zaar et al. (2017), compared the effect of non-linear frequency compression (NLFC) with and without the combination with INR on consonant perception while using the *NAL-NL2* fitting formula. It was confirmed that INR in isolation resulted in a 4% reduction in consonant recognition scores. When INR was combined in with NLFC the average participant consonant recognition score reduced by 40%. The present study did not have human participants who evaluated the consonant (click sound) perception, only theoretical, desktop measurements were recorded. Originally this study intended to measure if normal hearing participants could perceive a difference in click sounds in the selected test conditions in addition to the theoretical measurements, but due to the *COVID-19* pandemic it was not possible to safely recruit and utilise human participants without infringing social distancing rules that were in place at the time of the data collection. The study was adapted to only obtain desktop measures (gain reduction in decibel). The measurements obtained in this study provides objective, theoretical evidence of the effect of INR on isiXhosa click sounds. This theoretical, objective, evidence is in contrast to the subjective perception of human participants in the study by Zaar et al, (2017). The theoretical data generated in this study can possibly be used in future research and compared to perception data to shed light on if INR results in perception differences for isiXhosa speakers.

Published literature on African languages, particularly isiXhosa, and its interaction with hearing amplification technology did not exist during the completion of this study – which makes the findings in this study particularly significant. The data generated provides a glimpse into the unique language characteristics of one of the official languages in South Africa. One of the stand-out findings of this study is the higher level of amplification of click sounds when amplified through a hearing aid with the *DSL v5.0a* selected when compared to *NAL-NL2*.

In a previous study by Chasin (2011a), it was found phoneme-level differences between English and other languages and taking into account unique language characteristics could result in a change in the frequency response and output specification for hearing aids. The SII is an updated version of the articulation index which was created by the *American National Standards Institute* (ANSI) for the English language. The SII indicates the percentage of speech cues (phonemes) that are audible for English-speaking listeners. The SII also provides information on the frequency importance bands in different languages. Chasin (2011b) found distinct phoneme-level differences between English and other languages, e.g. Japanese, Hindi and Urdu. Similarly, African languages like isiXhosa have distinct phoneme-level differences, e.g. click sounds that should be taken into account when setting a hearing aid. The current study explored isiXhosa click sounds exclusively, but future study is recommended to investigate other isiXhosa phonemes to generate more information which can potentially be used to calculate the SII for isiXhosa. As important as it is to focus upcoming research on phoneme level Chasin (2011a) highlighted that it is also imperative to investigate word and sentence level grammatical differences which could inform further specific recommendations on how to program hearing aids for non-English speakers.

The information generated by this study can be utilised by audiologists when programming and fine tuning their isiXhosa patients' hearing aids. Hearing aid fine tuning can be guided by theoretical, evidence-based procedures (e.g., real ear measurement), but the patient's subjective experience of the amplified sound is equally important to achieve a successful hearing aid fitting (Boymans & Dreschler, 2012). Should an isiXhosa speaking patient fitted with hearing aids have the need for more audibility of the isiXhosa click sound, the *DSL v5.0a* fitting formula can be selected as the fitting formula. Alternatively, should an isiXhosa speaking hearing aid user experience loudness discomfort due to the click sounds in speech – the *NAL-NL2* fitting formula can be selected as this study proved that the *NAL-NL2* fitting formula prescribes less amplification, specific to isiXhosa click sounds, compared to the *DSL v5.0a* fitting formula.

Limited high-quality recordings of isiXhosa speech for research and/or clinical purposes exist currently. This study produced specific high-quality recordings of a female speaker producing words containing the different click sounds in the isiXhosa language as listed by Gxlishe (2004). The recordings as a data collection tool were titled the *isiXhosa Click Word List* (iXC-WL). The iXC-WL will become the property of the University of Cape Town and will be made available by the institution for use in further research. Future studies can be conducted to record more representative samples e.g. including male, female and children's voices as well as a wider variety of sounds, words, sentences and continuous speech. The information generated could be utilised in further studies to shed light on the unique language characteristics of isiXhosa and how hearing aid processing can affect the perception thereof. A follow up study to this study would be to evaluate the perception of isiXhosa mother tongue speakers with normal hearing of the processed click sounds and following that the study could be repeated with participants with hearing loss.

The findings of this study isolated isiXhosa click sounds and its peak volume while test parameters (fitting formula and INR) were manipulated. The effect of INR in this study was measured in isolation of other features. Other investigations (Ahn et al., 2021 and Palmer, Bentler & Mueller, 2006) measured the combination of INR and other features e.g., non-linear frequency compression and found interactions between the features and the subjective perception of participants. Future studies are warranted to fully explore the potential interactions between INR and other hearing aid features e.g., noise reduction, directional microphones, frequency lowering technology when processing languages other than English. Additionally, further measurements detailing the click sounds can be measured in future research as this study only focussed on the intensity measurement of the isiXhosa click sounds, but other possible measurements can be obtained e.g. duration and spectral characteristics.

Although the findings regarding the effects of INR in combination with the *NAL-NL2* or *DSL v5.0a* fitting formula on isiXhosa click sounds have implications for clinical practice as well as future research, some methodological choices may limit the study generalisability and warrant further investigation. The sample size of this study was limited to two example recordings of the different types of isiXhosa click sounds in words by a female speaker. The effect of INR was therefore only measured in words and not running speech which would be more representative of daily usage of a hearing aid. The environment for the measurements recorded during this study was limited to a quiet environment in a soundproof booth. In research by Santurette et al. (2023) it was indicated that INR would be activated more in loud environments as sudden loud sounds could become uncomfortable for the hearing aid user. A recommendation for further study would be to introduce background noise into the environment and measure the INR effect when isiXhosa speech is presented at a louder level than conversational speech e.g., 75dB or above.

A further limitation of the study is that the INR feature was measured when while the hearing aid was programmed to a flat audiogram of 40dB (from 250Hz to 8000Hz). A single audiogram was used to isolate the effect of the INR feature and to limit variables, but patients with hearing loss have great variability in their audiograms. It would therefore be interesting to investigate the INR effect with different degrees and/or configurations of hearing loss to assess if the audiogram in combination with INR has an effect on the amplification of isiXhosa click sounds.

Hearing aid technology advances at a rapid pace with new features and capabilities entering the hearing care industry. This study investigated a feature from a specific brand i.e., *Phonak Venture*. The *Venture* platform was launched in 2016. Therefore, the information generated in this study is specific to one brand and a model that has since been superseded by newer technology. Future research can be completed to investigate how different hearing aid manufacturers' processors and noise reduction algorithms respond to isiXhosa click sounds.

A characteristic of Nguni languages is the click sound which was the focus of this study specifically to isiXhosa. Previous research by Roux (1995), highlighted the fact that the effect of tone on isiXhosa and isiZulu has been researched observationally and descriptively, but no attempts have been made to validate or quantify the tonal data generated. The legacy of apartheid in South Africa is evident in the lack of published data on African languages. A variety of research possibilities exist which was identified (and mentioned in the discussion) by this study, but this is just the tip of the iceberg. A myriad of unexplored African language interactions with hearing technology exists and it would be of great value to be scientifically assessed, documented and eventually translated into practical considerations when programming hearing aids for this population.

Chapter 6: Conclusion

This research study has highlighted the fact that isiXhosa click sounds is processed differently depending on which prescriptive fitting formula is selected in a hearing aid. A definite need for further research into the interaction of African languages and hearing aid technology has been identified. The practice of audiology is based on clinical research completed over many years. In order for an audiologist to act in their patient's best interest – their clinical reasoning has to be informed by evidence-based research.

Due to the injustices perpetrated in the history of South Africa a vast gap in audiology research has been created. The intention of this study was not only to investigate the interaction of INR and isiXhosa click sounds, but to shed a glimmer of light on the rich tapestry of languages in South Africa and the boundless potential research opportunities that exist. It is therefore imperative that further research studies on African languages and its interaction with hearing technology is completed to ensure equity in the research base in South Africa and ensure that all language groups can be treated by audiologists whose clinical decisions are based on relevant research of the language of their patients.

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Appendices

Appendix I: The proposed isiXhosa word list as listed by Gxilishe (2004).

	Click type	Example 1	Example 2
	Dental Clicks		
1	Dental click (c)	Caca (be clear)	Icici (earring)
2	Nasalized dental click (nc)	Inconco (liquid for babies)	Ncinci (little)
3	Aspirated dental click (ch)	Chacha (recuperate)	Cheba (trim)
4	Voiced dental click (gc)	Gcagca (elope)	Gcina (preserve)
5	Nasalized voiced dental click (ngc)	Ingcongnconi (mosquito)	Iingceba (glass splinters)
6	Nasal dental click (nkc)	Nkcenkceshela (irrigate)	Inkcenckce (corrugated iron)
	Alveo-palatal clicks		
7	Palatal click (q)	Qaqamba (shine)	Iqanda (an egg)
8	Nasalized palatal click (nq)	Umnqonqo (spinal cord)	Umnqamlexo (cross)
9	Aspirated palatal click (qh)	Uqhoqhoqho (windpipe)	Qha (only)
10	Voiced palatal click (gq)	Gqogqa (search)	Gqiba (finish)
11	Nasalized Voiced palatal click (nq)	Isingqengqelo (couch)	Nqena (be lazy)
12	Nasal & palatal click combination (nkq)	Nkqonkqoza (knock)	Inkqekeko (division)
	Alveolar lateral clicks		
13	Lateral click (x)	Ixakuxaku (untidy person)	Uxolo (sorry)
14	Nasalised lateral click (nx)	Inxanxadi (butcher-bird)	Nxiba (wear)

15	Aspirated lateral click (xh)	Xhacha (chop meat)	isiXhosa (language)
16	Voiced lateral click (gx)	Gxagxamisa (hasten)	Gxotha (chase away)
17	Nasalised voiced click (ngx)	Ngxongxa (lie on the back)	Ngxola (make a noise)
18	Nasal & lateral click combination (nkx)	Inkxaso (support)	Inkxwaleko (misfortune)

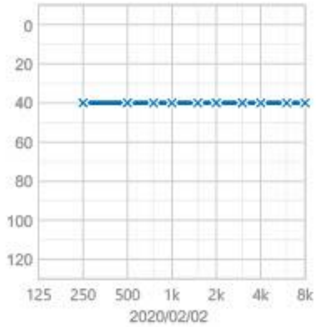
Appendix II: Fitting report of hearing aid setting 1

Stephan, Heinrich
Date of birth: 1986/03/07, Client number: 0013216

(L) Audéo B90-312 (1440H06EX)

Fitting report (short)

Audiogram



Automatic programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

Calm situation

WhistleBlock	Moderate (13)	
NoiseBlock	Weak (8)	
WindBlock	Moderate (16)	
SoundRelax	Weak (8)	
Microphone mode	Real ear sound (4)	
Noise generator	Off	

Speech in noise

WhistleBlock	Moderate (13)	
NoiseBlock	Weak (8)	
WindBlock	Moderate (16)	
SoundRelax	Weak (8)	
Microphone mode	UltraZoom & SNR-Boost (20)	
Noise generator	Off	

Speech in loud noise

(currently not accessible)

WhistleBlock	Moderate (13)	
NoiseBlock	Weak (8)	
WindBlock	Moderate (16)	
SoundRelax	Weak (8)	
Microphone mode	StereoZoom	
Noise generator	Off	

7 / 11 2020/02/02

PHONAK
life is on

Fitting report left

Fitting configuration

Acoustic parameters

Receiver	xP (Power)
Earpiece	Closed dome
Dome size	Small
Wire length	2xP (Power)

Details

Housing color	Silver Gray
Wax protection	Undefined

Fitting settings

Feedback & real ear test	2020/02/02
Fitting formula	DSL v5a Adult
Gain level of "All programs"	100%
BassBoost	Off
Occlusion compensation	Off
Compression	Prescribed compression

AutoSense OS options

Transition speed	Balanced

Automatic programs

Calm situation
Speech in noise
Speech in loud noise
Speech in car
Comfort in noise
Comfort in echo
Music

Streaming programs

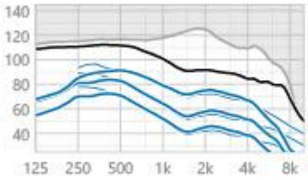
Bluetooth audio + mic
Bluetooth call / DECT + mic

Additional programs

Calm situation 1

Fitting report left

Bluetooth call / DECT + mic



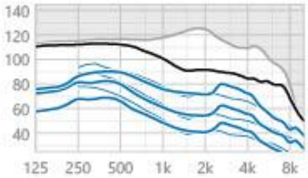
	310	850	1.5k	2.5k	3.6k	6.7k
MPO	111	104	92	90	87	76
G80	24	14	5	11	9	-13
G65	26	18	8	15	12	-11
G50	30	20	10	17	14	-10
CR	1,3	1,2	1,2	1,2	1,2	1,2
TK	30	27	22	18	16	17

Input source, Microphone	-6 dB
WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Off (0)
SoundRelax	Off (0)
Noise generator	Off

Additional programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

1 Calm situation 1



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	112	105	92	90	87	76
G80	25	10	5	14	14	-3
G65	26	14	8	16	16	-2
G50	27	16	10	17	18	-1
CR	1,1	1,2	1,2	1,2	1,1	1,1
TK	30	27	22	18	16	17

WhistleBlock	Off (0)
NoiseBlock	Off (0)
WindBlock	Off (0)
SoundRelax	Off (0)
Microphone mode	Omni directional (0)
Noise generator	Off

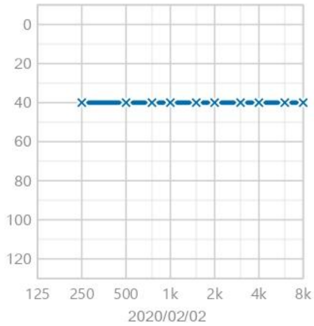
Appendix III: Fitting report of hearing aid Setting 2

Stephan, Heinrich
Date of birth: 1986/03/07, Client number: 0013216

(L) Audéo B90-312 (1440H06EX)

Fitting report left

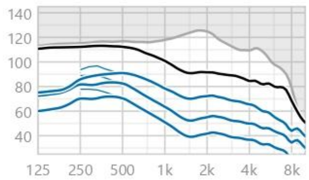
Audiogram



Automatic programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

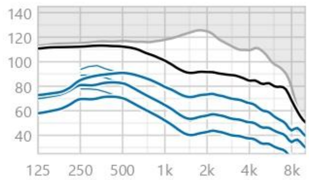
Calm situation



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	112	104	92	90	87	76
G80	24	13	3	8	6	-2
G65	27	17	6	12	10	0
G50	30	20	8	13	11	3
CR	1,3	1,2	1,2	1,2	1,2	1,2
TK	30	27	22	18	16	17

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	Real ear sound (4)
Noise generator	Off

Speech in noise



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	112	105	92	90	87	76
G80	24	14	4	10	7	-2
G65	26	18	8	13	11	0
G50	30	21	9	14	12	3
CR	1,3	1,2	1,2	1,2	1,2	1,2
TK	30	27	22	18	16	17

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	UltraZoom & SNR-Boost (20)
Noise generator	Off

Fitting report left

Fitting configuration

Acoustic parameters

Receiver	xP (Power)
Earpiece	Closed dome
Dome size	Small
Wire length	2xP (Power)

Details

Housing color	Silver Gray
Wax protection	Undefined

Fitting settings

Feedback & real ear test	2020/02/02
Fitting formula	DSL v5a Adult
Gain level of "All programs"	100%
BassBoost	Off
Occlusion compensation	Off
Compression	Prescribed compression

AutoSense OS options

Transition speed	Balanced

Automatic programs

Calm situation
Speech in noise
Speech in loud noise
Speech in car
Comfort in noise
Comfort in echo
Music

Streaming programs

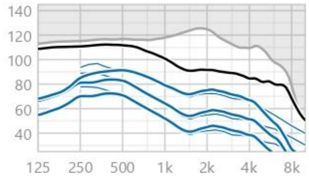
Bluetooth audio + mic
Bluetooth call / DECT + mic

Additional programs

Calm situation 1

Fitting report left

Bluetooth call / DECT + mic



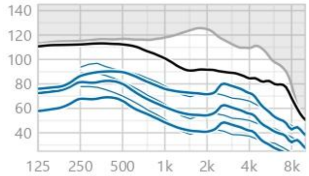
	310	850	1.5k	2.5k	3.6k	6.7k
MPO	111	104	92	90	87	76
G80	24	14	5	11	9	-13
G65	26	18	8	15	12	-11
G50	30	20	10	17	14	-10
CR	1,3	1,2	1,2	1,2	1,2	1,2
TK	30	27	22	18	16	17

Input source, Microphone	-6 dB
WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Off (0)
SoundRelax	Off (0)
Noise generator	Off

Additional programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

1 Calm situation 1



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	112	105	92	90	87	76
G80	25	10	5	14	14	-3
G65	26	14	8	16	16	-2
G50	27	16	10	17	18	-1
CR	1,1	1,2	1,2	1,2	1,1	1,1
TK	30	27	22	18	16	17

WhistleBlock	Off (0)
NoiseBlock	Off (0)
WindBlock	Off (0)
SoundRelax	Strong (20)
Microphone mode	Omni directional (0)
Noise generator	Off

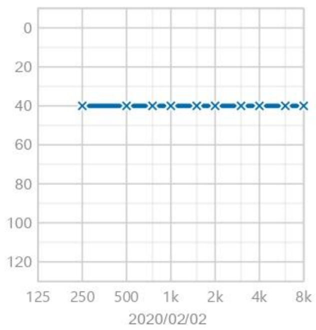
Appendix IV: Fitting report of hearing aid setting 3

Stephan, Heinrich
Date of birth: 1986/03/07, Client number: 0013216

Ⓛ Audéo B90-312 (1440H06EX)

Fitting report left

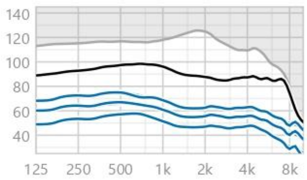
Audiogram



Automatic programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

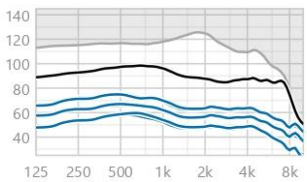
Calm situation



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	94	97	89	86	87	81
G80	2	4	1	5	6	0
G65	9	12	9	13	14	7
G50	14	18	15	19	21	12
CR	1,4	1,7	2	2,1	2,1	2
TK	31	27	22	18	16	16

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	Real ear sound (4)
Noise generator	Off

Speech in noise



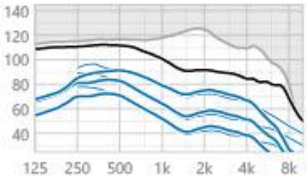
	310	850	1.5k	2.5k	3.6k	6.7k
MPO	94	97	89	86	87	81
G80	1	5	2	6	7	0
G65	8	13	10	14	15	7
G50	14	20	17	20	22	12
CR	1,5	1,9	2,1	2,1	2,1	2
TK	31	27	22	18	16	16

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	UltraZoom & SNR-Boost (20)
Noise generator	Off

PHONAK life is on

Fitting report left

Bluetooth call / DECT + mic



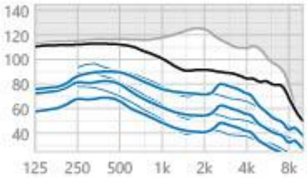
	310	850	1.5k	2.5k	3.6k	6.7k
MPO	111	104	92	90	87	76
G80	24	14	5	11	9	-13
G65	26	18	8	15	12	-11
G50	30	20	10	17	14	-10
CR	1,3	1,2	1,2	1,2	1,2	1,2
TK	30	27	22	18	16	17

Input source, Microphone	-6 dB
WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Off (0)
SoundRelax	Off (0)
Noise generator	Off

Additional programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

1 Calm situation 1



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	112	105	92	90	87	76
G80	25	10	5	14	14	-3
G65	26	14	8	16	16	-2
G50	27	16	10	17	18	-1
CR	1,1	1,2	1,2	1,2	1,1	1,1
TK	30	27	22	18	16	17

WhistleBlock	Off (0)
NoiseBlock	Off (0)
WindBlock	Off (0)
SoundRelax	Off (0)
Microphone mode	Omni directional (0)
Noise generator	Off

Fitting report left

Fitting configuration

Acoustic parameters

Receiver	xP (Power)
Earpiece	Closed dome
Dome size	Small
Wire length	2xP (Power)

Details

Housing color	Silver Gray
Wax protection	Undefined

Fitting settings

Feedback & real ear test	2020/02/02
Fitting formula	NAL-NL 2
Gain level of "All programs"	100%
BassBoost	Off
Occlusion compensation	Off
Compression	Prescribed compression

AutoSense OS options

Transition speed	Balanced

Automatic programs

Calm situation
Speech in noise
Speech in loud noise
Speech in car
Comfort in noise
Comfort in echo
Music

Streaming programs

Bluetooth audio + mic
Bluetooth call / DECT + mic

Additional programs

Calm situation 1

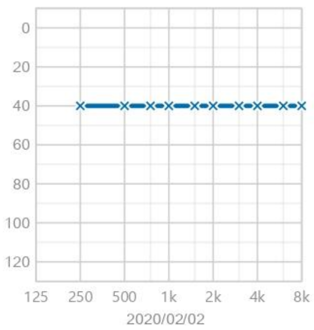
Appendix V: Fitting report of hearing aid setting 4

Stephan, Heinrich
Date of birth: 1986/03/07, Client number: 0013216

Ⓛ Audéo B90-312 (1440H06EX)

Fitting report left

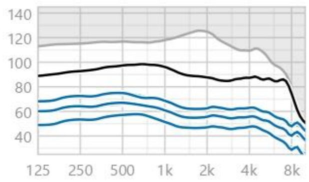
Audiogram



Automatic programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

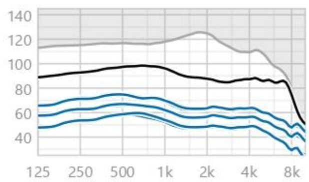
Calm situation



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	94	97	89	86	87	81
G80	2	4	1	5	6	0
G65	9	12	9	13	14	7
G50	14	18	15	19	21	12
CR	1,4	1,7	2	2,1	2,1	2
TK	31	27	22	18	16	16

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	Real ear sound (4)
Noise generator	Off

Speech in noise



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	94	97	89	86	87	81
G80	1	5	2	6	7	0
G65	8	13	10	14	15	7
G50	14	20	17	20	22	12
CR	1,5	1,9	2,1	2,1	2,1	2
TK	31	27	22	18	16	16

WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Moderate (16)
SoundRelax	Weak (8)
Microphone mode	UltraZoom & SNR-Boost (20)
Noise generator	Off

PHONAK life is on

Fitting report left

Fitting configuration

Acoustic parameters

Receiver	xP (Power)
Earpiece	Closed dome
Dome size	Small
Wire length	2xP (Power)

Details

Housing color	Silver Gray
Wax protection	Undefined

Fitting settings

Feedback & real ear test	2020/02/02
Fitting formula	NAL-NL 2
Gain level of "All programs"	100%
BassBoost	Off
Occlusion compensation	Off
Compression	Prescribed compression

AutoSense OS options

Transition speed	Balanced

Automatic programs

Calm situation
Speech in noise
Speech in loud noise
Speech in car
Comfort in noise
Comfort in echo
Music

Streaming programs

Bluetooth audio + mic
Bluetooth call / DECT + mic

Additional programs

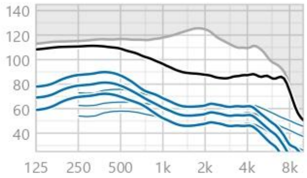
Calm situation 1

Stephan, Heinrich
Date of birth: 1986/03/07, Client number: 0013216

Ⓛ Audéo B90-312 (1440H06EX)

Fitting report left

Bluetooth call / DECT + mic



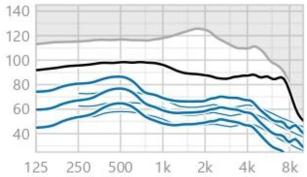
	310	850	1.5k	2.5k	3.6k	6.7k
MPO	110	100	89	86	87	81
G80	17	6	0	5	6	-12
G65	23	14	8	13	13	-5
G50	29	21	15	20	20	-1
CR	1,5	1,9	2,1	2,1	2,1	1,9
TK	31	27	22	18	16	16

Input source, Microphone	-6 dB
WhistleBlock	Moderate (13)
NoiseBlock	Weak (8)
WindBlock	Off (0)
SoundRelax	Off (0)
Noise generator	Off

Additional programs

Displayed values: Absolute / Measurement standard: SPL 2cc / Output

1 Calm situation 1



	310	850	1.5k	2.5k	3.6k	6.7k
MPO	96	97	89	86	87	81
G80	11	6	5	11	12	-4
G65	14	11	11	17	17	0
G50	16	15	16	22	22	3
CR	1,1	1,4	1,6	1,7	1,5	1,4
TK	31	27	22	18	16	16

WhistleBlock	Off (0)
NoiseBlock	Off (0)
WindBlock	Off (0)
SoundRelax	Strong (20)
Microphone mode	Omni directional (0)
Noise generator	Off

Appendix VI: Hearing aid technical data

Technical Data

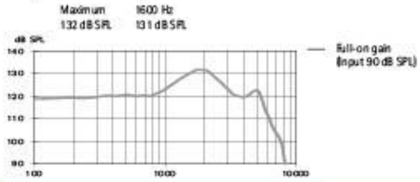
Phonak Audéo B

Phonak Audéo B-312 (B90/B70/B50/B30) (xP)

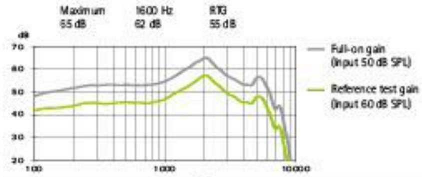
Ear simulator data

IEC 60118-0: 1994

Output sound pressure level



Acoustic gain

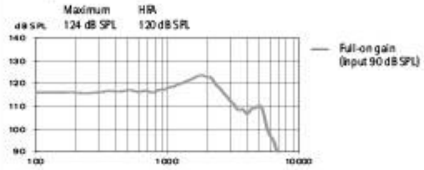


Frequency range	<100 Hz - 6400 Hz		
Total harmonic distortion	500 Hz 1.5%	800 Hz 1.5%	1600 Hz 1.5%
Battery current	Quiescent 1.1 mA	Working 1.2 mA	
Equivalent input noise level	19 dB SPL		

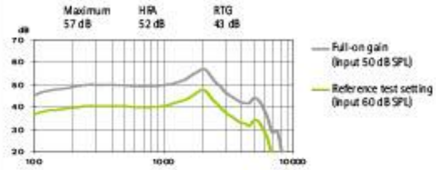
2cm^3 coupler data

ANSI/ASA S3.22-2014
IEC 60118-0: 2015

Output sound pressure level



Acoustic gain



Frequency range	<100 Hz - 6600 Hz		
Total harmonic distortion	500 Hz 1%	800 Hz 1%	1600 Hz 1%
Battery current	1.2 mA		
Equivalent input noise level	19 dB SPL		

V1.00/2016-01/DHO © Phonak AG All rights reserved/page 2/3

Appendix VII: **Data collection- Recorded words**

	Word	Formula	Impulse NR	Click group	Amplitude Syllable 1	Amplitude Syllable 2	Amplitude Syllable 3
1	Gxagxamisa	DSL V	OFF	Alveolar lateral	60.92	60.13	
		DSL V	ON	Alveolar lateral	61.25	60.32	
		NAL NL 2	OFF	Alveolar lateral	62.04	61.57	
		NAL NL 2	ON	Alveolar lateral	61.78	61.87	
2	Gxotha	DSL V	OFF	Alveolar lateral	62.62		
		DSL V	ON	Alveolar lateral	62.84		
		NAL NL 2	OFF	Alveolar lateral	62.32		
		NAL NL 2	ON	Alveolar lateral	61.91		
3	Inkxaso	DSL V	OFF	Alveolar lateral	63.37		
		DSL V	ON	Alveolar lateral	63.22		
		NAL NL 2	OFF	Alveolar lateral	63.73		
		NAL NL 2	ON	Alveolar lateral	63.77		
4	Inkxwaleko	DSL V	OFF	Alveolar lateral	63.35		
		DSL V	ON	Alveolar lateral	63.52		
		NAL NL 2	OFF	Alveolar lateral	62.62		
		NAL NL 2	ON	Alveolar lateral	62.71		
5	Inxanxadi	DSL V	OFF	Alveolar lateral	61.12	60.73	
		DSL V	ON	Alveolar lateral	61.52	61.15	
		NAL NL 2	OFF	Alveolar lateral	61.22	62.87	
		NAL NL 2	ON	Alveolar lateral	61.48	62.81	
6	isiXhosa	DSL V	OFF	Alveolar lateral	62.96		
		DSL V	ON	Alveolar lateral	63.05		
		NAL NL 2	OFF	Alveolar lateral	63.77		
		NAL NL 2	ON	Alveolar lateral	63.56		
7	Ixakuxaku	DSL V	OFF	Alveolar lateral	62.58	60.79	

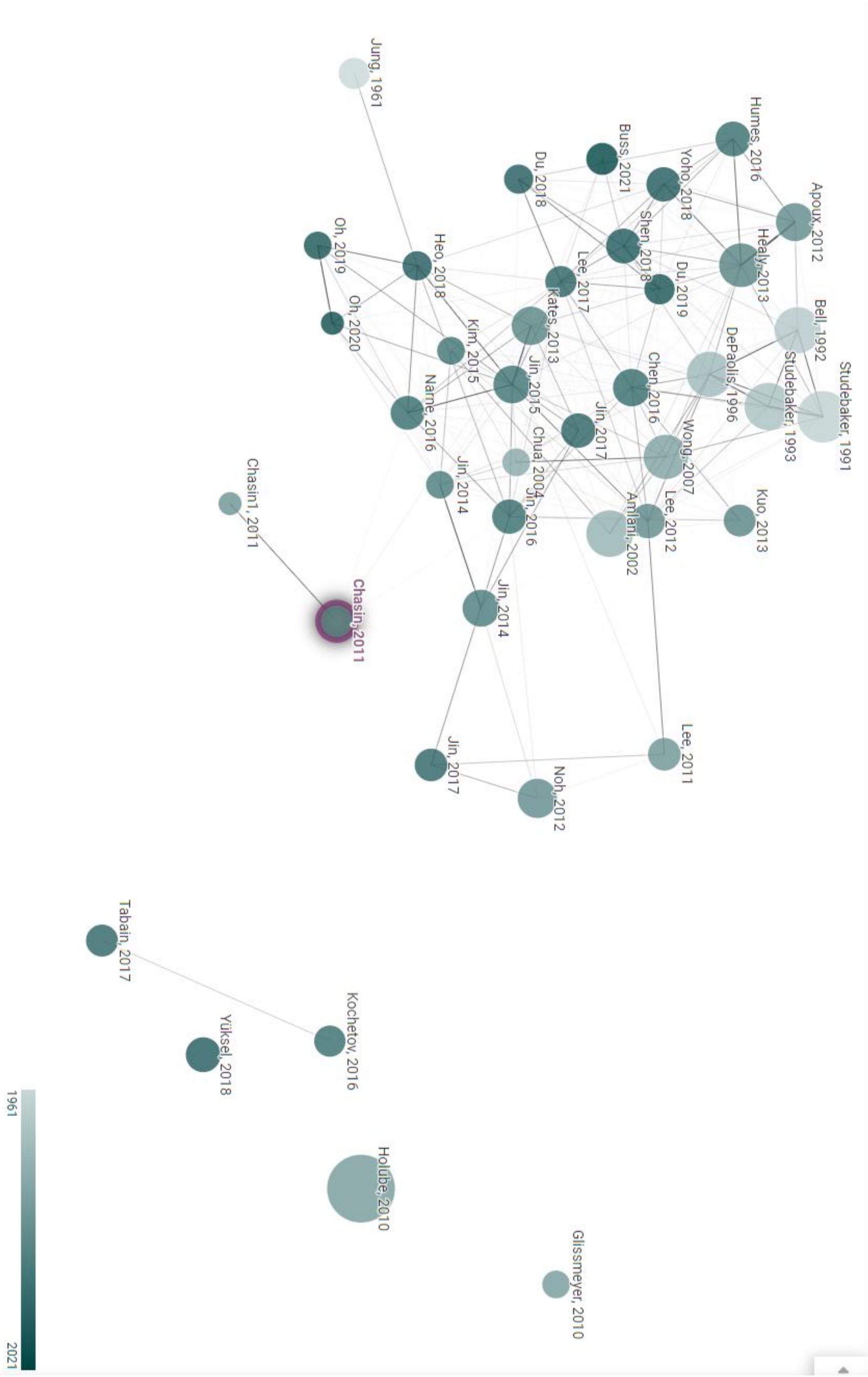
		DSL V	ON	Alveolar lateral	62.79	61.15
		NAL NL 2	OFF	Alveolar lateral	62.37	59.57
		NAL NL 2	ON	Alveolar lateral	62.54	59.5
8	Ngxola	DSL V	OFF	Alveolar lateral	63.75	
		DSL V	ON	Alveolar lateral	63.72	
		NAL NL 2	OFF	Alveolar lateral	64.05	
		NAL NL 2	ON	Alveolar lateral	64.08	
9	Ngxongxa	DSL V	OFF	Alveolar lateral	65.06	61.84
		DSL V	ON	Alveolar lateral	65.56	52.69
		NAL NL 2	OFF	Alveolar lateral	63.57	62.17
		NAL NL 2	ON	Alveolar lateral	63.52	62.43
10	Nxiba	DSL V	OFF	Alveolar lateral	64.56	
		DSL V	ON	Alveolar lateral	65.71	
		NAL NL 2	OFF	Alveolar lateral	60.58	
		NAL NL 2	ON	Alveolar lateral	60.35	
11	Uxolo	DSL V	OFF	Alveolar lateral	64.01	
		DSL V	ON	Alveolar lateral	63.49	
		NAL NL 2	OFF	Alveolar lateral	63.6	
		NAL NL 2	ON	Alveolar lateral	63.9	
12	Xhacha	DSL V	OFF	Alveolar lateral	61.19	60.37
		DSL V	ON	Alveolar lateral	61.23	60.36
		NAL NL 2	OFF	Alveolar lateral	61	60.06
		NAL NL 2	ON	Alveolar lateral	49.67	60.37
13	Gqiba	DSL V	OFF	Alveo-palatal	62.48	
		DSL V	ON	Alveo-palatal	62.98	
		NAL NL 2	OFF	Alveo-palatal	64.2	
		NAL NL 2	ON	Alveo-palatal	64.05	
14	Gqogqa	DSL V	OFF	Alveo-palatal	65.92	62.76
		DSL V	ON	Alveo-palatal	66.34	63.19
		NAL NL 2	OFF	Alveo-palatal	64.35	63.62

		NAL NL 2	ON	Alveo-palatal	64.51	63.61
15	Inkgekeko	DSL V	OFF	Alveo-palatal	61.87	
		DSL V	ON	Alveo-palatal	61.92	
		NAL NL 2	OFF	Alveo-palatal	61.05	
		NAL NL 2	ON	Alveo-palatal	61.11	
16	Iqanda	DSL V	OFF	Alveo-palatal	60.99	
		DSL V	ON	Alveo-palatal	65.64	
		NAL NL 2	OFF	Alveo-palatal	60.1	
		NAL NL 2	ON	Alveo-palatal	59.57	
17	Isingqengqelo	DSL V	OFF	Alveo-palatal	60	61.96
		DSL V	ON	Alveo-palatal	60.35	62.04
		NAL NL 2	OFF	Alveo-palatal	59.23	61.09
		NAL NL 2	ON	Alveo-palatal	59.25	61.07
18	Nkqonkqoza	DSL V	OFF	Alveo-palatal	63.11	66.5
		DSL V	ON	Alveo-palatal	63.26	64.63
		NAL NL 2	OFF	Alveo-palatal	61.73	63.03
		NAL NL 2	ON	Alveo-palatal	61.74	63.77
19	Nqena	DSL V	OFF	Alveo-palatal	64.96	
		DSL V	ON	Alveo-palatal	66.01	
		NAL NL 2	OFF	Alveo-palatal	63	
		NAL NL 2	ON	Alveo-palatal	62.44	
20	Qaqamba	DSL V	OFF	Alveo-palatal	62.86	64.79
		DSL V	ON	Alveo-palatal	63.43	64.19
		NAL NL 2	OFF	Alveo-palatal	62.55	63.47
		NAL NL 2	ON	Alveo-palatal	62.7	63.61
21	Qha	DSL V	OFF	Alveo-palatal	62.78	
		DSL V	ON	Alveo-palatal	62.37	
		NAL NL 2	OFF	Alveo-palatal	63.34	
		NAL NL 2	ON	Alveo-palatal	63.1	

22	Umnqamlexo	DSL V	OFF	Alveo-palatal	62.59		
		DSL V	ON	Alveo-palatal	62.68		
		NAL NL 2	OFF	Alveo-palatal	60.13		
		NAL NL 2	ON	Alveo-palatal	30.37		
23	Umnqonqo	DSL V	OFF	Alveo-palatal	64.09	63.99	
		DSL V	ON	Alveo-palatal	64.31	64.48	
		NAL NL 2	OFF	Alveo-palatal	61.02	63.29	
		NAL NL 2	ON	Alveo-palatal	61.15	63.27	
24	Uqhoqhoqho	DSL V	OFF	Alveo-palatal	63.39	60.69	61.8
		DSL V	ON	Alveo-palatal	63.78	61.44	62.29
		NAL NL 2	OFF	Alveo-palatal	62.5	60.5	61.11
		NAL NL 2	ON	Alveo-palatal	62.56	60.57	61.26
25	Caca	DSL V	OFF	Dental	64.29	60.65	
		DSL V	ON	Dental	69.45	67.4	
		NAL NL 2	OFF	Dental	65.23	63.17	
		NAL NL 2	ON	Dental	65.26	63.21	
26	Chacha	DSL V	OFF	Dental	64.29	60.65	
		DSL V	ON	Dental	64.65	59.92	
		NAL NL 2	OFF	Dental	62.77	59.14	
		NAL NL 2	ON	Dental	61.51	59.03	
27	Cheba	DSL V	OFF	Dental	55.91		
		DSL V	ON	Dental	56.08		
		NAL NL 2	OFF	Dental	55.27		
		NAL NL 2	ON	Dental	55.11		
28	Gcagca	DSL V	OFF	Dental	58.64	58.63	
		DSL V	ON	Dental	60.08	58.33	
		NAL NL 2	OFF	Dental	54.57	55.2	
		NAL NL 2	ON	Dental	55.64	55.25	
29	Gcina	DSL V	OFF	Dental	57.04		
		DSL V	ON	Dental	59		

		NAL NL 2	OFF	Dental	58.18	
		NAL NL 2	ON	Dental	57.52	
30	Icici	DSL V	OFF	Dental	58.9	60.99
		DSL V	ON	Dental	61.59	59.69
		NAL NL 2	OFF	Dental	55.77	57.65
		NAL NL 2	ON	Dental	52.82	56.28
31	Iingceba	DSL V	OFF	Dental	57.04	
		DSL V	ON	Dental	58.43	
		NAL NL 2	OFF	Dental	51.81	
		NAL NL 2	ON	Dental	50.94	
32	Inconco	DSL V	OFF	Dental	62.04	63.91
		DSL V	ON	Dental	63.05	59.94
		NAL NL 2	OFF	Dental	59.17	56.57
		NAL NL 2	ON	Dental	59.55	56.76
33	Ingcongnconi	DSL V	OFF	Dental	63.19	64.05
		DSL V	ON	Dental	63.76	63.59
		NAL NL 2	OFF	Dental	57.39	62.4
		NAL NL 2	ON	Dental	57.79	62.45
34	Inkcenckce	DSL V	OFF	Dental	71.37	67.39
		DSL V	ON	Dental	71.19	67.53
		NAL NL 2	OFF	Dental	67.73	64.81
		NAL NL 2	ON	Dental	67.43	64.76
35	Ncinci	DSL V	OFF	Dental	59.97	62.42
		DSL V	ON	Dental	58.41	61.11
		NAL NL 2	OFF	Dental	55.92	56.79
		NAL NL 2	ON	Dental	56.09	56.4
36	Nkcenkceshela	DSL V	OFF	Dental	68.09	67.92
		DSL V	ON	Dental	68.24	67.14
		NAL NL 2	OFF	Dental	63.71	63.45
		NAL NL 2	ON	Dental	63.28	62.48

Appendix VIII: Connected papers image



Appendix IX: Approval from the Human Research Ethics Committee

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: sumayah.ariefdien@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

18 September 2019

HREC REF: 470/2019

Ms L Petersen
Division of Audiology
Health & Rehab Sciences
F-45, OMB

Dear Ms Petersen

PROJECT TITLE: HEARING AID FITTINGS: DOES ONE SIZE FIT ALL? EXPLORING THE EFFECT OF HEARING AID IMPULSE NOISE REDUCTION ON IsiXhosa CLICK SOUNDS (MASTERS CANDIDATE: MR H STEPHEN)

Thank you for your response letter, addressing the issues raised by the Human Research Ethics Committee (HREC).

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 September 2020.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Mr Henrich Stephen will also be involved in this study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE