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User Preferences for Hearing Aid Features: Outcomes, Concepts, and Test Construction

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Abstract

Modern hearing aids can vary in both digital signal processing (DSP) and non-signal processing (non-DSP) features. The complexity and availability of these features can differ at opposite ends of the technology spectrum, potentially influencing aided benefit and preference. Furthermore, the amount of feature choices in modern hearing aids has led to increasing complexity in the selection process.

The first aim of this dissertation was to investigate the aided benefit and preference differences between premium and entry-level hearing aids, and to investigate the drivers of any preference differences. No significant differences were found between the entry-level and premium hearing aids in aided loudness ratings, speech quality, speech recognition, and consonant recognition. However, most participants preferred the premium hearing aids.

Investigation of this preference using group concept mapping revealed nine clusters, representing both DSP and non-DSP features. Three clusters were rated as significantly more important by participants that preferred the premium hearing aids. These three clusters represented technologies predominantly found in premium hearing aids (such as remote fitting compatibility).

The second aim was to design the Hearing Aid Feature Importance Evaluation (HAFIE) questionnaire. This provides clinicians with a methodology to gather patient feature importance ratings to facilitate hearing aid recommendations.

Questionnaire items were designed using concept mapping results as a theoretical framework. Hearing care professional focus groups provided feedback for modification. Validation of the 34-item questionnaire was conducted via Qualtrics. Exploratory factor analysis was used to assess factor structure, resulting in three subscales: “Advanced connectivity & streaming”, “Physical features & usability”, and “Sound quality & intelligibility”. Seven items were removed due to poor factor loading, resulting in a 28-item questionnaire with three subscales. Reliability of each of these subscales was assessed via Cronbach’s alpha and item-total correlation and was found to be appropriate.

This thesis has resulted in a conceptual framework of the different aspects of the hearing aid user experience, identifying features which may influence user preference. Furthermore, it has resulted in the development of an evidence-based hearing aid selection tool, providing a structured methodology which may potentially be useful in a clinical setting.

Keywords

Hearing aids, assistive technology, technology levels, concept mapping, user preference, drivers of preference, digital signal processing, non-signal processing features, hearing aid product profile, patient-centered care, patient preference, clinical decision-making, needs assessment, questionnaire, survey, hearing aid selection questionnaire, questionnaire development, feature-specific needs assessment, HAFIE, hearing aid feature importance evaluation, factor analysis, questionnaire validity, questionnaire reliability

Summary for Lay Audience

Modern hearing aids can differ in terms of the quality of the sound produced as well as other features (such as Bluetooth connectivity). The complexity and availability of these features can differ between premium and entry-level hearing aids, potentially influencing how much benefit the hearing aids give, and hearing aid user preference. Furthermore, the number of features in modern hearing aids has made choosing a hearing aid a more complex task.

The first aim of this dissertation was to investigate whether premium and entry-level hearing aids provide different sound benefits to hearing aid users, and whether they prefer one over the other (and why). The entry-level and premium hearing aids were found to benefit hearing aid users equally. However, most participants still preferred the premium hearing aids.

Investigation of this preference revealed nine distinct feature areas influencing preference, including features related to sound as well as features without a sound focus (such as physical comfort). Three feature areas were rated as significantly more important by individuals who preferred the premium hearing aids. These represented technologies predominantly found in premium hearing aids.

The second aim was to design the Hearing Aid Feature Importance Evaluation (HAFIE) questionnaire. This provides clinicians with an efficient way to recommend appropriate hearing aids to their patients by knowing how highly they rate different hearing aid features.

Questionnaire items were designed using the features identified in the previous preference investigation. Hearing care professionals were asked for their opinion on the items. Validation of the 34-item questionnaire was conducted via online survey. The internal structure of the data was statistically analyzed, resulting in three subscales: “Advanced connectivity & streaming”, “Physical features & usability”, and “Sound quality & intelligibility”. Seven items were removed due to poorly fitting onto the subscales, resulting in a 28-item questionnaire. The internal consistency and reliability of the questionnaire were found to be appropriate.

This thesis has added to the existing knowledge of the different aspects of the hearing aid user experience and how they affect preference. Furthermore, it has resulted in a hearing aid selection questionnaire which has shown potential for clinical use.

List of Abbreviations

ANOVA= Analysis of variance

APHAB = Abbreviated Profile of Hearing Aid Benefit

BTE= Behind-the-ear hearing aid

CFA= Confirmatory factor analysis

CIC= Completely-in-the-canal hearing aid

CM= Concept mapping

COSI = Client Oriented Scale of Improvement

CVI= Content validity index

DFD= Distinctive features difference

DM= Directional microphone

DSP= Digital signal processing

EFA= Exploratory factor analysis

EMO-CHeQ = Emotional Communication in Hearing Questionnaire

FDR= False discovery rate

GHABP = Glasgow Hearing Aid Benefit Profile

HAFIE= Hearing aid feature importance evaluation

HAPQ = Hearing Aid Performance Questionnaire

ITC= In-the-canal hearing aid

IIC= Invisible-in-the-canal hearing aid

KMO= Kaiser-Meyer-Olkin measure of sampling adequacy

MAP= Minimum average partial test

MAOF= Maximum audible output frequency

MAR= Missing at random

MCAR= Missing completely at random

MNAR= Missing not at random

NR= Noise reduction

Non-DSP= non-signal processing

PAF= Principal axis factoring

PHAP = Profile of Hearing Aid Performance

PTA= Puretone average

RAU= Rationalized arcsine units

RIC= Receiver-in-the-canal hearing aid

RMSE= Root-mean-square-error

SADL = Satisfaction with Amplification in Daily Life

Co-Authorship Statement

This thesis includes five chapters, comprised of an introductory chapter (Chapter 1), three integrated article body chapters (Chapter 2-4), and a concluding chapter (Chapter 5). I, Hasan Saleh, am responsible for the design, data collection, statistical analyses, and reporting of this work. I am the lead author on all chapters. I am the sole author of the introductory and concluding chapters (1 & 5). Susan Scollie reviewed drafts of these chapters prior to inclusion in this document. Chapters 2 and 3 are published and were co-authored by Paula Folkeard, Maaike Van Eeckhoutte, and Susan Scollie, who provided guidance on project design and statistical analyses, and assisted with manuscript review prior to submission. Chapter 4 was co-authored by Paula Folkeard, Selina Liao, and Susan Scollie, who provided guidance on project design and statistical analyses, and assisted with manuscript review. Susan Scollie and Paula Folkeard also provided support with obtaining ethical approval for the studies described in these chapters.

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Chapter 1

1 Introduction

1.1 An overview of hearing aids

Globally, there are almost 500 million people with a significant hearing loss (Brown et al., 2018; Wilson et al., 2017), defined by the World Health Organization (2021) as thresholds greater than 35 decibels in the better hearing ear. In Canada, nearly 20% of individuals aged 20 to 79 have a hearing loss, totaling 4.6 million adults as of 2013 (Feder et al., 2015). Sensorineural hearing loss is the most common type of hearing loss in adults, and a common non-surgical method of intervention is through the use of hearing aids (Chisolm et al., 2007; Gatehouse, 2002). As low as 1 in 5 individuals with hearing loss use hearing aids, with regular usage increasing depending on the severity of the hearing loss (Jorgensen & Novak, 2020; Lin et al., 2011). Furthermore, rates of non-use of already-owned hearing aids have been reported to be as high as 15.5% (Solheim & Hickson, 2017). This is despite the fact that hearing aid use has been demonstrated to provide benefit to individuals with even a mild hearing loss, improving listening ability and health-related quality of life (Ferguson et al., 2017; C. E. Johnson et al., 2016). In a recent review of hearing aid user satisfaction and benefit, however, 33% of hearing aids were found to have been acquired no longer than one year prior (Picou, 2020). This indicates potential increases in hearing aid acquisition and usage rates.

Hearing aids have undergone multiple technological advancements in their development; progressing from analog listening devices to digitally controlled analog, to the current era of modern digital hearing aids (Dillon, 2012; Schweitzer, 1997), with programmable digital signal processing and wireless technologies (Edwards, 2020). Early analog hearing aids converted sounds to an electric signal which passed through analog filters and was emitted from the receiver with linear gain and no additional processing (Chung, 2004; Valente et al. 1998; Valente et al. 1999). Digitally controlled analog, or analog programmable hearing aids, have the acoustic signal converted to an electric signal which is split into multiple frequency channels, which is programmed with channel-specific gain using fitting software. These provided different amplification levels between the channels and early versions may have not performed any dynamic signal processing (Chung, 2004; Ricketts & Bentler, 1992). Modern digital hearing aids convert the acoustic input signal to a digital signal using analog-to-digital converters (Schweitzer, 1997). All further processing on the signal is done entirely digitally, with filters and processing algorithms before converting the signal back to the sound output (Chung, 2004). This processing often includes noise reduction, beamforming, feedback cancellation, and scene analysis with scene-specific adjustment to signal processing in real time (Edwards, 2007, 2020).

A longstanding main concern for hearing aid users is their difficulty in hearing in noisy environments or environments with multiple speakers (Bentler, 2005; Desjardins & Doherty, 2009; Festen & Plomp, 1986; Picou et al., 2013). Hearing aid performance in noisy situations has been reported as the largest source of negative user perceptions (Kochkin, 2010). Data from the MarkeTrak 10 study (Jorgensen & Novak, 2020) revealed that hearing aid adoption is as low as 22% in individuals who could benefit from wearing them. The perception of benefit from amplification in difficult hearing situations has a major influence on the patient's decision to adopt hearing aids (Kochkin, 2005; Meyer & Hickson, 2012).

It is important for hearing aids to be useful in different listening environments, as there can be high variability between environments in terms of input levels (Kochkin, 2007; Wagener, 2008) and frequency (Abbad, 2014; Lesica, 2018) as well as background noise levels, reverberation, and signal source locations. Using the same hearing aid settings or features across different listening environments does not provide equal benefits (Cox & Alexander, 1991) and is not equally satisfactory for hearing aid users (Kates, 1995; Keidser et al., 2005; Smeds et al., 2006a, 2006b). Modern hearing aids have access to integrated features designed to adapt to complex acoustic environments and to alleviate users' difficulty in noisy and/or multi-talker environments by selectively providing environmentally specific signal processing features. The benefits to speech intelligibility of having appropriate settings for different listening environments have been demonstrated (Keidser, 1996; Searchfield et al., 2018). Chief among these signal processing features are microphone directionality, digital noise reduction, and multichannel dynamic range compression, described further below.

1.2 Digital signal processing features

1.2.1 Directionality

Hearing aids can contain one or more microphones. Directionality, or beamforming, uses both internal and external delay of the hearing aid microphones; the external delay is the difference in time for a target sound to reach both microphones. The internal delay is the time difference between the microphone outputs internally and this delay can be manipulated by the hearing aid digitally or through the use of an internal acoustic filter. An equal internal and external delay will cause cancellation of the target output either mechanically (an older method) (Chung, 2004) or digitally (a more modern technique) (Ricketts et al., 2017). This has the effect of nullifying sounds from certain angles, thereby attenuating sounds which come from those angles. The hearing aid can also actively alter the delay, and thereby alter the hearing aid sensitivity to the sounds in the 360º surrounding it, to maximize the ratio of energy coming from the front to improve the speech-to-noise ratio; this is known as adaptive directionality (Cord et al., 2004). Alternatively, the hearing aid can also be programmed to automatically switch in real-time between directionality settings based on the environment and the location of speech relative to the hearing aid user (Cox et al., 2014; McCreery et al., 2012; Wu et al., 2013). This process can also occur in multiple independent frequency channels (Cox et al., 2014; Wu et al., 2019).

A multitude of studies have reported the benefits hearing aid users experience from having access to DM features. This includes both objective (Bentler, 2005; Gnewikow et al., 2009; Picou & Ricketts, 2018; Ricketts, 2005; Saleh et al., 2021; Valente & Mispagel, 2008; Wagener et al., 2018; Walden et al., 2005; Wu & Bentler, 2010) and subjective benefits (Appleton & König, 2014; Park et al., 2018; Picou et al., 2017; Picou & Ricketts, 2019).

1.2.2 Noise reduction

Noise reduction (NR) algorithms are present in almost all modern hearing aids (Popelka et al., 2016), and are used to lower the gain applied to noisy signal segments, thereby reducing annoyance and fatigue in noisy environments (discussed below). It is useful when there is no speech present, and when speech and noise are both present in the sound environment.

Generally, noise reduction for continuous (non-transient) noises use three main strategies: multi-channel adaptive noise-reduction, synchrony-detection noise reduction, and spectral subtraction (Bentler & Chiou, 2006; Chong & Jenstad, 2018; Chung, 2004; Popelka et al., 2016). Once the signal's speech and noise content (and ratio) are identified, portions of the signal with significant background noise have their gain reduced based on the specific strategy implemented.

Noise reduction programs have been found to reduce hearing aid user annoyance, perceived sound quality, aversion to noise, and listening exertion (Bentler et al., 2008a; Brons et al., 2014; Desjardins & Doherty, 2014; Sarampalis et al., 2009; Wendt et al., 2017; Wu et al., 2019; Wu & Stangl, 2013) and to be preferred by hearing aid users to non-noise reduction algorithms when compared in different environments (Pittman & Hiipakka, 2013; Ricketts & Hornsby, 2005; Wu et al., 2019). NR neither improves nor degrades speech intelligibility when used at clinically-typical settings (Crukley & Scollie, 2014; Desjardins & Doherty, 2014; Mueller et al., 2006; Pittman et al., 2017; Pittman & Hiipakka, 2013). However, past an optimal range balancing intelligibility and comfort (Jenstad et al., 2007), it has been suggested that increasing noise reduction and comfort lead to decreased intelligibility (Brons et al. 2014). This corresponds to previous findings that reported sound "pleasantness" is not closely correlated to speech intelligibility (Byrne, 1986), and that listeners prioritize different sound quality dimensions based on the listening situation (fullness/sharpness in music and intelligibility/loudness in speech) (Vaisberg et al., 2021).

Hearing aids also contain other forms of noise reduction algorithms, targeting wind and transient noise (Chong & Jenstad, 2018). Wind noise is caused by fluctuations in the air pressure at the hearing aid microphone (Zakis, 2011), and is still a significant area of dissatisfaction for hearing aid users (Kochkin, 2010). Previously suggested approaches to protecting the microphone port from wind included physical modifications to reduce exposure (such as changing the microphone location or using a small windshield) (Dillon, 2012; Korhonen et al., 2017; Zakis, 2011). More recent approaches implement specific algorithms designed to detect wind noise and suppress its effect on the signal (Keshavarzi et al., 2018; Korhonen et al., 2017; Popelka et al., 2016) and have been shown to improve subjective annoyance ratings and speech identification in wind (Korhonen et al., 2017). Current developments include the use of machine learning algorithms and binaural processing to further improve wind noise reduction (Au et al., 2019; Keshavarzi et al., 2018).

Transient (or impulse) noises are those which occur rapidly and can be quite loud, such as a door slamming or a car horn (Liu et al., 2012; Popelka et al., 2016). This is not easily detected by the previously mentioned noise reduction algorithm strategies, and can be a source of discomfort in hearing aid users (Keidser et al., 2009; Moore et al., 2011). Specific algorithms targeting transient noise have been developed, detecting transient noises by assessing rapid changes in the input signal (DiGiovanni et al., 2011). These have been shown to be subjectively preferred by hearing aid users and contribute to a higher accepted overall gain (Korhonen et al., 2013), as well as provide benefits to speech intelligibility in certain acoustic environments rich in transient noises (DiGiovanni et al., 2011). Current strategies include application of machine learning techniques (Hao et al., 2021; Keshavarzi et al., 2021) and personalization to improve performance (Stronks et al., 2021)

1.2.3 Multi-channel dynamic range compression

Compression is a feature which allows non-linear level-dependent amplification, helping to ensure that more sounds processed by the hearing aid fit into the restricted dynamic range of the hearing aid user (Dillon, 2012; Hamacher et al., 2005; May et al., 2018). With compression, the amount of gain provided by the hearing aid for low-level input signals (softer sounds) is higher than that applied to higher-level input sounds. Some important characteristics of hearing aid compression include the compression thresholds, attack time, release time, and compression ratios (Dillon, 2012; May et al., 2018). The compression threshold is the SPL level above which compression is applied to the signal. The compression attack time is the time taken by the hearing aid to apply compression after the compression threshold is reached, and the release time is the time required for compression to stop being applied after the signal input returns below the compression threshold. The compression ratio is a value quantifying the amount of compression being applied on the signal; this is the change in input level required to change the output by 1 dB. For example, a 2:1 compression ratio indicates that for every increase in input of 2 dB, the output only increases by 1 dB (Dillon, 2012). Hearing aids can have multiple compression channels with different compression thresholds, allowing different compression ratios and attack/release times to be applied on frequency-specific regions within the signal, based on the input signal level.

The efficacy of wide dynamic range compression and its positive effects on hearing aid users' fitting outcomes are well-documented. In a systematic review by McCreery et al. (2012), audibility was found to be improved by wide dynamic range compression. Speech intelligibility was also found to either be equal or improved by wide dynamic range compression depending on the listening conditions. Subjective preference results were mixed between wide dynamic range compression and other compression (or linear gain) settings.

1.2.4 Automatic switching

Automatic program switching is a feature found in modern hearing aids, adapting directionality and noise reduction settings automatically to maximize intelligibility in the current acoustic environmental (de Graaff et al., 2018). This alternative to manual program switching is a technological attempt to recreate the human process of auditory scene analysis, in which the mixture of auditory input is separated and identified into its individual constituents (Bregman, 1994). It has been documented as being perceived as useful by most hearing aid users, as well as choosing the correct situation for the environment (Gabriel, 2002; Olson et al., 2004), albeit with significantly less accuracy classifying in speech in noise, traffic, and music (Büchler, 2001). In an assessment of automatic switching accuracy, Searchfield et al. (2018) found that the automatically selected settings provided a benefit over the users' selected settings in a variety of listening environments. This is consistent with previous literature reporting that hearing aid users typically do not change their manual program, and do not always select the appropriate manual setting based on their listening environment when they do (Cord et al., 2002). Current studies evaluate the role of environment-specific preferences in improved or personalized hearing aid settings, including how machine learning algorithms may contribute to improvement (Søgaard Jensen et al., 2019).

1.3 Non-signal processing features

Today's commercial hearing aid products, however, also includes features which are not related to the hearing aid's digital signal processing toolkit to improve audibility and speech intelligibility. These will hereby be referred to as non-signal processing features. The progress and development of non-signal processing features has mirrored that of signal processing features, and thus modern hearing aids have a multitude of features aimed at improving the overall fitting experience. These will be discussed below.

The first of these non-signal processing features is the physical style of the hearing aid, or the form factor of the hearing aid. Hearing aid development has given users access to different physical styles than the traditional behind-the-ear (BTE) hearing aid, such as in-the-ear (ITE), in-the-canal (ITC), completely-in-the-canal (CIC), invisible-in-canal (IIC), mic-in-helix (MIH) and receiver-in-the-canal (RIC) hearing aids, albeit with restrictions based on the individual circumstances of the hearing aid user, such as the extent of their hearing loss. These styles have markedly different physical characteristics which influence the cosmetics of the hearing aids as well as their ease of management by the hearing aid user. Accessory compatibility is also a common feature, and possible accessories include remote controls and television audio-steamers. In addition, modern hearing aids can also have Bluetooth connectivity. This provides compatibility with a smartphone/tablet for music and call streaming. Smartphone/tablet connection can also give the hearing aid user proprietary application access, when available. These applications are commonly called "apps" (Lewis et al., 2014). Via the app, the user can modify basic hearing aid settings (i.e., volume and clarity/comfort) control and, in some apps, more advanced settings such as the directionality polar plots. Furthermore, more recent phone app developments also allow the user to communicate with the hearing professional, give access to remote fitting and fine-tuning, allow accurate detection of falls and tracking of steps taken during the day (Rahme et al., 2021), and provide GPS tracking to help with locating a hearing aid as well as to allow the hearing aid to adaptively adjust settings to location-based preferences (Kollmeier & Kiessling, 2018; Wasmann et al., 2021).

1.4 Feature variety across hearing aids

When available, many of these features vary in sophistication between the different technology levels in modern available hearing aids, with higher technology levels typically including more sophisticated versions of features (Cox et al., 2014; Lansbergen & Dreschler, 2020). This applies to both signal processing and non-signal processing features.

Signal processing features differ in terms of complexity and efficacy across hearing aids. This includes the features described in Section 1.2 above. Directional microphones at their most basic level are single-channel and non-adaptive, whereas more complex forms of directionality use multi-channel strategies which can adapt to the environment signal and noises sources. Even more advanced are bilateral beamformer systems which use interaural hearing aid communication to achieve a very narrow directional focus, and speech-seeking directional microphones which can alter the polar plot to focus on speech not located in front of the hearing aid user (Wu et al., 2019). Noise reduction systems at different technology levels vary in their number of channels, the speed at which they function, and in the range of identifiable noise types (Wu et al., 2019). In terms of signal compression, hearing aids can also vary in the number of adjustable compression channels available (Lansbergen & Dreschler, 2020), with high-end hearing aids containing upwards of 16-22 channels whereas entry-level hearing aids have closer to between 6 and 8 channels (Cox et al., 2016; Saleh et al., 2021).

Non-signal processing (non-SP) features can also differentiate hearing aids. As mentioned, many physical styles of hearing aid are available depending on an individual's preference and needs. In addition, hearing aids can differ in their compatibility to accessories such as the TV streamer, remote microphones, and remote control. Bluetooth connectivity is also not available in all hearing aids. This also means that other features requiring Bluetooth, such as phone/tablet call and music streaming, along with smartphone/tablet app compatibility, are mostly available at the high end of the hearing aid technology spectrum (J.A Johnson et al., 2016) but are becoming prevalent in modern hearing aids (Bhowmik et al., 2021; Ross, 2020).

1.5 User preference in hearing aids

Preference is a complex construct representing the decision for one outcome or experience over another, and which involves an individual's previous experiences and personal values (Brennan & Strombom, 1998). The overall hearing aid experience can vary widely between users due to the multitude of differences that exist between hearing aids and their features (both signal processing and non-signal processing) and is affected by factors not solely limited to audibility. As discussed above, the effect of advancement in signal processing (specifically DM/NR) technology on aided audibility, intelligibility, and comfort has been well-established in the literature (Ahmadi et al., 2018; Bentler et al., 2006, 2008a; Bentler et al., 2004; Brons et al., 2014; Crukley & Scollie, 2014; Desjardins & Doherty, 2014;

Sarampalis et al., 2009; Walden et al., 2000; Wendt et al., 2017; Wu et al., 2019; Wu & Bentler, 2010b). The preference and satisfaction differences between different levels and types of signal processing features has also been studied and reported on, spanning different DM and NR technologies (Cox et al., 2011, 2016; Neher, 2014; Ricketts & Hornsby, 2005; Wu et al., 2019). However, these findings may not inform us about benefit or improved satisfaction from non-signal processing features.

Bridges et al. (2012) investigated, in a comparison of Likert scales and conjoint analysis, the value of seven hearing aid attributes that include both signal processing and other features: performance in quiet and noise, frequency of battery replacement, price, water and sweat resistance, feedback, and comfort. They found high concordance between the Likert scale and conjoint analyses, both revealing performance in noise as the most valuable feature for users. This was followed by physical comfort, performance in quiet settings, and resistance to water/sweat. Zhu et al. (2020) also included non-signal processing features into a study of the preference for different levels of specific hearing aid attributes. They conducted a discrete choice interview-based study with features asked about including cost, hearing aid style, HA effectiveness in quiet and noisy environments, feedback, connectivity, water resistance, and battery life. They found that, while effectiveness in noise was overall the most important to users, the preference across many of these features, both DSP and non-SP related, varied across participants from different demographic and socioeconomic backgrounds. Manchaiah et al. (2021) retrospectively analyzed hearing aid user feature selection choices across both DSP and non-DSP features and found that the most highly rated features were benefit in noise and quiet, comfort, and hearing aid reliability.

Experimental research on preference between different hearing aids has largely only included differences in certain DSP features, controlling for other DSP and all non-signal processing features (Cox et al., 2016; Wu et al., 2019). To the author's knowledge after a review of the available literature, there has been no experimental study on preference between varying overall hearing aid product profiles which include varying levels of non-signal processing features.

1.6 Implementation of patient preference in decision-making

Preference is a multidimensional concept representing the relative desirability of certain experiences or outcomes. It is influenced by an interaction of an individual's cognition, experiences, and personal values (Brennan & Strombom, 1998). In a healthcare setting, person-centered care is an approach which incorporates patients' individual needs and preferences into the decision-making process prior to treatment (Ekman et al., 2011; Jaarsma et al., 2018; Leplege et al., 2007), and has become more common (Woolf et al., 2005). Patient inclusion in the decision-making process has been reported to mitigate post-treatment regret and improve positive outcomes such as satisfaction (Mulley et al., 2012). Designing patient management and treatment plans around patient preference also improves compliance (Bratzke et al., 2015). Knowledge of patient preference can improve the efficacy and cost-effectiveness of care (Brennan & Strombom, 1998), as well as identify individual or group-level differences which can assist with clinical decision-making (Marshall et al., 2017).

Preference can represent both the final choice of overall treatment (Brennan & Strombom, 1998) and the features of certain treatment options (Moore & Kramer, 1996). In a hearing aid context, examples of this can include the decision to adopt a hearing aid, or the choice between features available in a hearing aid. In an hearing healthcare setting, patient involvement in treatment decision-making includes tailoring the choice between hearing aids, the parameters of signal processing features, and the availability of non-signal processing features, based on the participant's needs and preferences. The importance of these considerations can be seen in the recent hearing aid fitting guidelines published by the Audiology Practice Standards Organization (2021). These standards recommend a "needs assessment" to be conducted prior to fitting to identify the patient's audiological, communicative, and non-audiological needs. These are used to determine hearing aid candidacy, and the decision to include specific signal processing and non-signal processing features. The Help Me Choose tool offered by HearingTracker (https://www.hearingtracker.com/hearing-aids/personalized-match-survey) is an available example of a (remote) patient preference/needs assessment tool.

Patient-centered interaction has been highlighted as a way to improve hearing aid adoption (Poost-Foroosh et al., 2011). It may also lead to less regret and more compliance (Bratzke et al., 2015; Mulley et al., 2012), which could increase hearing aid uptake. Modern hearing aid selection requires the consideration of a vast assortment of features. This, coupled with the importance of patient inclusion in the hearing aid selection process, suggests a need for a feature-specific needs assessment, aimed at potential hearing aid users prior to hearing aid selection and fitting.

1.7 Methods of gathering patient preference

Patient inclusion in the decision-making process can be facilitated by gathering patient preference information. This can be done informally such as through patient interviews, or through more structured methodologies including surveys and questionnaires (Booij et al., 2013; Brennan & Strombom, 1998; Kaiser et al., 2020; Lin et al., 2005) which can be designed to be administered to the patient by the health service provider in person or to be completed by the patient independently. This may be completed either electronically, on paper, or both, depending on the questionnaire/survey design (Dillman et al., 2014).

1.7.1 Interviews

Interviews are a direct way to assess preference and subjective experience, and these can be done either in person, electronically, or by phone. Interviews consist of either structured close-ended questions regarding preference or open-ended questions to collect qualitative preference data, and they can have integrated rating scales within them. Interviews have been used as part of the concluding outcome measures (exit interviews) of real world experiments to assess the preference of features tested (Cox et al., 2011; Dahlquist et al., 2015; Keidser et al., 2007; Lunner, 1997), or to measure satisfaction (Kaplan-Neeman et al., 2012; Keidser et al., 2011).

1.7.2 Questionnaires/Surveys

Questionnaires, closely related to closed-ended interviews, are another way to measure subjective attitudes. These can be direct questionnaires asking about preference for certain HA features and the reasons for this preference (Mylanus et al., 1998), or they can increase in complexity and structure to assess multiple aspects of hearing aid users' subjective experience.

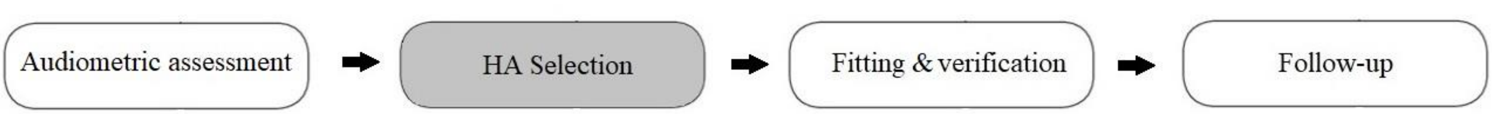
Many structured questionnaires are available which use rating scales to assess a wide range of factors such as perceived hearing aid benefit, performance, subjective emotional experiences, and satisfaction in different situations. These include the Glasgow Hearing Aid Benefit Profile (GHABP, Gatehouse, 1999), the Profile of Hearing Aid Performance (PHAP, Cox & Gilmore, 1990), the Satisfaction with Amplification in Daily Life scale (SADL, Cox & Alexander, 1999), the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox, 1997), the Client Oriented Scale of Improvement (COSI, Dillon et al., 1997), the Hearing Aid Performance Questionnaire (HAPQ, Gatehouse et al. 2006), the Emotional Communication in Hearing Questionnaire (EMO-CHeQ; Singh et al., 2019) and the International Outcome Inventory for Hearing Aids (IOI-HA, Cox & Alexander, 2002). These questionnaires are well-established in research and clinical settings, with purposes ranging from pre-fitting use to assess the situations needing amplification (such as the GHABP), after fitting to assess satisfaction with the hearing aid (SADL), and both before and after fitting to measure HA benefit (APHAB).

None of the previously discussed questionnaires are designed with a focus on hearing aid features and technology and as a candidacy tool to assess the specific features important to potential hearing aid users. There are questionnaires aimed at hearing aid selection or attribute importance. Some of these were developed for use in a limited research setting and are not published for clinical use (Meister et al., 2001). However, some questionnaires are designed for more general use, including the Hearing Aid Selection Profile (HASP;

Jacobson et al., 2001) and the Characteristics of Amplification Tool (COAT; Sandridge & Newman, 2006). These questionnaires elicit user ratings of subjective hearing aid features and attributes such as preferred form factor, cost, and overall communication needs. However, as will be discussed further in Chapter 4, these questionnaires do not include any specific hearing aid technologies and are dated, limiting their use in modern hearing aid selection. Furthermore, there are many proprietary hearing aid selection services and surveys designed to help clinicians and patients select an appropriate hearing aid (provided by hearing aid companies, clinics, and hearing care professionals), and these vary in scope of use. Some commercially-available online tools, such as the Help Me Choose tool offered by HearingTracker (https://www.hearingtracker.com/hearing-aids/personalized-match-survey), have provided novel insight into consumer attitudes and preferences (Manchaiah, Picou, et al., 2021). However, the theoretical framework behind these tools, and the steps taken to validate them, are unknown.

1.8 Research Objectives

Consumer preference for hearing aid technology level is important, given the strong relationship between technology level and cost. There has been literature assessing performance and preference between hearing aids at different technology levels, both with experimental in-lab and field trials (Cox et al., 2016; Wu et al., 2019) and via other techniques such as conjoint analysis (Bridges et al., 2012; Zhu et al., 2020). Hearing aid user preference for technology level has also not been previously investigated using group concept mapping techniques.



In summary, selecting an appropriate hearing aid is an integral step in the overall hearing aid experience, directly influencing user satisfaction and overall successful adoption. Hearing aid selection has become a complex decision requiring consideration not only of patient audibility needs, but also attitudes towards different available features (DSP and non-DSP). The importance of patient input in the patient journey has been highlighted, but there is a lack of evidence-based modern hearing aid selection questionnaires available for use in this regard.

The objectives of this doctoral work are:

1- To explore user preference differences for hearing aids at different levels of technology.

2- To use a concept mapping process to delineate the hearing aid features which differentiate these levels of technology, and to explore how these features influence user preference and their relative importance to hearing aid users.

3- Using the factors identified, to design a hearing aid pre-fitting candidacy questionnaire tool, incorporating patient-centered care into hearing services at the time of hearing selection. This tool may aid clinicians in gathering structured preference information from patients in a way that is highly aligned with the specific factors underlying hearing aid preference.

These steps will be conducted following the guidance of the knowledge-to-action process framework proposed by I. D. Graham et al (2006). This framework contains two general components. Knowledge creation represents the process by which general knowledge is attained (i.e., via research) and is refined and focused to ultimately be disseminated in the most relevant manner to the intended audience. The action component represents the process whereby attained knowledge is modified and tailored for implementation and application, in order solve a real-world problem which has been identified.

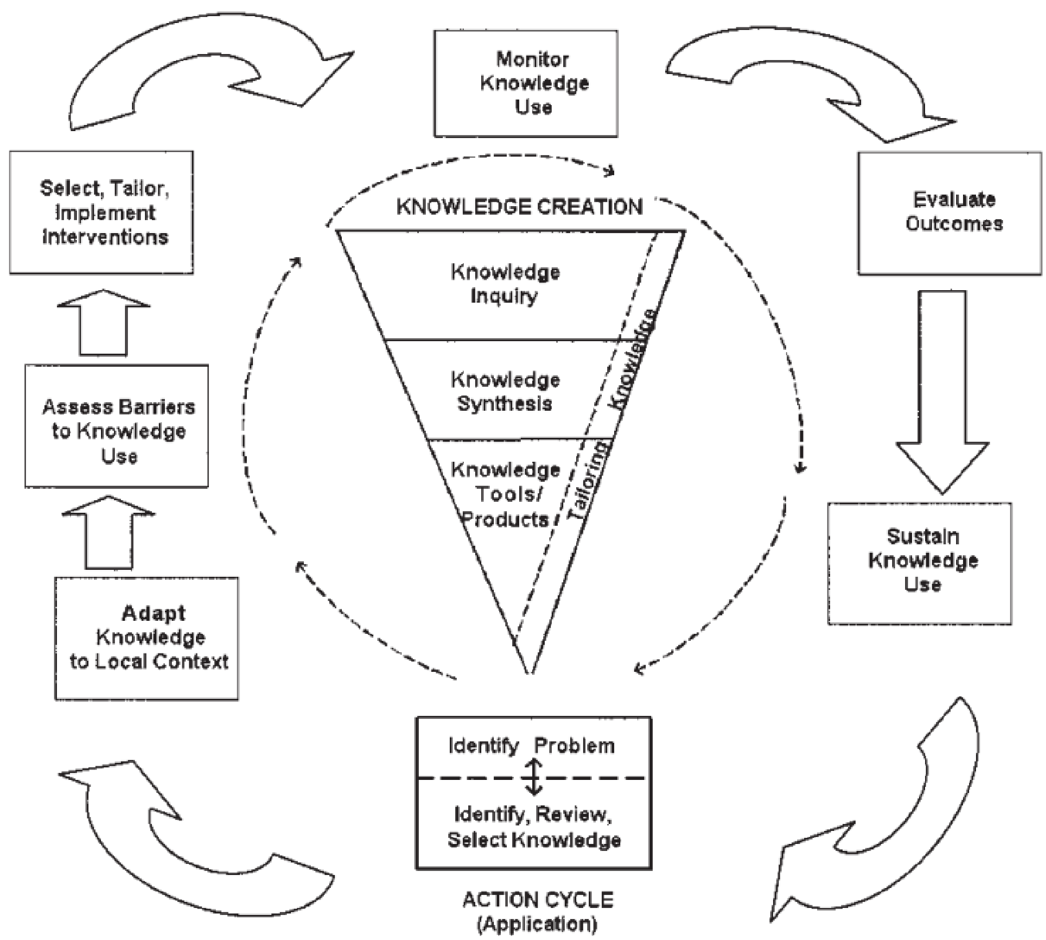


Figure 1-2 The knowledge-to-action process. Adapted from "Lost in knowledge translation: Time for a map?", by I.D. Graham, J. Logan, M. B. Harrison, S. E. Straus, J. Tetroe, W. Caswell, and N. Robinson. *Journal of Continuing Education in the Health Professions, 26*, p. 13-24. Copyright permission provided by Walter Kluwers Health, inc.

These steps have also been adapted in other frameworks aimed at translating stakeholder feedback and known issues into action plans, such as the systematic approach to developing an action plan in a health system quality improvement context by the Canadian Institute for Health Information (2017). This involves the following steps: identification of an existing real-world problem and determining the “know-do” gap between knowledge of best practices and actual current practice. Options for problem identification and gap determination can include reviews of evidence and literature, seeking clinician input, and seeking patient experiences (Registered Nurses’ Association of Ontario, 2022). Next, researchers engage in selecting and adapting relevant knowledge to the context of focus, implementing the knowledge to develop a solution that addresses the know-do gap. This involves recognition of which parts of the acquired knowledge can be adapted for use in addressing the know-do gap, followed by identification of the stakeholders who will be influenced from this new application of knowledge (such as end-users) (Health Canada, 2017). The following step of the integrated knowledge translation process includes assessing barriers to implementation and feasibility (I. D. Graham et al., 2006). Assessing barriers to implementation is also recommended in the development of an action plan for implementation of patient-centered care solutions (Canadian Institute for Health Information, 2017). This is often achieved through stakeholder involvement such as via surveys or focus groups (Glista et al., 2014). After identifying barriers to implementation, consideration must be given to addressing these barriers: This can be achieved by tailoring the implemented solution with these in mind (Moodie et al., 2011). Later stages of the cycle include monitoring the use of the developed solution and the resulting outcomes, and taking steps to sustain its use. Novel issues may be identified in the final sustaining phase, leading to a repetition of the cyclical action component (I. D. Graham et al., 2006). The application of specific components of the knowledge-to-action cycle in each chapter is summarized below.

1.9 Summary of chapters

The series of studies described in the upcoming chapters were designed to assess the outcomes and consumer preferences for differences between commercially available entry-level and premium hearing aids product profiles. In the first two chapters, the problem of patient preference for technology levels in hearing aids was explored. Specifically, we assessed the differences in behavioral outcome measures between these different technology levels, using laboratory measures (Chapter 2) to ensure that both technology levels had been fitted to provide appropriate patient outcomes, and to explore any lab-measured differences in benefit. Participant preference for the entry-level or premium hearing aids was also measured after a 3-week trial (Chapter 2) and, using a concept mapping process, the underlying drivers of the preference choices were assessed (Chapter 3). This resulted in a conceptual map delineating the different hearing aid features affecting preference between entry-level and premium hearing aids. The studies in Chapters 2 and 3 belong to the knowledge creation ("funnel") stage, with the results adding to the overall available knowledge about hearing aid preference and differences between technology levels in hearing aids. Furthermore, the concept map contains factors of patient preference that are not assessed in clinically available, validated assessments for use during technology selection (summarized in Chapter 4). This potential "know-do" gap suggests that there may be a lack of evidence-based tools appropriately addressing this need in the selection process, beginning the process of the action cycle at the problem identification stage. Chapter 4 describes the next 3 steps in the action cycle, adapting knowledge to the local context, assessing barriers to use, and tailoring the solutions to the barriers. The data gathered in the concept mapping process (specifically, during the brainstorming and sorting activities) were adapted to create a clinically valid pre-fitting survey tool and, using a focus group process, the barriers and facilitators to use were identified and used to tailor the tool appropriately. Furthermore, the initial validation of this tool was described. These chapters address some, but not all, components of the knowledge to action process, leaving future directions that are discussed in Chapter 5.

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Chapter 2

2 Behavioral outcome differences between premium and entry-level hearing aids[1]

2.1 Background

Untreated hearing loss can lead to a decline in quality of life at work, socially, and at home (Morris et al., 2013). The primary intervention for sensorineural hearing loss is the use of hearing aids (Chisolm et al., 2007; Gatehouse, 2002), which has been shown to provide quality of life, mental health, and social benefit to individuals with hearing loss (Chisolm et al., 2007; Kochkin, 2010; Picou, 2020). However, hearing aid adoption and usage rates remain low, and millions of individuals with hearing loss do not use hearing aids (Chien, 2012; Jorgensen & Novak, 2020). A factor possibly contributing to this is the difficulty hearing and understanding speech in different situations (Kochkin, 2010). This is a main concern reported by hearing aid users and is a significant driver of hearing aid satisfaction (Picou, 2020).

While all modern commercially available hearing aids are likely to have at least some form of directional microphone (DM) and digital noise reduction (NR) features, they can vary

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between hearing aids, which sometimes underlies different price points. The differences between premium and entry-level hearing aids are typically related to the features available and the technological sophistication of the features. A hearing aid comparison framework developed by Lansbergen and Dreschler (2020) suggests a classification system based on signal processing, comfort, and adaptation features that differentiates hearing aids between the upper and lower ends of technology levels. Differentiation is based on the presence of more complex versions of DM and NR features, a higher number of compression and gain-adjustable channels, as well as the availability of adaptive and automatic versions of these features (Cox et al., 2014; Wu et al., 2019). In spite of all these available benefits to a higher technology level, however, Gioia et al. (2015) found that technology level recommendations by hearing professionals were not based on any evidence of patient outcome benefit from different technology levels, but instead on variables such as patient lifestyle as perceived by the hearing professional after informal consultation.

Recent studies have investigated the difference in benefit between premium and entry-level hearing aids and features in a laboratory setting and in the real world. Johnson et al. (2016) compared two brands of hearing aids at a premium and entry-level and found no significant differences in objective behavioral outcome measures in aided speech recognition in noise and quiet and only a small improvement in localization scores in quiet in one of the hearing aid brands. Wu et al. (2019) also compared premium and entry-level directional microphone and noise reduction technologies and found a beneficial effect of premium technology on aided speech intelligibility in noise. They also found that self-reported sound quality did not differ significantly between premium and entry-level hearing features in a real-world setting, nor for most laboratory testing conditions. Cox et al. (2016) found that preference between the premium and entry-level devices was equally divided between the two technology levels, and these findings were supported by those of Wu et al. (2019) who reported no significant differences in user satisfaction between premium and entry-level signal processing features. Furthermore, in a recent study, Plyler et al. (2021) also investigated the effects of hearing aid technology level on behavioral outcomes. They measured speech perception, acceptable noise level (ANL), and speech satisfaction ratings, as well as participant preference for technology level. They found that most measures were not significantly affected by hearing aid technology level. However, participants reported a significantly higher acceptable noise level and satisfaction with speech when in large groups when using the premium hearing aid technology. There was also no significant preference for either technology level.

Bandwidth can also differ between modern premium and entry-level hearing aids for two possible reasons. First, entry-level devices are more likely to use slimtube-style couplings to the ear which may provide less output in the higher frequencies. Second, the adjustability of premium hearing aids may offer greater fine tuning and improved fittings, with less acoustic feedback, allowing better matching to targets and more audibility in higher frequencies (Arbogast et al., 2019). In a recent a study comparing direct-to-consumer hearing devices and commercially available hearing aids, it was found that the hearing aids had a significantly lower root-mean-square-error (RMSE) from the prescribed targets than the direct-to-consumer devices, indicating a better goodness of fit in the more technologically complex hearing aids (Almufarrij et al., 2019). The perceptual effects of bandwidth have also been recently studied. Van Eeckhoutte et al. (2020) investigated the effect of bandwidth in current hearing aids on consonant recognition, loudness rating, and preference outcomes. Consonant recognition in noise was significantly improved in the extended bandwidth condition, while loudness perception did not differ significantly between the extended and restricted bandwidth conditions. Additionally, participants showed a small but significant overall preference for the extended bandwidth condition (Van Eeckhoutte et al., 2020).

However, the difference in the overall hearing aid experience between entry-level and premium hearing aids is not limited solely to signal processing features and outcomes related directly to sound audibility and clarity via signal processing. Modern hearing aids also include non-signal processing features which can also differ between entry-level and premium commercially available hearing aids. These include device style, Bluetooth connectivity, binaural data streaming, rechargeability (Johnson, 2017), and smartphone/tablet compatibility (Maidment & Ferguson, 2018), and compatibility with various accessories. However, recent studies investigating premium and entry-level technology which controlled for non-signal processing factors in their experimental design were more focused on the effect of signal processing features on user preference and satisfaction. However, according to recent MarkeTrak data (Picou, 2020) these non-signal processing factors have a beneficial effect on hearing aid users' self-reported satisfaction with their devices, and can therefore affect impact user preference. This is also supported by other recent literature (Zhu et al., 2020) which reports that non-signal processing factors, such as battery life and water resistance, significantly affected hearing aid choice.

The purpose of this study was to investigate the impact of premium versus entry-level technology on hearing aid outcomes and preference. We aimed to do this using product profiles that included signal processing features, but also others outside the scope of signal processing that contribute to technology-level variations in the overall hearing aid package. The rationale for this design is that non-signal processing features may impact user preference, possibly in combination with signal processing sophistication (Meister et al., 2001; Picou, 2020; Zhu et al., 2020). In this study, an effort was made to ensure that the hearing aids chosen gave a realistic and generalizable comparison for the different ends of the feature spectrum in one specific line of modern hearing aids. According to the hearing aid comparison framework developed by Lansbergen and Dreschler (2020), these premium and entry-level hearing aids correspond to the upper and lower levels of hearing aid feature domains. As such, non-signal processing features included form factor, linked smartphone applications, Bluetooth connectivity and data-streaming, and available accessories.

2.2 Methods

2.2.1 Study approval and ethics

The study was approved by the Western University's Research Ethics Board. All participants provided written informed consent and were financially compensated for their time. Participants were referred to local clinics for follow-up care upon request.

2.2.2 Set-up and calibration

All testing was conducted at the Hearing Aid Technologies and Outcomes for Adults lab of the National Centre for Audiology at Western University in London, Canada. All testing was completed in a double-walled sound treated booth which contained an adjustable chair. Anthony Gallo Acoustics A'Diva Ti speakers were used, with eight speakers placed every 45º, encircling the listener at a radius of 1.1 m from the central calibration point. A ninth speaker was used to present stimuli from 0º, located just above and behind the noisepresenting speaker at 0º, at 1.2m from the central calibration point. A Larson Davis 824 Type 1 sound level meter coupled to a PCB Piezotronics ½" random incidence microphone was used to calibrate the stimulus and background noise in preparation for the study. Daily calibration checks were completed using the MTP ST-805 type 2 sound level meter.

2.2.3 Study design, materials, and equipment

The two models of hearing aids used in this study were acquired from the same manufacturer and were chosen to represent the opposite ends of the brand's technology levels: premium and entry-level. The premium hearing aid was a receiver-in-canal (RIC) style of hearing aid. It provided rechargeability, binaural connectivity, and was compatible with wireless TV and remote microphone accessories as well as smartphone/tablet connectivity via Bluetooth using a proprietary application. This application allows the participant to change HA programs, choose among directional microphone modes, and contact the hearing aid professional for access to remote fitting sessions. The directional mode feature allowed the user to force the hearing aid's directional polar plot into different azimuths including back, left, right and forward, with additional choice between the standard fixed directionality and the more focused bilateral beamforming. This hearing aid had twenty compression channels.

The entry-level hearing aid was a behind-the-ear (BTE) style of hearing aid that could be coupled to the ear using a standard ear-hook with earmold or slim tube and cone based on participant preference. It used disposable batteries (no recharging feature) and offered no binaural connectivity. In terms of accessories, the entry-level hearing aids were compatible with a proprietary remote control (to switch between programs) and did not support

Bluetooth smartphone or tablet application connectivity. This hearing aid had six compression channels.

The study followed a single-blinded crossover trial design in which the participants were not informed of the differences between the hearing aid models which were referred to as hearing aids X and Y. The hearing aids were described only as "different technology packages or flavors", and the participants were told that the focus of the study was their opinion of the different aspects of each "technology flavor". Allocation of entry-level or premium hearing aids for the first arm of the trial was randomized and counterbalanced, using procedures described below. Outcome measures including laboratory evaluation of speech intelligibility in noise, loudness, sound quality, and preference. The hearing aids were re-programmed to only have programs needed for outcome measures (Table 1). The entry-level hearing aid had an omnidirectional program, an automatic switching adaptive program, and a fixed forward directionality program. The premium hearing aids had an omnidirectional program, an automatic switching adaptive program, a proprietary pinna-effect omnidirectional program, and two forward-facing directional programs – fixed forward and narrow beamforming - which were accessible through the proprietary smartphone application. Digital noise reduction was switched off in all test conditions except the automatic switching adaptive program in both hearing aids.

Table 2-1 Feature profiles of the hearing aid programs used when testing laboratory outcome measures in two different hearing aids.

Premium HA programs	Entry-level HA programs	Digital Noise Reduction

Automatic switching adaptive	Automatic switching adaptive	On
Fixed forward directional	Fixed forward directional	Off
Omnidirectional	Omnidirectional	Off
Narrow beamforming		Off
Pinna-effect omnidirectional		Off

2.2.4 Test procedures

For all tests, an unscored practice run was administered prior to scored testing as needed to familiarize participants with the tasks. The order of the outcome measures and the programs used (when changing within an outcome measure) were randomly assigned prior to each appointment. For all behavioral outcome measures, the average of two trials was taken.

2.2.4.1 Sentence recognition in noise

The US English version of the Matrix test (Kollmeier et al., 2015), hereby referred to as the US Matrix test, was used to assess recognition of sentences in noise. The test consists of 36 lists each containing 20 sentences. Each sentence has five randomly generated keywords words that follows the form “name-verb-number-adjective-noun”. The sentences are grammatically correct but are semantically unpredictable. Scoring consists of marking the correctly repeated keywords using the Oldenburg Measurement Applications, a graphical user interface (GUI) created and distributed by the HörTech gGmbH organization affiliated with the University of Oldenburg. The sentences were presented from 0º through the GUI and the speech-shaped US Matrix noise was presented from seven speakers from 45º to 315º through a separate playback program. The stimuli and noise were both presented at 65 dB SPL (0 dB SNR) for the first sentence, and the stimulus level was adaptively adjusted via the GUI in order to bracket the reception threshold for sentences (Kollmeier et al., 2015; M. Nilsson et al., 1994), at the 50% correct level.

2.2.4.2 Sound quality

Sound quality across the two hearing aids was assessed using participant ratings on the "total impression" and "clarity" Gabrielsson scales (Gabrielsson et al., 1988; Gabrielsson & Sjögren, 1979). The "Dove" passage from the Connected Speech Test, re-recorded in an accent appropriate for our sample of listeners (Cox et al., 1987; Saleh et al., 2020), was used as the stimulus and presented at 60 dB SPL from the speaker at a 0º azimuth. Ratings were completed in both quiet (Dove passage only) and in noise (Dove passage plus babble). When required, multi-talker babble was presented from the seven surround speakers from 45º to 315º at 55 dB SPL (+5 dB SNR). Babble was presented ten seconds prior to stimulus presentation. Participants listened to the passage in each hearing aid setting available within the hearing aid under test, and the hearing aid settings were randomized. Participants were asked to rate both total impression and clarity on a scale from 0-10 with 0 indicating a very poor score and 10 indicating the maximum score. All the hearing aid programs in the participants' most recently trialed hearing aid were tested.

2.2.4.3 Consonant identification

Aided consonant identification in noise was measured with the University of Western Ontario Distinctive Features Difference test (DFD; Cheesman & Jamieson, 1996). It consists of a closed set of 21 phonemes located between /a/ and /il/ to create a nonsense 3-phoneme word. This test has been used to assess aided speech benefit and speech recognition in quiet (Easwar et al., 2015; Jenstad et al., 2007; Wolfe et al., 2015) and in noise (Van Eeckhoutte et al., 2020) in previous studies assessing hearing aid outcomes. The 21 consonants are spoken by two male and two female talkers equalling a total of 84 consonants per trial. Background speech-shaped noise was presented from 0º at 54 dB SPL (+6 dB SNR) followed by the stimuli which was presented from 0º at 60 dB SPL. Participants identified the medially located phoneme in each presentation by clicking on the orthographic representation of it from a 21-choice display on a computer monitor. Both hearing aids were set to their program for speech in quiet during this test (omnidirectional microphone setting). Two trials were conducted for each session, and the average score of the two trials was calculated.

2.2.4.4 Aided loudness growth

The aided loudness growth testing for the sound field followed the procedures similar to that used by Van Eeckhoutte, Wouters, & Francart (2016) and Van Eeckhoutte, Scollie, O'Hagan & Glista (2020), implemented on custom software. A portion of the "Wolf" passage from the Connected Speech Test was used as the presented stimulus (Cox et al., 1987; Saleh et al., 2020) was presented on each trial at levels ranging from 52-80 dB SPL in 2dB steps. At each presentation, the participant had to indicate the loudness of the stimulus by choosing a position on a Graphic Rating Scale on a computer monitor using a mouse. The software coded this position as a number between 0 and 1. The participant could choose any position on the scale, with category names indicated next to the scale ("Did not hear", "Too soft", "A bit soft", "Just right", "A bit loud", "Too loud", "Much too loud”). Graphical illustrations of facial expressions representing moods were visible next to the Graphic Rating Scale, serving as guidelines. The stimulus level was first presented at 64 dB SPL, and this served as a practice trial. Next, trials were presented in pseudo-random order in order to avoid context effects (Brand & Hohmann, 2002). The pseudo-randomization was implemented such that the level of two consecutive stimuli was never more than 12 dB apart. Each level was presented twice, for a total of 30 tested loudness judgments for each hearing aid. Both entry-level and premium hearing aids were set to their program for speech in quiet during this test (omnidirectional microphone setting).

2.2.4.5 Appointment 1: Hearing test, participant inclusion, and first fitting

Case history and otoscopic examination were followed by audiological testing to determine hearing thresholds. This included standard air and bone conduction, followed by tympanometry. Participants who met the inclusion criteria were randomly assigned to either to the entry-level or premium hearing aid for the first arm of the study and were assessed for hearing aid fitting.

Participants who did not require an earmold were fitted with the premium receiver-in-canal hearing aid with an appropriate dome, or with the entry-level behind-the-ear hearing aid with a slim-tube open fit and an appropriate dome. Participants requiring an earmold had an earmold impression taken and were scheduled another appointment to be fitted with their hearing aid. The hearing instruments were fine-tuned to meet DSL v5-adult targets (Scollie et al., 2005) and verified with real ear measurements using calibrated speech passages at 55, 65- and 75-dB SPL. This fitting procedure complies with best practices protocols recommended by the American Academy of Audiology (Valente et al., 2006). Participants were given the choice to use any of the accessories compatible with their hearing aids. During the trial period, any needed hearing aid adjustments were made by the researcher team in person or, for participants trialing the premium hearing aids, using the remote tele-audiology system through the smartphone app.

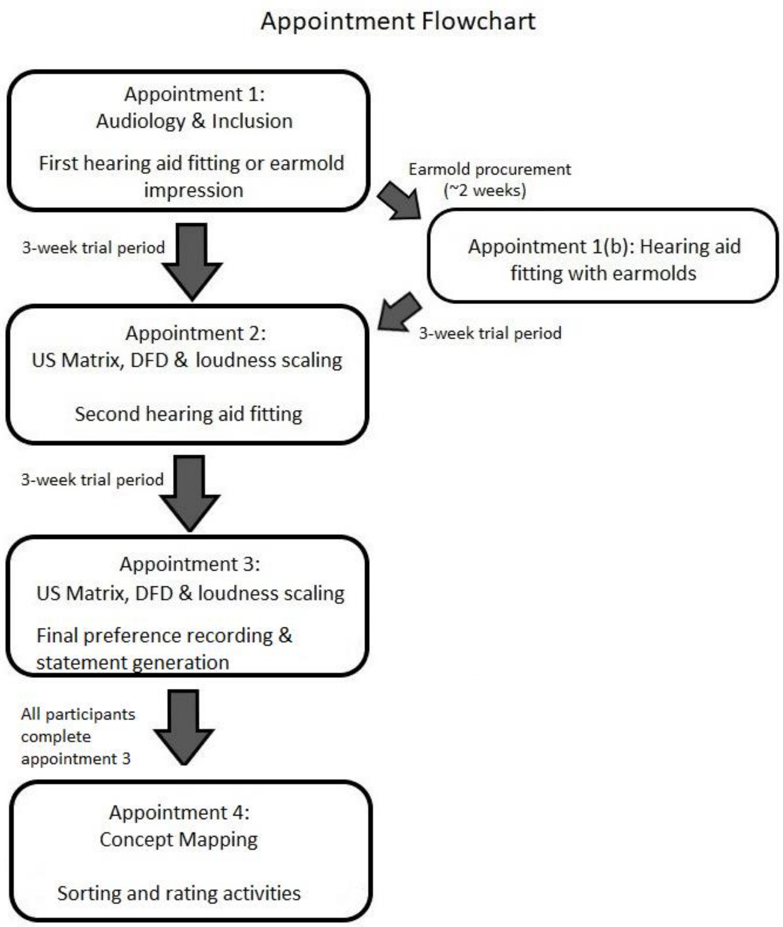

Figure 2-1 Study timeline and appointment flowchart.

2.2.4.6 Appointment 2: Behavioral measures and second fitting

Three weeks after the first fitting, participants returned for the second appointment. The participants were asked to remark on their experiences with the first pair of hearing aids. These remarks were audio recorded to allow participants to listen to them in future appointments to refresh their memory about the experience of both hearing aids before a final preference decision.

The hearing aids used for outcome measures in appointment 2 depended on which hearing aid the participant was randomly assigned in the previous appointment. After the completion of the appointment 2, participants were fitted with the second pair of hearing aids using the same fitting procedure as the previous appointment.

2.2.4.7 Appointment 3: Behavioral measures and final preferences

After trialing the second pair of hearing aids for 3 weeks, the participants returned for the final appointment.

The participants were asked to listen to their recorded remarks regarding the previously worn pair of hearing aids. They then discussed the current pair of hearing aids, once again being recorded. They were asked to rate their preference between the hearing aids on a 7-point Likert scale. This included “strongly preferred”, “moderately preferred”, and “slightly preferred” options towards one of the hearing aids, as well as a “no preference” option.

The hearing aids were then re-programmed to lab settings (see appointment 2) and the US Matrix, DFD, and loudness scaling tests were repeated with the second pair of hearing aids.

Appointment 4 (Figure 2-1) contained the concept mapping activities related to Chapter 3, and will be described in following chapter.

2.3 Data analysis

All data analyses were conducted using the R statistical software.

2.3.1 Sentence recognition in noise

To analyze the sentence recognition in noise results, a linear mixed-effects model was used, with participants as the random effect and hearing aid type and microphone condition set as the fixed effects. The significance of each effect was analyzed by log-likelihood analysis of variance (ANOVA) model comparisons. Paired t-tests were used to assess the significance of differences between the microphone conditions within each hearing aid, with the p-value adjusted using the False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995).

2.3.2 Consonant identification

Paired t-tests were used to analyze the significance of the consonant identification results.

2.3.3 Sound quality

To analyze the sound quality results, a linear mixed-effects model was conducted. For this model, participants were set as the random effect, while hearing aid type and microphone condition and sound setting (in noise or quiet) were set as the fixed effects. The significance of each effect was analyzed by log-likelihood analysis of variance (ANOVA) model comparisons

2.3.4 Loudness growth ratings

To assess the impact of hearing aid type and test level on loudness growth ratings, a linear mixed-effects model was used. For this model, participant was set as the random effect, while level and hearing aid type were set as fixed effects. The significance of each effect was analyzed by log-likelihood analysis of variance (ANOVA) model comparisons

2.3.5 Preference ratings

A one-sample Kolmogorov-Smirnov test was conducted to determine the significance of the preference rating results.

2.4 Results

2.4.1 Participants

Participants included current hearing aid users (with at least one month of experience) with a bilateral mild to moderately severe sensorineural hearing loss, to own a smartphone and/or tablet, and to be fluent in English. Twenty-three participants (mean of 62.4 years; range: 24-78 y; 15 males, 8 females) were recruited via email.

2.4.2 Audibility

The ability for each hearing aid to match the prescriptive target, or the goodness of fit, was measured using the root-mean-square-error (RMSE) between the fitting and the DSL v5 targets at 500, 1000, 2000 and 4000 Hz. The RMSE of the premium hearing aid was 3.99 (SD = 2.01) and that of the entry-level hearing aid was 5.35 (SD = 2.90). A paired t-test showed that this difference is significant ($t(45) = 2.69$, $p = 0.001$).

The Maximum Audible Output Frequency (MAOF) was also measured, using the intersection between auditory thresholds and the peaks of speech. The mean MAOF for the ear with the better 4-frequency pure tone average was 6427 Hz for the premium hearing aids and 5931 Hz for the entry level hearing aids at 65 dB SPL. This difference was found to be significant ($t(21) = 2.12$, $p < 0.05$).

Due to technical issues, data from one participant's fitting sessions was lost. Therefore, the participant was excluded from the audibility measurements (MAOF and RMSE) to ensure a balanced comparison between the two hearing aids.

2.4.3 Sentence recognition in noise

Mean reception thresholds for sentences ranged from -9.43 (omnidirectional entry-level) to -13.8 dB SNR (fixed directional, premium) across settings. Microphone condition was found to have a significant effect on score in the model, χ^2 (3) = 13.27, p < 0.01, with a large partial eta-squared (η_p^2) effect size of 0.38. Effect size interpretations Hearing aid type (premium or entry-level) did not significantly improve the model, χ^2 (1) = 3.17, p = 0.07 and hearing aid type had a small effect size of η_p^2 = 0.04. The interaction between hearing aid and condition also did not have a significant effect on the model, χ^2 (3) = 7.74, p = 0.051 and had a small effect size of η_p^2 = 0.06. Effect size interpretations are based on suggestions by Cohen (1988) that partial eta-squared values of 0.01, 0.06, and 0.14 corresponding to small, medium, and large effects, respectively.

Within the premium hearing aid, significant differences were found between the omnidirectional and adaptive directional microphone settings (t (22) = 3.53, p < 0.01) with a Cohen's d of 1.10 (large effect size), the omnidirectional and fixed forward microphone settings (t (22) = 2.94, p =0.02) with a Cohen's d of 0.69 (moderate effect size), the omnidirectional and narrow beamforming microphone settings (t (22) = 2.69, p =0.03) with a Cohen's d of 0.55 (moderate effect size), and the omnidirectional and pinna-effect omnidirectional settings - labelled in Figure 2-2 as "Premium (Advanced)" - (t (22) = 2.29, p =0.03) with a Cohen's d of 0.48 (small effect size). No other combinations of microphone settings were found to differ significantly. Effect size interpretations are based on suggestions by Cohen (1988) that a Cohen's d value 0.2, 0.5, and 0.8 correspond to small, medium, and large effects, respectively.

Within the entry-level hearing aid scores, three conditions were tested. The omnidirectional microphone setting differed significantly in score from both the fixed forward microphone setting, (t (22) = 4.44, p <0.001) with a Cohen's d of 1.67 (large effect size), and adaptive microphone setting (t (22) = 4.78, p <0.001) with a Cohen's d of 1.80 (large effect size).

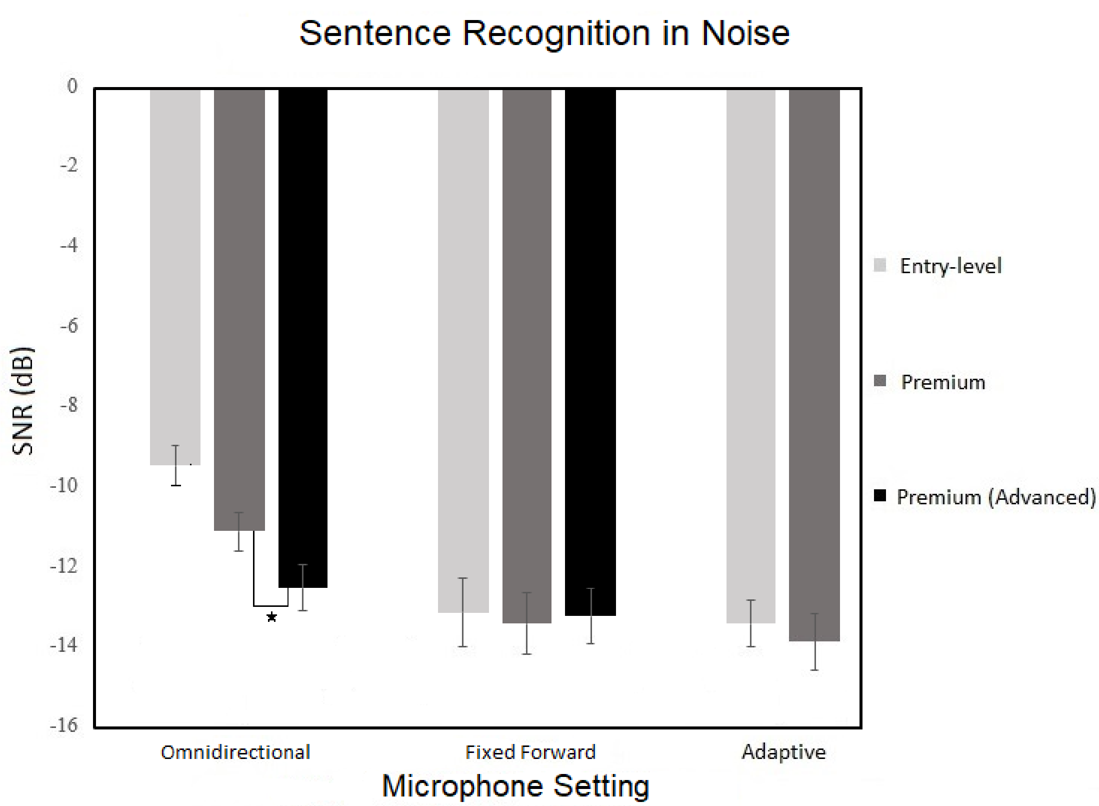

Figure 2-2 US Matrix series test results for the directionality settings of the premium and entry-level hearing aids for 23 participants. The Y-axis represents the SNR at which a 50% correct score on the test was achieved. Premium-only settings (black) are the pinna-matched omnidirectional (left) and te narrow beamforming (middle) microphone settings. Significant differences between premium and premium-only settings are indicated by an asterisk (significant differences between different microphone settings not denoted). Error bars represent 1 standard deviation from the mean.

2.4.4 Consonant identification

The mean entry-level and premium hearing aid DFD scores were 75.5 and 76.11, respectively. When converted to rationalized arcsine units (Rau) (Studebaker, 1985) these correspond to 74.55 and 75.20. These results indicated no significant difference between the premium and entry-level conditions; t (22) = 0.73, p =0.47, with a small effect size of Cohen's d = 0.06.

2.4.5 Sound quality

Mean total impression ratings exceeded 7 out of 10 on average across all conditions, corresponding to "rather clear" in noise and between "rather clear" and "very clear" in quiet, on average. The only significant effect on the model was the sound setting (noisy or quiet), χ^2 (1) = 124.79, p <0.001 (effect size η_p^2 = 0.30. Microphone condition, χ^2 (4) = 1.96, p = 0.75 (effect size $\eta_p^2 < 0.01$), hearing aid type, χ^2 (1) = 0.93, p = 0.33 (effect size $\eta_p^2 < 0.01$), interaction between hearing aid and sound setting (noisy or quiet) χ^2 (1) = 2.83, p = 0.09 (effect size $\eta_p^2 < 0.01$), and the interaction between hearing aid and condition, χ^2 (7) = 3.22, p = 0.86 (effect size $\eta_p^2 < 0.01$), did not significantly improve the model.

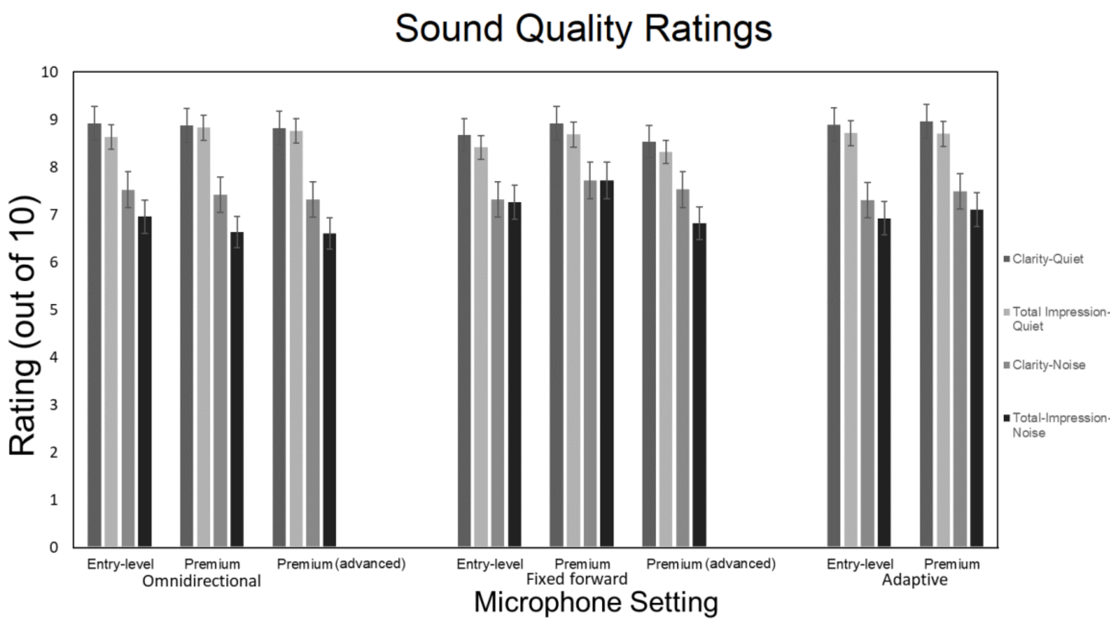

Figure 2-3 Total impression and clarity Gabriellson ratings for the directionality settings of the premium and entry-level hearing aids for 23 participants in noise and quiet. The Y-axis represents the subjective rating out of 10. Premium-only settings (black) are the pinna-matched omnidirectional (left) and the narrow beamforming (middle) microphone settings. Error bars represent 1 standard deviation from the mean.

Mean sound clarity ratings also exceeded 7 out of 10 across all conditions. The results of the linear mixed-effects model analysis mirrored those of the total impression ratings. The only effect found to have a significant effect on the model was the sound setting (noisy or quiet), χ^2 (1) = 113.86, p <0.001 (effect size η_p^2 = 0.28). Microphone condition, χ^2 (4) = 0.61 p = 0.96 (effect size η_p^2 < 0.01), hearing aid type, χ^2 (1) = 0.14, p = 0.71 (effect size η_p^2 < 0.01), the interaction between hearing aid and sound setting (noisy or quiet), χ^2 (1) = 0.24, p = 0.62 (effect size η_p^2 < 0.01), and the interaction between hearing aid and condition χ^2 (7) = 2.23, p = 0.95 (effect size η_p^2 < 0.01) were not significant.

2.4.6 Aided loudness growth

The loudness category “Just right” corresponded to an input level of 62.5 dB for the entry-level devices and 61.8 dB for the premium devices, indicating that conversation-levels of speech were presented at mid-range loudness for both devices.

Data points exceeding ±2 SD from the mean loudness growth rating results were considered unreliable responses and were removed from the data as outliers, as described in Van Eeckhoutte et al. (2020). This resulted in the removal of 64 out of 1380 data points. The loudness responses of the first and second trial repetitions were then averaged and the data was modelled with sigmoidal fits for each hearing aid type. Results indicated a significant effect of level, χ^2 (610) = 54.94, $p < 0.001$ (effect size of $\eta_p^2 = 0.37$) but the effect of hearing aid type was not significant χ^2 (22) = 0.02, $p = 0.99$ (effect size $\eta_p^2 = 0.04$), nor was the interaction between level and hearing aid type χ^2 (610) = 0.40, $p = 0.69$ (effect size $\eta_p^2 = 0.02$).

2.4.7 Preference

Out of the 23 participants, nineteen preferred the premium hearing aids and four preferred the entry-level hearing aids (Figure 4). The magnitude of preference ranged from mild to strong preference. There were no participants who indicated “no preference”. Analysis indicated a significant overall preference for the premium hearing aids (p < 0.001).

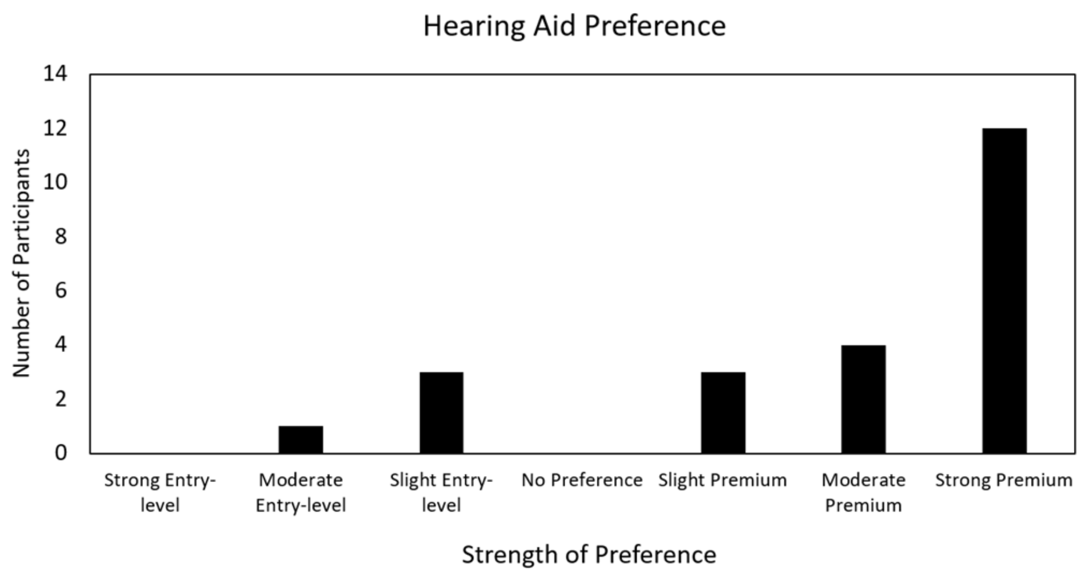

Figure 2-4 Overall hearing aid preference ratings for the 23 participants ranging from a strong preference to the entry-level to strong preference for the premium hearing aids.

2.5 Discussion

Previous comparisons of high versus low-level hearing aids, when both fitted to the same prescription, have reported limited perceptual differences. When comparing speech in noise outcomes between premium and entry-level hearing aids, Johnson et al. (2016) and Plyler et al (2021) found no significant difference while Wu et al. (2019) found that in most test conditions the premium hearing aids provided significant improvement. In our study, the difference in sentence recognition scores between the premium and entry-level hearing aids was not found to be significant in any hearing aid setting. However, the directional microphone settings in both hearing aids provided significant benefit compared to the omnidirectional settings. This is consistent with Johnson et al. (2016). The differences across studies could also be idiosyncratic to the specific devices and settings used in each study.

Consonant recognition results indicate that closely fitting both hearing aids to the DSL-prescribed target resulted in similar access to speech cues. Although the premium-level receiver-in-the-canal devices provided an upper bandwidth limit that was approximately 500 Hz higher than that of the entry-level earmold and slim-tube device, this difference did not significantly affect speech recognition scores on the tests used in this battery. This result may be viewed in context of recent results reported by Van Eeckhoutte et al. (2020) who reported significant improvement on the same test when a RIC device was fitted to full bandwidth versus restricted bandwidth. In that study, a larger bandwidth difference of 1500 Hz was observed and was clearly associated with improved recognition of high-frequency consonants, similar to other studies with large bandwidth differences (Alexander & Rallapalli, 2017). This indicates that the bandwidth difference between the hearing aids used in this study, although observable on verification, was not substantial enough to cause a change in consonant recognition scores.

Aided loudness results showed no significant difference between the premium and entry-level hearing aids. Once again, this result can be interpreted in context of previous literature on bandwidth effects on loudness. Van Eeckhoutte et al. (2020) found that an increase in bandwidth of 1500 Hz did not contribute to a significant increase in subjective loudness ratings. In our study, the hearing aids only differed in bandwidth by 500 Hz. This amount of bandwidth difference, while significant, was again not substantial enough to see a difference in loudness perception ratings, in line with previous literature. The importance of this non-significant loudness rating difference between the hearing aids is highlighted by previous literature in which comfort with loud sounds was reported to improve satisfaction (Hickson et al. 2010).

The sound quality results indicated that the sound quality was acceptable and similar for both hearing aids. Perceived sound quality was lower for noisy speech than for quiet speech, as expected. These results are mostly consistent with previous literature by Wu et al. (2019) where sound quality ratings were found to be similar between premium and entry-level hearing aids in most, but not all, conditions tested. The few inconsistencies between some of our results and those of Wu et al. (2019) may be attributable to the laboratory conditions tested. The present study used a sound-field with an unchanging signal location (0º azimuth), consistent with Cox et al. (2016), whereas the methods used by Wu et al. (2019) consisted of a dynamic sound-field with different signal azimuths. Specifically, the condition in which Wu et al. found a significant improvement in sound quality presented the signal at 0º and babble noise at 180º, a condition not specifically tested in the present study.

Preference

Despite the similar electroacoustic and laboratory outcomes reported above, the participants of this study reported a preference for the premium hearing aids following real-world use of both devices. This finding differs from that of Cox et al. (2016) and Plyler et al. (2021) who did not report a significant difference in participant preference between two hearing aid technology levels, as well as from that of Wu et al. (2018) who found no difference in preference between the different technology levels of directionality and noise reduction. Several factors may relate to this difference in outcome. First, the hearing aids used were different across these studies. Although the brands used by the researchers were not reported, they were released in 2011 (Cox et al. 2016) and 2013 (Wu et al. 2018). The premium hearing aids used in the present study were released in 2019 and therefore may have offered updated features and had more differences between the premium and entry-level devices. Second, the premium hearing aids used in the present study offered smartphone and tablet compatibility and applications for microphone steering, music streaming, and remote care, features not differentiating the technology levels in the hearing aids used by Cox et al. (2016), Plyler et al. (2021), or Wu et al. (2018). Third, the hearing aids used in the mentioned studies controlled for form factor. In the present study, we allowed form factor to be dictated by the actual product variation available across price points, to facilitate a generalizable measurement of preference between high and low technology levels present in modern hearing aids. It is possible that form factor or device appearance could have influenced user preference, as has been reported previously (Meister, 2001). Furthermore, while lab outcomes were measured to compare aided benefit between hearing aids, this was done in a controlled laboratory setting which may not have represented hearing aid outcomes in real world environments and may not have fully captured the difference in performance between the hearing aids.

2.6 Limitations

This study had several limitations. First, the hearing aids used differed in form factor and accessories/apps between the two technology levels. While this provided a realistic representation of the actual product variation in commercial devices, it can also present as a confound as participants may have inferred cost ranges, may have experienced different fitting durations (due to phone and device pairing and orientation), or may otherwise have been biased by the non-signal processing aspects of the devices, similar to the digital labelling effect that has been reported previously (Bentler et al., 2003; Dawes et al., 2013). This potential for bias due to perceived superiority of the premium device could have influenced preference results. Second, lab-based benefit measures were collected using nonsense syllables (for sensitivity to bandwidth) and sentences in noise bracketed to measure the 50% correct point (to avoid ceiling and floor effects). Although these measurement types are commonly used in hearing aid research, neither reflects real-world speech communication (see Naylor (2016) for discussion of this issue) and did not appear to predict real-world preferences in this study.

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Chapter 3

3 Using concept mapping to find the drivers of hearing aid preference[2]

3.1 Background

3.1.1 Differences in hearing aid technology levels

Hearing aids are complex devices with the main purpose of providing people experiencing hearing loss with access to sound and speech. Previous literature has reported the importance of hearing aid performance in different acoustic environments for continued user satisfaction (Kochkin, 2007). This has led to the development of digital signal processing (DSP) features aimed at improving speech audibility and clarity, such as digital noise reduction, directional microphones, and wide dynamic range compression (Lansbergen & Dreschler, 2020; Picou, 2020). These features, while typically present in most commercially available modern devices, can also differ in complexity between different levels of hearing aid technology. Premium hearing aids typically have more sophisticated versions of these features and provide access to more options and programming flexibility than entry-level hearing aids. For example, directional

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microphone (DMs) technology can range from basic algorithms aimed at improving signal-to-noise ratio to an automatic system which can adapt to the current acoustic environment and the location of speech (Wu et al., 2019). Digital noise reduction (NR) technologies also range in technology level, with more advanced versions having more channels and the ability to process more types of sounds (Wu et al., 2019). The wide dynamic range compression in upper levels of technology also has a higher number of compression channels than basic versions (Cox et al., 2016).

Aided benefit in noise is important in ensuring successful hearing aid uptake and improving compliance among hearing aid owners (Kochkin, 2000; Lupsakko et al., 2005). However, modern commercially available hearing aids also include advanced features and technologies with a non-audiological focus. These can also differ in complexity between entry-level and premium devices but in some cases may only be available in premium devices (Cox et al., 2016). These include physical features such as device style as well as connectivity and convenience factors such as Bluetooth connectivity, binaural data streaming, rechargeability, smartphone/tablet compatibility and external accessory compatibility (Cox et al., 2016; Maidment et al., 2019).

3.1.2 The effect of technology on preference

As previously mentioned, preference is a multidimensional, complex interaction of many patient and treatment-centered aspects of healthcare. The implementation of patient preference into healthcare decisions has been shown to improve successful hearing aid outcomes (Poost-Foroosh et al., 2011).

Multiple studies have investigated hearing aid user preference for hearing aid features. For hearing aid microphone directionality, many report preference for access to this feature (Amlani et al., 2006; Surr et al., 2002; Walden et al., 2005; Wu & Bentler, 2010b). The effects of directional microphones (DM) on user preference have been investigated, including preference for types of directional microphone technologies, preference for directional microphone bandwidths (Goyette et al., 2018), and preference for microphone settings based on acoustic environment or audiovisual cues (Walden et al., 2005; Wu & Bentler, 2010a). Digital noise reduction (NR) technologies have also been preferred versus hearing aid without noise reduction (Neher, 2014; Ricketts & Hornsby, 2005). Similarly, preference for specific aspects of noise reduction have been investigated. This includes onset time (Bentler et al., 2008), strength (Neher & Wagener, 2016), and different noise reduction algorithms (Brons et al., 2014). Furthermore, studies have also investigated preference between different hearing aid bandwidths (Van Eeckhoutte et al., 2020) and hearing aid initial gain settings (Boymans & Dreschler, 2012; Valente et al., 2018). While these studies have provided insight into the preferences for different versions of each of these features, further work is required to address how DSP and non-DSP features of hearing aid technology, across varying levels, can influence user preference.

Recently, studies have investigated outcomes between different hearing aid technology levels, rather than individual feature differences. Studies by Cox et al. (2014, 2016) and Johnson et al. (2016) investigated laboratory outcomes, subjective preference and user outcome differences between hearing aids containing features at the premium and entry-level ends of hearing aid technology complexity. Their differences included types of directionality and noise reduction, number of compression channels, and binaural streaming capability. They found no significant differences between technology levels in most laboratory measures of speech understanding and listening effort, nor in user preference or subjective outcomes. Wu et al. (2018) assessed the difference between premium and entry-level directional microphone and noise reduction settings on laboratory aided benefit outcomes, and on user satisfaction. While aided benefit was significantly improved by premium settings over basic settings, there was no significant difference in user satisfaction between technology levels. Plyler et al. (2021) also investigated behavioral and subjective outcomes and preference differences between different hearing aid technology levels. They found that most outcomes, as well as preference, did not differ significantly between premium and basic technology levels.

As such, experimental research on preference between different hearing aids has largely only included differences in certain DSP features, controlling for other DSP and all non-signal processing features (Cox et al., 2016; Wu et al., 2019). This warrants a study of preference between different overall hearing aid product profiles which include varying levels of non-signal processing features, and an investigation of how this wide array of features can driver hearing aid user preference.

3.1.3 Concept mapping as a method for studying stakeholder perspectives

Concept mapping is an umbrella term for methodologies which follow a participant-inclusive process to allow investigation of complex and intangible concepts and visual representation of these concepts in a clear and interpretable manner (Kane & Trochim, 2007, Rosas & Ridings, 2017). The process is stakeholder inclusive and allows the investigation of intangible opinions The map is generated from similarity and importance weightings of statements, which are rated and sorted using a structured process, by multiple participants. Statement rating and sorting data are then located on the map via multidimensional scaling and hierarchical cluster analysis. This produces an interpretable visualization of people’s ideas and how these ideas relate to each other (Trochim, 1989). This process can be divided into six stages: Preparation of the study and the goals of the process, generation of the statements through brainstorming, structuring the data through sorting and rating as well as collecting descriptive data, representation of the data visually on a map, interpreting the resulting map, and using the map in future planning and development. This method is described in more depth by Trochim & McLinden (2017) and Kane & Trochim (2007).

Group concept mapping has been used for a wide variety of topics ranging from medical outcomes (Nilsson et al., 2012) to psychobehavioral studies (Donohoe et al., 2020) and implementation strategies (Green & Aarons, 2011; Joukes et al., 2016; Waltz et al., 2015). In each of these studies, the process was used to successfully integrate ideas from the group of interest onto an interpretable map. Group concept mapping has also been used in the hearing science field to study factors affecting clinical uptake of remote hearing aid support by pediatric and adult-focused clinicians (Glista et al., 2020), and for understanding factors in hearing aid uptake (Poost-Foroosh et al., 2011) and management (Bennett, 2019; Bennett et al., 2018) from both client and clinician perspectives. Concept mapping was chosen in this study as a method for examining factors affecting preference for technology levels in hearing aids.

Concept mapping can also be used in scale development by providing a more detailed understanding of the constructs of focus, resulting in a conceptual framework prior to the development of the scale and, therefore, content validity (Rosas & Camphausen, 2007).

This can address the risk in scale development of including items and concepts which lack evidence-based validity, due to a lack of knowledge of the underlying theoretical framework and the relationships within (DeVellis & Thorpe, 1991).

3.2 Methods and materials

3.2.1 Participants

This study included the same participants as reported in the previous chapter assessing outcome measures and preference differences. Participants were adult, English-speaking hearing aid users. Twenty-three participants (mean of 62.4 y; range: 24-78 y; 15 males, 8 females) with a mild to moderately severe sensorineural hearing loss and at least one month of hearing aid experience were recruited. The study was approved by the Western University Research Ethics Board. All participants provided written informed consent and were financially compensated for their time. All outcome testing was completed in individual sessions by each participant, and all participants completed the full concept mapping procedure.

3.2.2 Statement generation

Participants were asked to provide reasons for their preferences for one type of hearing aid over the other in individual brainstorming sessions at the end of the second hearing aid trial. The participant was given the focus prompt "One thing that influenced my preference for one model of hearing aid was…" and asked to respond with as many statements as they could provide. Once brainstorming was completed, participants were told that they could also reach the researchers via e-mail or telephone with more statements if they wished to do so. Approximately 10 to 15 statements were elicited per participant. The statements were collated across the entire group, and duplicate statements were removed. The resulting list of unique statements were edited for grammatical and syntactical equivalence and coherence while ensuring that the underlying meaning of the statements were not changed.

3.2.3 Sorting

A follow-up session was conducted once all participants had completed brainstorming. Participants sorted the collated, edited statements that were generated. Sorting was done individually on a provided touchscreen monitor using Groupwisdom™ software (Concept Systems, 2019). The participants were oriented to the drag-and-drop interface, and asked to sort the statements into categories, or "clusters" based on common ideas or themes, but not on perceived importance. Participants were also asked to create a name for each category using the underlying theme of the statements within. A training example related to features in high- versus low-featured commercially available cars was provided verbally to clarify the tasks. The researchers were available throughout this session to clarify the meaning of any of the statements upon request, or to assist with the software interface.

3.2.4 Rating

Once the statements were sorted into categories, the participants were directed to the statement rating activity in the same software. Here, they were asked to rate each statement based on the prompt "How important is this factor when choosing a hearing aid?". Ratings were done on a 5-point Likert scale of importance with 1-5 corresponding to "not important", "slightly important", "moderately important", "very important", and "extremely important".

3.3 Data analysis & representation

Behavioral and subjective outcome statistical analyses were completed using the R statistical software. Linear mixed models were used for most outcome measures. Concept mapping data analysis and graphical representation were completed using the Groupwisdom™ software. The software first placed each statement in a two-dimensional space using multidimensional scaling, based on the sorting results (how closely statements were sorted together). Then, multiple cluster solutions were generated to group the statements using hierarchical cluster analysis. Two audiologists not involved in the outcome measurement portion of this study were invited to help determine the appropriate cluster solution (further details below).

3.4 Results

A total of 83 unique statements were generated during the brainstorming stage, and these statements were sorted based on common meaning and then rated in importance by all participants in the sorting and rating stages.

3.4.1 Cluster analysis

The creation of the cluster map followed published methods (Kane & Trochim, 2007). A similarity matrix was created from the sorting data which represents the number of times each statement was sorted with all other statements. Non-metric multidimensional scaling was used to create a two-dimensional point map with the distances between the statements based on the similarity matrix (i.e., how many times they were sorted together). Although similarity cut-offs can be used to exclude random sorting, no similarity cut-off was used, so the point map presented represents all statement sorting combinations. The stress value is a diagnostic statistic measuring how well the distances between the points on the map represent the original input matrix taken from the sorting data. A large stress value indicates a large discrepancy between the input data and the resulting map, and that the map is not a suitable representation of the sorting data (Kane & Trochim, 2007; Kruskal & Wish, 1978). For our map, the stress value calculated was 0.219, which is within the normally accepted range (0.205 to 0.365) (Kane & Trochim, 2007) indicating that the point map is a suitable representation of the data (Trochim, 1993). The split-half reliability of the sorts in this study was found to be 0.80. This is slightly below the average reported split-half reliability of 0.86 found across 69 studies in a meta-analysis by Rosas and Kane (2012), but well above the lowest reported split-half reliability of 0.65. Cronbach's alpha was also calculated to determine the internal reliability of the rating data by comparing the average correlation of the rating items. The resulting Cronbach's alpha score of 0.93 suggests high internal consistency (Rosas & Kane, 2012).

Following multidimensional scaling, a hierarchical cluster analysis was conducted, based on the sum of the squares of the distances between the points on the point map (Kane & Trochim, 2007). This leads to the creation of groups (clusters) of points that reflect the number of times that statements were sorted together, which originally determined their position on the point map. The process requires careful selection of an appropriate cluster solutions because multiple solutions are generated. For this study, solutions ranging between 6 and 9 clusters were reviewed. Members of the combined researcher and external audiologist team were given access to the final list of generated statements along with plots of the possible cluster solutions for review and met as a group after interpreting the sensibility of the different cluster solutions based on the process outlined by Kane &

Trochim (2007). The researcher group chose the 9-cluster solution (Figure 3-1a) and came to a unanimous consensus on the name of each cluster based on the contents and an analysis of the names given to the clusters by the participants during the sorting stage. The cluster names, overall themes, and example statements from each cluster are presented in Table 1.

Table 3-1 List of the different cluster names, their overall themes, total number of statements, example statements, and average bridging values.

Cluster name	Overall theme	Number of statements	Example statement (s)	Average bridging value
Feedback	Issues related to acoustic feedback and how the hearing aid manages these	15	“Less feedback (whistling)”	0.46
Sound quality & intelligibility	Factors related to audibility sound/speech quality	11	“The audibility of high-pitched sounds”	0.17
Multi-environment functionality	The hearing aid features’ performance in different acoustic environments	7	“The directional microphones of the hearing aid worked well”	0.5

User-controlled DSP (app)	The ability to control the digital signal processing of the hearing aid through the smartphone application	9	"Having access to the phone app's directionality steering feature"	0.35
Streaming	Factors related to the music/call streaming feature of the hearing aid	14	"The ability to listen to music through the phone directly into my hearing aids"	0.38
Convenience & connectivity	Overall technological convenience (such as remote care) and accessory compatibility	7	"The ability to contact the hearing professional through the app" "Having remote control (fob) compatibility"	0.42

Ease of use	The general simplicity of the hearing aid use experience	7	“Ease of use; not too technically complex to use”	0.58
Comfort & appearance	Physical comfort of wearing the HA and how they look	9	“The ease of putting the hearing aids into the ears”	0.23
Complex factors	Factors which can be linked thematically to more than one cluster depending on experience	4	“The amount of frustration caused by the hearing aid” “Noticeable changes when switching programs”	0.81

Visual interpretation of the cluster map shows that certain areas of the map contain clusters with a related concept. For example, the right side of the map comprises clusters related to the hearing aid’s signal processing and higher technology features, such as “multi-environment functionality” and smartphone/tablet application-based “user-controlled DSP”. The top portion of the map contains clusters related to the sound of the hearing aid, such as “feedback” and “sound quality & intelligibility”. The bottom left of the map contains one cluster representing the physical “comfort & appearance” of the hearing aid. The “complex factors” cluster is centrally located due to its interrelatedness to different areas of the concept map (explained further below).

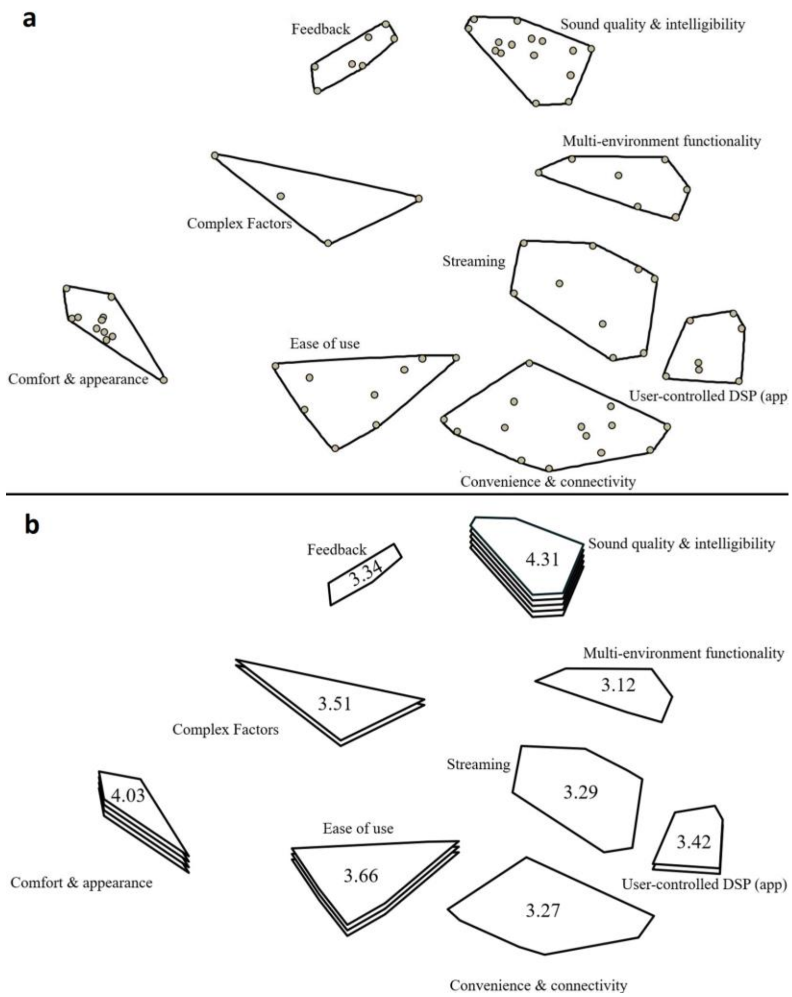

Figure 3-1 (a) **Nine-cluster solution of the 83 statements. Cluster names are representative of the overall theme of the cluster statements. Individual points each represent one statement.** (b) **Cluster rating map of the 83 statements. Cluster names are representative of the overall theme of the cluster statements. Each cluster's average statement rating from 1 (not important) to 5 (extremely important) is shown within the cluster. Clusters with more depth are of relatively higher average importance.**

To determine how interconnected the statements (and therefore, the clusters) in the map are, the bridging value is used. This is a value from 0 to 1 assigned to each statement which represents the likelihood of the statement to be sorted with other statements nearby in the multidimensional map (Kane & Trochim, 2007). A value closer to 1 indicates that statements in a cluster were regularly sorted with non-adjacent statements, thus bridging between different parts of the map. Conversely, a lower bridging value means that the statement was more likely to be placed with statements within its cluster during the sorting activity. The bridging values of the clusters in this study ranged from 0.17 to 0.81. The bridging value of each cluster is also reported in Table 1. A wide range of cluster bridging values, based on the conceptual complexity of each cluster, has been reported in different concept mapping studies (Donohoe et al., 2020; Sjödahl Hammarlund et al., 2012). This difference in conceptual complexity can explain the highest and lowest bridging clusters, “complex factors” and “sound quality & intelligibility”, respectively. The statements within the lowest bridging cluster, “sound quality & intelligibility”, are all conceptually related to one another and were regularly sorted together. The highest bridging cluster, “complex factors”, is comprised of statements which are conceptually linked by the fact that their sorting placement depends on each participant’s unique hearing aid experience. For example, the statement “the amount of frustration caused by the hearing aid” could be sorted into different clusters depending on a participant’s individual experience and perceived sources of frustration. Clusters containing highly bridging statements are typically placed in an central position by the concept mapping software (Kane & Trochim, 2007), as is seen with the “complex factors” cluster.

3.4.2 Importance ratings

All statements were rated by each participant on a 1-5 Likert scale in response to the prompt “How important is this factor when choosing a hearing aid?”. Using the average rating score for the statements in each cluster, the cluster map can be modified to represent each cluster's average importance for the overall participant group (Figure 5b).

The overall cluster rating map indicates that certain clusters were of higher average importance to the overall participant group, based on the results of the rating activity. Factors related to audibility (sound quality & intelligibility), the physical comfort and appearance, and the ease of use of the hearing aids were found to be, on average, of the highest importance to the overall participant group. This indicates that regardless of participants' technology level preferences, they prioritized the physical comfort and appearance of the hearing aid and the audibility it provides over other features.

3.4.3 Subgroup analysis

Recall that not all participants had the same overall preference (entry-level or premium). It was therefore of interest to determine whether entry-level and premium choosers had differences in their concept maps and relative cluster importance ratings. It is possible to assess this using a *pattern match* diagram. This is a ladder graph representation which allows the comparison between different participant groups' cluster importance ratings: clusters higher on the ladder have higher relative importance. A pattern match analysis was conducted between the study participants who preferred the premium (n = 19) and entry-level (n=4) hearing aids, displayed in Figure 6, with stars indicating clusters that differ significantly in average rating between the groups.

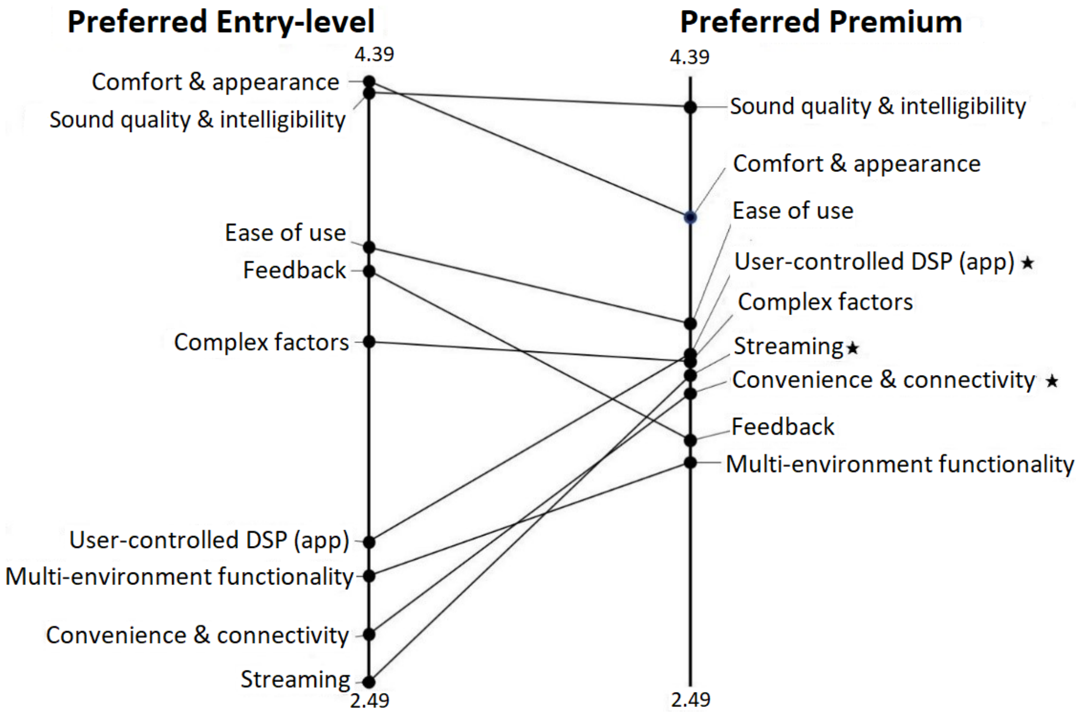

Figure 3-2 Pattern match diagram of the cluster importance ratings for ratings made by entry-level (left) and premium hearing aid choosers (right). Clusters displayed higher on the ladder have higher average ratings on the 5-point Likert rating scale. Maximum and minimum scores are displayed on the top and bottom of the ladders, respectively. Stars indicate clusters with significantly different ratings between the groups.

Overall, there was a moderate correlation between average cluster importance across the two participant groups ($r = 0.66$, $p < 0.05$). Paired t-tests showed that the clusters which were rated as significantly more important to the premium hearing aid choosers were: “User-controlled DSP (app)” ($t\,(12) = 4.19$, $p < 0.01$), “Streaming” ($t\,(16) = 3.10$, $p < 0.01$), and “Convenience & connectivity” ($t\,(26) = 3.37$, $p < 0.01$). This suggests that having access to these premium-level features was important to premium-preferring participants when considering a new hearing aid.

3.5 Discussion

This study aimed to identify the factors contributing to the significant preference for the premium hearing aids described in chapter 2. The concept mapping procedure resulted in 83 unique statements which were sorted into 9 distinct feature clusters by the study participants. These feature clusters were then rated based on importance.

3.5.1 Concept mapping

We used concept mapping (Trochim & Kane, 2007) to gain insight into the reasons underlying significant preferences for one aid over the other. The study resulted in a detailed concept map outlining the factors affecting these user preferences and the importance of each of these factors relative to one another. The map was found to be reliable with high internal reliability and consistency in the rating data.

The resulting map clustered the different 83 different ideas related to hearing aid preference into nine distinct themes. These related to audibility and signal processing such as sound quality, intelligibility, and feedback, and to non-audiological issues such as having access to a smartphone app and physical comfort and appearance. Because concept mapping is non-orthogonal, clusters could be correlated to one another (represented by the bridging values). The statements within the lowest bridging cluster, “sound quality & intelligibility”, are all conceptually related to one another and were regularly sorted together. The highest bridging cluster, “complex factors”, is comprised of statements which are conceptually linked by the fact that their sorting placement depends on each participant’s unique hearing aid experience. For example, the statement “the amount of frustration caused by the hearing aid” could be sorted into different clusters depending on a participant’s individual experience and perceived sources of frustration. This is consistent with the complexity of hearing aid use, which may be affected by many individual factors.

3.5.2 Feature importance

Across all age-groups, certain feature themes were rated more highly than all other features in terms of importance, regardless of preference between entry-level or premium hearing aids. These were physical comfort & appearance, sound quality & intelligibility, and ease of use, the top three highly rated clusters in importance for both groups. This is consistent with previous literature, as several similar observations have been made in large-scale studies of factors associated with positive hearing aid outcomes and user satisfaction (Baumfield & Dillon, 2001; Hickson et al., 2010; Humes, 2003; Humes et al., 2017; Kumar et al., 2000; Meister et al., 2001; Meyer, Hickson, Khan, et al., 2014; Picou, 2020), as well as investigations of issues experienced by hearing aid users (Solheim et al., 2018), and barriers to success for hearing aid users (Meyer, Hickson, & Fletcher, 2014). With only one of the highest rated clusters being strictly related to audibility, our findings are also consistent with recent findings by Zhu et al. (2020) who reported multiple non-signal processing factors that were significantly associated with hearing aid preference. The effect of non-signal processing features on preference highlights the importance of non-DSP as well as DSP features in the overall hearing aid experience.

In addition, our findings identified a difference in priorities between individuals who preferred the higher and lower ends of the hearing aid technology spectrum. The clusters which differed significantly in importance between the premium and entry-level choosers were: (1) user-controlled DSP through the smartphone application, (2) convenience & connectivity, and (3) streaming ability. This is noteworthy, as these feature clusters consist of features more commonly found in premium hearing aids. It is, however, important to also note that further technological advancement will likely see an increase in their accessibility in lower and mid-range technology levels. Within the context of our data, this suggests that the inclusion of these advanced connectivity non-DSP features significantly influenced the preference choice for the premium hearing aids. These findings can also help to explain the difference between our preference results and those of previous studies that controlled for both form factor and accessories (Cox et al., 2016; Johnson et al., 2016; Wu et al., 2019). In contrast, we implemented a study design which included using hearing aids at different technology levels for both audiological and non-audiological features, such form factor and smartphone application access, represented by the “comfort and appearance” and “user-controlled DSP (app)” clusters, respectively. The inclusion of these feature differences may therefore relate to the preference results, as some of these features (e.g. smartphone application access) were rated highly by participants who preferred the premium hearing aids. Interestingly, four participants who preferred the premium hearing aid preferred the physical form factor of the BTE. While anecdotal, this further indicates that, while comfort & appearance is one of the major drivers of preference, other factors also may contribute. This also supports the need for individualized fittings and consideration of preferences of all features in the decision-making process.

Furthermore, the findings of this study suggest that, for hearing aid users, certain features are more important than others. The participants assigned the highest importance weightings to the clusters related to the “basics”, such as good audibility and speech clarity by their hearing aids, having a comfortable physical fit, and not having a complicated device. This supports previous literature which reported that a lack of audibility benefit from the hearing aids or the device being too complicated reduces user satisfaction and leads to discontinuation of use (Kochkin, 2000; Lupsakko et al., 2005). Our preference results were gathered in a context in which these basic fitting needs were according to best practices with each device, yet users still recognized their importance when assigning importance weightings to these factors. This suggests that hearing aids at all technology levels continue to require basic audibility, physical fit, and ease of use as a priority over any advanced features.

Within this context, the majority of our participants also valued more technologically advanced features on their hearing aids, such as the ability to stream calls and music, the ability to contact the hearing aid professional and have remote fitting changes made, and access to a smartphone application allowing setting modification. In today's hearing aids, these are considered non-DSP examples of technology features, and contribute to the assignment of technology level (Cox et al., 2016). The concept maps in this study suggest that these features should therefore be given specific consideration when measuring hearing aid preference.

3.5.3 Implications for patient care

Consideration of patient desires and preferences in the decision-making process is an accepted part of person-centered care (Leplege et al., 2007). Person-centered care plays a role in mitigating post-treatment regret and improving satisfaction (Mulley et al., 2012), along with increasing patient compliance (Bratzke et al., 2015). Furthermore, a better understanding of preference can improve the efficacy and cost-effectiveness of treatment choices (Brennan & Strombom, 1998). Moreover, differences between patients can be more easily determined, improving the decision-making process in their treatment

(Marshall et al., 2017). Specifically, in a clinical hearing care setting, Poost-Foroosh et al. (2011) reported the influence of a patient-centered interaction, and the consideration of patient needs on hearing aid uptake. This is especially relevant with modern hearing devices, as consumers today are faced with a plethora of choices regarding hearing aid types and features.

This study resulted in a conceptual framework delineating the different aspects of hearing aid user preference and displaying how these factors influence preference between different technology levels. These include variations of both DSP and non-DSP features, both of which were shown in this study to influence hearing aid preference. Within a clinical context, the findings of the current study highlight the necessity for appropriate consideration and best-practice selection of these features. This may include obtaining patient input regarding available variations in feature technology including form factor, streaming, apps, remote connectivity, and accessories. This provides conceptual areas upon which user preference can be measured. Having the ability to assess hearing aid user preference and understanding the influence of different features may be relevant to the incorporation of patient preference in the hearing aid selection process, leading to a more individualized and person-centered fitting which can ultimately improve overall patient satisfaction and hearing aid success.

3.5.4 Limitations

This study had some limitations to be addressed. The concept map was created with mostly older adult participants who had similar hearing losses and the hearing aids represented only two hearing aids from one manufacturer. Therefore, the generalizability of this concept map to hearing aids from other manufacturers and across larger age groups and hearing loss types requires further investigation. This is also indicative of a larger limitation within concept mapping in which participant contribution is limited only to their specific perspective (in this case, hearing aid users) and will likely not be a comprehensive representation of the content related to the area of focus (Rosas & Ridings, 2017). This can be alleviated by supplementing the brainstorm results to expand the comprehensiveness of the concept map.

In addition, because this study did not investigate the preference between the hearing aids in a purchase context, the hearing aids cost was not included in our study design. Therefore, the results reflect preferences in the absence of user perception of cost and may not generalize to other contexts. The effect of hearing aid cost on user satisfaction is a contentious matter, with different reports of an cost negatively influencing satisfaction (Kochkin, 2005), higher cost correlating with higher satisfaction (Picou, 2020), and cost having no effect on satisfaction (Humes et al. 2017). The role of cost may therefore be important for future studies. Furthermore, while rating data suggested the importance of having access to smartphone related features when considering a new hearing aid, we did not log participant use of these features and thus do not know how often they were used.

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Chapter 4

4 Development and initial evaluation of the Hearing Aid Feature Importance Evaluation (HAFIE) questionnaire

4.1 Introduction

4.1.1 Hearing aid selection

Hearing aid development has led to the evolution of a hearing aid from a simple listening instrument to a complex device with many available features. Furthermore, features differ in complexity between hearing aids at the upper and lower levels of the technology spectrum (Lansbergen & Dreschler, 2020). Digital signal processing features can differ between basic and advanced hearing aids: advanced aids are more likely to offer more complex DM, NR, and compression technologies, with more accurate environmental adaptation and a higher number of channels (Cox et al., 2016; Lansbergen & Dreschler, 2020; Wu et al., 2019). Product variation is not solely limited to digital signal processing technology, but also includes non-signal processing features such as form factor and smartphone compatibility (Saleh et al., 2021). Non-signal processing factors have been shown to influence user preference, with previous literature showing that both DSP and non-DSP features may contribute to hearing aid user satisfaction (Meister et al., 2001; Picou, 2020; Zhu et al., 2020), but also to the cost of hearing aids.

This increase in hearing aid complexity may impact the hearing aid selection process. Hearing aid selection has been an area of clinical practice for much of the history of hearing aid development and use (Audiology Practice Standards Organization, 2021; Carhart, 1950; Valente et al., 2006). In today's hearing aids, the hearing aid selection process must consider the increased complexity of the hearing aid user experience and the multitude of features at different levels of the technology spectrum, including but not limited to the frequency response of the hearing aid (Keidser et al., 2011; Scollie et al., 2005). Although having access to different technology-level features has been shown to influence user preference for hearing aids technology level (Saleh et al., 2021), previous literature has found that hearing professionals may not base their technology level recommendations on benefit, but instead are most significantly influenced by their own perception of the patient's lifestyle and activity levels, among other factors (Gioia et al., 2015). For this reason, systematic approaches to hearing aid selection are recommended (Audiology Practice Standards Organization, 2021; Turton et al., 2020) but validated tools are lacking. One possible category of tool is subjective questionnaires, discussed further below.

4.1.2 Questionnaire use in assessment of hearing aid candidacy, preference, and outcome:

Questionnaires have been developed to assess a wide range of patient perspectives, such as expectations, subjective experiences, and opinions. Questionnaires can be used at different points of the hearing aid user experience (selection/candidacy, pre-fitting, or post-fitting). Many hearing aid questionnaires exist to measure hearing aid benefit, performance, and satisfaction. These include the Glasgow Hearing Aid Benefit Profile (GHABP, Gatehouse 1999), the Satisfaction with Amplification in Daily Life scale (SADL, Cox & Alexander 1999), the Client-Oriented Scale of Improvement (COSI, Dillon et al. 1997) the Hearing Aid Performance Questionnaire (HAPQ, Gatehouse et al. 2006), the International Outcome Inventory for Hearing Aids (IOI-HA, Cox & Alexander 2002), and the Abbreviated Profile of Hearing Aid Benefit (APHAB, Cox 1997). These hearing aid questionnaires (and others), however, are focused on aspects of the hearing aid experience outside of hearing aid selection, such as user satisfaction or benefit from hearing aids.

The abundance of choice in modern hearing aid features, along with a lack of an evidence-based methodology in selection may increase the relevance of and need for a tool to aid hearing care professionals and patients in selecting an appropriate hearing aid based on self-reported patient needs. There are questionnaires designed specifically to address this: The Hearing Aid Selection Profile (HASP; Jacobson et al., 2001) and, more recently, the Characteristics of Amplification Tool (COAT; Sandridge & Newman, 2006). These include ratings of subjective factors such as patient motivations, opinions, and attitudes regarding different aspects of hearing aid use including perceived communication needs, cosmetics, cost, and technological sophistication. These questionnaires successfully incorporate patient input into the selection process and provide a structured methodology to elicit patient perspectives in pre-fitting candidacy and selection. However, the questions regarding technology focus more heavily on patient attitude towards technology rather than specific hearing aid features. Furthermore, the questions may not represent current hearing aid features because of technology changes since the development of the questionnaires. In summary, these questionnaires may provide hearing professionals with overall patient attitude information to inform hearing aid selection, but this may not measure patient preferences for specific, modern hearing aid features that drive cost, function, and that may relate to overall preference of technology level.

More recently, online hearing aid selection tools have been made available which are aimed at helping potential hearing aid users choose devices appropriate to them. One such example is the Help Me Choose tool offered by HearingTracker (https://www.hearingtracker.com/hearing-aids/personalized-match-survey), which addresses some of the issues found in using the HASP and COAT by including modern, specific examples of technologies in its assessment of what the respondent finds important to have in their hearing aid. It has also proved to be a valuable research tool, allowing collection of information regarding hearing aid user preferences and attitudes. The large number of respondents has allowed studies of user preferences, behavioral trends, and expressed opinions (Heselton et al., 2022; Manchaiah et al., 2020; Manchaiah, Picou, et al., 2021; Manchaiah, Swanepoel, et al., 2021).

To the author's knowledge, however, of these tools, only the developers of the HASP have published the process of item development and questionnaire evaluation. Therefore, the aim of the current study was to develop a feature-driven preference assessment tool, following well-established test construction methodologies.

4.1.3 Current study

In this study, a novel questionnaire called the Hearing Aid Feature Importance Evaluation (HAFIE) was developed. The aim of this self-administered questionnaire is to gather patient attitude and self-reported importance ratings for different modern hearing aid features, to assist with hearing aid selection. The concepts driving hearing aid preference (Saleh et al., 2021) were used as the conceptual foundation for the constructs in the HAFIE.

The steps in the development of the questionnaire were as follows, and each is described further below:

1. Construction of a first version based on the concept map.
2. Conducting a series of focus group and interviews with clinicians to review the clinical purpose of the questionnaire and the first version items.
3. To revise the first version based on focus group input, with the aim of developing a pre-fitting questionnaire-based tool for assessing feature-specific preferences that is compatible with modern hearing aids, and that can be self-administered. Distribution of the reviewed version using online distribution.
4. Analysis of the questionnaire results from the online distribution: item evaluation, internal factor structure, and internal consistency.
5. The creation of a final, shortened questionnaire based on the analysis results.

4.2 Methods

4.2.1 Initial questionnaire design

4.2.1.1 Item design and questionnaire format

As a framework for the initial version of the questionnaire, the thematic dimensions (clusters) identified by Saleh et al., (2022) were analyzed and used as thematic subscales. Statements within these clusters, and the features which they represent, were reworded to produce a list of questions within each of these subscales. Duplicates and statements referring to the same features were excluded. Some current hearing aid features were not present in the hearing aids used in the preference study and were thus not identified in the resulting concept map. For the questionnaire to have a comprehensive list of features within each subscale, an environmental scan of currently available features was conducted, and questions added to represent additional features (e.g., step counting, falls detection). The questionnaire items were worded to ensure a similar format, clarity, and suitability for a Likert scale, according to the suggestions by Dillman et al. (2014).

A subsection for the collection of demographic information was included at the start of the questionnaire. This allowed the analysis of demographic variables including: respondent age, hearing aid experience, and features of previous hearing aid worn (if applicable).

Each question contained the prompt "How important is this to you if deciding on a new hearing aid to use?", with a 5- point unipolar Likert scale including the responses "Not important at all", "Slightly important", "Moderately important", "Very important", and "Extremely important". The use of a 5-point scale and the decision to allow a neutral response is debated (Garland, 1991), however Krosnick and Presser (2009) recommend 5-7 point scales over 3-point scales to produce reliable results.

The order of items in a questionnaire is an important factor to consider (Simon et al., 2003). We grouped the questions into their subscales, according to the suggestion by Wilson & McClean (1994). Walker (1996) suggests placing more sensitive items in the middle of the questionnaire to increase compliance; however, due to the non-sensitive nature of this questionnaire's items, the subscales, and items within them were placed in a random order.

4.2.1.2 Focus group(s) and focused interviews

The aim of this stage of the study was to assess clinician attitudes about the need for a pre-fitting hearing aid selection questionnaire, and to gather suggestions about what should be included in such a questionnaire. Ten experienced hearing care professionals (mean of 38.6 years old, range: 26 -53y; 1 male, 9 females; clinical experience: mean of 16.7 years, range:

1 – 27 years) were recruited via email recruitment and word of mouth. Three focus groups and one focused interview were conducted, with the sessions involving four, three, two, and one participant (s), respectively. These sessions were scheduled to accommodate participant availability. The focus groups were conducted virtually, with two researchers present as moderators. Recommended focus group best practices were followed (Krueger and Casey, 2002), with a semi-structured group interview style, where all participants were given the opportunity to share their opinions by opening the focus group with inclusive ground rules, and using follow-up prompts throughout the session to elicit a wide range of responses. Interview questions related to questionnaire use in practice, the feasibility of a hearing aid selection questionnaire, a desirable length/number of questions, and what hearing aid technologies and features should be included. Focus group participants were also shown the first version questionnaire containing a list of possible questions for their review. Features suggested by the hearing care professionals were considered for addition. All sessions were audio-taped and transcribed. The study was approved by the Western University's Research Ethics Board (project # 119016).

The opinions gathered in the focus group were used to modify the initial draft version of the questionnaire and resulted in a questionnaire consisting of 34 items, shown in Appendix D.

4.2.2 Questionnaire evaluation: factor structure, validity, and reliability

4.2.2.1 Sampling

The questionnaire was implemented in an online administration tool (Qualtrics). Participant inclusion criteria included individuals aged above 18 years with a self-reported hearing loss. Participation was anonymous, and participants were allowed to skip any questions after consenting to take part in the survey. Participant recruitment for the validation of this questionnaire was primarily conducted via internet recruitment, including social media (LinkedIn, Twitter, and Facebook) and by posting invitations to participate on online hearing aid user forums. Recruitment emails were also sent to hearing care professionals within the researchers' professional network to circulate to patients and colleagues, and through word of mouth.

4.2.2.2 Sample size estimation

Sample size requirements for validation and factor analysis vary. For example, some recommend a participant to item ratio, ranging between 5:1 to 10:1 or 20:1 (Akkuş, 2019; Costello & Osborne, 2005; Hair, 2009), while others recommend minimum participant numbers, ranging between 100 and 500 participants (Goretzko et al., 2021; Hair, 2009; Howard, 2016). However, there have been criticisms of these (Akkuş, 2019; Gaskin & Happell, 2014), as they do not necessarily consider the quality of the data collected or the interaction between different characteristics of the data. Attributes such as the number of items, number of factors determined, factor loadings, number of items per factor, and the measured item communalities are all reported to influence the minimum sample size required for an appropriate factor analysis (Gaskin & Happell, 2014; Howard, 2016; Watkins, 2018). Mundfrom et al. (2005) recommend different minimum sample sizes based on the number of items per factor extracted and the communalities of the items. The target sample size in this study was to recruit the greater of 200 participants or a 5:1 participant to item ratio (corresponding to 170 participants in this questionnaire), a conservative cut-off recommended by Howard (2016), with follow-up assessment of data quality following published guidelines (Costello & Osborne, 2005; Hinkin, 1998; Howard, 2016).

4.2.2.3 Factor structure evaluation

Exploratory factor analysis (EFA) is a technique used to identify patterns in the data between the different items and their underlying constructs, therefore highlighting the factor structure of the data. This is a common step used in questionnaire development to determine questionnaire subscales (Howard, 2016), and has been used in hearing healthcare-related questionnaire development (Singh et al., 2019). In this study, the Principal Axis Factoring method (PAF) was used. This is due to reports of PAF being more suitable for EFA than Principal Component Analysis (PCA) due to more accurate accounting of correlation structure and more realistic variance assumptions (Costello & Osborne, 2005). Prior to exploratory factor analysis (EFA), the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (Kaiser, 1970) and Bartlett's Test of Sphericity (Bartlett, 1950) were conducted to assess data quality. The Bartlett's test of sphericity was significant (χ^2 (561) = 3412.15, p<.001). The result of the KMO Measure of Sampling Adequacy was 0.87, a satisfactory value and well above the suggested 0.60 minimum before performing an EFA (Dziuban & Shirkey, 1974; Kaiser, 1970). These results support continuing with EFA by disproving assumption violations, namely that there are no common variances between the items in the dataset, and that the dataset is not significantly different from an identity matrix (Dziuban & Shirkey, 1974; Howard, 2016). All statistical analyses were conducted using the SPSS version 28 software.

4.3 Analysis

4.3.1 Data cleaning & missing data replacement

Typically, some items in a questionnaire will be skipped by participants, resulting in missing data. Without replacement of this missing data, conducting the factor analysis would require deletion of the incomplete respondents' results, which reduces the statistical power of the data and introduces bias (Nakagawa & Freckleton, 2008). Therefore, we addressed the missing responses before conducting factor analysis. Prior to this, the nature of the missing data must be assessed, Missing data can be classified as missing completely at random (MCAR), missing at random (MAR) or missing not at random (MNAR) (Dray & Josse, 2015; J. W. Graham, 2009; Schafer & Graham, 2002). MCAR and MAR refer to the missingness of the data not being related to the unobserved data (and in the case of MCAR, the observed data as well) and can be classified as ignorable, allowing methods to replace this data. In MNAR data, however, the cause of the missingness is dependent on the unobserved data itself, indicating systematic issue with the data itself, and bias in the results (J. W. Graham, 2009). To classify if the missing data is MCAR, Little's test of missing completely at random (Little, 1988) must be conducted. If the data is found to be

MCAR, the missing item values can be replaced by the mean of that item across all respondents. This is one of the simplest missing data replacement techniques (Nakagawa & Freckleton, 2008), and has been reported to be a suitable method of missing data replacement (Parent, 2013), particularly in Likert scale data (Downey & King, 1998).

4.3.2 Factor analysis

A direct Oblimin oblique rotation (delta of zero) was used, allowing correlations between the rotated factors (Costello & Osborne, 2005). This was selected as the appropriate rotation method for the questionnaire data, because preference factors for hearing aid features were expected to be multidimensional (Manchaiah, Picou, et al., 2021; Saleh et al., 2021; Zhu et al., 2020) and likely to have some correlation.

The cluster solution was chosen using scree plot analysis and Velicer’s Minimum Average Partial (MAP) test. Furthermore, inspection of the different factor solutions was conducted. The items within the factors and factor loadings in each of these solutions were also assessed through a hearing care clinician’s (the researcher’s) perspective to determine their appropriateness.

4.3.3 Item retention & removal

To identify the items that do not represent any distinct factors well, thereby warranting review, the factor loadings of each item was assessed. Retention criteria is a contentious topic, with different recommended guidelines for primary and alternative factor loading requirements (Howard, 2016), and this was considered when reviewing factor loadings for item removal. The criteria we used for item retention were: (1) a primary factor loading of 0.45 (Tabachnick et al., 2019); (2) no secondary factor loadings above 0.3 (Howard, 2016); and (3) a minimum difference of 0.2 between primary and secondary factor loadings (Hinkin, 1998). Items that met these criteria were retained, and items that did not meet these criteria were reviewed further.

While the suggested criterion provides guidance for item retainment, inspection of the items for their content and the context of their factor loadings is also recommended (Costello & Osborne, 2005), and was conducted.

4.3.4 Internal reliability & consistency

Assessment of internal reliability of the questionnaire was conducted via inter-item correlation. According to Clark & Watson (1995), inter-item correlation between 0.15 and 0.50 is recommended, with anything above 0.50 indicating possibly redundant items.

Internal consistency was assessed by measuring Cronbach's alpha (Cronbach, 1951). To identify items suitable for removal, the Cronbach's alpha following sequential item deletion in each factor was assessed ("Alpha if item deleted"; Gliem & Gliem, 2003). Any items which improved alpha once removed were likely suitable for removal from the questionnaire and were subjected to review.

4.4 Results

4.4.1 Focus groups and focused interview

Overall clinician feedback during the focus groups was overwhelmingly positive. Clinicians supported the usefulness of a modern hearing aid questionnaire in practice, as this can both "help new clinicians keep track of what features to offer when suggesting hearing aid options" and "can give the patient a list of the features available to them before choosing". It can also provide evidence of justification regarding the hearing aid suggestions made to the patient. Furthermore, it was suggested that having a pre-fitting questionnaire prior to their visit may allow the patient more time to consider their options, and can give their family and support system an opportunity to be involved in the selection process without needing to be present at the hearing care clinic. It was also mentioned that this questionnaire would be useful for managing patient expectations, and would therefore be most helpful for new hearing aid users.

A barrier to use mentioned in each of the focus groups was the time required to complete the questionnaire. The requirement for the questionnaire to be short was relevant both in clinical and self-administration, due to lack of appointment time and patient burden, respectively. Clinicians suggested having online and paper versions of the questionnaire to facilitate its use for different participant demographics as well as in different clinical settings. In addition to formatting suggestions, it was also recommended to add certain features which are becoming more common in modern premium hearing aids (such as the step-counter). Furthermore, they suggested including open-ended lifestyle questions in the final version of the questionnaire.

Clinician feedback was incorporated into the next version of the questionnaire prior to distribution to individuals with hearing loss for evaluation.

4.4.2 Questionnaire evaluation participants

A total of 345 individuals accessed and initiated the online questionnaire and agreed to the anonymous consent form, causing the software to record the instance, and ensuing responses. Due to the nature of the online questionnaire, any individual could open it to inspect the questionnaire (including the researchers) and this would be counted as a response. Therefore, this number of 345 included both those not self-reporting a hearing loss (not the target demographic) or those with no questions completed. We therefore removed the responses with no self-reported hearing loss (N=57) or those with the questionnaire accessed but none of the 34 items in the questionnaire completed (N=114). This resulted in 218 responses.

The 218 respondents included 114 females, 96 males, 3 non-binary, and 5 who did not complete the question regarding gender. Ages ranged from 18 to 93 years, with a median of 48 years. All participants self-reported a hearing difficulty. Of these, 84 participants reported currently using a hearing aid, while 133 did not, and 1 did not respond. When asked about smartphone usage, the vast majority (207) of the participants reporting owning and using a smartphone, 8 did not, and 3 did not respond.

4.4.3 Data cleaning & missing data replacement

Within the 218 responses, 2.80% of questions received no response (7,202 out of 7,412 item responses), which indicates a high completion rate. This ranged from 0.92% to 6.42% on the most to least responded to questions, respectively. Of the respondents, 37 did not respond to at least one question, and 181 completed the entire questionnaire.

Little's test of MCAR was not significant (χ^2 (888) = 955.56, $p > 0.05$), indicating that the missing data can be classified as MCAR. Therefore, the missing item values were replaced by the mean of that item across all respondents. For our dataset, mean substitution was found to produce nearly identical factor analysis results (discussed below) when compared to more complex missingness replacement methods, such as multiple imputation (MI) (Royston, 2004). This is likely due to the very low rate of missingness across the items (Parent, 2013) and the MCAR nature of the missing data.

4.4.4 Factor analysis

Analysis of the scree plot and the Velicer's Minimum Average Partial (MAP) tests gave conflicting suggestions for the number of factors to be retained (3 and 4, respectively). Upon inspection, the three-factor solution was selected as being the most interpretable, as the fourth factor in the four-factor solution loaded too few items and had no clear clinical interpretation and relevance.

This resulted in Factors 1 (Advanced connectivity & streaming), 2 (Physical features and usability), and 3 (Sound quality & intelligibility), which accounted for 29.5%, 9.3% and 7.5% of the variance, respectively, totaling 46.3%.

4.4.5 Item retention & removal

A total of seven items failed to meet the factor-loading item retention criteria listed above, as follows.

Three statements (‘The app allows me to contact the hearing professional directly.’), (‘The hearing aid settings can be changed remotely by my audiologist without needing to visit the clinic physically.’) and (‘The hearing aid can count the number of steps that I take throughout the day’) did not have a minimum difference of 0.2 between primary and secondary factor loadings.

The item (‘The hearing aids are linked so program or volume changes only need to be made on one hearing aid for both sides to change.’) did not load on any factors. This was also the case with the three items (‘having this style of hearing aid’) for ITE, RIC, and BTE hearing aids.

The statements (‘The hearing aid settings can be changed remotely by my audiologist without needing to visit the clinic physically.’) and (‘The hearing aid can count the number of steps that I take throughout the day’) represent features that are relatively newly available in hearing aids, and which should be included in a questionnaire focused on current available features. This is supported by positive feedback during the focus group; support for the inclusion of the item regarding remote fittings was expressed (it was in the initial draft questionnaire), and the step-counter item was suggested by more than one focus group participant. Furthermore, the difference between primary and secondary factor loadings, although not 0.2 as the criteria above recommends, is close at 0.18 and 0.16 respectively. Furthermore, exemplifying the contention in item removal guidelines, these items would not be removed based on other alternative factor loading cut-off recommendations (less than 0.32; Costello & Osborne, 2005). Therefore, these items were retained in the final questionnaire.

Out of the four items related to form factor, all except one (‘having this style of hearing aid’: CIC style of hearing aid) did not load on any factors and were thus excluded. However, removing three of the form factor choices while retaining the last would not be reasonable. Furthermore, introspection revealed an oversight in the design of these four items. Splitting the form factor inquiry between four items causes a situation not seen in other items in the questionnaire; the form factor items were mutually exclusive if the user prefers only one form factor, which causes a relation between the variance patterns across these four items. It was therefore decided to remove all four form factor items, and to merge all form factor choices into a non-Likert, ranking based, qualitative preference question in the next questionnaire version (i.e., ‘rank these different hearing aid types based on your preference’).

Seven items were removed in total, resulting in a final questionnaire of 28 items in three subscales (Table 1).

Table 4-1 Questionnaire items in the Hearing Aid Feature Importance Evaluation subscales, and factor loading values.

Item	Factor Loading
Factor 1: Advanced connectivity & streaming (α = 0.897)	
The hearing aid can connect to my smartphone or tablet through a specialized phone/tablet application.	0.691
The app which connects my phone to my hearing aid is clear and easy to use.	0.639
Using my smartphone, I can make the hearing aid focus on speech from a certain direction (e.g. to my side if someone is sitting beside me).	0.617
Using my smartphone, I can adjust the hearing aids volume and sound clarity through my phone.	0.712
The hearing aid has a special program to use when I am outside (e.g. for natural wind sounds).	0.532
The hearing aid has a special program to use when I am listening to live music.	0.628
The hearing aid has a wide choice of programs which are specialized for different surrounding sounds.	0.610
The hearing aid can connect to a remote microphone which sends sounds directly to your hearing aid. This makes it easier to hear people at a distance or in a noisy place.	0.670
The hearing aid settings can be changed remotely by my audiologist without needing to visit the clinic physically.	0.506

My hearing aid can connect to a TV streaming device that sends my TV sound directly into my hearing aid.	0.730
The hearing aid can connect wirelessly to a remote control which allows you to change hearing aid volume.	0.673
The hearing aid allows me to stream phone calls directly into my ear, including in the car.	0.632
The hearing aid allows direct music streaming from my phone into my ears.	0.634
The hearing aid can count the number of steps that I take throughout the day.	0.481
Factor 2: Physical features & usability (α = 0.848)	
The hearing aid does not have many accessories to use and maintain.	0.551
The hearing aid's volume and program buttons are easy to find and use.	0.496
The hearing aid is comfortable to wear with eyeglasses.	0.521
The hearing aid is easy to put into my ear.	0.683
The hearing aid looks good aesthetically.	0.646
The hearing aid is small in size and width.	0.771
The hearing aid is rechargeable.	0.541

Having a power bank to charge a rechargeable hearing aid.	0.532
If using batteries, having a small sized battery.	0.588
Factor 3: Sound quality & intelligibility (α = 0.815)	
The hearing aid makes my own voice sound natural.	0.510
The hearing aid has a feature to reduce the noise from wind.	0.584
The hearing aid can reduce background noise.	0.644
The hearing aid makes external sounds have a natural sound quality	0.738
The hearing aid makes speech sound clear and of high quality.	0.648

4.4.6 Internal reliability & consistency

The HAFIE was found to have inter-item correlation coefficients of 0.43, 0.40, and 0.48 on average for factors one, two and three, respectively. Upon inspection of factor three, the item (‘the hearing aid sound quality sounds natural.’) contributed most clearly to higher inter-item correlation, with a correlation above 0.60 with two other items in the factor. The ambiguity in the wording of this item likely contributed to this higher correlation, specifically to items such as (‘the hearing aid makes my own voice sound natural’). To alleviate this issue without removing the item and losing the distinct aspect of the hearing aid experience, (‘the hearing aid sound quality sounds natural.’) was reworded to (‘the hearing aid makes external sounds have a natural sound quality.’).

For factors 1-3, Cronbach’s alpha was 0.90, 0.85, and 0.815, respectively. This is within the acceptable range of values, indicating high internal consistency between the items in each factor scale (Tavakol & Dennick, 2011). It was found that the Cronbach’s alpha of each factor only decreased if any items were removed (Alpha if deleted), ruling out the need for any further item removal.

4.5 Discussion

Hearing aid selection includes consideration of a complex set of features that span hearing aid signal processing, form factor, and other features including linkage to apps in smart devices. Although patient involvement in the decision-making process is considered preferred practice (Bratzke et al., 2015; Brennan & Strombom, 1998), few tools have been available to support assessment of patient preference at the selection stage. One complicating factor in development and sustained use of such tools is the evolution of new hearing aid features over time, which may contribute to well-developed tools becoming outdated. This study aimed to develop a questionnaire designed to assess feature-specific preference from potential hearing aid users at the selection stage. The theoretical framework for this questionnaire was based on an end-user concept map of features that influence choice for one hearing aid over another, that was based on relatively current technology (Saleh et al., 2021), along with consideration of current evidence on features across brands (Lansbergen & Dreschler, 2020), and input from a focus group of experienced clinicians. This tool is called the Hearing Aid Feature Importance Evaluation (HAFIE), and was implemented as a self-directed online questionnaire.

Initial distribution and validation of the HAFIE was completed by 218 respondents who self-reported as having hearing loss. The questionnaire was determined to have appropriate internal reliability and internal consistency, as well as a stable internal factor structure. Furthermore, the questionnaire achieved face validity and construct validity.

Assessment of the item factor loadings in parallel with inspection of their content led to the removal of seven items from the original questionnaire, resulting in a 28-item shortened questionnaire, called the Hearing Aid Feature Importance Evaluation (HAFIE). The HAFIE includes three subscales (derived from the factors) which correspond well to the cluster themes identified in our prior concept mapping study (Saleh et al., 2021): “Advanced connectivity & streaming”, “Physical features & usability”, “Sound quality & intelligibility”. Specifically, statements contained within the same factor were more likely to be found in neighboring, related clusters in the published concept map. For example, Factor 1 (‘Advanced connectivity & streaming’) contained items derived from statements in the clusters “app-based DSP”, “streaming”, and “convenience & connectivity” (Saleh et al., 2021). In the previous study, these features differentiated hearing aids at different ends of the technology spectrum and are therefore relevant to selection of hearing aids at different cost levels. Similarly, Factor 2 (‘Physical features & usability’) contained items derived from statements in the adjacent “Comfort & appearance” and “Ease of use” clusters. Factor 3 (“Sound quality & intelligibility”) contained items from a single identically named cluster in the concept map.

4.5.1 Implications in audiology

Questionnaires are used to assess the attitudes and opinions of hearing aid users. While hearing aid questionnaires are widespread in use, they vary both in terms of the specific aspect of the hearing aid user experience as well as the stage in the patient journey (assessment/selection/pre-fitting/post-use) being assessed. While there is a wide range of validated questionnaires that measure hearing aid benefit, performance, and overall user satisfaction, there are few published questionnaires developed for use at the hearing aid selection stage. This stage of the patient journey is characterized as a “needs assessment” within recently-developed clinical practice guidelines (Audiology Practice Standards Organization, 2021).

The Hearing Aid Selection Profile (HASP; Jacobson et al., 2001) and the Characteristics of Amplification Tool (COAT; Sandridge & Newman, 2006) questionnaires were designed to fill the gap in hearing aid selection tools. However, these questionnaires were not focused on specific hearing aid feature selection, instead gathering data on user attitudes towards technology in general, as well as other factors such as cosmetics and communication needs. Moreover, these were created prior to the development of many current hearing aid technologies, which may limit their utility with today's hearing aid technological landscape.

Other available online tools, namely HearingTracker's Help Me Choose tool (https://www.hearingtracker.com/hearing-aids/personalized-match-survey) better address the previous tools' datedness and their lack of technology-specific questions. However, the theoretical framework behind the items and subscales in these tools and any steps taken to validate them are unknown at this time. However, inspection of the items in the Help Me Choose tool reveals some similarities with the items developed in this study via concept mapping and the subsequent focus group process, which may be supportive of validity in both Help Me Choose and the HAFIE. This also highlights the importance of these technology-specific questions in modern hearing aid selection.

This study developed the HAFIE, a shortened questionnaire that measures hearing aid feature importance. The HAFIE may address the need for a hearing aid selection tool for clinical use, by providing a structured process of incorporating patient input into the hearing aid selection process, allowing potential hearing aid users the ability to evaluate a wide range of hearing aid features that vary between hearing aid models and cost levels.

4.5.2 Limitations

The number of participants who did not complete the questionnaire (no hearing loss, no responses) nearly matched the number of adequate responses. Given that the survey invitations were sent to professional communities, we speculate that many of these were audiologists who were wishing to see the questionnaire. However, we don't know that so this could also flag low feasibility for some users.

The sample size was adequate for performing an exploratory factor analysis aimed at identifying the factor structure of the dataset. However, to verify and validate the factor structure, confirmatory factor analysis (CFA) is recommended (Harrington, 2009). CFA should be done on a different sample than the EFA to have accurate results, so this conformation could be a future direction Similarly, while other forms of reliability were assessed, test-retest reliability for the questionnaire was not assessed in this study and remains to be evaluated.

Although the content of the questionnaire was judged as appropriate by the overall positive feedback from the hearing care professionals during the focus group, content validity has not been formally assessed. A content validity index calculation (Martuza, 1977) should be conducted on the individual items and the subscales of the final version of the questionnaire.

Lastly, the relationship to product price and the interaction between cost and overall preference and feature importance is unknown at this time, and warrants further investigation.

4.6 References

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Chapter 5

5 Discussion

5.1 Contributions and future directions

5.1.1 Study aims and findings

Modern hearing aids have advanced over time from simple listening devices into complex machines, with a variety of features and technologies aimed at improving the hearing aid user experience. Early feature development prioritized implementing digital signal processing (DSP) technologies aimed at improving the audibility, sound quality, and speech intelligibility provided by the hearing aid. This includes directional microphone, noise reduction, multi-channel dynamic range compression, amongst others (Lansbergen & Dreschler, 2020; Picou, 2020). In addition, the overall hearing aid user experience also includes features unrelated to auditory benefit, referred to in this thesis as non-signal processing (non-DSP) features. Examples of these non-DSP features include hearing aid form factor, Bluetooth connectivity, and smartphone/tablet application compatibility. While further hearing aid development will likely lead to improved DSP functionality, it will also promote the implementation of more sophisticated non-DSP features into the hearing aid experience, as demonstrated by the recent implementation of activity and safety features such as step-counting and fall-detection (Rahme et al., 2021), respectively. Currently available hearing aids can be acquired at a high (premium) or low (entry-level) technology level. These can differ both in terms of the availability of certain DSP and non-DSP features, as well as the technological sophistication of the features available at both technology levels (Cox et al., 2014; Lansbergen & Dreschler, 2020; Plyler et al., 2021; Saleh et al., 2020).

The aims of this doctoral thesis fall into two related themes. The first was to better understand the drivers of hearing aid user preference between hearing aids providing comparable audiological benefit, and how they affect hearing aid user preference between different devices at a higher (premium) and lower (entry-level) technology levels. The second thematic aim of this thesis was the development of a clinically relevant, evidence-based hearing aid selection tool to allow a more patient-centered hearing aid selection process, using the previously gathered data as a theoretical framework. These aims were developed to address specific portions of the knowledge-to-action process (Figure 1-2) suggested by J. W. Graham et al (2006), namely, contributing to the knowledge creation stage "funnel" in aim 1 (chapters 2 and 3) and the action-cycle steps related to the implementation of this knowledge into a new tool in aim 2 (chapter 4).

5.1.1.1 Preference investigation

The non-audiological aspects of hearing aid use have been reported to influence hearing aid user preference and satisfaction (Bridges et al., 2012; Manchaiah, Picou, et al., 2021, 2021; Zhu et al., 2020). Furthermore, while experimental investigations of user preference between hearing aids at different technology levels have been conducted (Cox et al., 2016; Wu et al., 2019), the hearing aids profiles only differed in terms of DSP feature sophistication, but did not include non-DSP features. The rationale behind this thesis objective is that the overall hearing profile includes both DSP and non-DSP features, and each of these have been reported to influence the patient experience via preference and satisfaction. Therefore, an experimental investigation of preference which includes realistic variance in both DSP and non-DSP is warranted.

Chapter 2 addresses the first part of this objective and describes a study in which premium and entry-level hearing aids were compared in terms of the aided benefit provided to 23 hearing aid users, and the overall user preference for the hearing aids (measured on a Likert scale). This was done with commercially available hearing aids that, at the time of the study, represented current technology. These devices offered overall product profiles which differed realistically in terms of DSP feature sophistication as well as non-DSP feature availability such as form factor and apps. Both devices were fitted following best practices. It was found that the hearing aids provide similar benefits to sentence in noise perception, loudness growth ratings, consonant identification, and sound quality ratings (Saleh et al., 2020). These results are mostly consistent with the previous literature, which found limited differences in the majority of laboratory-based behavioral outcome measures, namely speech perception (Cox et al., 2016; Plyler et al., 2021). However, some studies have found significantly higher aided benefit from the premium hearing aid to speech perception in noise (Wu et al., 2019). A possible explanation for the inconsistency in speech perception results, however, is the difference in the laboratory conditions used for speech perception testing between this study and that by Wu et al., (2019). Furthermore, the relative inconsistency in aided benefit may also be attributable to idiosyncratic differences between the hearing aids used for each study, and the relative gap in technology level between the premium and entry-level hearing aids. Overall, these results agree with most previous literature which reported limited differences in aided benefit between premium and entry-level hearing aids.

There was a significant preference for the premium hearing aids (19/23 participants) despite the similar behavioral outcome and electroacoustic measures. This is inconsistent with previous investigations of preference between different technology levels (Cox et al., 2016; Plyler et al., 2021; Wu et al., 2019). Idiosyncratic, brand-specific differences between the hearing aids used in each study may have contributed to this difference in results. However, a major contributor may also be the inclusion of non-DSP features in the comparison between the hearing aids. These features, such as Bluetooth and app compatibility, add realistic differences in the overall user experience which were not present in previous literature. Furthermore, this is consistent with the large-scale hearing aid survey results investigated by Manchaiah et al. (2021), who found that nearly half of respondents expressed a desire to purchase premium-level devices. This agrees with previous findings highlighting the importance of certain non-DSP features to hearing aid users (Manchaiah, Picou, et al., 2021; Picou, 2020; Zhu et al., 2020). The novelty in the results shown in Chapter 2, however, is in experimentally demonstrating influence of technology level (specifically the availability of non-DSP features) on overall hearing aid preference when aided benefit is equal.

Chapter 3 follows up on Chapter 2, by exploring the reasons behind the participants' overall preferences for one device over another. Chapter 3 describes a group concept methodology which was used to investigate the underlying drivers of preference. Group concept mapping is a methodology used to produce a visual representation of intangible ideas and attitudes (Kane & Trochim, 2007). It has been used in a wide range of fields, including medicine

(Nilsson et al., 2012) and psychology (Donohoe et al., 2020). It has also been recently implemented in audiological research, to understand and interpret different aspects of clinician and patient attitudes (Bennett, 2019; Bennett et al., 2018; Glista et al., 2020; Poost-Foroosh et al., 2011) as well as to better understand patient needs in implemented healthcare service solutions (Meyer et al., 2022). After completing the study described in chapter 2 and expressing their preference for one of the hearing aids, a concept mapping study was undertaken, resulting in a concept map containing 83 total statements grouped into nine distinct clusters (or themes), each containing features or ideas contributing to hearing aid preference. In a comparison of the cluster importance ratings between the premium and entry-level hearing aid choosers (Figure 3-2), clusters related to “Comfort & appearance”, “Sound quality & intelligibility”, and “Ease of use” were the most important clusters for both groups. This highlighted the importance of meeting basic requirements such as audibility needs, a factor influencing hearing aid uptake and continued use (Jorgensen & Novak, 2020; Kochkin, 2012) and comfort/satisfactory appearance, the lack of which can lead to non-use (McCormack & Fortnum, 2013). These results are also consistent with those of Manchaiah et al. (2021), who surveyed a large number of hearing aid users and found that improved speech intelligibility in quiet and noise, as well as the comfort and reliability of the hearing aid were reported as the most desirable features to them.

The clusters “User-controlled DSP (app)”, “Streaming”, and “Convenience & connectivity” were the only ones rated significantly higher by the premium hearing aid choosers. Interestingly, these clusters were primarily comprised of high technology level non-DSP features only available in the premium hearing aids used (such as app-based remote clinician support and smartphone-based DSP control). These findings are consistent with previous literature reporting the importance of non-DSP features to hearing aid users (Picou, 2020). Plyler et al. (2021) did not include non-DSP differences between devices and did not find a significant difference in preference between the premium and entry-level technology levels. However, they found that participants who preferred the premium devices benefitted significantly more from premium-only features than those who preferred the basic devices. This may seem intuitive, but it supports the idea that hearing aid users value having access to features which they find useful; this influences their preference and supports our findings that, since basic audibility needs are highly valued by everyone, individual differences in hearing aid benefit may influence preference. These findings allow us a better understanding of the relationship between technology-specific features and hearing aid preference, and correspond to the knowledge creation "funnel" in the knowledge-to-action process (I. D. Graham et al., 2006).

5.1.1.2 Questionnaire development

Our results highlight the influence of patient individuality in preference. Previously, Gioia et al. (2015) found that hearing aid technology level recommendations made by clinicians lack evidence-based justification, and are mostly made based on patient lifestyle as perceived by the clinician. However, a patient-centered approach to treatment decision-making has been suggested to reduce post-treatment regret (Mulley et al., 2012) in medical care and to improve hearing aid adoption rates (Poost-Foroosh et al., 2011) in hearing care. When interpreted within this context, the need for a structured method to incorporate this individuality into the hearing aid selection process is apparent. The identification of this problem and need for intervention corresponds to the problem identification stage following knowledge creation in the knowledge-to-action process (I. D. Graham et al., 2006). To this aim, we developed a clinically relevant, evidence-based hearing aid selection questionnaire to allow a more patient-centered hearing aid selection process. We used the concept mapping results of chapter 3 as a theoretical framework for this tool, and conducted focus groups with hearing care professionals to gather feedback which we used to tailor the tool for clinical use. These steps correspond to the stages related to adapting knowledge to the local context, assessing barriers to use, and tailoring the intervention based on these barriers, respectively (I. D. Graham et al., 2006).

Questionnaires are instruments used for gathering patient attitudes and opinions. They are widespread in audiology and hearing care and used to gather patient input in many different aspects of the hearing aid user experience. Recently, web-based guides and questionnaires are becoming more available, allowing selection of available hearing aid options (with some providing suggestions based on these). However, there is a lack of available recent, evidence-based, and peer-reviewed hearing aid feature selection questionnaires. The aim of chapter 4 was to develop a modern hearing aid selection questionnaire using the results of the concept mapping study as a theoretical framework. This study resulted in a 28-item questionnaire within three subscales defined by exploratory factor analysis, “Advanced connectivity & streaming”, “Physical features & usability”, and “Sound quality & intelligibility”. These subscales and their contents were demonstrated to have appropriate internal consistency, internal reliability, and face validity. This questionnaire, when fully validated and finalized (to be discussed further below), will give clinicians a structured tool to gather patient input regarding the relative importance of different features of the hearing aid. This will allow clinicians to better implement a patient-centered approach, incorporating patient needs and preferences into the hearing aid selection decision.

5.2 Future directions

Questionnaire development typically involves item development (sometimes including expert involvement via focus groups) followed by factor structure analysis and evaluation of questionnaire validity and reliability. In this thesis, the item development stage and the initial evaluation of factor structure, validity and reliability were addressed.

Future directions of this research will be aimed at addressing some of the limitations in this study, as well as preparing the final version of the questionnaire for distribution and clinical use by following the additional steps outlined in the knowledge-to-action process (I. D. Graham et al., 2006). Further steps would be conducted on the final version of the HAFIE as this is the version that will be made available for clinical use. These steps are discussed further below.

5.2.1 Confirming factor structure

However, further work is still required to complete the development of the HAFIE, with a clear next step being to confirm the factor structure that was described in Chapter 4. Confirmatory factor analysis (CFA) can be used to verify the factor structure identified by exploratory factor analysis (Harrington, 2009). CFA is recommended to be conducted on a different sample from that of the initial exploratory factor analysis, to avoid forcing a verified factor structure result. One method includes splitting the data in half randomly to conduct CFA and EFA on each half. However, the sample size of the initial validation study was not adequate to allow this based on the sample size guidelines followed. Interestingly, attempting to split the responses in half produced similar EFA results which were in turn verified by the CFA. However, this can only be considered in the context of curiosity, due to the inappropriate sample size. Therefore, as a future direction, the questionnaire validation can be extended to allow another 200 (adequate) responses for a CFA to be conducted. While discriminant and convergent construct validity was calculated on the EFA results, these can be re-calculated and confirmed after the factor structure is verified via CFA.

5.2.2 Validity assessment

While the focus group feedback was positive regarding the content of the questionnaire, content validity was not specifically measured and could not be confirmed. Therefore, another proposed next step would be to calculate the content validity index (CVI) both at the item (I-CVI) and scale (S-CVI) level. This would include a group of experienced clinicians rating the relevance of the item content on a 4-point Likert scale. CVI can be calculated using the proportion of the items judged as appropriately valid (3-4 on the scale) (Martuza, 1977; Polit & Beck, 2006). Items with low I-CVI can be removed from the questionnaire or reworded based on the clinician feedback.

5.2.3 Reliability assessment

Finally, test-retest reliability was not assessed in this study. This is an important measure in questionnaire development, demonstrating the reliability and stability of results. Test-retest reliability may be assessed by administering the final questionnaire to the same group of participants at two different points in time and comparing the results. A participant: item ratio of 1:1 to 4:1 can be used as a sample size guideline, with approximately 14 days between the two test sessions. These study parameters have been identified, in a systematic review of 95 studies, as being frequent in the assessment of test-retest reliability (Park et al., 2018).

5.2.4 Further directions

As discussed, one of the objectives of this study was to adopt an integrated knowledge translation (IKT) approach (I. D. Graham et al., 2006; Moodie et al., 2011) to the creation of this clinical tool. In the hearing care context, this involves incorporating clinician input in the early stage of clinical tool development, to increase feasibility and applicability. An existing example of this in this doctoral work is the focus group study in chapter 4, which was conducted prior to the initial distribution and validation of the questionnaire and corresponds with the stage of the knowledge-to-action cycle related to assessment of barriers to use (I. D. Graham et al., 2006). This allowed gathering clinician inputs and opinions regarding an early version of the questionnaire and subsequent improvements based on these recommendations. Further clinician input may be gathered to improve the current near-final version of the questionnaire via an investigation of the clinical feasibility of the questionnaire. Survey-based feasibility assessment has been conducted for previous tools intended for use by hearing care clinicians (Glista et al., 2014; Moodie et al., 2011) as a means to implement IKT in the tool-development process.

Lastly, Andresen (2000) developed an operational grading system to evaluate adult and pediatric outcome tools. This is based on criteria related to tool development, derived from literature review (such as validity/reliability), as well as practical considerations (such as respondent burden). This assessment system has been used in previous critical reviews, assessing existing pediatric audiological outcome tools (Bagatto et al., 2011). While the HAFIE is not an outcome measurement tool, most criteria within the Andreson grading system are applicable to this questionnaire, and can be used to produce a score for the finalized version of the HAFIE and, potentially, can allow a critical comparison to other hearing aid selection tools.

5.3 Conclusions

This dissertation aimed to investigate modern hearing aid features and their relative importance in influencing hearing aid preference, and to use this data as a theoretical framework for the development of a hearing aid selection tool. The themes and clusters identified in the concept mapping study, coupled with the associated importance ratings, have increased our current understanding of the drivers of hearing aid user preference and highlighted the importance of the individuality in preference. The questionnaire developed in this study, once finalized, is anticipated to support the implementation of an evidence-based, patient-centered approach to hearing aid selection, better incorporating patient individuality and preference into the hearing aid recommendation.

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Appendices

Appendix A: HSREB approval (Chapters 2 and 3 technology level study)

Western Research

Date: 21 February 2019

To: Dr. Susan Scollie

Project ID: 112802

Study Title: Factors that Influence Preference for Technology Level in Hearing Aid Devices

Study Sponsor: Sivantos GmbH

Application Type: HSREB Initial Application

Review Type: Delegated

Meeting Date / Full Board Reporting Date: 12/March/2019

Date Approval Issued: 21/Feb/2019

REB Approval Expiry Date: 21/Feb/2020

Dear Dr. Susan Scollie

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date
Consent Form to Email_20_01_2019	Written Consent/Assent	20/Jan/2019
Laminated_Gabrielson SQ rating scale	Other Data Collection Instruments	20/Jan/2019
Laminated_Likert	Other Data Collection Instruments	20/Jan/2019
Letter of Information_2019-02-13	Written Consent/Assent	13/Feb/2019
Online Questionnaire 2019-02-13	Online Survey	13/Feb/2019
OwnVoiceRatings	Other Data Collection Instruments	13/Feb/2019
Protocol_2019_02_13	Protocol	13/Feb/2019
Recruitment_Email_2019-02-13	Email Script	13/Feb/2019
Scollie_112802_Data_collection_sheet	Other Data Collection Instruments	20/Jan/2019
Telephone_Script_20_01_2019	Telephone Script	20/Jan/2019

Documents Acknowledged:

Document Name	Document Type	Document Date
References	References	20/Jan/2019

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REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Patricia Sargeant, Ethics Officer (ext. 85990) on behalf of Dr. Philip Jones, HSREB Vice-Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B: HSREB approval (Chapter 4 focus group)

Western Research

Date: 13 July 2021

To: Dr. Susan Scollie

Project ID: 119016

Study Title: Zoom-based Clinician Focus Group for the Design of a Hearing Aid Questionnaire

Application Type: HSREB Initial Application

Review Type: Delegated

Meeting Date / Full Board Reporting Date: 20/July/2021

Date Approval Issued: 13/Jul/2021

REB Approval Expiry Date: 13/Jul/2022

Dear Dr. Susan Scollie

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Focus_Guide_2021_06_04	Focus Group(s) Guide	04/Jun/2021	1
Email_Script_2021_07_10	Email Script	10/Jul/2021	2021_07_10
Protocol_2021_07_10	Protocol	10/Jul/2021	2021_07_10
Twitter_Script_2021_07_10	Recruitment Materials	10/Jul/2021	2021_10_07
Letter_of_information_2021_07_10	Written Consent/Assent	10/Jul/2021	2021_07_10
Qualtrics_Demographics_Survey_2021_07_10	Online Survey	10/Jul/2021	2021_07_10
Reminder_Email_Script_2021_07_13	Email Script	13/Jul/2021	2021_07_13

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
Rationale_References_2021_06_04	References	04/Jun/2021	1
Budget_2021_06_04	Study budget	04/Jun/2021	1

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REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Patricia Sargeant, Ethics Officer (psargean@uwo.ca) on behalf of Dr. Philip Jones, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix C: HSREB approval (Chapter 4 questionnaire evaluation)

Western Research

Date: 14 October 2021

To: Dr. Susan Scollie

Project ID: 119444

Study Title: Validating a hearing aid feature importance questionnaire

Application Type: HSREB Initial Application

Review Type: Delegated

Meeting Date / Full Board Reporting Date: 02/Nov/2021

Date Approval Issued: 14/Oct/2021

REB Approval Expiry Date: 14/Oct/2022

Dear Dr. Susan Scollie

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study.**

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Questionnaire_Wordversion_2021_10_09	Online Survey	09/Oct/2021	2
Facebook_Script_2021_10_09	Recruitment Materials	09/Oct/2021	2
Linkedin_Script_2021_10_09	Recruitment Materials	09/Oct/2021	2
Twitter_2021_10_09	Recruitment Materials	09/Oct/2021	2
Email Script_2021_10_09	Email Script	09/Oct/2021	2
LOI_2021_10_09_	Written Consent/Assent	09/Oct/2021	2
Protocol_2021_10_09	Protocol	09/Oct/2021	2

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
Rationale_References_2021_09_01	References	01/Sep/2021	1
Budget_2021_09_01	Study budget	01/Sep/2021	1

No deviations from, or changes to, the protocol or WREM application should be initiated without prior written approval of an appropriate amendment from Western HSREB , except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions. Sincerely,

Patricia Sargeant, Ethics Officer (psargean@uwo.ca) on behalf of Dr. Emma Duerden, HSREB Vice-Chair

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Appendix F: Initial version of the HAFIE questionnaire

HAFIE Questionnaire

Hearing aids are complex devices consisting of many different technologies. The following sections will contain descriptions of these technologies, and will assess your opinions towards them.

End of Block: Intro Description

Start of Block: App-Based DSP

Some hearing aids can connect to your smartphone via Bluetooth. Depending on the type of hearing aid, a specialized smartphone/tablet app can connect to your hearing aid and allow you to make changes to your hearing aid through your phone.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (15)	Slightly important (16)	Moderately important (17)	Very important (18)	Extremely important (19)
The hearing aid can connect to my smartphone or tablet through a specialized phone/tablet application. (4)	○	○	○	○	○
The app which connects my phone to my hearing aid is clear and easy to use. (1)	○	○	○	○	○
Using my smartphone, I can make the hearing aid focus on speech from a certain direction (e.g. to my side if someone is sitting beside me). (2)	○	○	○	○	○
Using my smartphone, I can adjust the hearing aid's volume and sound clarity through my phone. (3)	○	○	○	○	○

End of Block: App-Based DSP

Start of Block: Multi-environment Functionality

Hearing aids can come with different settings (called "programs") designed to improve your experience in different listening environments. An example of this is having a hearing aid program that lowers background noise when you are in a noisy environment. You can either change the settings based on your preference, or the hearing aid can change them automatically by sensing the environment you are in.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (16)	Slightly important (17)	Moderately important (18)	Very important (19)	Extremely important (20)
The hearing aid has a special program to use when I am outside (e.g. for natural wind sounds). (1)	○	○	○	○	○
The hearing aid has a special program to use when I am listening to live music. (2)	○	○	○	○	○
The hearing aid has a wide choice of programs which are specialized for different surrounding sounds. (4)	○	○	○	○	○

End of Block: Multi-environment Functionality

Start of Block: Convenience and Connectivity

Some hearing aids have features focused on convenience. This can include being able to communicate with your hearing professional through your smartphone app and allowing them to make changes to your hearing aids without having to visit the clinic in person. Some hearing aids can also connect to devices to help improve the hearing aid experience.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (27)	Slightly important (28)	Moderately important (29)	Very important (30)	Extremely important (31)
The hearing aid can connect to a remote microphone which sends sounds directly to your hearing aid. This makes it easier to hear people at a distance or in a noisy place. (1)	o	o	o	o	o
The app allows me to contact the hearing professional directly. (2)	o	o	o	o	o
The hearing aid settings can be changed remotely by my audiologist without needing to visit the clinic physically. (3)	o	o	o	o	o
My hearing aid can connect to a TV streaming device that sends my TV sound directly into my hearing aid. (4)	o	o	o	o	o

The hearing aid can connect wireless to a remote control which allows you to change hearing aid volume. (5)	o	o	o	o	o
The hearing aid can count the number of steps that I take throughout the day. (6)	o	o	o	o	o

End of Block: Convenience and Connectivity

Start of Block: Ease of Use

An important aspect of hearing aids is their ease of use. Some hearing aids have features focused on improving their simplicity and making them easy to use.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (21)	Slightly important (22)	Moderately important (23)	Very important (24)	Extremely important (25)
The hearing aid does not have many accessories to use and maintain. (1)	○	○	○	○	○
The hearing aid's volume and program buttons are easy to find and use. (3)	○	○	○	○	○
The hearing aids are linked so program or volume changes only need to be made on one hearing aid for both sides to change. (4)	○	○	○	○	○

End of Block: Ease of Use

Start of Block: Sound Quality and Intelligibility

The hearing aid takes sound from your environment and modifies it based on your hearing loss. Certain hearing aid technologies are designed to improve the quality of the sound to be more comfortable to you and to make speech easier to hear and understand.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (16)	Slightly important (17)	Moderately important (18)	Very important (19)	Extremely important (20)
The hearing aid makes my own voice sound natural. (1)	○	○	○	○	○
The hearing aid has a feature to reduce the noise from wind. (2)	○	○	○	○	○
The hearing aid can reduce background noise. (4)	○	○	○	○	○
The hearing aid sound quality sounds natural. (5)	○	○	○	○	○
The hearing aid makes speech sound clear and of high quality. (6)	○	○	○	○	○

End of Block: Sound Quality and Intelligibility

Start of Block: Comfort and Appearance

Hearing aids can differ in size and appearance. This can change how they look cosmetically as well as how comfortably they sit in and on your ear.

Page Break

Q21 How important is this to you if deciding on a new hearing aid to use?

	Not at all important (17)	Slightly important (18)	Moderately important (19)	Very important (20)	Extremely important (21)
The hearing aid is comfortable to wear with eyeglasses. (2)	o	o	o	o	o
The hearing aid is easy to put into my ear. (3)	o	o	o	o	o
The hearing aid looks good aesthetically. (4)	o	o	o	o	o
The hearing aid is small in size and width. (7)	o	o	o	o	o

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (16)	Slightly important (17)	Moderately important (18)	Very important (19)	Extremely important (20)
Having this style of hearing aid: (2) (Gif of CIC)	○	○	○	○	○
Having this style of hearing aid: (3) (Gif of RIC)	○	○	○	○	○
Having this style of hearing aid: (4) (GIF of BTE)	○	○	○	○	○
Having this style of hearing aid: (5) (GIF of ITE)	○	○	○	○	○

End of Block: Comfort and Appearance

Start of Block: Streaming

Some hearing aids can connect to your smartphone with Bluetooth. This gives you the option to hear your phone calls or play music from your phone directly in your hearing aids, rather than placing the phone over your ears.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
The hearing aid allows me to stream phone calls directly into my ear, including in the car. (1)	○	○	○	○	○
The hearing aid allows direct music streaming from my phone into my ears. (2)	○	○	○	○	○

End of Block: Streaming

Start of Block: Batteries & Charging

Some hearing aids are powered by batteries which are placed inside the hearing aids and must be replaced upon consumption. Larger hearing aids have larger batteries which last longer, and smaller hearing aids have smaller batteries with a shorter duration. Smaller batteries might also be more difficult to handle. Rechargeable hearing aids do not need batteries but can be recharged electrically by plugging into a power source (i.e. a wall socket or power bank). These must be charged for a short period every night when not in use.

Page Break

How important is this to you if deciding on a new hearing aid to use?

	Not at all important (16)	Slightly important (17)	Moderately important (18)	Very important (19)	Extremely important (20)
The hearing aid is rechargeable. (4)	○	○	○	○	○
Having a power bank to charge a rechargeable hearing aid. (1)	○	○	○	○	○
If using batteries, having a small sized battery. (6)	○	○	○	○	○

Curriculum Vitae

Name:	Hasan Saleh
Post-secondary Education and Degrees:	University of Ottawa Ottawa, Ontario, Canada 2010-2014: BSc. (Hons) Biology
	Queen Margaret University Edinburgh, Scotland, United Kingdom 2014-2017: MSc. (distinction) Audiology
	Western University London, Ontario, Canada 2017- present: PhD. Hearing Science
Related Work Experience	Audiologist: 2016-2017 Queen Victoria Hospital Belfast, North Ireland, United Kingdom
	Teaching Assistant: 2017-2021 Western University London, Ontario, Canada

Publications:

Saleh, H. K., Folkeard, P., Van Eeckhoutte, M., & Scollie, S. (2021). Premium versus entry-level hearing aids: using group concept mapping to investigate the drivers of preference. *International Journal of Audiology*, 1-15.

Saleh, H. K., Folkeard, P., Macpherson, E., & Scollie, S. (2020). Adaptation of the Connected Speech Test: Rerecording and passage equivalency. *American Journal of Audiology*, *29*(2), 259-264.

Koch, R. W., **Saleh, H.,** Folkeard, P., Moodie, S., Janeteas, C., Agrawal, S. K., Ladak M., Hanif, & Scollie, S. (2020). Skill Transference of a Probe-Tube Placement Training Simulator. *Journal of the American Academy of Audiology*, *31*(1), 40-49.