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Trainable Hearing Aids in Practice: Impact and Application

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Abstract

In clinical practice, hearing aids are typically fitted using a prescription based on average data. However, some users will request changes or fine-tuning of their hearing aid settings. Fine-tuning can be difficult in the clinic as it relies on users adequately recalling and describing the problems they experienced and the acoustic environment they were in, and on the clinician translating the descriptions to changes in hearing aid settings. Additionally, complex acoustic environments cannot easily be recreated in the clinic, leaving the user to evaluate the fine-tuned settings in their own listening environment and return to the clinic for further fine-tuning, if needed. As pressure on clinician time is increasing due to an ageing population, fine-tuning would be a clinical task which some aid users could perform themselves. Based on consistent adjustments a user makes to the settings, a trainable hearing aid can learn the user's preferred settings and modify the settings to match the user's preference.

Previous research on trainable hearing aids concluded that the majority of users were able to train and obtain settings they preferred over the prescribed settings. To advance the field further, this project evaluated the impact of trainable aids in clinical practice; the consistency of listening preference of older adults; the time-course, outcomes and prediction of obtaining trained settings; and how users reported making adjustments to their hearing aid settings in their own listening environments.

The first study was a survey of 259 clinicians and 104 adults with a hearing loss (including 81 hearing aid users) about the impact of trainable aids in clinical practice. Responses showed that over half of the clinicians activated training, and that one fifth of the users had experience with training hearing aids. Survey responses from clinicians and users with trainable aid experience were mostly positive, indicating the usefulness of trainable aids in clinical practice.

The second study evaluated consistency of listening preference, as a repeatable preference is necessary for fine-tuned settings to be a reflection of the actual preference. Fifty-two participants with normal hearing or mild to moderate hearing loss selected their preference for hearing aid settings in simulated real-world environments in the laboratory. The settings differed in intensity, gain-frequency slope, and directionality. Additionally, nine psychoacoustic, cognitive and personality measures were obtained and evaluated for their predictive value of consistent preferences. Consistency of preference was variable across participants and depended on the difference between settings, the environment, and their interaction. More participants had a consistent preference for large intensity and large gain-frequency differences, and in less complex listening environments. The selected psychoacoustic, cognitive and personality measures could not predict who was more likely to obtain more consistent preferences. These findings questioned the effectiveness of fine-tuning as commonly performed in the clinic, and of successfully training hearing aids in complex listening environments.

The last study was a mixed methods trial evaluating the time-course, outcomes and prediction of training when hearing aids were provided in a typical clinical context. Also, participants were interviewed about how they went about making adjustments to their hearing aid settings in their own listening environments. The 23 participants were recruited among participants who completed study two and were fitted with receiver-in-the-canal hearing aids and provided with a remote control. After 2 weeks, half of the participants who made adjustments obtained trained settings different from the prescribed, increasing to 61% after 6 weeks. There was no difference in hearing aid fitting outcomes between those who obtained trained settings and those who did not. Measures obtained in the second study could not predict who was likely to obtain trained settings. These findings suggested that training could be activated for those who can manage the user controls, and that a review of users' progress is recommended 2 weeks after hearing aid fitting.

The interviews investigating how participants made adjustments to their hearing aid settings revealed two themes: barriers and facilitators to making adjustments. Both barriers and facilitators concerned the perceived need to make adjustments, remote control use, and the difficulty or ease of making adjustments to the settings. Additionally, time to learn was a facilitator to making adjustments. Reported strategies to adjust the settings suggested that trainable hearing aid users might benefit from additional counselling about the training process, and from specific advice to make adjustments in the moment they were needed.

This thesis provided new evidence about the impact and application of trainable hearing aids by providing insight into the attitudes of clinicians and adults with hearing loss towards trainable aids, the ability of adults with hearing loss to select consistent preferences when comparing different hearing aid settings, how users adjust trainable aids in everyday environments, and into the time-course and outcomes of training. Research findings overall demonstrate a need for user-driven fine-tuning and provide support for the use of trainable hearing aids in clinical practice.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Els Walravens (Candidate)	Conception and design (80%) Analysis and interpretation (70%) Drafting and production (70%)
Gitte Keidser	Conception and design (10%) Analysis and interpretation (15%) Drafting and production (15%)
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Contributions by others to the thesis

The majority of the work included in this thesis was conducted by the candidate. Professor Louise Hickson and Adjunct Professor Gitte Keidser advised and assisted with designing the protocols, interpretation of the findings and editing the manuscripts.

The devices used for study described in Chapter 5 and 6 were on loan from Sivantos Pte. Ltd., a partner of the The HEARing CRC.

All intellectual property vested in the trainable hearing aid is legally owned by HEARworks Pty Ltd. HEARworks Pty Ltd was founded in 1999 by the Cooperative Research Centre (CRC) HEAR as the intellectual property (IP) holding and commercialisation arm of the current CRC (The HEARing CRC).

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Table of contents

Abstract ii

Declaration by author iv

Publications during candidature v

Publications included in this thesis vi

Contributions by others to the thesis vi

Statement of parts of the thesis submitted to qualify for the award of another degree vii

Research Involving Human or Animal Subjects vii

Acknowledgements viii

Financial support ix

Keywords ix

Australian and New Zealand Standard Research Classifications (ANZSRC) ix

Fields of Research (FoR) Classification ix

Figures and Tables xv

- Figures xv
- Tables xvi

Abbreviations xvii

Chapter 1 - Introduction 1

- 1.1 Importance of This Research 1
- 1.2 Approach and Aims 2
- 1.3 Outline of the Thesis 3
- 1.4 References 5

Chapter 2 - Literature 7

- 2.1 Background 7
  - 2.1.1 Hearing Loss in Adults 7
  - 2.1.2 Hearing Aid Fitting 8
- 2.2 Trainable Hearing Aids 9

2.2.1 Training Algorithms 9
2.2.2 Evolution of Trainable Hearing Aids 10
2.2.3 Potential Benefit and Impact of Trainable Hearing Aids 14
2.2.4 Factors Influencing Successful Use of Trainable Hearing Aids 16
2.2.5 Clinical Applications 23
2.2.6 Gaps in Evidence and Rationale for Research 24
2.3 References 25
Chapter 3 - Provision, Perception and Use of Trainable Hearing Aids in Australia: a Survey of Clinicians and Hearing-Impaired Adults 30
3.1 Abstract 30
3.2 Introduction 30
3.3 Method 33
3.3.1 Material 33
3.3.2 Analysis 34
3.4 Clinician Survey 34
3.4.1 Design 34
3.4.2 Results 35
3.5 Survey for Hearing-Impaired Adults 40
3.5.1 Design 40
3.5.2 Results 41
3.6 Discussion 43
3.6.1 Limitations and Future Directions 45
3.7 Conclusion 46
3.8 References 47
Chapter 4 - Consistency of Hearing Aid Setting Preference in Simulated Real-World Environments: Implications for Trainable Hearing Aids 50
4.1 Abstract 50
4.2 Introduction 51

4.3 Method 53
  4.3.1 Participants 53
  4.3.2 Profile Measures 54
  4.3.3 Hearing Devices and Test Settings 56
  4.3.4 Equipment and Stimuli 58
  4.3.5 Procedure 59
4.4 Results 61
  4.4.1 Consistency of Preferences 61
  4.4.2 Relationship Between Profile Measures and Consistency of Preferences 69
4.5 Discussion 71
  4.5.1 Study Limitations 74
  4.5.2 Implications and Future Directions 75
4.6 Conclusion 75
4.7 References 76
Chapter 5 - Activating Training in Hearing Aids: Time-Course, Outcomes, and Prediction of Training 81
5.1 Abstract 81
5.2 Introduction 81
5.3 Materials and Methods 84
  5.3.1 Participants 84
  5.3.2 Devices 84
  5.3.3 Outcome Measures 85
  5.3.4 Consistency of Listening Preference Measures 85
  5.3.5 Procedure 86
  5.3.6 Data Analysis 88
5.4 Results 89
  5.4.1 Time-Course 89

    - 5.4.2 Outcomes of Training 91
    - 5.4.3 Prediction of Obtaining Trained Settings 92
- 5.5 Discussion 93
    - 5.5.1 Limitations 95
    - 5.5.2 Implications and Future Directions 96
- 5.6 Conclusion 97
- 5.7 References 97

Chapter 6 - Barriers and Facilitators to User-Driven Fine-Tuning 99

- 6.1 Abstract 99
- 6.2 Introduction 100
- 6.3 Materials and Methods 101
    - 6.3.1 Participants 101
    - 6.3.2 Devices and Fitting 104
    - 6.3.3 Procedure: Appointment Structure 105
    - 6.3.4 Procedure: Interviews 107
    - 6.3.5 Analysis 107
- 6.4 Results 109
    - 6.4.1 Facilitators to Making Adjustments 109
    - 6.4.2 Barriers to Making Adjustments 109
    - 6.4.3 Opinions on Trainable Hearing Aids 111
- 6.5 Discussion 116
    - 6.5.1 Limitations 118
    - 6.5.2 Implications and Future Directions 119
- 6.6 Conclusion 119
- 6.7 References 119

Chapter 7 - Conclusion 122

- 7.1 Summary of Findings 122

7.1.1 Comparison Between Survey and Mixed Methods Study 124

7.1.2 Qualitative Findings Informing Quantitative Results of the Mixed Methods study.......125

7.2 Limitations and Future Directions 125

7.3 Clinical Implications 127

7.3.1 Suggestions for Managing Trainable Hearing Aids in Clinical Practice 127

7.4 Conclusion 128

7.5 References..130

Appendices..131

Appendix A - Questions From Surveys Described in Chapter 3 131

A.1 Clinician Survey...131

A.2 Survey for Adults With Hearing Loss..150

Appendix B - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 3..159

Appendix C - Ethical Approval From the University of Queensland Behavioural & Social Sciences Ethical Review Committee for the Study Described in Chapter 3 160

Appendix D - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 4 and 5...161

Appendix E - Ethical Approval From the University of Queensland Behavioural & Social Sciences Ethical Review Committee for the Study Described in Chapter 4 and 5......................162

Appendix F - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 5 and 6...163

Appendix G - Ethical Approval From the University of Queensland Human Research Ethics Committees A & B for the Study Described in Chapter 5 and 6 164

Appendix H - Raw Data of Profile Measures (Chapter 4)...166

Appendix I - Performance on profile measures (Chapter 4)..172

Figures and Tables

Figures

Figure 3-1. Overview of the clinicians based on their reported experience activating a trainable feature (total n = 259): providers (n = 137) activated trainable features, passive non-providers (n = 87) made no active decision on whether to provide a trainable feature, and active non-providers (n = 35) disabled the trainable features. 36

Figure 3-2. The proportions of disadvantages (left) and advantages (right) to using trainable aids for the clinician and their practice (top) and the user (bottom), viewed by providers (n = 137, dark grey) and non-providers (active and passive non-providers, n = 122, light grey) of trainable hearing aids. 39

Figure 3-3. Overview of the groups of hearing aid candidates and users based on their experience with trainable hearing aids (total n = 104). 43

Figure 4-1. The spread in binaural average hearing loss represented by the four-frequency average hearing loss, and the slope, that is the difference between the average thresholds across 250, 500 and 1000 Hz (low-frequency average) and across 2, 3 and 4 kHz (high-frequency average). 53

Figure 4-2. The levels of speech (full line) and noise (dashed line) across the four listening environments in third octave bands (dB SPL long-term average): traffic noise; monologue in traffic noise at 5 dB SNR; dialogue in café noise at 5 dB SNR; and at 0 dB SNR. 59

Figure 4-3. The number of consistent preferences obtained by participants (n = 52) across all pairs of hearing aid (HA) settings in the different listening environments. 61

Figure 4-4. The number of participants with a consistent preference for the five pairs of HA settings across the four listening environments from easiest to most difficult: traffic noise, monologue in traffic noise, dialogue in café noise at 5 dB SNR and 0 dB SNR. 63

Figure 5-1. Average changes in high-frequency gain (HF gain) between 2 and 6 weeks of HA use. A positive value indicates that gain continued to be changed in the same direction. The whiskers indicate the 95% confidence intervals, with the circles depicting outliers. 91

Figure 5-2. Average IOI-HA ratings after 6 weeks of use for those who had obtained trained settings (grey; n = 11) and those who had not (white; n = 7). The whiskers indicate the 95% confidence intervals, with the circles depicting outliers. 92

Figure 6-1. One-page user guide for the remote control for those not using a telecoil (Sivantos Pte. Ltd.). 105

Figure 6-2. Representation of the remote control display when changing the volume (left), increasing the sharpness (middle) and decreasing the sharpness (right). 106

Tables

Table 3-1. Trainable features used in hearing aids from the main manufacturers. 32
Table 3-2. Demographic characteristics of clinicians (n = 259). 35
Table 3-3. Demographic description of the hearing aid users and candidates (n = 104). 41
Table 4-1. Description of the different comparison pairs, including their variation from the baseline and rms difference. 57
Table 4-2. Written instructions for the preference task. 60
Table 4-3. Pairwise comparisons with the odds ratio (OR) quantifying the influence of environment on consistency of preference. P1 represents the sample proportion for the probability estimate (p2 est) for which the 95% confidence interval (CI) and their comparative value (p2/p1) is displayed. The pairwise comparisons reaching significance are shown in bold. 65
Table 4-4. Pairwise comparisons with the odds ratio (OR) quantifying the influence of the difference between HA settings on consistency of preference. P1 represents the sample proportion for the probability estimate (p2 est) for which the 95% confidence interval (CI) and their comparative value (p2/p1) is displayed. The pairwise comparisons reaching significance are shown in bold. 67
Table 4-5. The loadings of the different profile measures on three factors referred to as 'High-Frequency Hearing', 'ACE Personality Traits', and 'Low-Frequency Hearing'. Loadings greater than 0.6 are shown in bold. 70
Table 5-1. Verbal instructions provided at the end of Appointment 1. 87
Table 5-2. Percentages of measures of trained gain changes (low-frequency gain (LF gain), low-frequency compression (LF CR), high-frequency gain (HF gain), and high-frequency compression (HF CR)) differing from the prescribed by less than 2 dB, from 2 to 4 dB, and from 4 to 6 dB after 2 and 6 weeks of HA use. 90
Table 6-1. Description of the participants, with an asterisk indicating participation in trainable hearing aid research in the last five years. 102
Table 6-2. Verbal instructions provided at the end of the fitting appointment. 106
Table 6-3. Two-week interview topic guide. 108
Table 6-4. Six-week interview topic guide. 108
Table 6-5. Theme of facilitators to making adjustments: subthemes, categories and example quotes. Participant number and appointment interview are shown in brackets after each quote. 112
Table 6-6. Theme of barriers to making adjustments: subthemes, categories and example quotes. Participant number and appointment interview are shown in brackets after each quote. 113
Table 7-1. Summary of the proposed follow-up management of trainable hearing aid users. 129

Abbreviations

COSI	Client Oriented Scale of Improvement
DiaCafe0dB	Dialogue in café noise at 0 dB SNR
DiaCafe5dB	Dialogue in café noise at 5 dB SNR
HA	Hearing aid
HF CR	Difference between the starting and trained response for the difference between a 50 and 80 dB input across the average of the two high-frequency bands
HF gain	Difference between the starting and trained response for a 65 dB input across the average of the two high-frequency bands
IOI-HA	International Outcome Inventory for Hearing Aids
LF CR	Difference between the starting and trained response for the difference between a 50 and 80 dB input across the average of the two low-frequency bands
LF gain	Difference between the starting and trained response for a 65 dB input across the average of the two low-frequency bands
MoCA	Montreal Cognitive Assessment
MonTraf5dB	Monologue in traffic noise at 5 dB SNR
NAL-NL1	National Acoustic Laboratories non-linear version 1 fitting rule
NAL-NL2	National Acoustic Laboratories non-linear version 2 fitting rule
NAL-RP	National Acoustic Laboratories revised-profound fitting rule
Rms	Root-mean-square
SNR	Signal-to-noise ratio
Traf	Traffic noise

Chapter 1 - Introduction

1.1 Importance of This Research

Pressure on available clinical audiology services is expected to increase with an increasing number of ageing adults needing hearing help (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011; Lin et al., 2013; Mitchell et al., 2011). Although alternative delivery models are available, such as completing a hearing test and fitting hearing aids (HAs) at home using a computer, it is expected that these may not be a viable option for all older adults with a hearing loss. HAs set-up by the user require completing several potentially difficult tasks, for example, automated audiometry (Convery, Keidser, Seeto, & McLelland, 2017). Despite the availability of these alternative delivery models, the vast majority of HAs are still provided and fitted by clinicians in the audiology clinic environment (Hosford-Dunn, 2015), not least because HAs and their provision are highly regulated and their distribution systems are well-established.

One way to address the potential future pressure on clinical audiology services is to redistribute clinical time, allowing for an increased clinician caseload. Traditionally, clinicians may spend a considerable amount of their time fine-tuning HAs in the clinic, that is, adjusting the HA settings after the initial fitting. A fitting is based on the user’s hearing loss, for which fitting rules provide amplification targets derived from the preference of an average person with a given hearing loss (Byrne & Dillon, 1986). However, not all users prefer this average and they may request fine-tuning (Dillon, 2012; Valentine, Dundas, & Fitz, 2011; Zakis, 2003). Fine-tuning can be a complex task, as it depends on the HA user’s recall and description of the listening environment where they experienced difficulty, and on the clinician knowing which of the many HA features to adjust to improve hearing in that particular listening situation (Nelson, 2001; Valentine et al., 2011). Additionally, the success of the fine-tuned HA settings often cannot be verified easily because a similar acoustic situation cannot be recreated in the clinic (Dreschler, Keidser, Convery, & Dillon, 2008). Consequently, the HA user may repeatedly have to return days or weeks later if the fine-tuning did not have the desired effect. If some HA users could perform fine-tuning themselves, the clinician could spend that time with other clients.

One way for users to fine-tune their own HA settings in their own listening environment is by using a trainable algorithm or trainable HAs. A trainable HA was patented by HearWorks and described as “an auditory prosthesis that adjusts its sound processing characteristics in a particular acoustic environment in a manner that is similar or identical to that previously determined by the user of the prosthesis as optimal for that environment” (Dillon, Zakis, McDermott, & Keidser, 2003, p. 1). Based on consistent user-adjustments to the HA controls (e.g. a volume control) and the acoustic environment at the time of the adjustments, the trainable algorithm will change the HA settings to match the user’s listening preference. The user trains the HAs by adjusting the HA control(s) to vary the HA setting when they are unhappy with the performance of the HAs and then evaluates if their adjustment results in a setting they prefer to the original. In other words, the HA user selects a preference between the new and original setting, completing one or more paired-comparisons to improve the performance of their HAs. However, the HAs will only modify the HA settings if their preference is consistent and their adjustments result in similar settings for similar acoustic environments. Trainable HAs were anticipated to have advantages for both clinicians and clients, summarised as spending less time fine-tuning in the clinic, and obtaining personalised settings and improving satisfaction with the HAs, respectively (Dillon et al., 2006).

After the successful implementation of a trainable algorithm (Zakis, 2003), research focused on evaluating its implementation, with participants encouraged to make adjustments to the HA controls to explore different settings in different environments. Research findings indicated that most participants could train successfully, obtaining HA settings they preferred over the starting response, provided that there was a difference between them (Keidser & Alamudi, 2013; Zakis, Dillon, & McDermott, 2007). Training was also found to be reliable (Keidser & Alamudi, 2013).

The motivation for this research was that, although trainable HAs have been commercially available for over 10 years, little published data were available about their impact in clinical practice, including opinions and experiences of clinicians, users and potential users. Also, for fine-tuning to be effective, such that the fine-tuned response is likely to be a true reflection of the user’s preference, a user needs a consistent listening preference. In this thesis, the repeatable selection of the same HA settings as a preference is referred to as consistency of preference. Despite its importance, consistency of preference for different HA settings was unknown. Similarly, it was unknown whether consistency of preference could be predicted using measures that are already available. Further unanswered questions remained, such as: What training would HA users undertake when not explicitly asked to make adjustments, as is the case in clinical practice? What are the time-course and outcomes of training, and can training be predicted from laboratory-based tests such as consistency of preference, psychoacoustic, cognitive or personality measures? And how do users go about making adjustments to their HA settings in their own listening environments?

1.2 Approach and Aims

To address these research questions, three studies were conducted. The aim of study 1 was to evaluate the impact of trainable HAs in clinical practice. Using an online survey, clinicians were asked about their use of and experience with trainable HAs. Adults with a hearing loss were invited to share their expectations for and experiences with trainable HAs.

Study 2 was set-up to evaluate consistency of preference for HA settings. Preference measures are the basis of fine-tuning, whether performed in the clinic by a clinician or in users' own listening environment using a trainable algorithm. When the HA user reports a complaint, the clinician may adjust a HA setting and ask the user whether this is an improvement, or the new setting is preferred over the original. The user needs a consistent listening preference for fine-tuning to be effective. In study 2, participants selected their preference for pairs of HA settings when listening to simulated real-world environments in the laboratory using a two-alternative forced-choice task. Furthermore, it was investigated whether consistency of preference could be predicted from measures that could be assessed more easily, such as psychoacoustic, cognitive and personality measures.

Lastly, the aim of study 3 was to evaluate the time-course, outcomes and prediction of training, and how HA users went about making adjustments to their HA settings in their own listening environments. Participants who took part in this mixed methods study were told that the HAs would try to learn from the adjustments they made, but they were not explicitly encouraged to make adjustments, resembling clinical practice. Participants who had previously contributed to study 2 and who had a hearing loss that could benefit from HAs were invited to participate in this 2- to 6-week field trial. After using trainable HAs for 2 weeks, participants attended an appointment during which their logged HA information was retrieved, and they completed outcome measures and were interviewed. All but those who had made no adjustments using the HA controls and were happy with the settings, were offered to continue using the HAs for another 4 weeks, after which participants returned and the same information was obtained again. A secondary aim of study 3 was to evaluate whether measures obtained in study 2 – consistency of preference and performance on psychoacoustic, cognitive and personality measures – could predict whether participants were likely to obtain trained settings different from the prescribed settings.

Findings from this research into the impact and application of trainable HAs will be consolidated with the available research to provide a basis for developing recommendations for how clinicians should provide trainable HAs and support trainable HA users.

1.3 Outline of the Thesis

Each chapter of the thesis except for this introduction and the final chapter have been prepared in journal article format, as they have been accepted (Chapter 3), are under review (Chapter 4) or in preparation for submission to a peer-reviewed journal (Chapters 5 and 6). Changes have been made to ensure that formatting, terminology, referencing and spelling are uniform across the thesis.

Chapter 2 contains a review of key literature on trainable HAs, including their potential benefit, suggested requirements for successful use, and current clinical applications. It concludes with an overview of the gaps in evidence and the rationale for this research.

Chapter 3 describes the findings from study 1, a survey evaluating the impact of trainable HAs in Australian clinical practice. As no peer-reviewed information was available on the impact of trainable HAs, adults with a hearing loss and clinicians were invited to share their experience and expectations in a survey.

Chapter 4 reports study 2, which investigated the consistency of listening preference of 52 adults. Participants selected their preference between pairs of HA settings differing in intensity, gain-frequency slope and directionality in four simulated real-world environments, for a total of 19 conditions. Additionally, measures proposed to influence the consistency of preference were evaluated for their predictive value.

Chapters 5 and 6 report on study 3, the mixed methods study evaluating what training users undertake when protocols similar to clinical practice are used. This approach is different to earlier research, which focused on evaluating the implementation of training, where participants were explicitly asked to make adjustments and try different settings in different environments. To also investigate the relationship between consistency of preference in the laboratory (Chapter 4) and the use of trainable HAs in the real world, participants who were part of study 2 were invited to take part in this 2- to 6-week field trial.

Chapter 5 contains the quantitative findings from the mixed method study, evaluating the time-course and outcomes of training over 6 weeks. Furthermore, measures from the study on consistency of preference (Chapter 4) were assessed for their predictive value for obtaining trained settings different from the prescribed settings.

Chapter 6 reports on the findings from the semi-structured interviews conducted during the field trial after 2 and after 6 weeks of HA use. This investigation builds on a gap in knowledge about how users go about making adjustments to their HA settings in their own listening environments. This information adds to trainable HA research and more broadly to other audiological areas using self-adjustments.

Chapter 7 provides a summary of the findings, both within and between the studies, and an overview of the limitations, future directions and implications of this work.

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Chapter 2 - Literature

The focus of this thesis is on the use of trainable HAs for adults with acquired hearing loss. In this chapter, background information about hearing loss and HA fitting for this population are briefly described initially. Following that, the concept of trainable HAs is described, their evolution and potential benefit and impact, as well as factors influencing successful use and clinical applications. Finally, the gaps in evidence and the rationale for this research project are described.

2.1 Background

2.1.1 Hearing Loss in Adults

The prevalence of hearing loss increases with age, with the proportion of those with a four frequency average hearing loss (at frequencies 0.5, 1, 2 and 4 kHz) over 25 dB HL in the better ear reaching 33.0% (95% CI 31.3–34.7) in adults aged 55 years and over (Mitchell et al., 2011), 59% in a group of 70 to 79 year-olds (Lin et al., 2013), and 63.1% (95% CI 57.4–68.8) in adults 70 years and over (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). Each decade over 60 years of age has been associated with a threefold increase of the risk of hearing loss (95% CI 2.3–3.8) (Mitchell et al., 2011).

Davis, Smith, Ferguson, Stephens, and Gianopoulos (2007) investigated the best cut-off for considering when hearing loss in older adults should be treated. Based on several studies, they established that the quality of life, HA benefit and benefit for speech intelligibility in noise were improved significantly when aiding adults aged 55 to 74 with a better ear four frequency average hearing loss of 35 dB HL and over. Many older adults however do seek help for when they have lesser degrees of hearing loss and have been found to benefit from HAs (Timmer, Hickson, & Launer, 2017b).

The impact of hearing loss reaches beyond the ability to hear, and is, for example, associated with depression (Keidser & Seeto, 2017; Li et al., 2014). Furthermore, after adjustments for potential influence of confounders, those with a moderate to severe hearing loss had a 1.5 (Dalton et al., 2003) to 2.9-fold increased likelihood (Gopinath et al., 2012) of reporting difficulties with Activities of Daily Living compared to those without a hearing loss. Similarly, health-related quality of life shows a significant relationship with the degree of hearing loss, with those having a greater degree of hearing loss showing poorer health-related quality of life (Dalton et al., 2003).

The most common treatment for hearing loss in older adults is the fitting of HAs, and a systematic review has shown HAs improve hearing-specific health-related quality of life (e.g. feeling less frustrated when talking to family members), general health-related quality of life and listening ability in adults with mild to moderate hearing loss (Ferguson et al., 2017).

2.1.2 Hearing Aid Fitting

In clinical practice, HAs are typically fitted based on the individual's hearing loss using generic prescription methods or manufacturers' proprietary fitting rules. Such prescription methods or fitting rules are available in the manufacturer's programming software and operationalized by selecting the "first fit" option. The settings can then be verified using real-ear measurements and adjusted so they match the target prescribed by the selected prescription method as closely as possible. Generic prescription methods use different philosophies to recommend HA settings for a particular hearing loss. For example, the Desired Sensation Level [input/output] (DSL i/o) aims to restore normalised loudness perception (Jenstad et al., 2007), the National Acoustic Laboratories non-linear version 2 fitting rule (NAL-NL2) attempts to make speech intelligible and overall loudness comfortable (Keidser, Dillon, Flax, Ching, & Brewer, 2011), and the Cambridge Method for Loudness Equalization 2 - High Frequency CAM2 attempts to amplify as much of the speech spectrum as possible within the audible range at similar loudness levels (Moore & Sęk, 2013).

With different prescription rules, different targets may be recommended for the same hearing loss (e.g. Keidser, Brew, & Peck, 2003). These targets may vary for the same hearing loss, however, Jenstad et al. (2007) concluded that HA users may have a range of acceptable responses, rather than a single ideal setting. Jenstad et al. (2007) evaluated the sound quality, loudness and consonant identification of HA users with a mild to moderately-severe hearing loss for responses as changes were made to low- and high-frequency gain from DSL (v4) targets. The advanced features were disabled and monaural, linear amplification was provided. The majority of participants performed well for all tasks within 10 dB of the levels prescribed for low- and high-frequency gain. Although HA users may accept a range of HA settings, in clinical practice many HA users will request changes to their HA settings, referred to as fine-tuning of HAs (Valentine et al., 2011; Zakis, 2003).

Research into the benefit of fine-tuning by the clinician is limited and has not shown an improvement in HA satisfaction, measured using questionnaires (Cunningham, Williams, & Goldsmith, 2001; Saunders, Lewis, & Forsline, 2009). Cunningham et al. (2001) evaluated the impact of fine-tuning on speech recognition in noise, sound quality and benefit in two groups of nine first-time HA users with a moderate hearing loss. All participants received counselling when they attended every 30 days for five sessions after the fitting, but for only one group changes were made to the HA settings if requested. After the five follow-up sessions, fine-tuned settings differed from the initial settings by 1 to 10 dB, but no significant differences were evident between groups on sound quality and benefit questionnaires. Only one of the 24 measures of speech recognition in noise was significantly different between groups, but this result was not consistent, leading the researchers to view this as a spurious finding. Cunningham et al. (2001) concluded from this pilot study that there was no benefit from fine-tuning. However, Saunders et al. (2009) did find that those who had fine-tuned aid settings were using their aids significantly more. In their study of 20 participants who had fine-tuned settings, 40% reported wearing their HAs for 8 hours per day or more, compared to 12.5% in a group of 40 whose aids were not fine-tuned. Despite limited evidence for the benefit of fine-tuning, clinicians will often be asked to improve users' listening experience, and need to decide whether to change the HA settings or counsel users that they will acclimatise to the sound (e.g. Cunningham et al., 2001; Dillon et al., 2012).

Fine-tuning can be a complex and drawn-out task due to its dependence on the user's recall and description of the problem (Nelson, 2001; Valentine et al., 2011) and the clinician's interpretation of the problem into changes to HA settings (Zakis, 2003). Furthermore, an assessment of the changes made to the HA settings is often not possible until the user returns to the same or a similar listening environment, as recreating the same scene in the clinic is difficult (Dreschler et al., 2008; Zakis, 2003). A potential solution for clients who need a lot of fine-tuning would be to let them fine-tune their own HAs in their own listening environments, using HAs with a trainable algorithm.

2.2 Trainable Hearing Aids

2.2.1 Training Algorithms

A training or learning algorithm adjusts HA settings based on consistent user-adjustments to the HA control(s) and information about the acoustic environment, allowing the user to optimise or fine-tune their HA settings.

There are a number of different trainable algorithms and they differ in three ways: 1) implementation, 2) information taken into account and 3) the HA settings modified. Firstly, the implementation of algorithms can vary for example in when the settings are recorded, their processing technique and when training is implemented. A trainable algorithm may be time- or event-based: either the algorithm extracts information at regular intervals or when the user makes an adjustment of the HA settings (Bentler, Ricketts, & Mueller, 2016). Algorithms may use different processing techniques, such as averaging (Chalupper, 2006) or probability theory (Dijkstra, Ypma, de Vries, & Leenen, 2007), and vary in the speed and reliability criteria that need to be met before changes are implemented. The algorithm may adjust the settings continuously or store the resulting settings until they are implemented using clinical software (Bentler et al., 2016; Phonak, 2005).

Secondly, information that can be taken into account by the trainable algorithm can be limited to the adjustments the user makes, or also include acoustic information on the environment. User adjustments that can be taken into account are most often volume (e.g. Chalupper 2006) but can include, for example, the gain-frequency response (Chalupper, Junius, & Powers, 2009).

Characteristics of the acoustic environment can include the level (Scheller, 2011), gain-frequency response (Chalupper et al., 2009), type of sound (e.g. music or speech-in-noise; Siemens AG, 2010) or a combination.

Thirdly, the HA settings that can be modified by the trainable algorithm based on volume adjustments can range from the start-up volume (Chalupper, 2006) to compression when taking the level of the environment into account (e.g. Chalupper et al., 2009). Furthermore, the settings may be applied based on the type of sound (e.g. Siemens AG, 2010), and may be trained in different frequency bands (Chalupper et al., 2009). Some trainable algorithms use a single user input, for example a clarity-comfort feature, which modifies multiple settings including noise reduction, directionality and gain (Taylor, 2011).

Although the training algorithm modifies the settings programmed by the clinician, based on user-adjustments, the clinician's input is not limited to deciding when to activate and deactivate the algorithm. The clinician will evaluate with the user if they are able to make adjustments and if they would like to use this feature; if so, the clinician instructs the user on the process. Additional choices have to be made in some fitting software, such as limiting the degree of change (Siemens, 2013), or whether to activate the fine-tuning suggestion (Fabry & Tchorz, 2005). The clinician can also review the outcome of the training period with the user, for example based on the trained gain changes and satisfaction with the HA performance (Keidser & Alamudi, 2013).

Before a trainable algorithm was implemented in stand-alone hearing devices for evaluation in the early 2000s, research into self-adjustments for fine-tuning was conducted.

2.2.2 Evolution of Trainable Hearing Aids

Research on self-adjustments for fine-tuning

Before the trainable HA provided a way for the user to fine-tune HA settings in their own listening environment, research was undertaken into user-driven fine-tuning in the laboratory, for example based on particular listening criteria (Lunner, Hellgren, Arlinger, & Elberling, 1997) or preference (Elberling & Vejlby Hansen, 1999). Lunner et al. (1997) asked 8 participants to adjust the low- and high-frequency gain based on the perception of their own voice while reading and clarity of voices and music, respectively. Starting from a generic prescription, the gain-frequency response was not changed. Participants used the prescribed and fine-tuned setting for one week each and then compared them for two weeks. Performance on a speech recognition task in noise showed no difference between settings. However, the fine-tuned response rated higher than the prescribed for ratings of overall impression and loudness, assessed using a questionnaire and laboratory presentations. These findings confirm listeners may prefer different HA settings than prescribed.

Elberling and Vejlby Hansen (1999) asked 13 hearing-impaired participants to adjust the “bass”, “middle” and “treble” of different speech-in-noise scenes to their preference while listening using insert earphones, starting from a proprietary prescription. Elberling and Vejlby Hansen (1999) reported that participants obtained settings expected for their hearing loss and that the settings participants obtained were repeatable. When reviewing the insertion gain difference for three of the scenes, the authors found a maximal average difference between two trials for 50 dB SPL inputs of 1.6 dB (SD = 3.0 dB) at 500 Hz and for 80 dB SPL inputs of 1 dB (SD = 4.1 dB) at 2000 Hz. Structured interviews showed participants found the process easy, exciting, and liked that they did not have to explain what they wanted to do but could try different settings themselves. This early research suggested that HA users could obtain HA settings appropriate for their hearing loss and do so reliably for different speech-in-noise environments and that participants found this a positive experience.

Initial trainable hearing aid research

Early proof of concept work was conducted by Zakis (2003), based on a patent awarded to HEARworks (Dillon et al., 2003). A digital body-worn HA was developed that provided slow-acting non-linear amplification across three channels with centre frequencies 375, 1250 and 4000 Hz. The device regularly evaluated the overall signal-to-noise ratio (SNR) and the SNR across the three amplification channels of the user’s listening environment. The HA was programmed to match the National Acoustic Laboratories non-linear fitting procedure, version 1 targets (NAL-NL1; Byrne, Dillon, Ching, Katsch, & Keidser, 2001) and adjustments were made to the gain below the compression threshold for own voice comfort, to avoid feedback and insufficient or excessive loudness. Participants were invited to a training trial and subsequently two comparison trials (Zakis, 2003). Depending on the trial, participants were given different instructions which they practiced, a different user guide, and only the relevant HA controls were enabled. The processor contained the following controls: a voting button, program switch, on/off switch and a rotary control. During the training trial, the rotary control made changes in 2 dB steps with a range of ± 14 dB, cycling through three different functions. When the device was turned on, the control first functioned as a volume control. After pressing the vote button, the control changed to one that could increase gain in the mid-frequencies, while changing the low- and high-frequencies in the opposite direction, each by factor 0.5 per adjustment step, so that the overall volume remained the same. After pressing the vote button again, the rotary control enabled changes to gain in the low and high frequencies only, in opposite directions, again maintaining the overall volume. Participants were instructed to set the rotary position to their preferred setting and then to vote, and to do this at least three times each time they were in a new listening environment. After voting, the trainable algorithm stored the preferred gain levels and corresponding SNR setting for the three channels, and overall SNR. As soon as sufficient data was available for the algorithm to provide a reasonable prediction of the preferred amplification setting, based on the relationship between the preferred gain setting and the channel-dependent and overall SNRs, the settings that were predicted to be most appropriate for the current acoustic environment were implemented. This implementation enabled participants to train the compression ratio, the compression threshold, the gain provided below the compression threshold, and noise reduction across the three channels (Zakis, 2003).

Eighteen participants with a mild to severe sensorineural hearing loss participated in the training trial, with four not reaching the preferred number of 150 votes after 4 weeks (Zakis, 2003). On average, participants decreased the gain especially in the mid- and high-frequency channels, at higher input levels and for lower SNRs. A change of 3 dB or more for an SNR difference between the channel and the overall SNR of 10 dB was considered significant. This value was reached 17%, 36% and 14% of the time for the low-, mid- and high-frequency channel, respectively. During the next trial, participants were asked to compare two settings in their own listening environment and vote for the one that “best met their needs and preferences at the time”. Participants were not advised that they were comparing their fitting response and trained settings, but settings generated by the device. Of the 13 participants who took part in the first comparison trial, 10 obtained a significant preference, nine of whom preferred their trained rather than their untrained setting. As participants could train noise reduction settings, but the prescribed response did not contain recommendations for noise reduction settings, Zakis (2003) next compared like with like, by disabling the trained noise reduction in the second comparison trial. Participants who had trained to reach high noise suppression strength in the first comparison trial were invited. This criterion ensured those with low trained noise suppression did not complete a second comparison trial which would be similar to their first comparison trial. All eight participants who completed the trial recorded more votes for the trained than the untrained response, with the number of votes of seven participants reaching significance. These findings showed participants could obtain personalised settings which most preferred over their untrained settings.

Commercial availability

Trainable algorithms have been present in commercially available HAs since 2006 (for an overview of the trainable features used in HAs from the main manufacturers, see Table 3-1, p. 32). Compared to initial trainable HA research by Zakis (2003), some of the early commercial devices took a more cautious approach by only providing the user the ability to train their preferred start-up volume for different programs (Chalupper, 2006). This implementation was accompanied by a feature which communicated the volume control and program setting between HAs, to ensure these were matched when using the HAs together. Based on the average changes made to the volume control over time, independently across the different HA programs, the trainable algorithm calculated a preferred start-up volume, and implemented this when the HAs were next turned on. No changes were made to the amplification settings, that is the change of the start-up volume moved the range of the available volume for the listener, for example from a starting range of +8 and -8dB to a range of +10 dB and -6 dB from the starting volume, if the user had trained the HA to lower the start-up volume by 2 dB. Upon review, the clinician could decide to change the master gain, such that the preferred start-up volume for a particular program was again in the middle of the available volume range.

Along with improvements in HA technology, the number of features that can be trained has increased over time. At the time of writing, the most advanced all-in-one implementation is that of Sivantos, under the name of SoundLearning 2.0 (Siemens AG, 2010). Based on the user-adjustments to the volume or high-frequency gain, this algorithm will change the gain-frequency response, compression ratio, gain below the compression threshold, and the Maximum power output. Values for the band levels in between those that are trained are interpolated. Changes to these settings can occur in four frequency bands and across different sound classes. If the input level of the signal is lower than the midpoint between the compression threshold and maximum power output, consistent adjustments will change the compression and the gain below the compression threshold, keeping the maximum power output unchanged. On the other hand, if the input level of the signal is higher than the same midpoint, consistent adjustments will change the compression and the maximum power output, while maintaining the gain below the compression threshold. When consistent adjustments are made at input levels below the compression threshold, the resulting gain change will be applied to all input levels. The available sound classes are quiet, noise, speech in quiet, speech in noise, car noise and music.

More recently, another form of learning was made commercially available by Widex (Barnes, 2018). By using a smartphone app, the user can select their preferred HA setting by completing A-B comparisons. The settings are suggested based on machine learning from other listeners' experiences, making the comparisons more efficient, so fewer comparisons need to be completed to optimise the multiple HA settings. Once the user has found a setting they prefer, they can save this as a new program. The user benefits from machine learning based on other HA users' preferences though this will not change their default HA settings.

Currently devices with a mid-to-high technology level from some manufacturers are trainable. However, as manufacturers' device ranges change at least in part every 6 months, the percentage of trainable aids in each manufacturer's product range is not known.

In parallel with the HA industry, algorithms are developed which are not implemented in HAs but so far used in the laboratory only (e.g. Yoon et al., 2017).

Future

It is possible that wireless connectivity of smartphones to HAs and other hearing devices will see an increase in the use of trainable algorithms as smartphones can provide additional processing power for algorithms which cannot currently be implemented in HAs. Furthermore, connectivity of hearing devices to smartphones will continue to provide additional information that can be used to improve the default settings by training, such as movement detection. For example, the HA microphones can change the directionality of the microphones when the smartphone senses that the user is walking (Jacobs, 2018).

Definition

For the purpose of this thesis, a trainable HA is defined as a wearable HA with an active algorithm that modifies the HA settings based on user-adjustments to the HA controls and the acoustic environment in which the adjustments are made, with the algorithm implementing the modifications incrementally over time.

The use of trainable HAs is proposed to have benefits beyond the user obtaining personalised HA settings and the clinician saving the time assigned to fine-tuning in the clinic.

2.2.3 Potential Benefit and Impact of Trainable Hearing Aids

Information is available about the potential impact of trainable HAs proposed by the research group responsible for the first implementation in a wearable HA (Dillon et al., 2006) and about views from potential users from the time trainable HAs were just becoming commercially available (Keidser, Convery, & Dillon, 2007). More recently, comments from clinicians made to researchers working with trainable HAs have been compiled (Bentler et al., 2016).

Dillon et al. (2006) indicated that clinicians might save time because their clients would need fewer visits to complete the fine-tuning in the clinic, and because a close match to the prescribed target during the appointment would be less important when the user would be fine-tuning themselves (Dillon et al., 2006). With extra time available, clinicians could provide more counselling and information on other assistive devices. Clinicians would also have more time to spend with more complex clients and to fit additional clients expected due to the increase in the number of people with age-related hearing loss. Users were expected to experience benefits such as improvements listening in different acoustic environments, fewer visits for further fine-tuning, fewer adjustments over time and increased ownership of the fitting (Dillon et al., 2006).

Keidser et al. (2007) conducted a survey of 100 HA candidates about their views on the concept of trainable HAs. As part of the survey, participants read a description of a trainable HA and used a keypad to adjust the overall volume and gain-frequency slope of a speech-in-noise signal. Presented in the free field, participants could make adjustments to a female voice in background noise to improve their listening experience for as long as they liked. This demonstrated the potential adjustments that could be made to train a HA, but not the step-by-step learning process. The majority of respondents (93%), ranging from 23 to 95 years of age (median = 77), understood the concept when it was described to them. Of those who understood the concept, 91% reported that they liked the concept, and 66% expected to experience benefits from using trainable aids if they had access to them (Keidser et al., 2007). The authors advised that these very positive findings should be interpreted cautiously as the outcome may have been influenced by the short time participants were given to consider the consequences and requirements of training. In addition, participants had already taken action for their hearing and were therefore more likely to be highly motivated to try HAs (Keidser et al., 2007). Responding to open-ended survey questions, users reported adjusting the HAs in their own listening environment without the need to return to the clinician as a potential benefit, but expressed some concern that they may not have sufficient knowledge to complete this process without support from an audiologist.

More recently, Bentler et al. (2016) reported anecdotal comments they received from clinicians who experienced advantages in using trainable HAs or who did not provide them for a variety of reasons. Advantages cited were a reduction in return visits in the first week after fitting and users preferring personalised settings. Clinicians also reported as advantages that users made fewer adjustments over time, and took ownership of the fitting and “bought into” the outcome of the fitting. Reasons why clinicians did not provide trainable HAs were related to the perception of their job and its future, and the users’ perceived difficulties with training and possible dissatisfaction with trained settings. Clinicians were concerned that their clients might question the clinician’s abilities if they were asked to do the fine-tuning instead of the clinician, and clients might undo the time-consuming HA programming that the clinician had undertaken. Some clinicians indicated that the client not attending for further appointments removed the clinician’s opportunity to show their skills while troubleshooting, which they saw as increasing client retention and a source of referrals. Trainable HAs were also perceived by some clinicians as a step in doing away with clinicians altogether during the fitting process. Some also expressed that their clients wanted things to be simple and that the additional information explaining training may confuse them (Bentler et al., 2016).

It was expected that not every user would benefit from trainable HAs, and several user and fitting factors have been suggested as important.

2.2.4 Factors Influencing Successful Use of Trainable Hearing Aids

The successful use of trainable HAs depends on a number of factors: ability to make adjustments to the HA controls, starting training from an appropriate response, having a consistent listening preference, and obtaining an acceptable response. Research has been done into reliability of training.

Management of user controls

An initial requirement for training is the user's ability to adjust the HA controls to ensure comfort in different listening environments (Dillon et al., 2006). HA management can be problematic for users (Bennett, Meyer, Eikelboom, & Atlas, 2018). In addition, users may have a preference for which platform they use to make adjustments to the HA controls (e.g. a remote control; Keidser et al., 2007), and which features they would like to adjust (Dreschler et al., 2008), though knowing the function of the available controls is not a necessity for successful use of the controls (Zakis, 2003).

Some HA users have difficulty with HA management, including volume adjustments and this would be problematic for training HAs. For example, Bennett et al. (2018) found that 29% of 518 HA users reported difficulty making adjustments to the onboard volume control of their HA, with clinicians judging that to be the case for 37% of the same participant group. Using an alternative platform to make adjustments may help some HA users who have difficulty managing the onboard controls. HA settings can be adjusted using a remote control or, increasingly, a smartphone app. Remote controls provide larger buttons than those onboard the HAs and a visual representation of the function of the controls. Smartphone apps also provide a visual representation, but their use may be less conspicuous, and more controls could be provided.

A survey by Keidser et al. (2007) highlighted the importance of the platform which users prefer to make adjustments. When surveying hearing centre clients about the concept of trainable HAs, Keidser et al. (2007) enquired about the preference for onboard controls or a remote control and the number of controls. Just over half of the participants (54%) indicated a preference for the remote control and the other half preferred onboard controls, the authors commenting that participants had strong preferences.

The efficiency of and preference for different configurations of controls to make adjustments to the HA settings were investigated by Dreschler et al. (2008). Participants evaluated four different control configurations, containing two or three pairs of buttons to increase or decrease the volume and/or gain-frequency response across three frequency bands. Listening to audio-visual stimuli presented in the free field, participants were asked to make adjustments to reach their preferred setting. To encourage adjustments, the starting response slope was adjusted to ±2.4, ±3.6 or ±4.8 dB/oct and an overall gain was applied of 0, 2, 4 or 6 dB lower than the National Acoustic

Laboratories Revised Profound fitting rule (NAL-RP; Byrne, Parkinson, & Newall, 1991). None of the controller configurations was more efficient in obtaining participants' preferred responses based on the number of adjustments made. Half of the 22 participants had a preference for the combination of a volume control and a tone control which changed the gain in the lowest and highest frequency bands in opposite directions. The second-most preferred configuration was a volume control, and a bass and treble control, affecting the lowest and the highest frequency bands respectively.

Early research found that knowing the function of the user control was not necessary for research participants to train their HAs. Zakis (2003) asked participants to use a rotary control on a body-worn HA to select their preferred setting and to vote once this setting was reached. The function of the rotary control changed every time a vote for a setting was made, cycling through three volume and gain-frequency configurations. Blinded to the actual functions of the control, most participants were able to use this configuration to make adjustments in their own listening environments.

Starting response

When evaluating the effect of using different control configurations on hearing-impaired listeners' preferred settings, Dreschler et al. (2008) found an influence of the starting response. To compare the efficiency of and preference for different controls, the gain-frequency response and level of the prescribed responses was modified from the prescribed to be steeper or flatter. This modification was found to have a significant effect. Results showed that, on average, lower gain in the starting response resulted in lower gain than prescribed in the preferred response, and a steeper starting response resulted in a steeper preferred response than that prescribed. The authors suggested three possible explanations for this finding. Firstly, participants may have been cautious in making changes to the starting response for fear of ending up too far from their preferred response. Secondly, participants may have had a range of acceptable responses, and stopped making adjustments as soon as the response was in this range. Lastly, Dreschler et al. (2008) indicated that participants evaluated one controller each in one session, always starting from the modified baseline response. They raised the possibility that participants might obtain different settings if they had additional opportunities to continue making adjustments to the response, similar to training HAs over time.

Keidser, Dillon, and Convery (2008) followed up on the findings from Dreschler et al. (2008) and investigated the influence of the starting response on preferred settings. Participants could adjust the overall gain ("volume"), the gain at 400 Hz ("bass") and at 4000 Hz ("treble"). Adjustments to the latter two controls also gradually modified the gain for frequencies up to 1250 Hz, based on interpolation. Participants' prescribed NAL-RP responses (Byrne et al., 1991) were modified to create the starting response by changing the gain by + or - 4.8 dB/oct, or an 8 dB change at 400 and 4000 Hz in opposite directions, without changing the gain at 1250 Hz. Participants were not merely asked to make adjustments to reach their preferred setting, but advised to experiment with the changes that the adjustments made, that there were no right or wrong settings, and that they could take as long as they needed. Spread over three appointments, participants adjusted the settings of two starting responses for 12 audio-visual stimuli, five times each. Starting from the + or – 4.8 dB/oct response in the first session, the resulting response of that session was used as the starting response for the second session etc. Keidser et al. (2008) found that participants made, on average, changes of more than 4 dB during the first round, for all three points where gain was measured (400, 1250 and 4000 Hz). The gain change between rounds reduced to less than 1 dB in the following rounds for most participants. However, a few participants continued to make larger changes, especially in the high frequencies when starting from a steep response. Thus, Keidser et al. (2008) found that there was an influence of the baseline response, though there was a large individual variation in the degree of influence. These findings suggested that the influence of the baseline response was not due to participants' conservative adjustments, a possibility raised by Dreschler et al. (2008), but were more in line with the proposition that some listeners may have a large range of acceptable or preferred HA settings.

The same year, Mueller, Hornsby, and Weber (2008) reported on the influence of the starting response on preferred gain using HAs that trained the start-up volume. In this cross-over study 22 participants wore the HAs twice for 10 to 14 days. For one trial the starting response was 6 dB higher in overall volume than the listener's NAL-NL1 response (Byrne et al., 2001) and for the other trial it was 6dB lower. Participants were encouraged to change the volume when needed to obtain the best loudness levels, but not advised that the HAs could train. They were provided with a volume range of +8 and -8 dB from these starting points. Ten of the 22 participants were excluded from the analysis due to floor and ceiling effects caused by the volume control range. The average results of the remaining 12 participants showed a significant influence of the starting gain (Mueller et al., 2008). With reference to NAL-NL1, when the starting gain was -6 dB, the preferred gain was on average -5dB, whereas when the starting gain was +6dB, the preferred gain was about +4dB. This study was the first to show the impact of the starting response on preferred gain following a field trial.

Finally, there is some evidence that for experienced HA users, the starting response is more influential than their current HA settings. In a presentation, Mueller and Hornsby (2014) shared findings from a study with 20 HA users who were fitted with HA settings to match their prescribed NAL-NL1 targets (Byrne et al., 2001). After a 2-week period using compression training, the authors found that although participants had decreased the prescribed settings somewhat, they had not returned to the settings of their own HAs, which were fitted below NAL-NL1 targets by approximately 5 and 7 dB for the average low- and high-frequency real-ear aided response for a 65 dB SPL input.

Consistency of preference

For fine-tuning to reflect the user's preference, their listening preference needs to be consistent, whether fine-tuning is performed in the clinic or by the user themselves during training. In this thesis, the repeatable selection of the same HA settings as a preference is referred to as consistency of preference. When training, if the user is unhappy with the HA performance, they make one or more adjustments and compare the new settings with the previous ones and select their preference. Training HAs can therefore be seen as a series of paired comparisons while making adjustments to improve listening experience. For the trainable HA to adjust the settings based on these preferences, the preferences have to be consistent. Listening preference is often used in HA evaluation (for an overview, see Amlani & Schafer, 2009; Kuk, 2002), however little is known about the reliability of preference. Furthermore, there is little research on factors that might influence consistency of preference.

Keidser et al. (2008) followed up their research into the influence of the starting response by recruiting 12 participants to investigate the possibility that some may have a large range of acceptable responses. Three baseline responses varying in gain-frequency slope were applied to six audio-visual stimuli and to the participants' NAL-RP responses (Byrne et al., 1991), resulting in an rms difference between responses of a pair ranging from 1 to 10 dB. For each pair of responses, participants selected the response "they would prefer if the same listening situation were encountered in real life". Each comparison was completed 10 times, and if the same response was preferred 9 or 10 times out of 10, it was considered to be a reliable preference, based on binomial distribution (Kuk & Lau, 1995). As well as selecting a preference between each pair, participants indicated the perceived difference between the responses: greatly, moderately, somewhat or not different. Results showed a large variation in reliability of preferences based on the rms difference between them: some participants obtained reliable preferences for response pairs with rms differences of 2 dB, while others did not have a reliable preference for pairs with differences of 10 dB. Ten of the 12 participants indicated a perceived increase in difference between responses with an increasing rms difference, and three of these ten obtained a reliable preference for the majority of comparisons. Keidser et al. (2008) found reliability of preference for responses differing in gain-frequency slope was variable, and proposed that the slope of hearing loss, cognitive factors, and the difference between the acoustical environments represented in the laboratory set-up and real-life listening environments may be influencing factors.

In general, the slope of hearing loss has been shown to be an important factor for self-adjusting to reach a preferred response, however findings have been mixed. Keidser et al. (2008) found that two of the three participants who had a reliable preference for the majority of comparisons had a sloping hearing loss. They proposed that those with a narrower audible dynamic range could more reliably select or reach a preference between two responses as one response may fall into the audible range more than the other. Similarly, Keidser et al. (2005) reported that listeners with more high-frequency hearing loss were more reliable when selecting their preferred gain-frequency response. Twenty-one participants with a mild to moderately-severe sensorineural hearing loss selected their preferred response for conditions differing in SNR, gain-frequency response of the background noise and listening criterion. Participants were encouraged to explore the different settings before selecting their preferred slope, which they completed three times for each condition. Different findings were reported by Dreschler et al. (2008), who evaluated the influence of different controller configurations to adjust volume and/or gain-frequency slope on the preferred response, when also starting from slopes with a different gain-frequency response to the prescribed. These researchers found that, on average, test-retest standard deviations increased with increasing slope of hearing loss.

The potential influence of cognition on reliability of preference was proposed by Keidser et al. (2008) in view of the consistency required to obtain a reliable response and the influence of working memory capacity on listening preference found by Lunner (2003). More recently, working memory capacity and executive function have been related to preference for different HA settings (Neher, 2014; Neher, Grimm, Hohmann, & Kollmeier, 2014). Lunner (2003) asked participants with a hearing loss and low or high working memory capacity to evaluate the performance of two programs. Participants compared a program with a speech-dependent algorithm to one without in their own listening environment. They rated both programs on a scale from 0 to 10 with 1 marked "very poor" and 9 "very good" across different listening situations. Participants with low working memory capacity showed similar preferences for both programs, whereas those with a high working memory capacity showed preferences depending on the listening situation. A connection between selectivity of preference and working memory capacity was also found by Neher et al. (2014). The researchers evaluated hearing-impaired listeners' preference for different degrees of noise reduction when listening to sentences in cafeteria noise at different SNRs using paired comparisons. The listeners with lower working memory capacity preferred the strong over the moderate noise reduction, independent of the SNR, whereas those with higher working memory capacity showed a preference dependent on the SNR. This finding could not be replicated in a follow-up study, in which Neher (2014) evaluated preference for different degrees of noise reduction again, including an additional condition of microphone mode (omnidirectional or cardioid). This study included a larger group of different participants who were also selected based on their working memory capacity and whose scores matched those of the earlier study. Although the relationship with working memory capacity could not be replicated, Neher (2014) found a significant interaction between an executive control measure and preference. For the omnidirectional condition, those with worse results on the executive function task disliked the lack of noise reduction more and liked strong noise reduction better than those with better results on the executive function task. This difference was only statistically significant for one of the three SNRs (+4 dB). The author was unsure why this measure could explain some of the variability in the preference results and proposed that the executive function measure was better able to capture the process involved with selecting a preference. In summary, some cognitive factors have been shown to influence selectivity of auditory preference in some conditions.

Acceptability of trained settings

A requirement for successful training would be obtaining settings acceptable to both the user and the clinician, which has been evaluated by establishing the user's preference for their trained settings over the prescribed settings, and evaluating the difference between those settings, respectively. Two peer-reviewed works have evaluated training when starting from a prescribed response, and the user's preference for their trained response (Keidser & Alamudi, 2013; Zakis, 2003). Zakis (2003) evaluated participants' preference for their trained settings, obtained using a prototype trainable HA, by asking participants to vote between their trained and initial settings in their own listening environments. Seven of eight participants logged significantly more votes for the trained setting.

Keidser and Alamudi (2013) asked their participants to complete a diary when comparing their trained settings to those prescribed by NAL-NL2 (Keidser et al., 2011), with each setting used every second day for a period of 2 weeks. The diary instructed participants on which program to use each day, and contained daily satisfaction ratings for overall and individually selected listening situations. Participants were invited to complete a training and comparison trial and to repeat these to evaluate reliability, so two series of preference data were available. For each trial, preference was established based on three different measures derived from an exit interview and the diary: the preference in the exit interview; the difference in average overall daily satisfaction scores between the prescribed and trained program retrieved from the diary; and the difference in average satisfaction scores for individually selected situations assigned to a sound class in which the trained setting was deemed significantly different from the prescribed. The satisfaction scores, on a scale from 0 (not at all) to 10 (very much), were considered to be different if they differed by more than 0.2 points. The comments from the exit interview and satisfaction ratings associated with other sound classes were used to obtain a final preference if the three measures had inconsistent outcomes. Preference data from 20 and 15 participants were available, with 10 and 4 obtaining a consistent preference for the first and repeat trial, respectively. Eight and three of these participants preferred their trained response over their prescribed response. Most participants were reported to be able to train their HAs, but Keidser and Alamudi (2013) found that 2 out of 26 participants in their study obtained a response they did not prefer, with the trained responses described as inferior to those prescribed. The authors noted that their outcome may have been different if participants had not been encouraged to make adjustments: these participants possibly had difficulty distinguishing between smaller differences between settings and were consequently unable to modify the settings back to the prescribed.

Reliability of training

Only a study by Keidser and Alamudi (2013) has so far evaluated the reliability of training HA settings in real life. Participants were encouraged to try different HA settings in different situations, wearing HAs with sound class specific compression training that could modify the gain independently across four frequency bands. For each of the six environmental sound classes that could be trained, the authors evaluated the correlation between the variations from the initial response across two trials for 19 participants. Their chosen measures were: the average gain change for a 65 dB SPL input (a) across the 2 lowest frequency bands, and (b) across the two highest frequency bands; the difference of the gain change for 40 and 90 dB SPL inputs (c) in the lowest 2 frequency bands, and (d) in the highest 2 frequency bands; and (e) the difference in gain change between the two lowest and two highest frequency bands for a 65 dB SPL input. Significant correlations were found for 12 participants, explaining between 29 and 81% of test-retest variability. Of the remaining 7 participants without significant correlations between test and retest values, 3 did not obtain a response different from the prescribed during the retest and 4 obtained different trained settings between both trials. Keidser and Alamudi (2013) reported that participants made fewer adjustments during their repeat trial, potentially resulting in less agreement between the settings obtained after both trials. Study fatigue or reduced novelty of experimenting with the controls were raised as potential influential factors for the reduced number of adjustments made.

Although information on the reliability of training is limited, further information can be gained from laboratory studies evaluating listeners’ adjustments of responses varying in gain-frequency slope from their prescribed response. When evaluating the preference of hearing-impaired listeners for different gain-frequency responses, Keidser et al. (2005) found that 73% of the responses for 20 conditions across three trials had an acceptable reliability, with an intra-participant standard deviation smaller than 5 dB. Evaluating different controller configurations to make adjustments, Dreschler et al. (2008) found that the mean test-retest standard deviation across stimuli, controllers and starting baseline for two trials ranged from 0.9 to 4.5 dB for the 24 participating HA users, with most participants obtaining a 2 to 3 dB standard deviation.

Several of the requirements for successful use of trainable HAs have been aggregated to provide suggestions for the clinical application of trainable HAs.

2.2.5 Clinical Applications

There are currently no guidelines on how to the fitting of manage trainable HAs in clinical practice, however some suggestions have been made about selection, instruction and evaluation. Although not evidence-based they are included here to provide background information about likely current clinical approaches.

Firstly, it is recommended to offer the feature to those interested (Keidser & Alamudi, 2013), ensure the client is willing and able to make adjustments in real-world situations (Bentler et al., 2016) and exclude those with poor manual dexterity or low cognitive function (Keidser & Alamudi, 2013). Bentler et al. (2016) suggest about 60 to 70% of the clinical population should be able to train.

Secondly, Bentler et al. (2016) suggest providing the client with detailed instructions for training, to ask them to go to different situations, and to make changes when needed to improve loudness, comfort and intelligibility. Additionally, a diary for ticking off different listening situations (e.g. loud noise, soft noise) is recommended to provide structure to the training process (Bentler et al., 2016).

Finally, to follow-up, the client’s progress should be monitored 2 weeks after the fitting, and their listening environments and trained changes should be evaluated by consulting the logged data. A month after the fitting, the clinician can deactivate the training feature if they want, reactivating it in the future when needed, for example when the client’s hearing loss has changed (Bentler et al., 2016). A more detailed approach to follow-up was provided by Keidser and Alamudi (2013), based on the changes made to the HA settings and the client’s satisfaction with HA performance. They suggest that a client who obtained changes to the HA settings and is satisfied with the HA performance should continue with an active training feature. If the client is satisfied but has not made considerable changes to the HA settings, they are expected to be satisfied with the fitting response. That fitting response should be reprogrammed and training deactivated so the settings are as intended at the fitting. Dissatisfied clients who did not obtain considerable changes to their HA settings should be encouraged to continue training and return for a further follow-up. If clients are dissatisfied and obtained changes to their HA settings, training should be deactivated and their settings reprogrammed to those from the fitting. Keidser and Alamudi (2013) further advised that this latter approach is required until more information is available about why some obtain HA settings they are dissatisfied with.

2.2.6 Gaps in Evidence and Rationale for Research

Although trainable HAs have been commercially available for over a decade, some important questions remain unanswered. Firstly, there is only very limited information on the views of clients and clinicians with experience using trainable HAs, or on the expectations of HA candidates. Therefore, the first study in this thesis was a survey of clinicians and adults with a hearing loss to explore the impact of trainable HAs in clinical practice (see Chapter 3).

Secondly, although consistency of preference seems an integral component of successful training, it has not been evaluated in a larger participant group (research to date describes a maximum of 12 participants), using more life-like listening environments and amplification. Additionally, the predictive value of psychoacoustic and cognitive factors on consistency of preference and how consistency of preference relates to training outcome has not been evaluated. A laboratory study was conducted as the second study in this thesis to evaluate consistency of auditory preference and whether any psychoacoustic, cognitive and personality measures could predict consistency of preference (see Chapter 4).

Finally, research to date has not included field trials of what HA users do when following procedures used in clinical practice, only making adjustments when needed. Furthermore, it is unknown how HA users go about making adjustments to their HA settings in the real world. When Keidser and Alamudi (2013) encouraged participants to try different HA settings in different environments, 2 out of 26 participants obtained trained settings they did not prefer. This meant that, during their training process, these users had consistently selected settings they did not prefer, raising the question of how they had made adjustments to their HA settings (Keidser & Alamudi, 2013). Therefore, the third study in this thesis was a mixed methods study was implemented to evaluate the time-course, outcomes and prediction of training following clinical practice procedures, and how HA users went about making adjustments to their HA settings in their own listening environments. Additionally, measures from the laboratory study of consistency of preference were evaluated for their ability to predict who was likely to obtain trained settings different from the prescribed settings in the real world (see Chapters 5 and 6).

It is envisaged that information gathered from these studies will contribute to the development of evidence-based guidelines for managing the fitting of trainable HAs in clinical settings.

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Chapter 3 - Provision, Perception and Use of Trainable Hearing Aids in Australia: a Survey of Clinicians and Hearing-Impaired Adults

This chapter is an adaptation of the following manuscript: Walravens, E., Keidser, G., & Hickson, L. (2016). Provision, perception and use of trainable hearing aids in Australia: a survey of clinicians and hearing impaired adults. International Journal of Audiology, 55(12), 787-795. doi:10.1080/14992027.2016.1219776.

The online supplemental material containing the questionnaires is included as Appendix A (p. 131). Thank you to Audiology Australia, the Australian College of Audiology, the Hearing Aid Audiometrist Society of Australia, Australian Hearing and Neurosensory for their recruitment effort and their members and clients for their participation.

3.1 Abstract

Objective. This study set out to obtain information on the impact of trainable hearing aids among clinicians and hearing aid users and candidates.

Design. Two online adaptive surveys were developed to evaluate provision, uptake, and experience or expectation of trainable hearing aids.

Study Sample. Responses from 259 clinicians, 81 hearing aid users and 23 candidates for hearing aids were included.

Results. Over half of the clinicians surveyed activated trainable features in hearing aids. Most of these clinicians activated trainable features for selected users, and reported positive findings. Most commonly trainable features were not activated because the hearing aid controls had already been disabled for management or client preference. One-third reported that they had no access to trainable aids or they were unsure about the presence or activation of trainable features. The remaining clinicians never activated trainable features. One in five users reported having used trainable aids and 93% would train again. Over 85% of the remaining hearing-impaired adults were interested in trainable aids.

Conclusions. Positive reports from most providers and users who had experience with the trainable feature support the provision of trainable aids to selected clients, pending more evidence-based data to support the clinical management of such devices.

3.2 Introduction

Hearing aids are typically fitted based on the individual’s hearing loss using established prescriptions aiming to provide benefit by improving audibility of speech and ensuring listening comfort for loud sounds (Abrams, Chisolm, McManus, & McArdle, 2012). These prescriptions are based on average data (Byrne & Dillon, 1986), and therefore it is expected that some listeners need fine-tuning of the prescribed response (Dillon, 2012; Valentine et al., 2011). Research into the benefit of fine-tuning (any changes made after the initial fitting) is limited and has not shown an improvement in satisfaction as measured using questionnaires (Cunningham et al., 2001; Saunders et., 2009). However, Saunders et al. (2009) did find those who had fine-tuned HA settings were using their HAs significantly more. In the group of 20 participants who had fine-tuned settings, 40% reported wearing their HAs for 8 hours per day or more, compared to 12.5% in the group of 40 whose HAs were not fine-tuned. Despite limited evidence for the benefit of fine-tuning, clinicians will often be asked to improve users' listening experience and need to decide whether to change the HA settings or counsel the user that they will adapt to the sound (Cunningham et al., 2001; Dillon, 2012).

Fine-tuning can be a complex and drawn-out task due to the number of available HA features, and its dependence on the user's recall and description of the problem (Nelson, 2001; Valentine et al., 2011). Furthermore, an assessment of the changes made to the HA settings is often not possible until the user returns to the same or a similar listening environment and recreating the scene in the clinic is difficult (Dreschler et al., 2008). Most of the difficulties of fine-tuning in the clinic could be overcome by a user-directed process: a trainable feature that is designed to learn the user's preferred settings in different listening environments. Based on the user's consistent changes to the HA controls and concurrent acoustic information from the environment, the trainable feature modifies the HA settings over time to match the user's preference (Dillon et al., 2006). The most common feature the user can change is volume, with some devices enabling users to adjust more sophisticated features such as noise reduction. A summary of the trainable features used in traditional HAs is displayed in Table 3-1.

The proposed advantages of successful trainable HA fitting for the client and clinician were described by Dillon et al. (2006). They can be summarised as obtaining personalised HA settings in fewer visits and improving satisfaction for clients, and reducing the time needed for HA fitting and fine-tuning for clinicians. Consequently, there could be (i) more time available to clinicians for counselling activities; and (ii) more capacity to provide services to a hearing-impaired population which is expected to increase in size. Although trainable HAs have been commercially available since 2006, there are few reports of perceptions of this HA feature and no reports of its use. It is therefore unclear as to whether the suggested benefits of training HAs for both clients and clinicians would be realised in clinical practice.

Table 3-1. Trainable features used in hearing aids from the main manufacturers.

Manufacturer	**Training name**	**Trained HA settings**
Bernafon	Data Learning	Overall gain
Interton	Learning volume control	Overall gain
Oticon	Life Learning	Environment specific overall gain, level-dependent
Phonak	Self Learning	Environment specific overall gain
	User Preference Learning	Environment specific, frequency selective volume, directionality, noise cancellation, wind noise and reverberation suppression
	User Preference Tuning	As User Preference Learning, but only applied after clinician accepts settings
ReSound	Environmental Learner	Environment specific overall gain
Siemens	DataLearning	Overall gain
	SoundLearning	Overall gain and compression in four frequency bands
	SoundLearning 2.0	Environment specific overall gain and compression in four frequency bands
Sonic	Data Learning	Overall gain
Starkey	Self Learning	Overall gain
Unitron	Self Learning	Environment specific gain, noise reduction, speech enhancement, (directionality)

Research that has been conducted into trainable HAs has shown that the concept was perceived positively by those already receiving hearing care, and that most research participants could train successfully and preferred their trained settings. A survey by Keidser et al (2007) showed that 93 out of 100 participants ranging in age from 23 to 95 years (median = 77) understood the concept when described to them and that 91% of them thought the concept was positive, with 66% expecting a personal benefit if they could access trainable HAs. Although research into the training process is limited, it shows most volunteers can train their HAs, with 24 out of 26 (Keidser & Alamudi, 2013) and all but “a couple” out of 36 research participants (Palmer, 2012) obtaining a response appropriate for their hearing loss. Listeners’ preference for their trained response has been assessed in the field in three studies: Zakis et al. (2007); Palmer (2012) and Keidser and Alamudi (2013). Although preference was evaluated differently in each study, all report that the majority of participants preferred their trained over the prescribed setting or had no preference for either. Using a prototype trainable HA, seven out of eight participants preferred their trained response when voting in real time between their trained and prescribed settings (Zakis et al., 2007). Referring to an unpublished study, Palmer (2012) reports that 22 out of 36 participants (61%) preferred their trained settings based on diary entries. Lastly, Keidser and Alamudi (2013) established preference based on three measures derived from an exit interview and a diary kept during a comparison trial. Eight out of ten, and three out of four listeners with a consistent preference, preferred their trained over their prescribed response (Keidser & Alamudi, 2013).

Suggestions on how to implement trainable HA fitting in clinical practice have been made (Keidser & Alamudi, 2013; Mueller, 2014). However, no evidence-based guidelines are currently available to assist clinicians, raising questions about how potential users' candidacy is currently evaluated and how best to support clients who choose to train their device. To address this, the overall aim of this study was to investigate perceptions of and experience with trainable HAs as reported by clinicians and hearing-impaired adults. The clinician survey was developed to evaluate (1) the provision of trainable HAs, (2) experiences with fitting trainable HAs, (3) perceived advantages and disadvantages, (4) used or proposed candidacy criteria, and (5) if there was a relationship between clinician demographic characteristics and the willingness to provide a trainable feature. The survey designed for hearing-impaired adults aimed to investigate (1) awareness of the concept of trainable HAs, (2) willingness to use trainable HAs and reasons for this, (3) advantages and disadvantages of usage, (4) if access to trainable HAs would make HA rehabilitation more attractive to HA candidates, and (5) if there is a relationship between client demographic characteristics and interest in using trainable HAs.

3.3 Method

3.3.1 Material

Two online surveys (one for clinicians and one for hearing-impaired adults) were developed for the study (the surveys are available online or in Appendix A, p. 131). Both surveys were built using SurveyGizmo (www.surveygizmo.com) and were adaptive: questions displayed were based on the respondent's familiarity with trainable HAs and previous responses. To balance the exploratory nature of the study and the time needed for completion, most items were forced-choice with the option to provide an additional response. Items and response options were based on several sources: theoretical expectations (Dillon et al., 2006), researchers' experience, group discussions with hearing-impaired adults, and interviews with clinicians. Preliminary surveys were piloted with 8 clinicians and 8 adults with hearing loss. Both surveys were composed of four sections: 1) qualifying items, 2) contingency items, 3) items on experience or expectations and 4) demographic items. Firstly, qualifying items ensured only the targeted audience participated. Next, contingency items provided a description of trainable HAs and established the degree of experience. Based on their responses, respondents were shown items evaluating their experience with or expectations of trainable HAs. Both surveys closed with demographic items, including for example the inviting organisation.

The format of the questions depended on the section of the survey. Qualifying, contingency and demographic items were all compulsory and in a multiple-choice format. To evaluate experiences or expectations, different formats were used: Likert scale rankings, forced-choice responses with the option to add an item, as well as open-ended questions. In total, participants were shown 18 to 38 items (clinicians) or 14 to 20 items (hearing-impaired adults) based on their experience with trainable HAs. The average completion time for the surveys was just under 15 minutes for clinicians, and around 6 minutes for hearing-impaired adults. Approval for the surveys was granted by the Australian Hearing Human Research Ethics Committee and the Behavioural and Social Sciences Ethical Review Committee of the University of Queensland. Responses were obtained from July until September 2015.

3.3.2 Analysis

Non-parametric tests were used for analysis: two-group comparisons were made using the Chi-square test for categorical information and the Mann-Whitney U test for ordinal data; differences in continuous variables measured on an ordinal scale between three groups were assessed using the Kruskal-Wallis analysis of variance by rank test. Responses added to a forced-choice list were evaluated for overlap with existing items, and the remainder were reviewed to evaluate common themes (Braun & Clarke, 2006). Comments and responses to open questions were reviewed for information not covered by the survey.

3.4 Clinician Survey

3.4.1 Design

Clinicians were invited via email by professional organisations: Audiology Australia, the Australian College of Audiology and the Hearing Aid Audiometrist Society of Australia. To qualify for participation, clinicians needed to be practising as an audiologist or audiometrist with a workload involving product training and sales of HAs or adult HA fitting and rehabilitation. Clinicians also needed to indicate they had discussed HA selection in the last month with either adult clients, clinicians or students. Just over 2900 clinicians were contacted and, after a reminder was sent out, a total of 259 clinicians completed the survey. The response rate across the different organisations ranged from 5 to 11% of the membership. The majority of the respondents were from Audiology Australia (77%). Depending on their experience with trainable HAs, clinicians were asked about training outcome, candidacy criteria, barriers and facilitators for use and advantages and disadvantages to the user, themselves or their practice. Clinicians were also shown a list of trainable HAs and asked to indicate the ones they had fitted.

3.4.2 Results

Demography

Table 3-2 shows the characteristics of the clinicians who responded to the survey. Almost half were over 40 years of age (49%), two thirds were women (69%), and the majority were audiologists (79%). Half of the clinicians had up to 10 years of fitting experience (52%). With some professionals combining work environments, the largest proportion worked in private practice (47%), 29% worked for the Commonwealth Government solely providing services under the Australian Government scheme, and 28% worked in independent practice. On average, more audiometrists were male ($\chi^2 = 14.9$; $p = 0.001$), older ($U = 2776$; $p < 0.001$) and had fitted hearing HAs for longer than audiologists ($U = 4140$; $p < 0.01$). The age and gender characteristics of respondents from Audiology Australia were compared to the characteristics of the entire membership. Gender balance was similar, but the responders skewed slightly older than the membership.

Table 3-2. Demographic characteristics of clinicians (n = 259).

Variable	**Response category**	**Number of responses**	**Percentage**
Age (years)	<25	7	3
	25 to 30	43	17
	31 to 40	83	32
	41 to 50	76	29
	51 to 60	37	14
	older than 60	13	5
Gender	female	180	69
	male	75	29
	indeterminate/intersex/unspecified	4	2
Profession	audiologist	205	79
	audiometrist	54	21
Fitting experience (years)	< 1	12	5
	1 to 5	63	24
	6 to 10	60	23
	11 to 20	73	28
	21 to 30	29	11
	31 to 40	20	8
	> 40	2	1

Variable	Response category	Number of responses	Percentage
Work setting	Commonwealth government	75	29
	private practice	122	47
	independent practice	72	28
	private hospital/ medical practice	9	3
	not-for-profit	20	8
	manufacturer	9	3

Provision of trainable aids

Different provider groups, their demographic differences and reasons for provision of trainable HAs were evaluated. Figure 3-1 shows the clinicians' responses on activation of the trainable feature. Two thirds of respondents actively decided whether to enable the trainable feature (66%): 53% activated it (referred to as providers) and 13% disabled it (referred to as active non-providers). The remaining 34% of clinicians did not make an active decision on whether to activate the trainable feature, and were labelled passive non-providers. As there were no significant differences in the proportions of audiologists and audiometrists across provider groups, findings from both professions are described together.

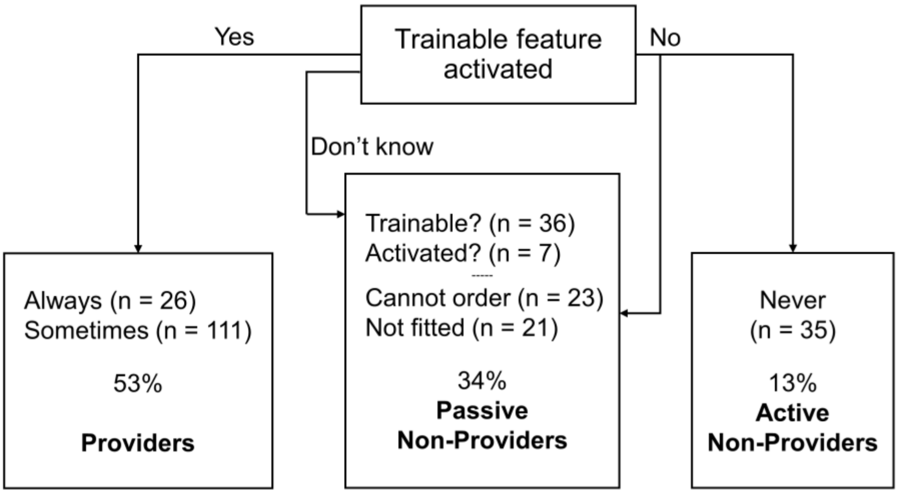

Figure 3-1. Overview of the clinicians based on their reported experience activating a trainable feature (total n = 259): providers (n = 137) activated trainable features, passive non-providers (n = 87) made no active decision on whether to provide a trainable feature, and active non-providers (n = 35) disabled the trainable features.

Comparison of the three provider groups (providers, active non-providers and passive non-providers) showed they differed significantly in age (H(2, n = 259) = 7.7; p = 0.02) and experience with fitting HAs (H(2, n = 259) = 8.0; p = 0.02). Paired comparisons of the demographic characteristics showed there was no significant difference between providers and passive non-providers in terms of age (U = 5584; p = 0.4), gender ($\chi^2 = 0.17$; p = 0.7) and years of HA fitting experience (U = 5242; p = 0.1). There were significant differences between providers and active non-providers in terms of age (U = 1794; p = 0.02) and years of experience (U = 1713; p = 0.009). The largest proportion of both groups was aged 31 to 40 years, however, 47% of providers were aged over 41 years compared to 31% of active non-providers. Similarly, the median provider had 11 to 20 years of experience, compared to 6 to 10 years for the active non-provider. Lastly, the active non-providers were more likely to be male (χ^2 = 12.8; p = 0.0003) and younger (U = 1066; p = 0.01) than the passive non-providers, with the median active non-provider reporting to be aged 31 to 40 years and the median passive non-provider 41 to 50 years.

When asked about the availability of trainable HAs, almost half of all providers (47%) reported up to 25% of the HAs fitted were trainable, reaching up to 50% for 28% of the providers. Most of the providers (81%) activated trainable features for selected clients only. The majority of selective providers (n = 73/111) estimated that trainable features were activated for up to 25% of clients with trainable HAs. Although audiometrists had, on average, more HA fitting experience, the proportion of those with experience fitting trainable HAs was not significantly different across professions (χ^2 = 1.1; p = 0.3). Half of the passive non-providers (51%) indicated they could not order trainable HAs or had not fitted them in the last 6 months, the other half (49%) stated they did not know if they could order trainable HAs or whether a trainable feature was activated. Across these two groups, clinicians were similar in age (U = 729; p = 0.07), fitting experience (U = 804; p = 0.2), and profession (χ^2 = 0.2; p = 0.6) and only differed significantly based on gender (χ^2 = 6.2; p = 0.01), with more women unsure about the availability or activation of the trainable feature than men. Furthermore, when asked if they would consider activating a trainable feature if it were available, their responses were not significantly different (U = 828; p = 0.3).

Just under 65% of clinicians who responded were activating or would consider activating a trainable feature. Most of the providers fitted trainable HAs because they believed such aids could benefit their clients (88%), and because they wanted to find out how it would affect clients' outcomes (43%). Passive non-providers were asked if they would consider providing the feature if it were available. Opinions were split evenly: a third thought future provision unlikely (33%), another third was neutral (32%), while another third considered provision likely (35%). The following groups of clinicians were asked why they did not or would not activate a trainable feature: providers activating sometimes (n = 111), active non-providers (n = 35), and passive non-providers who considered it unlikely they would activate a trainable feature (n = 29). The most common reasons why providers would not activate a trainable feature was because the HA controls were already disabled (71%) or they thought the user might not understand the concept (68%). In addition to these reasons, passive non-providers feared the user would not be able to train successfully (66%). Lastly, active non-providers had the same concerns, but also preferred manual fine-tuning (49%) and felt the potential user might not have enough experience for successful training (43%).

After answering items on the availability of trainable HAs at the beginning of the survey, further awareness of the concept was obtained by asking respondents to indicate all the trainable HAs they had fitted. Over 80% of the clinicians who were unsure if they had fitted trainable HAs (n = 34/36), or reporting they could not order them (n = 20/23), had indeed fitted HAs with a trainable feature.

Experiences

Providers (n = 137) were asked if and how they evaluated the trainable feature, what the outcome was and whether activating it had changed their fitting procedures. The majority evaluated the trained settings (83%). Most of these providers evaluated the trained settings by obtaining a subjective report from the user (83%), combined with other approaches: evaluation as part of the fitting (70%), or comparison of the initial and trained HA settings (49%) or measured HA responses (25%). Most providers (91%) reported accepting the trained settings the client had obtained most of the time, and a third reported these were similar to the original settings. Interestingly, a third (37%) reported to keep the settings but provided further fine-tuning. A small proportion of providers (5%) reported that most of the time they would reprogram the pre-trained settings. Most providers (85%) indicated that providing trainable HAs had not, or only slightly, changed their fitting and follow-up procedures, and 3% reported that they had stopped activating this feature.

Advantages and disadvantages of provision

Respondents were asked about advantages and disadvantages of activating trainable features to themselves or their practice, and HA users. An overview of responses from providers and non-providers (active and passive) are shown in Figure 3-2. Advantages were similar irrespective of experience in providing the trainable feature, however disadvantages differed. Increased client retention and a simpler fine-tuning process were advantages that providers most often reported (58%; 39%) and non-providers expected (57%; 45%). As advantages to the user, increased psychological ownership and an improved outcome were also most frequently selected by both providers (69%; 64%) and non-providers (61%; 61%). While over half of the providers (63%) indicated no disadvantage to themselves, the disadvantage selected by the largest proportion of non-providers (60%) was that the training process could be time-consuming. Providers of trainable HAs were mainly concerned that using a trainable feature could mask slowly developing hearing problems (45%). This was also a concern for non-providers (63%), but accompanied by additional concerns, including: a negative outcome (73%), the need for extra appointments (63%) and the feeling of personal failure in the user (62%). Similarly, more providers (26%) than non-providers (4%) thought there were no disadvantages from using trainable features to their clients.

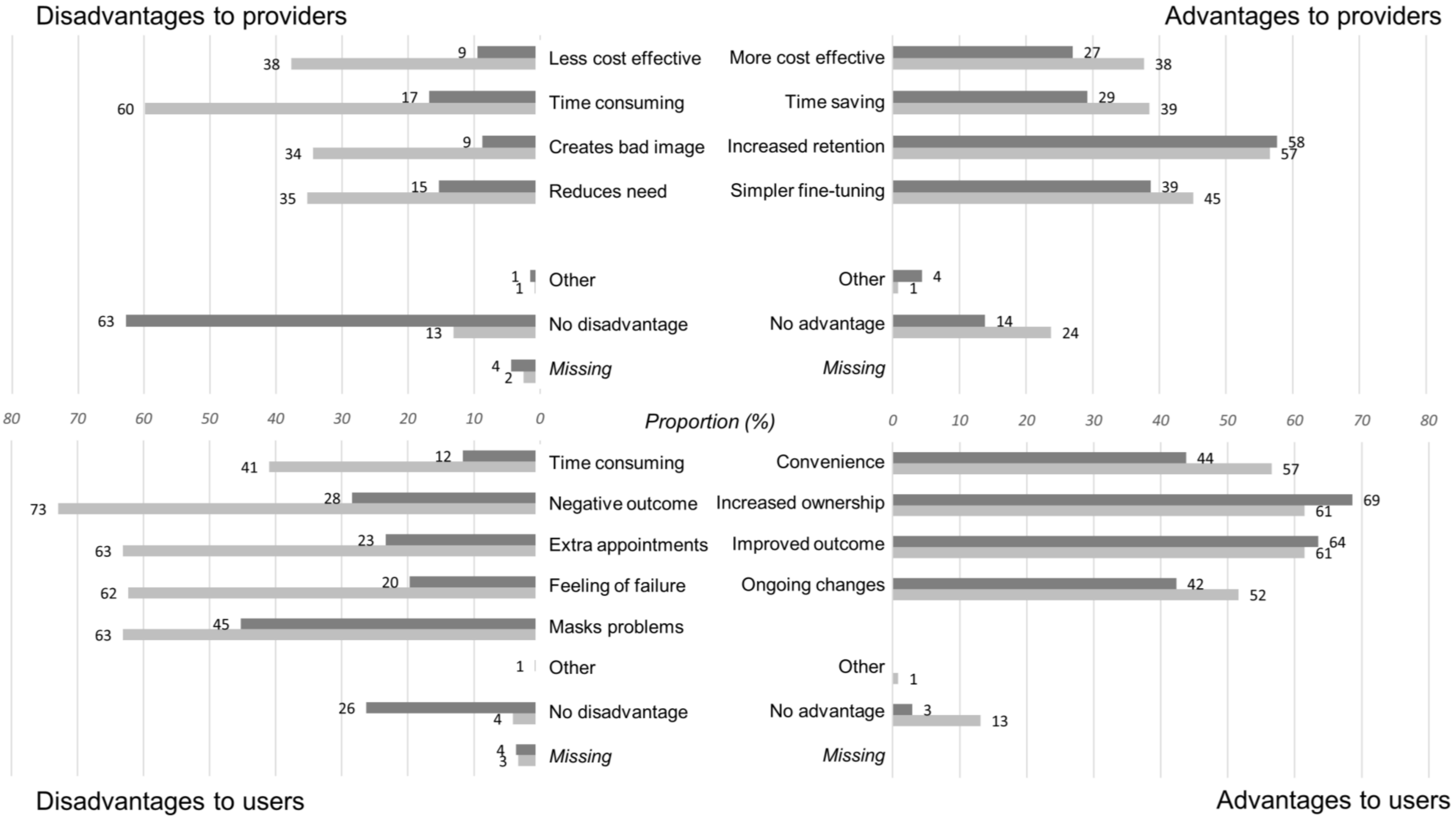

Figure 3-2. The proportions of disadvantages (left) and advantages (right) to using trainable aids for the clinician and their practice (top) and the user (bottom), viewed by providers (n = 137, dark grey) and non-providers (active and passive non-providers, n = 122, light grey) of trainable hearing aids.

Used and proposed candidacy criteria

Providers who activated the trainable feature sometimes (n = 111), and passive non-providers who were neutral or likely to activate the feature if it were available (n = 58) reported similar candidacy criteria. A user's cognitive status was the most likely reason for not recommending training by providers (85%) and passive non-providers (91%). The remaining criteria chosen by at least one in two providers and passive non-providers were users' finger dexterity (62%; 76%), personality (59%; 72%), interest in the feature (56%; 72%), HA experience (69%; 66%) and diverse listening needs (57%; 59%). There was no relationship between attitude towards activating trainable features and the demographic characteristics of clinicians: there was no significant difference in age (U = 4869; p = 0.3), fitting experience (U = 4612; p = 0.1), gender ($\chi^2 = 1.36$; p = 0.2) and profession ($\chi^2 = 1.43$; p = 0.2) between those activating or predisposed to activate trainable features (n = 167), and those not or unlikely to activate trainable features (n = 64).

3.5 Survey for Hearing-Impaired Adults

3.5.1 Design

Hearing-impaired adults were either research volunteers listed in the National Acoustic Laboratories Volunteer Database or clients of two hearing care providers: Australian Hearing and Neurosensory. Overall, just under 600 participants aged 18 years or over were invited via email and 104 valid responses (81 HA users and 23 HA candidates) were obtained. The response rate for those invited via their provider was 14%, and it was 44% for the research volunteers. HA candidates qualified if they reported any difficulty hearing, ranging from slight to very much difficulty (Dillon, 2008), but had never used HAs. The Australian Government Hearing Services Program provides fully or partially subsidised hearing care to those receiving government support, veterans, and their dependents, as well as indigenous Australians aged 50 years and over. Trainable features are currently available in HAs with a mid-to-high technology level from some manufacturers, requiring the user's financial contribution.

Hearing-impaired adults with training experience answered items on the training process and outcome, while those without experience were asked if and why they would like to train HAs. In addition to basic demographic information, respondents were also asked about their HA use (IOI-HA item 1, Cox & Alexander, 2002) or readiness for change. As the uptake of HAs is a health behaviour change, candidates were asked to indicate which of the following statements matched their readiness for change, with the stages known to be related to compliance with health recommendations (Prochaska et al., 1994). This established if they were in the contemplation (I am not ready to take action now), preparation (I will take action soon) or action stage (I am ready to take action now) (Milstein & Weinstein, 2002). The survey for hearing-impaired adults followed the health literacy guidelines from Caposecco et al. (2011) to ensure accessibility.

3.5.2 Results

Demography

The majority of respondents were over 60 years of age (82%), retired (74%) and HA users (78%) (Table 3-3). More men (60%) than women responded and 70% had completed a degree beyond high school. Unsurprisingly, the HA users reported more difficulty hearing ($U = 421$; $p < 0.0001$) and a longer duration of hearing loss ($U = 442$; $p < 0.0001$) than the candidates. As could be expected (Bekkers, 2010), the research volunteers had a significantly higher level of education than the hearing centre clients ($U = 686$; $p = 0.009$). There was also a difference in education level between those with trainable HA experience and those with non-trainable HA experience ($U = 239$; $p = 0.002$). The 15 participants with trainable HA experience had, on average, a lower level of education than users of non-trainable HAs ($n = 66$). As the proportion of HA users who had used the trainable feature was similar for the research volunteers (18%) and hearing centre clients (19%), they were evaluated as one group.

Awareness

HA users ($n = 81$) were first asked if they had heard about trainable or learning HAs and then shown a description and asked if they had trained. Only 11% of HA users had heard about trainable HAs, but those with trainable HA experience were four times more likely to recognise this phrase than those without such experience.

Table 3-3. Demographic description of the hearing aid users and candidates (n = 104).

Variable	Response category	Number of responses	Percentage
Age (years)	18 to 30	4	4
	31 to 40	3	3
	41 to 50	3	3
	51 to 60	8	8
	61 to 70	31	30
	71 to 80	39	37
	81 to 90	15	14
	older than 90	1	1
Gender	female	42	40
	male	62	60
	indeterminate/intersex/unspecified	0	

Variable	Response category	Number of responses	Percentage
Employment	student; apprentice	3	3
	employed full-time	11	11
	employed part-time	10	10
	house duties (stay at home parent)	1	1
	unemployed	2	2
	retiree	77	74

		Aid users (n = 81)		Candidates (n = 23)	
Variable	Response category	Number of responses	Percentage	Number of responses	Percentage
Hearing difficulty	no difficulty	2	2	0	
	slight difficulty	9	11	9	39
	moderate difficulty	26	32	13	57
	quite a lot of difficulty	27	33	1	4
	very much difficulty	17	21	0	
Duration hearing loss (years)	less than 1	0		0	
	1 to 5	11	14	11	48
	5 to 10	17	21	6	26
	10 to 20	21	26	5	22
	20 to 30	10	12	0	
	30 to 40	5	6	0	
	over 40	17	21	1	4

Advantages and disadvantages of use

The 15 HA users who reported to have trained (19% of HA users; Figure 3-3) were asked about their impressions of the process, outcome and any experienced advantages or disadvantages. The majority (n = 13) found it easy to train their HAs, however one respondent reported an overall negative experience, being the only one to report worse sound quality after training. The positive findings reported by the majority of users was reflected in the advantages they had experienced. They had obtained personalised settings (n = 8), felt more involved in their hearing care (n = 5) and made fewer changes to their HA controls over time (n = 5). Additionally, a third of trainable HA users (n = 5) reported no disadvantages. Seven participants did report a disadvantage, most commonly that training was time consuming (n = 3). While two users reported that training improved sound quality, they also selected the response option “Worse sound quality: I didn’t like the settings I obtained" as a disadvantage. Only the respondent with an overall negative outcome thought it unlikely they would train again. There was no significant difference in gender (Fisher's p = 0.3), age (U = 395; p = 0.2) and hours of HA use (U = 420; p = 0.4), between HA users with and without experience of trainable devices.

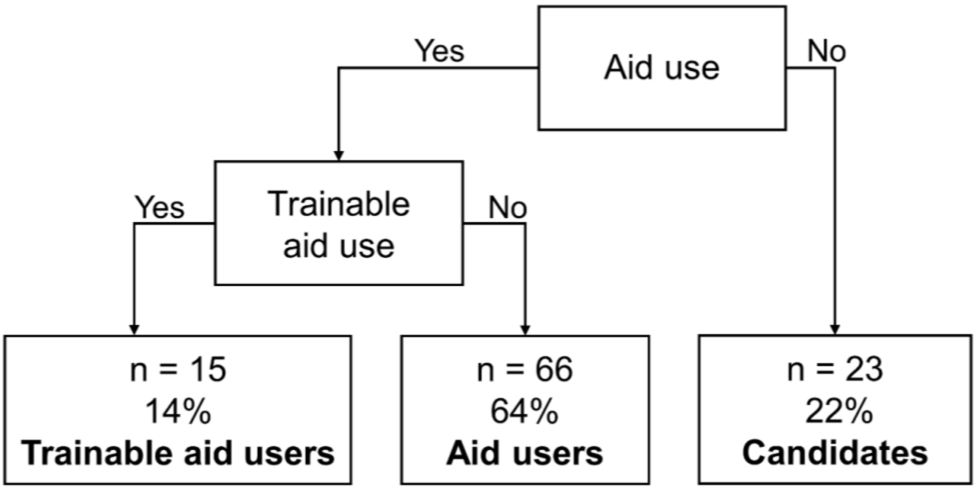

Figure 3-3. Overview of the groups of hearing aid candidates and users based on their experience with trainable hearing aids (total n = 104).

Willingness to train hearing aids

Users of non-trainable HAs (n = 66) and HA candidates (n = 23) were asked about their willingness to use trainable HAs. Over 85% of these participants indicated they would like to try training, or be given the option to train, respectively; selecting personalising their HA settings for different situations as the most common reason (85%). There was no significant difference in age (U = 375; p = 0.5), gender (Fisher's p = 0.2) and education (U = 380; p = 0.5) between those willing (n = 87) and not willing (n = 11) to trial trainable HAs. In the small group of those who preferred not to train (n = 11), the eight HA users mainly indicated they preferred professionals to set their HAs (n = 6), whereas the three candidates were especially concerned about the potential extra cost (n = 3). Lastly, the 23 HA candidates were asked whether knowing about trainable HAs made them feel more ready to obtain HAs. Half (52%) felt more ready to obtain a HA, with another third (35%) unsure. There was no relationship between candidates' willingness to try HAs and their readiness for change (Fisher's p = 0.4).

3.6 Discussion

This first study looking into the application of trainable HAs found that these are being used selectively in clinical practice. As the trainable feature is not available in all technology levels and brands, and is only provided to selected clients, the actual number of users fitted is naturally limited. This is further evident by the relatively small proportion of surveyed HA users who were fitted with trainable HAs. Providers of trainable aids were older and had more experience than those never activating trainable features. This observation is in line with findings on patient-centredness in audiology, with older audiologists who had practiced longer showing a significantly greater preference for increased client-involvement in hearing care (Laplante-Lévesque, Hickson, & Grenness, 2014). Although half of the clinicians activated the trainable feature, awareness of this feature amongst clinicians and clients was still relatively low. It seems the trainable feature is not as actively promoted as it could be, potentially due to the lack of evidence-based information on candidacy for and outcomes with trainable HAs.

Reports from the majority of providers and users with trainable HA experience were positive. Most providers accepted the trained settings the clients had obtained, but a third of the providers continued fine-tuning after training. The survey did not reveal the reasons why further fine-tuning was provided and more systematic research is needed to determine the reasons for this, for example, because the training period had been too short, users needed more support in how to train effectively or the training algorithm did not enable the user to alter the HA settings they wished to change. Only one HA user fitted with the trainable feature reported an overall negative experience. This finding is similar to outcomes from other trials where a minority of participants obtained settings that were inferior to those prescribed (Keidser & Alamudi, 2013; Palmer, 2012). Two users of the feature in the current study reported seemingly contradictory experiences, indicating training had improved sound quality, but also citing the disadvantage that they obtained settings they did not like. It is open to speculation whether these users found training improved sound quality but not sufficiently so.

Both providers and users with experience of the trainable feature indicated more advantages than disadvantages from having the trainable feature activated, and the largest proportion of both providers and users experienced no disadvantages from providing and using trainable HAs. Parallels can be drawn between the advantages providers attributed to users and the advantages users reported themselves. Providers mainly indicated users had increased psychological ownership and an improved outcome, with users reporting feeling more involved with their hearing care and obtaining personalised settings. This observation is of interest as self-management has been shown to result in greater adherence to treatment and better outcomes in other health areas (Ory et al., 2013; Simmons, Wolever, Bechard, & Snyderman, 2014).

A comparison with proposed advantages reported by Dillon et al. (2006) and Keidser et al. (2007), shows that these benefits have been realised only to a certain degree. A third of providers reported having more time available when fitting trainable HAs; however the majority also reported limited changes to their fitting and follow-up procedure. It is possible that the number of trainable HAs fitted has not been sufficient to change practices, or that deviation from standard practice has been limited because of the need to comply with the requirements of the Australian Government Scheme for the provision of HAs. Half of the trainable HA users indicated the advantage of obtaining personalised settings, with a third reporting that they made fewer changes to the HAs over time. Attending fewer appointments was not a clear advantage for many users, in line with providers reporting trainable HAs had a limited impact on their fitting practices. Perhaps there is a need to review clinical practices and appointment structures to allow for some of the potential benefits of providing trainable HAs to take effect.

Interestingly, the selection criteria for when to activate the trainable feature were similar irrespective of providers' experience with providing the feature. Two common criteria were poor cognitive status and finger dexterity, both associated with older age. Without the availability of evidence-based criteria, providers selected factors known to influence HA manipulation (Erber, 2003; Kricos, 2006; Kumar, Hickey, & Shaw, 2000) as important for training HAs. This is further supported by providers indicating the most common reason why training was not offered, was that the HA controls had already been deactivated.

This survey found over 85% of hearing-impaired adults expressed interest in trainable HAs. Comparison with survey results from hearing centre clients before trainable HAs were commercially available, showed this result was similar to the 91% of respondents who found the training concept positive but higher than the 66% of participants who expected a personal benefit from training (Keidser et al., 2007). A general positive attitude towards new technology has been observed with HA users reporting better outcomes with a “digital” (Bentler, Niebuhr, Johnson, & Flamme, 2003) or “new” HA (Dawes, Hopkins, & Munro, 2013) compared to a “conventional” HA, even though the HAs compared were identical. Despite the expressed interest in training, it is unlikely all those willing to train would be suited for using the feature, considering the requirement for manipulation of small controls and repeated HA adjustments. Potential users might underestimate the need to, or overestimate their ability to (Doherty & Desjardins, 2012; Dullard & Cienkowski, 2014), make adjustments. Finally, half of the candidates indicated that knowing about trainable HAs made them feel more ready to obtain a HA. Despite this positive result, the next step to taking action cannot be assumed. Laplante-Lévesque et al. (2012) found that 24% of adults who had decided upon an intervention after shared decision making had not taken action 6 months later.

3.6.1 Limitations and Future Directions

The main limitation of this study is the potential response bias created by the recruitment methods. Firstly, the invitation sent to clinicians mentioned that experience with trainable HAs was not necessary to complete the survey, but lack thereof might have stopped some from participating, increasing the proportion of clinicians with trainable HA experience in the study sample. Secondly, all users and potential users had received some degree of hearing care, suggesting their attitude towards HAs was likely more positive than among hearing-impaired people who had not sought help (Meyer, Hickson, Lovelock, Lampert, & Khan, 2014). Of interest is that the experience with and attitude towards training among the research volunteers, who made up 26% of respondents, was not different from the hearing centre clients. Another limitation was the low number of clinicians responding, even though the majority of members were expected to be working in adult HA fitting. Potential reasons for the low response rate could include the time advised it would take (up to 20 minutes) or unfamiliarity with the topic. A further limitation was that the proportion of trainable HA users captured may be underestimated; either because users did not recognise that they were provided with a trainable HA from the description provided in the survey, or they have forgotten, or because their clinician may not have advised them about the activation of this feature. A final limitation was that this study was set up to obtain an overall picture of the provision and activation of trainable HAs. As the majority of providers indicated they provided trainable aids from more than one manufacturer, their impressions are based on a mix of different trainable features. More systematic research is needed to examine if provision of and experience with trainable features differ between the various implementations.

Overall, the results suggest a future for trainable HAs, but further research is needed to help clinicians support people with hearing loss to obtain the best possible training outcome. There are currently no evidence-based candidacy criteria or guidelines on how to assist clients during the training process. To develop such guidelines, it is necessary to obtain a better understanding of the efficacy of different training strategies.

3.7 Conclusion

Given the positive reports from most providers and users who had experience with the trainable feature, trainable HAs could be provided to selected clients, pending the availability of evidence-based guidelines for recommending and managing trainable aids.

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Chapter 4 - Consistency of Hearing Aid Setting Preference in Simulated Real-World Environments: Implications for Trainable Hearing Aids

This chapter is an adaptation of the manuscript with the same title, which is under review with the following author list: Walravens, E., Keidser, G., & Hickson, L.

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4.1 Abstract

Trainable hearing aids let users fine-tune their hearing aid settings in their own listening environment: based on consistent user-adjustments and information about the acoustic environment, the trainable aids will gradually change environment-specific settings to the user’s preference. A requirement for effective fine-tuning is consistency of preference for similar settings in similar environments. The aim of this study was to evaluate consistency of preference for settings differing in intensity, gain-frequency slope and directionality when listening in simulated real-world environments, and to determine if participants with more consistent preferences could be identified based on various profile measures.

Fifty-two adults (63 to 88 years) with hearing varying from normal to a moderate sensorineural hearing loss selected their preferred setting from pairs differing in intensity (3 or 6 dB) or gain-frequency slope (±1.3 or ± 2.7 dB/octave), or directionality (omnidirectional vs cardioid) in four simulated real-world environments: traffic noise; a monologue in traffic noise at 5 dB SNR; and a dialogue in café noise at 5 and at 0 dB SNR. Forced-choice comparisons were made 10 times for each combination of pairs of settings and environment. Participants also completed nine psychoacoustic, cognitive and personality measures.

Consistency of preference, defined by a setting preferred at least 9 out of 10 times, varied across participants and depended on the difference between settings, the environment and their interaction. More participants obtained consistent preferences for larger differences between settings and for less complex environments. The psychoacoustic, cognitive and personality measures did not predict consistency of preference.

4.2 Introduction

Fine-tuning of HA settings is often requested after HA fitting as not everyone is happy with the prescribed response (e.g. Valentine et al. 2011). Fine-tuning can be done by a clinician or by the HA user themselves, for example using a trainable algorithm. Trainable algorithms use as input acoustical information from the user's listening environment, such as the type of background noise and its level, and the listener's adjustments made to the HA controls in those environments. Adjustments can be made using the controls on the HA, if available, or using a remote control or smartphone app. Based on the consistent user-adjustments in the same or similar acoustic environments, the trainable algorithm will gradually modify the HA settings for that listening situation to the user's preference. For example, if the HA user reduces the volume every time they go for a walk in a busy street, the trainable algorithm will over time reduce overall gain for that situation, so that the user will have less need to make adjustments in that situation. Inconsistent adjustments on the other hand will result in settings marginally changed from the original. For example, a HA user might listen to classical music on the radio set at a particular level, reducing the HA volume some of the time and increasing it at other times depending on the type of music and/or how much they like the piece. If the HA user makes a similar amount of changes in volume in opposite directions and of a similar magnitude, this will result in HA settings marginally changed from the original.

For the trainable algorithm to effectively fine-tune the HA settings, adjustments need to be made that result in similar HA settings in similar acoustic environments. This assumes that listeners have a preference for a given HA setting and can select it reliably every time they are in similar listening environments. However, Keidser et al., (2008) found reliability of preference to be variable in a follow-up study with 12 participants, using a two-alternative forced-choice task. Although most of the participants could perceptually distinguish between pairs of gain-frequency slopes differing in rms value from 1 to 10 dB, only 25% could reliably select a preferred response for most pairs. Participants with a steeply sloping audiogram were better at selecting a reliable preference, suggesting those with a narrower audible dynamic range might have a smaller range of signals they consider comfortable (Keidser et al., 2008). Although this study provided useful insights into the reliability of listeners' preferences, participant numbers were small, linear amplification was applied and only gain-frequency slope differences were evaluated.

Another limitation of research in this area is that little information is available about factors that may influence consistency of auditory preference. There is some evidence however about the likely importance of psychoacoustic and cognitive factors. Since participants with greater high-frequency hearing loss have been found to have more consistent preferences for gain-frequency differences

(Keidser et al., 2008) and more preference for directionality (Wu, 2010), measures of low- and high-frequency average hearing loss, dynamic range and intensity discrimination might predict consistency of preference. Additionally, in view of the differences in gain-frequency evaluated and listening environments used in the current study, spectral and temporal resolution were included as potential predictive factors. Participants with better spectral resolution were considered more likely to have consistent preferences for gain-frequency differences. Participants with better performance on the temporal resolution task, which has been found to correlate with performance on speech-in-noise tests (Dreschler & Plomp, 1985), were considered more likely to have more consistent preferences when listening to speech in noise using the speech signal as their reference.

In terms of cognitive factors that might influence consistency of preference, Lunner (2003) found that listeners with poorer working memory recall showed a preference for the same HA program when listening in different environments, whereas those with better working memory recall showed a preference for different HA programs. Similarly, listeners with poorer working memory recall showed a preference for the highest degree of noise reduction irrespective of the listening situation, whereas those with better working memory recall preferred different degrees of noise reduction (Neher et al., 2014), though not when adding directionality to noise reduction (Neher, 2014). Additionally, participants with better results on an executive function task showed more selective preferences for strong noise reduction when listening using an omnidirectional microphone (Neher, 2014). As measures of working memory and executive function seem to influence preference for HA settings, they were also included in this study. Furthermore, because of the relationship between executive function and preference for HA settings, working memory updating, a component of executive function (Miyake et al., 2000), was included. Working memory updating tracks new and discards unnecessary information, a task that seems inherent to the fine-tuning process when comparing different HA settings. Finally, a measure of personality was included to explore if consistency of preference might be influenced by how the task is approached rather than by underlying psychoacoustic and cognitive abilities.

In summary, this study set out to investigate consistency of preference for HA settings differing in intensity, gain-frequency slope and directionality, when listening in simulated real-world environments using non-linear amplification. Additionally, a range of factors were included that might predict which listeners were more likely to obtain consistent preferences. Psychoacoustic and cognitive measures were included, along with a personality screening test.

4.3 Method

4.3.1 Participants

Fifty-two adult volunteers (23 women) with an average age of 73 years (63 to 88 years) participated. While three participants were non-native English speakers, all were fluent in English. Their hearing was symmetrical, defined as the difference between ears in four-frequency average hearing loss not exceeding 10 dB, and the difference between thresholds at individual frequencies up to 4000 Hz not exceeding 20 dB. Participants were selected to represent a range of degrees (i.e. average binaural four-frequency average hearing loss) and slopes of hearing loss (binaural average difference between the average thresholds across 250, 500 and 1000 Hz (low-frequency average) and across 2, 3 and 4 kHz (high-frequency average)), see Figure 4-1. Participants included those in the same age range with normal hearing to make it clearer if better hearing and psychoacoustic characteristics were needed to be able to make consistent preferences.

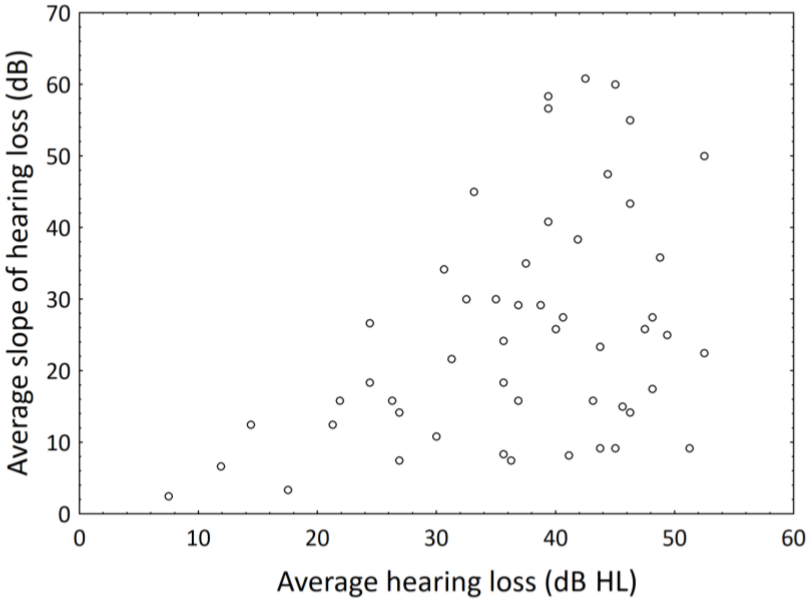

Figure 4-1. The spread in binaural average hearing loss represented by the four-frequency average hearing loss, and the slope, that is the difference between the average thresholds across 250, 500 and 1000 Hz (low-frequency average) and across 2, 3 and 4 kHz (high-frequency average).

According to the Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005), 41 participants performed within the normal range of the test (score ≥ 26), 10 displayed a mild cognitive impairment (21 ≤ score < 26), and one participant produced a score of 19. Participants relying on HAs wore their own devices during this paper-and-pen cognitive screening measure to control for any hearing difficulty.

All participants provided written informed consent. The research was approved by the Australian Hearing Human Research Ethics Committee (AHHREC2016-3) and the Behavioural & Social Sciences Ethical Review Committee of The University of Queensland (2011000857). Participants were offered a small gratuity at the end of their final appointment to offset their transport costs.

A power analysis was conducted to select the number of participants. Power calculations were based on the test of the null hypothesis of no effect of environment on consistency of preferences, with environment being a categorical variable with four categories in a mixed-effects logistic regression model for consistency. The power calculations were made using a simulation approach, with a significance level of 5% and target power of 80%. Using one environment as a reference category, we assumed that the effect of the other environments would be odds ratios of r, r^2 and r^3 relative to the reference category. The other parameter values were estimated based on preliminary data. For r = 1.50, the required sample size for 80% power was approximately 70, and for r = 1.65, the required sample size for 80% power was approximately 44. Because of budget and time constraints, a sample size of 70 was not feasible and instead a sample size of 50 was chosen. The power analysis estimated that for r = 1.65 the sample size of 50 would give high power (85%) and for r = 1.50 the power would still be moderately high (66%).

4.3.2 Profile Measures

Psychoacoustic measures

Average low- and high-frequency thresholds

Based on the audiogram, obtained using insert earphones, the low-frequency average (250, 500 and 1000 Hz) and high-frequency average (2000, 3000 and 4000 Hz) were calculated. Measures for both ears were averaged to obtain one low- and high-frequency average.

The remaining psychoacoustic measures were presented using a computer and included practice trials, except for the comfortable dynamic range measure. Measures were completed under Sennheiser HD 215 headphones unless indicated otherwise.

Intensity discrimination

Individual ear thresholds were obtained for 500 and 3000 Hz pure tones of 600 ms duration with reference tones presented at 30 dB SL, using a three-interval forced-choice task, with participants selecting the interval that contained the louder pure tone. The step-size of the 1-up 2-down procedure varied adaptively from an initial difference of 4 dB and completed when 71% correct detection was reached. The threshold was calculated as the average of the levels of the last 8 reversals at the final step size of 1 dB (Hansen, 2006; Jepsen & Dau, 2011). Each frequency was assessed twice in each ear and the result was averaged per ear; the better-ear result at each frequency was used for further analysis.

Comfortable dynamic range

Using the Contour Test of Loudness Perception (Cox, Alexander, Taylor, & Gray, 1997), participants were asked to report which category best described the loudness of a 5-second fragment of a monologue when listening unaided in the sound field. Starting from 35 or 50 dB SPL, depending on the participant's hearing loss, the level was increased in 3-dB steps until the speech fragment was reported to be "loud but ok", or a level of 83 dB SPL was reached. The median level difference between the level perceived as "comfortable" and "loud but ok" was calculated based on three trials.

Spectral and temporal resolution

Ear-specific detection thresholds for pulsed pure tones of 500 and 3000 Hz with a 275 ms duration were obtained using a Békésy technique. Presentation levels were derived from the one-third gain formula as recommended by Athalye (2010). Tones were varied by 3 dB/s and presented in octave-band noise (a) without gaps, (b) with continuous half-octave spectral gaps around the test frequency or (c) with 50 ms temporal gaps. The threshold was defined by the average value of six upper and six lower reversals after two initial turning points. The difference in threshold obtained when listening to pulsed tones in noise with continuous half-octave spectral gaps around the test frequency and noise without gaps, and noise with 50 ms temporal gaps and noise without gaps quantified the listener's spectral and temporal resolution, as conceived by Larsby and Arlinger (1998) and further developed by van Esch et al. (2013). Each threshold was established twice and averaged; a third was completed when the difference between the initial pair was 5 dB or more. Any trial with a trace exceeding a range of 20 dB after the first reversal was discarded and repeated. The better-ear result for each of the four conditions (500 and 3000 Hz, spectral and temporal resolution) was used for analysis.

Cognitive measures

Cognitive measures were presented visually only, using a computer, and practice trials were provided.

Working memory recall

The Reading Span test adapted from Daneman and Carpenter (1980) and Rönnberg, Arlinger, Lyxell, and Kinnefors (1989) was used to measure recall in working memory. Sentences were presented in three parts on a computer screen: the subject, verb and an object or descriptor. At the end of each sentence, the participant was asked to indicate verbally whether that sentence made sense. Two sets of three, four and five sentences were presented. After a set of sentences was presented, participants were asked to recall the first or last words of as many of the sentences as they could. The final score was the percentage words recalled correctly out of a total of 24, independent of order.

Executive function

The Executive Control subtest of the Test of Attentional Performance – Mobility version (Zimmermann & Fimm, 2014) measured executive function. Participants were presented with letters or numbers shown in red or blue on a computer screen, and instructed to push the left button when they saw a red number and the right button when they saw a blue letter as fast as they could, while ignoring the red letters and blue numbers. In total 80 items were presented with a duration of 0.5 and an inter-stimulus interval between 2 and 3 seconds. The buttons registered responses and reaction time; the median response time of the correct responses was used for further analysis.

Working memory updating

The Letter Memory Task was adapted from Morris and Jones (1990) and Miyake et al. (2000). Sequences of 5, 7, 9 or 11 consonants were presented on a computer screen one at a time, in large font. Blinded to the length of a sequence, participants were asked to recall the last four letters of 12 trials. The number of letters recalled correctly, independent of order, was used as a measure of working memory updating.

Personality measure

The Ten-Item Personality Inventory (Gosling, Rentfrow, & Swann, 2003) evaluated the Big Five personality traits (their convergent correlation with the Big-Five Inventory (John, Donahue, & Kentle, 1991) is shown in brackets): extraversion (0.87), agreeableness (0.70), conscientiousness (0.75), emotional stability (0.81) and openness to experiences (0.65). Using pen and paper, participants scored 10 statements on a 7-point Likert scale, with two statements for each trait. The average score for each trait was used for further analysis.

4.3.3 Hearing Devices and Test Settings

An in-house real-time master HA was used for this study. The master HA contained microphones and receivers embedded in behind-the-ear (BTE) shells wired to a sound card and a computer, performing all the signal processing. The HA parameters were manipulated via a GUI, providing 16 independent gain and compression channels, with a centre frequency of 62.5 Hz (125 Hz bandwidth), 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250 Hz (250 Hz bandwidth), 2625 Hz (500 Hz bandwidth), 3250, 4000 Hz (750 Hz bandwidth), 5000 Hz (1250 Hz bandwidth), 6375 Hz (1500 Hz bandwidth) and 9562.5 Hz (4875 Hz bandwidth). The compression was fast-acting (t_a = 10 ms and t_r = 100 ms) and matched the NAL-NL2 prescription (Keidser et al., 2011). No other sound processing features were activated for the baseline setting in the master HA, but when feedback was detected, measurements were done to estimate and add a filter to reduce feedback. The BTE HAs were coupled to participants' ears using HAL-HEN 2602 occluding foam ear tips. Real-ear insertion gain using the International Speech Test Signal (Holube, Fredelake, Vlaming, & Kollmeier, 2010) as input was used to adjust the HA gain to match targets, with participants with normal hearing to minimal loss all fitted to a 25 dB HL loss across all frequencies. A minimum amplification of 5 dB (measured by insertion gain) was provided at any frequency with targets below this level, to ensure amplification dominated the signal so differences in HA settings (see below) could be achieved. A monologue was presented at 60 dBA to ensure the amplification was comfortable to the participant. Using the Contour Test of Loudness Perception scale (Cox et al., 1997), the overall gain was adjusted until the participant indicated the setting was "comfortable", or "comfortable but slightly loud" for those with normal hearing and minimal hearing loss. Both the minimum amplification and listening comfort criteria were met for all participants. Although the NAL-NL2 target was used to set the HA gain, the adjustments made to meet the above criteria could modify the participant's baseline response from the prescription.

Based on the participant's baseline response, five pairs of HA settings were created, differing in directionality, intensity or gain-frequency slope (Table 4-1). The directionality pair was composed of the omnidirectional baseline and a fixed cardioid microphone response with a Directivity Index of 5.4 dB (measured using white noise presented from all loud speakers with the master HA positioned on a Head And Torso Simulator). The cardioid setting had the same gain-frequency response as the omnidirectional baseline setting at 0° azimuth (i.e. compensating for the low-frequency roll-off). Two pairs differing in intensity were created by changing the overall level of the baseline response to create a 6 dB (+2 dB and -4 dB from baseline) and 3 dB (+1 dB and -2 dB from baseline) overall gain difference. Pairs differing in gain-frequency slope had an overall loudness presumed equal to that of the baseline response, but different slopes, created by increasing the gain at 500 Hz by 4 or 2 dB and decreasing the gain by a similar amount at 4000 Hz and vice versa, using 1500 Hz as the cross-over frequency, resulting in a slope of ±2.7 dB/oct or ±1.3 dB/oct compared to the baseline response, see Table 4-1. An rms difference of 6 and 3 dB between intensity and gain-frequency responses was chosen to represent differences that were easily discernible and challenging respectively based on previously observed gain-frequency (Keidser et al., 2008; Lentz & Leek, 2003) and SNR differences (McShefferty, Whitmer, & Akeroyd, 2015).

Table 4-1. Description of the different comparison pairs, including their variation from the baseline and rms difference.

	Difference from baseline		**Measured**
Comparison pairs	**Response 1**	**Response 2**	**rms difference mean (SD)**
Directionality	/	Cardioid	1.2 (0.5)
Intensity – large difference	+ 2 dB	- 4 dB	5.6 (0.5)
Intensity – small difference	+1 dB	- 2 dB	2.9 (0.3)
Gain-frequency slope – large difference	+ 2.7 dB/oct	- 2.7 dB/oct	5.6 (0.6)
Gain-frequency slope – small difference	+ 1.3 dB/oct	- 1.3 dB/oct	2.9 (0.3)

4.3.4 Equipment and Stimuli

The listening environments were presented in a horizontal ring (radius of 1.2 m) of 16 Genelec 8020C loudspeakers, situated in a test booth with a reverberation time of 0.3 seconds. The loudspeakers, spaced uniformly at 22.5º intervals, were driven by an RME Fireface UFX interface (44.1 kHz output) and two ADI-8 DS digital-to-analogue converters. Two target and two noise recordings were combined to create four listening environments: traffic noise (Traf); a monologue in traffic noise at 5 dB signal-to-noise ratio (SNR; MonTraf5dB); and a dialogue in café noise at 5 dB (DiaCafe5dB) and at 0 dB SNR (DiaCafe0dB). The target recordings were two monologues and two dialogues from the NAL Dynamic Conversations Test described in Best, Keidser, Freeston, and Buchholz (2016). This material is considered to approximate natural speech as talkers were instructed to play out transcripts rather than read them out loud, so it contained variations in speed, pauses, disfluencies, and interjections. The two monologues were by a female speaker and the two dialogues were between a male and a different female speaker. Each chosen passage was about 5 minutes, resulting in almost 10 minutes of continuous speech for both the monologue and dialogue. The monologue was presented from 0° azimuth, the dialogue with the two talkers spatially separated at +22.5° and -22.5° azimuth.

The background noises were recordings of real-life acoustic environments obtained using a three-dimensional 62-channel hard-sphere microphone array built in-house. The recorded signals were transformed into loudspeaker signals using the higher-order Ambisonics method (Oreinos, 2015; Oreinos & Buchholz, 2016). Only the horizontal components were taken into account (up to an Ambisonics order of N = 7) in the sound reproduction process (e.g. Oreinos 2015), which has been shown to be adequate for HA settings for sounds arriving from the horizontal plane (Oreinos & Buchholz, 2015). Sounds arriving from above or below were reproduced with a decreased spatial resolution.

Measured in the centre of the array using a Brüel & Kjær sound level meter with a model 4166 microphone, the traffic noise, coming from all 16 loudspeakers, was presented at 67.3 dBA, and the café noise at 67.6 dBA long-term average. Speech was presented at 5 dB SNR for both the MonTraf5dB and DiaCafe5dB, based on the SNRs regularly experienced by HA users in Smeds, Wolters, and Rung (2015). The dialogue in cafeteria noise was also presented at 0 dB SNR, reflecting the SNR experienced by normal-hearing researchers in Pearsons, Bennett, and Sanford (1977), assumed to be a rather challenging environment for those with a hearing loss. The third-octave band levels of the speech and noise stimuli across the four listening environments are represented in Figure 4-2.

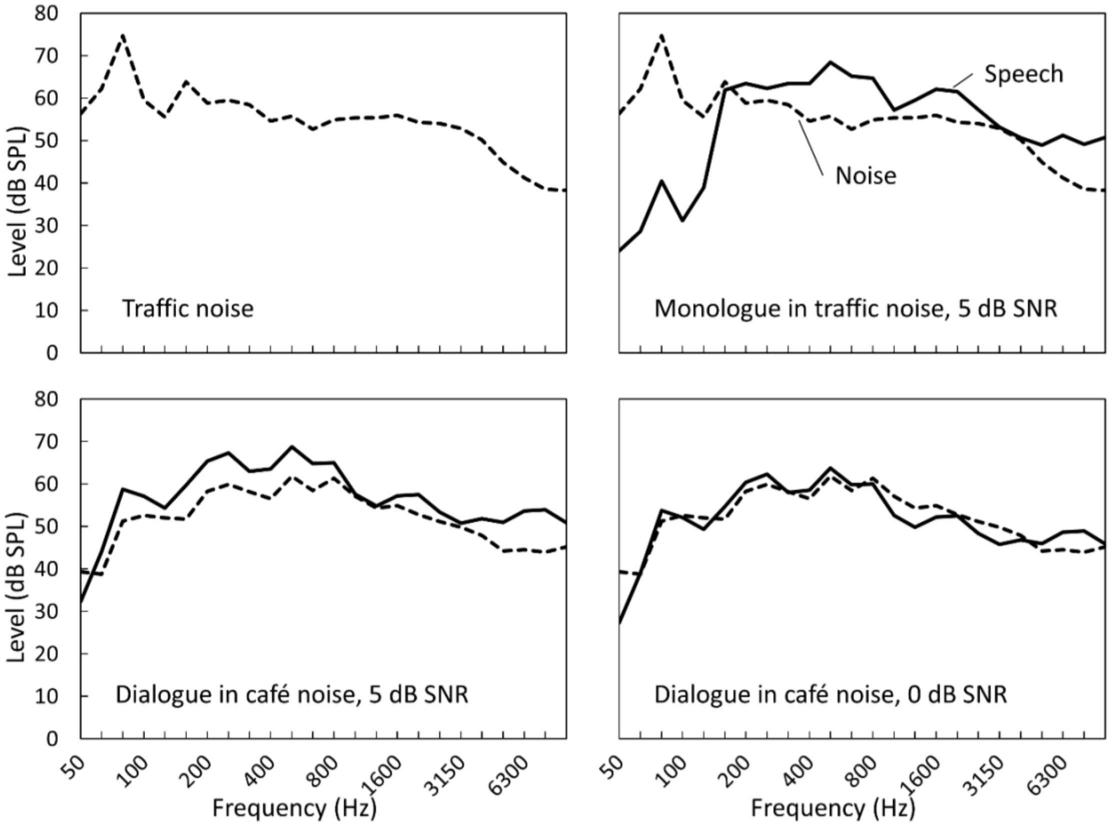

Figure 4-2. The levels of speech (full line) and noise (dashed line) across the four listening environments in third octave bands (dB SPL long-term average): traffic noise; monologue in traffic noise at 5 dB SNR; dialogue in café noise at 5 dB SNR; and at 0 dB SNR.

4.3.5 Procedure

Each participant attended three appointments ranging in duration from 1 to 2.5 hours. All participants were offered a break mid-way through each appointment. Participants completed their final appointment, on average, 30 days after the first (range = 3 to 146 days). Across the three appointments, participants completed nine assessments (as described above) and the preference tasks. All written instructions were provided in large print and those written specifically for this project did not exceed Flesch-Kincaid grade 6 reading level (Kincaid, Fishburne, Rogers, & Chissom, 1975).

Using a two-alternative forced-choice paradigm, participants selected their preference between five pairs of HA settings differing in directionality (one pair), intensity (two pairs) or gain-frequency slope (two pairs, Table 4-1). Preference measures for intensity and gain-frequency comparisons were completed across all four listening environments (Traf, MonTraf5dB, DiaCafe5dB and DiaCafe0dB). In total, 19 measures were completed as preference for directionality was not evaluated in Traf, as the difference between the omnidirectional and directional setting was considered to most noticeably be a small level difference, already assessed in the intensity condition. At the start of the first preference task of every appointment, participants were provided with written instructions (Table 4-2) and advised, "Your task is to choose which setting you would prefer […] for listening to each situation.", and any questions were addressed. Using a small keypad of which three buttons were labelled 'A', 'B', and VOTE', participants listened to setting A first, would then push B and listen to B; they could go back and forth as often as they liked and listen for as long as they liked. They were instructed to ensure they were listening to their preferred setting and then to press "VOTE" for their preference to be registered. As soon as they pressed "VOTE", the next comparison would start with A. This process would be repeated until they had completed all comparisons. Both the environments and the pairs of settings were presented in a randomised order and the recordings were looped so participants could listen for as long as they liked. Participants selected their preference between each pair 10 times in each of the four environments, with settings for each presentation randomly assigned to the A and B buttons. Participants were advised which listening environment would be presented, including, if applicable, the number of talkers and where they were located. This was done to avoid participants waiting for speech signals when none would be presented or spending time to try to localise the talkers.

The preference task was automated so the duration of each vote was recorded and any trial where the participant selected "VOTE" accidentally before changing to "B" was repeated at the completion of that preference task. When asked, all but two participants reported being able to follow the target speech during the preference task: one when listening to the MonTraf5dB and one participant when listening to the DiaCafe0dB. Participants completed the preference task for one environment in the first and final appointment and two environments in the second appointment, except for two participants completing two preference tasks in the second and final appointment.

Table 4-2. Written instructions for the preference task.

You will be listening to different situations that you may experience in real life. In each situation, you will listen to different hearing aid settings in pairs. The settings can be different in volume, pitch or direction.

Imagine you are given new hearing aids that can be set up with different settings for different situations. Your task is to choose which setting you would prefer in your new hearing aids for listening to each situation.

The situations you will be listening to are:

- traffic noise;
- one woman talking in traffic noise;
- two people talking in café noise.

The levels are based on the levels experienced during the recording. In the test booth, they seem to be louder than in real life, but they aren't.

Listen to each situation and compare two settings by pushing buttons A and B on the controller in front of you. Listen to settings A and B for as long as you like.
Once you have chosen your preferred setting, push the button for that setting and then press VOTE. The settings of A and B will differ from trial to trial.
Please consider your choice carefully. You can listen for as long as you like. You will listen to 50 pairs of settings.
Do you have any questions?

4.4 Results

4.4.1 Consistency of Preferences

The main aim of this study was to evaluate consistency of preference for five pairs of HA settings differing in intensity (two pairs: 3 or 6 dB difference in overall gain), gain-frequency slope (two pairs: ±1.3 or ±2.7 dB/oct), or directionality (one pair: omnidirectional vs cardioid), when listening in simulated real-world environments. If the participant selected the same setting of a pair 9 or 10 out of 10 times, the choice of setting was considered consistent. Across HA settings and environments, a total of 19 measures of consistency of preference were obtained for each participant. Figure 4-3 shows the variation in the number of consistent preferences across participants, ranging from two participants with three consistent preferences to three with 17 consistent preferences (mean and median = 11). Only 17% of participants had a consistent preference for at least 80% of the measures, with 37% of participants obtaining a consistent preference for fewer than half of the measures.

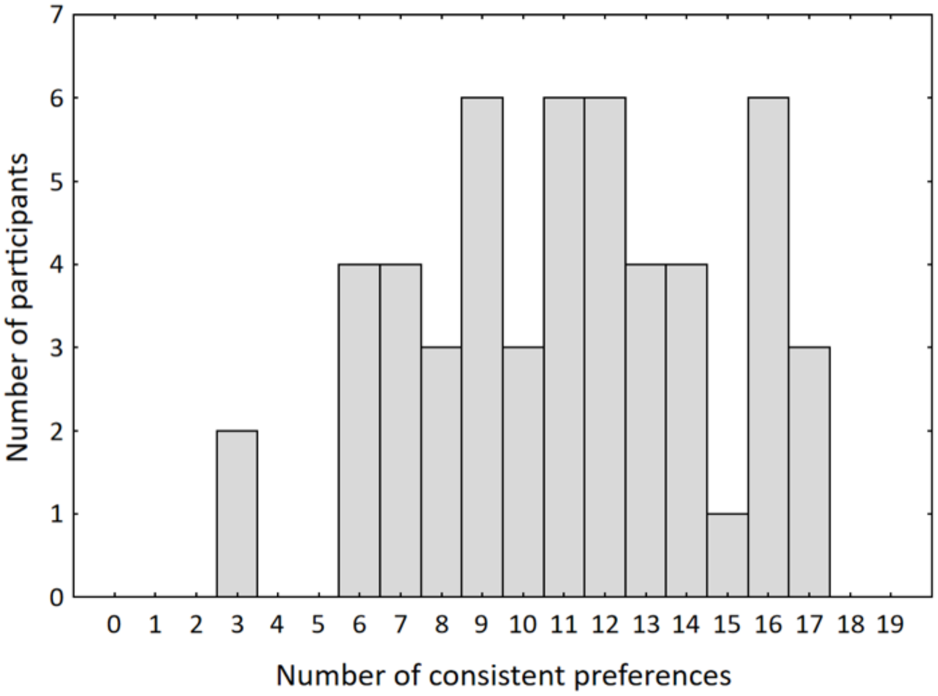

Figure 4-3. The number of consistent preferences obtained by participants (n = 52) across all pairs of hearing aid (HA) settings in the different listening environments.

Results for participants who did not pass the MoCA screening measure and for those who did not have English as a first language but were fluent in English, were examined in more detail. There was no significant difference in the number of consistent preferences for participants with a MoCA score outside the normal range (n = 11; median = 12) and within the normal range (n = 41; median = 11; U = 166; p = 0.2). Additionally, participants did not perform significantly differently on any of the included profile measures, except for agreeableness, for which those who scored within the normal range of the MoCA (median = 6) rated themselves higher than those who did not (median = 4.5). Of the three participants who did not have English as a first language, all obtained MoCA scores within the normal range, and one had a consistent preference for 14 out of 19 conditions and the other two obtained six consistent preferences each. Thus there was no evidence of mild cognitive impairment or language ability impacting on the preference task and hence all data were included in the further analysis.

Figure 4-4 shows the number of participants with a consistent preference for each of the five pairs of HA settings across the four environments ranked by increasing difficulty. This ranking order was based on the average Speech Intelligibility Index (American National Standards Institute, 1998) measured across participants' intensity and gain-frequency slope responses in these environments. Traf was considered the easiest environment as it was a relatively steady sound with no speech target present. The mean Speech Intelligibility Index across HA settings was 0.55 (SD = 0.03), 0.50 (SD = 0.04), and 0.36 (SD = 0.03) for the MonTraf5dB, DiaCafe5dB, and DiaCafe0dB, respectively. This ranking was further supported by the average time participants took to complete the preference trials. Across HA settings, the average duration per trial increased significantly with increasing difficulty of the environment (Friedman's ANOVAs for all HA settings $p < 0.0001$), from 14.7 seconds (SD = 9.8) for a trial in Traf to 17.3 seconds (SD = 10.1) for the MonTraf5dB, to 21.9 seconds (SD = 11.5) for the DiaCafe5dB, reaching 24.5 seconds (SD = 12.1) for the DiaCafe0dB.

More participants had a consistent preference for HA settings with large rather than small differences (Figure 4-4). Across environments, 57 to 96% of those with a consistent preference for HA settings with large differences also had a consistent preference for the corresponding small differences. For 37 of the 85 cases where participants had a consistent preference for large differences only, the participant had selected the same preference eight times, one vote short of being consistent for the corresponding small difference. Cases where participants obtained a consistent preference for the small difference only were less common, and for 9 of those 13 cases, the participant was one vote short of a consistent preference for the corresponding large difference. The variability in the number of consistent preferences each participant obtained (see Figure 4-3) also extended to the distribution of consistent preferences across the different environments and differences between the HA settings. For example, the number of participants with a consistent preference for large gain-frequency differences was similar (39 or 40) across three environments (Traf, MonTraf5dB and DiaCafe5dB; Figure 4-4). However, only 24 participants had a consistent preference for all three environments.

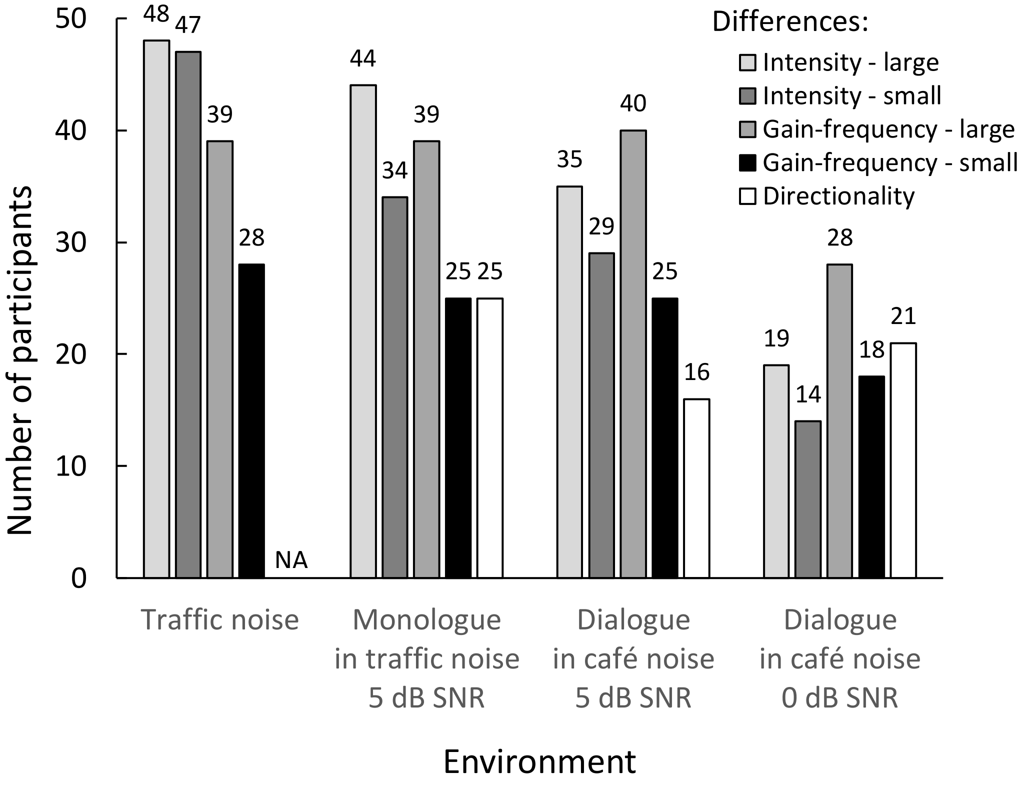

Figure 4-4. The number of participants with a consistent preference for the five pairs of HA settings across the four listening environments from easiest to most difficult: traffic noise, monologue in traffic noise, dialogue in café noise at 5 dB SNR and 0 dB SNR.

A mixed-effects logistic regression was conducted to evaluate the difference between the number of participants with a consistent preference across the 19 different conditions, with the environment, the difference between HA settings, and their interaction as fixed effects and a subject-specific intercept as the random effect. Consistency of preference depended on both the environment and the difference between HA settings, with both main effects and their interaction being statistically significant ($p < 0.001$). To further investigate the influence of the environment and the difference between HA settings on consistency of preference, pairwise comparisons were completed. Comparisons were quantified as the change in probability a participant would have a consistent preference in one situation over another. Table 4-3 and Table 4-4 list the pairwise comparisons showing the influence of environment (across the differences between HA settings) and difference between HA settings (across the different environments), respectively, with the original probability (p1) used as the sample proportion for the probability estimate, and their comparative probability. The p-values were adjusted for multiple comparisons using a simultaneous inference procedure

(Hothorn, Bretz, & Westfall, 2008). For example, Table 4-3 shows the odds ratio associated with a consistent preference for large intensity differences in Traf compared to DiaCafe5dB was estimated to be 7.20 (CI 1.05-49.5), or participants were 1.39 times more likely to have a consistent preference for large intensity differences when listening to Traf compared to DiaCafe5dB ($p = 0.04$). Only when comparing HA settings differing in intensity, did participants show significant differences in probability of a consistent preference between different environments, ranging from 1.39 to 3.49 (see Table 4-3). The largest significant probability was for a consistent preference for small intensity differences in Traf compared with DiaCafe0dB, which was 3.49 times more likely ($p < 0.001$).

Although the difference between HA settings also had a significant influence on consistency of preference, fewer comparisons reached significance across environments compared to the influence of the environment (Table 4-4). Significant probability estimates ranged from 1.68 (a consistent preference was 1.68 times more likely for large than small gain-frequency slope differences listening to the DiaCafe5dB) to 2.68 (a consistent preference for large gain-frequency slope differences was 2.68 times more likely than for directionality differences in DiaCafe5dB). No significant difference in probability was measured between any of the HA settings when listening in the most difficult environment of DiaCafe0dB.

The interaction between environment and difference between HA settings is visible in the different patterns of consistent preferences for the different HA settings across environments (Figure 4-4). Both the patterns for intensity and gain-frequency slope differences show a reduction in the number of consistent preferences with increasing complexity of environment. While the reduction of preferences is systematic for the intensity pairs, it is similar across the three least complex environments for the gain-frequency slope pairs, before dropping in the dialogue in café noise at 0 dB SNR. As shown in Table 4-3, participants were significantly more likely to obtain a consistent preference for intensity differences when listening in less rather than more complex environments, while no differences in consistent preferences reached significance between any environments for large or small gain-frequency slope differences. The interaction between environment and HA setting was different for directionality: the number of participants with a consistent preference dropped from MonTraf5dB to DiaCafe5dB, but increased from DiaCafe5dB to DiaCafe0dB (comparisons not reaching significance; Figure 4-4).

Table 4-3. Pairwise comparisons with the odds ratio (OR) quantifying the influence of environment on consistency of preference. P1 represents the sample proportion for the probability estimate (p2 est) for which the 95% confidence interval (CI) and their comparative value (p2/p1) is displayed. The pairwise comparisons reaching significance are shown in bold.

Environments (p2 vs p1)	**Difference between HA settings**	**OR (95% CI)**	**p1**	**p2 est (95% CI)**	**p2/p1**	**p**
DiaCafe5dB vs DiaCafe0dB	**Intensity, large**	**4.50 (1.13; 17.86)**	**0.37**	**0.72 (0.39; 0.91)**	**1.97**	**0.02**
MonTraf5dB vs DiaCafe0dB	**Intensity, large**	**13.82 (2.83; 67.63)**	**0.37**	**0.89 (0.62; 0.97)**	**2.43**	**< 0.001**
MonTraf5dB vs DiaCafe5dB	Intensity, large	3.07 (0.63; 15.05)	0.67	0.86 (0.56; 0.97)	1.28	0.47
Traf vs DiaCafe0dB	**Intensity, large**	**32.38 (4.70; 223.33)**	**0.37**	**0.95 (0.73; 0.99)**	**2.60**	**< 0.001**
Traf vs DiaCafe5dB	**Intensity, large**	**7.20 (1.05; 49.53)**	**0.67**	**0.94 (0.68; 0.99)**	**1.39**	**0.04**
Traf vs MonTraf5dB	Intensity, large	2.34 (0.30; 18.59)	0.85	0.93 (0.62; 0.99)	1.10	0.98
DiaCafe5dB vs DiaCafe0dB	**Intensity, small**	**4.25 (1.05; 17.20)**	**0.27**	**0.61 (0.28; 0.86)**	**2.27**	**0.04**
MonTraf5dB vs DiaCafe0dB	**Intensity, small**	**6.85 (1.64; 28.50)**	**0.27**	**0.72 (0.38; 0.91)**	**2.66**	**0.001**
MonTraf5dB vs DiaCafe5dB	Intensity, small	1.61 (0.42; 6.19)	0.56	0.67 (0.35; 0.89)	1.20	1.00
Traf vs DiaCafe0dB	**Intensity, small**	**41.90 (6.6; 265.91)**	**0.27**	**0.94 (0.71; 0.99)**	**3.49**	**< 0.001**
Traf vs DiaCafe5dB	**Intensity, small**	**9.85 (1.66; 58.35)**	**0.56**	**0.93 (0.68; 0.99)**	**1.66**	**0.002**
Traf vs MonTraf5dB	**Intensity, small**	**6.12 (1.02; 36.82)**	**0.65**	**0.92 (0.66; 0.99)**	**1.41**	**< 0.05**
DiaCafe5dB vs DiaCafe0dB	Gain-frequency, large	3.41 (0.82; 14.24)	0.54	0.80 (0.49; 0.94)	1.48	0.18
MonTraf5dB vs DiaCafe0dB	Gain-frequency, large	3.02 (0.74; 12.36)	0.54	0.78 (0.46; 0.94)	1.45	0.30
MonTraf5dB vs DiaCafe5dB	Gain-frequency, large	1.13 (0.25; 5.11)	0.75	0.77 (0.43; 0.94)	1.03	1.00
Traf vs DiaCafe0dB	Gain-frequency, large	3.02 (0.74; 12.36)	0.54	0.78 (0.46; 0.94)	1.45	0.30
Traf vs DiaCafe5dB	Gain-frequency, large	1.13 (0.25; 5.11)	0.75	0.77 (0.43; 0.94)	1.03	1.00
Traf vs MonTraf5dB	Gain-frequency, large	1.00 (0.23; 4.44)	0.75	0.75 (0.40; 0.93)	1.00	1.00

Environments (p2 vs p1)	Difference between HA settings	OR (95% CI)	p1	p2 est (95% CI)	p2/p1	p
DiaCafe5dB vs DiaCafe0dB	Gain-frequency, small	1.93 (0.50; 7.41)	0.35	0.51 (0.21; 0.80)	1.46	0.92
MonTraf5dB vs DiaCafe0dB	Gain-frequency, small	1.93 (0.50; 7.41)	0.35	0.51 (0.21; 0.80)	1.46	0.92
MonTraf5dB vs DiaCafe5dB	Gain-frequency, small	1.00 (0.27; 3.72)	0.48	0.48 (0.20; 0.77)	1.00	1.00
Traf vs DiaCafe0dB	Gain-frequency, small	2.54 (0.66; 9.77)	0.35	0.57 (0.26; 0.84)	1.66	0.50
Traf vs DiaCafe5dB	Gain-frequency, small	1.31 (0.35; 4.89)	0.48	0.55 (0.25; 0.82)	1.14	1.00
Traf vs MonTraf5dB	Gain-frequency, small	1.32 (0.35; 4.89)	0.48	0.55 (0.25; 0.82)	1.14	1.00
DiaCafe5dB vs DiaCafe0dB	Directionality	1.64 (0.42; 6.47)	0.31	0.42 (0.16; 0.74)	1.37	1.00
MonTraf5dB vs DiaCafe0dB	Directionality	1.45 (0.39; 5.44)	0.40	0.50 (0.21; 0.79)	1.23	1.00
MonTraf5dB vs DiaCafe5dB	Directionality	2.37 (0.61; 9.28)	0.31	0.51 (0.21; 0.80)	1.67	0.65

Note: DiaCafe0dB = dialogue in café noise at 0 dB SNR; DiaCafe5dB = dialogue in café noise at 5 dB SNR; MonTraf5dB = monologue in traffic noise at 5 dB SNR; Traf = traffic noise

Table 4-4. Pairwise comparisons with the odds ratio (OR) quantifying the influence of the difference between HA settings on consistency of preference. P1 represents the sample proportion for the probability estimate (p2 est) for which the 95% confidence interval (CI) and their comparative value (p2/p1) is displayed. The pairwise comparisons reaching significance are shown in bold.

Differences between HA settings (p2 vs p1)	Environment	OR (95% CI)	p1	p2 est (95% CI)	p2/p1	p
Intensity, large vs Intensity, small	Traf	1.30 (0.13; 12.85)	0.9	0.92 (0.55; 0.99)	1.02	1.00
Intensity, large vs Gain-frequency, large	Traf	4.65 (0.62; 34.85)	0.75	0.93 (0.65; 0.99)	1.24	0.36
Intensity, large vs Gain-frequency, small	**Traf**	**14.05 (1.99; 99.31)**	**0.54**	**0.94 (0.70; 0.99)**	**1.75**	**< 0.001**
Intensity, small vs Gain-frequency, large	Traf	3.58 (0.54; 23.55)	0.75	0.91 (0.62; 0.99)	1.22	0.57
Intensity, small vs Gain-frequency, small	**Traf**	**10.80 (1.75; 66.80)**	**0.54**	**0.93 (0.67; 0.99)**	**1.72**	**0.001**
Gain-frequency, large vs Gain-frequency, small	Traf	3.02 (0.71; 12.80)	0.54	0.78 (0.45; 0.94)	1.45	0.35
Intensity, large vs Intensity, small	MonTraf5dB	3.40 (0.67; 17.19)	0.65	0.87 (0.56; 0.97)	1.32	0.38
Intensity, large vs Gain-frequency, large	MonTraf5dB	1.99 (0.37; 10.59)	0.75	0.86 (0.53; 0.97)	1.14	0.99
Intensity, large vs Gain-frequency, small	**MonTraf5dB**	**7.89 (1.59; 39.14)**	**0.48**	**0.88 (0.60; 0.97)**	**1.83**	**0.002**
Intensity, large vs Directionality	**MonTraf5dB**	**7.89 (1.59; 39.14)**	**0.48**	**0.88 (0.60; 0.97)**	**1.83**	**0.002**
Intensity, small vs Gain-frequency, small	MonTraf5dB	2.32 (0.59; 9.20)	0.48	0.68 (0.35; 0.89)	1.42	0.73
Intensity, small vs Directionality	MonTraf5dB	2.32 (0.59; 9.20)	0.48	0.68 (0.35; 0.89)	1.42	0.73
Gain-frequency, large vs Intensity, small	MonTraf5dB	1.71 (0.39; 7.43)	0.65	0.76 (0.43; 0.93)	1.17	1.00
Gain-frequency, large vs Gain-frequency, small	MonTraf5dB	3.97 (0.94; 16.85)	0.48	0.79 (0.46; 0.94)	1.64	0.08
Gain-frequency, large vs Directionality	MonTraf5dB	3.97 (0.94; 16.85)	0.48	0.79 (0.46; 0.94)	1.64	0.08
Directionality vs Gain-frequency, small	MonTraf5dB	1.00 (0.26; 3.84)	0.48	0.48 (0.19; 0.78)	1.00	1.00
Intensity, large vs Intensity, small	DiaCafe5dB	1.78 (0.44; 7.14)	0.56	0.69 (0.36; 0.90)	1.24	0.99
Intensity, large vs Gain-frequency, small	DiaCafe5dB	2.57 (0.64; 10.28)	0.48	0.70 (0.37; 0.90)	1.46	0.56
Intensity, large vs Directionality	**DiaCafe5dB**	**6.09 (1.44; 25.78)**	**0.31**	**0.73 (0.39; 0.92)**	**2.37**	**0.003**

Differences between HA settings (p2 vs p1)	**Environment**	**OR (95% CI)**	**p1**	**p2 est (95% CI)**	**p2/p1**	**p**
Intensity, small vs Gain-frequency, small	DiaCafe5dB	1.44 (0.37; 5.56)	0.48	0.57 (0.26; 0.84)	1.19	1.00
Intensity, small vs Directionality	DiaCafe5dB	3.42 (0.84; 13.92)	0.31	0.60 (0.27; 0.86)	1.96	0.16
Gain-frequency, large vs Intensity, large	DiaCafe5dB	1.75 (0.39; 7.80)	0.67	0.78 (0.45; 0.94)	1.16	1.00
Gain-frequency, large vs Intensity, small	DiaCafe5dB	3.11 (0.72; 13.48)	0.56	0.80 (0.47; 0.94)	1.43	0.33
Gain-frequency, large vs Gain-frequency, small	**DiaCafe5dB**	**4.48 (1.03; 19.42)**	**0.48**	**0.81 (0.49; 0.95)**	**1.68**	**0.04**
Gain-frequency, large vs Directionality	**DiaCafe5dB**	**10.63 (2.32; 48.68)**	**0.31**	**0.83 (0.51; 0.96)**	**2.68**	**< 0.001**
Gain-frequency, small vs Directionality	DiaCafe5dB	2.37 (0.59; 9.60)	0.31	0.51 (0.21; 0.81)	1.67	0.72
Intensity, large vs Intensity, small	DiaCafe0dB	1.68 (0.40; 7.14)	0.27	0.38 (0.13; 0.72)	1.42	1.00
Intensity, large vs Gain-frequency, small	DiaCafe0dB	1.10 (0.27; 4.46)	0.35	0.37 (0.13; 0.70)	1.07	1.00
Gain-frequency, large vs Intensity, large	DiaCafe0dB	2.30 (0.58; 9.08)	0.37	0.57 (0.25; 0.84)	1.56	0.74
Gain-frequency, large vs Intensity, small	DiaCafe0dB	3.88 (0.93; 16.20)	0.27	0.59 (0.25; 0.86)	2.19	0.08
Gain-frequency, large vs Gain-frequency, small	DiaCafe0dB	2.54 (0.64; 10.11)	0.35	0.57 (0.25; 0.84)	1.66	0.57
Gain-frequency, large vs Directionality	DiaCafe0dB	1.90 (0.49; 7.41)	0.4	0.56 (0.25; 0.83)	1.39	0.95
Gain-frequency, small vs Intensity, small	DiaCafe0dB	1.53 (0.36; 6.51)	0.27	0.36 (0.12; 0.71)	1.34	1.00
Directionality vs Intensity, large	DiaCafe0dB	1.21 (0.31; 4.81)	0.37	0.41 (0.15; 0.73)	1.12	1.00
Directionality vs Intensity, small	DiaCafe0dB	2.04 (0.49; 8.55)	0.27	0.43 (0.15; 0.76)	1.59	0.93
Directionality vs Gain-frequency, small	DiaCafe0dB	1.34 (0.33; 5.35)	0.35	0.41 (0.15; 0.74)	1.20	1.00

Note: DiaCafe0dB = dialogue in café noise at 0 dB SNR; DiaCafe5dB = dialogue in café noise at 5 dB SNR; MonTraf5dB = monologue in traffic noise at 5 dB SNR; Traf = traffic noise

4.4.2 Relationship Between Profile Measures and Consistency of Preferences

Before investigating what profile measures may predict the number of consistent preferences obtained by each participant, data were manipulated as follows: missing values of measures were filled, measures with non-normal distribution were transformed, and a correlation and factor analysis were completed. Missing values were filled by selecting the result of the worst participant for that task. Missing values occurred because of audibility issues: three participants could not complete the task to measure their spectral and temporal resolution at 3000 Hz in either ear, and five participants were unable to complete the intensity discrimination task at 3000 Hz in either ear due to loudness tolerance problems. (The raw data used for the factor analysis is included in Appendix H, p. 166, and summarised per measure in Appendix I, p. 172). Variables that displayed a non-normal distribution were transformed to improve linearity as assessed using the Shapiro-Wilk test: the working memory updating scores were transformed using the square root, intensity discrimination at 500 Hz was transformed by using the logarithmic value, and intensity discrimination at 3000 Hz was reciprocated.

To evaluate if a single profile measure predicted the number of consistent preferences, a first-order correlation analysis was done. This revealed no significant relation between any of the profile measures and the number of consistent preferences (all $p > 0.12$), but there were significant correlations between the profile measures, with correlation coefficients varying from 0.28 to 0.87. Then, a factor analysis was undertaken to reduce the number of independent variables to reduce the risk of overfitting (Peduzzi, Concato, Kemper, Holford, & Feinstein, 1996). A factor analysis with normalised varimax rotation was performed using the variables average low- and high-frequency thresholds; intensity discrimination and spectral and temporal resolution at 500 and 3000 Hz; comfortable dynamic range; working memory recall; executive function; working memory updating and the five personality traits. The scree plot suggested four factors to be extracted (Cattell & Vogelmann, 1977) however, the data appeared to be best summarised by three factors, because extracting more factors resulted in the additional factor(s) not being easily interpretable (Costello & Osborne, 2005). Three variables did not load onto a factor with a weight ≥ 0.3, nor were correlated with another variable with a coefficient ≥ 0.3, and were removed from the factor analysis: executive function, and the personality traits extraversion and openness to experiences. A factor analysis with the remaining variables showed the three factors accounted for 55% of the total variance and represented composite measures which are labelled High-Frequency Hearing, ACE (Agreeableness, Conscientiousness, and Emotional stability) Personality Traits, and Low-Frequency Hearing, with High-Frequency Hearing accounting for most of the total variance (23%; Table 4-5). Factor scores were higher for those with a better high-frequency average, and better spectral and temporal resolution at 3000 Hz. The remaining factors each accounted for 18 and 15% of the total variance, respectively. Higher factor scores for the ACE Personality Traits factor were associated with higher scores on the agreeableness, conscientiousness and emotional stability subscales. Lastly, Low-Frequency Hearing factor scores were higher for those with a better low-frequency average, and better spectral and temporal resolution at 500 Hz.

Table 4-5. The loadings of the different profile measures on three factors referred to as 'High-Frequency Hearing', 'ACE Personality Traits', and 'Low-Frequency Hearing'. Loadings greater than 0.6 are shown in bold.

	High-Frequency Hearing	**ACE Personality Traits**	**Low-Frequency Hearing**
Low-frequency average	-0.27	0.44	**-0.71**
High-frequency average	**-0.89**	0.15	-0.03
Comfortable dynamic range	0.12	-0.48	0.14
Agreeableness	-0.03	**0.69**	-0.10
Conscientiousness	0.15	**0.75**	-0.10
Emotional Stability	-0.29	**0.62**	0.36
Spectral resolution 500 Hz	0.05	0.02	**0.86**
Spectral resolution 3000 Hz	**0.89**	-0.19	-0.05
Temporal resolution 500 Hz	0.15	0.12	**0.63**
Temporal resolution 3000 Hz	**0.87**	0.03	0.02
Intensity discrimination 500 Hz	-0.26	-0.32	0.44
Intensity discrimination 3000 Hz	0.50	0.44	0.24
Working memory recall	0.54	0.14	0.22
Working memory updating	0.06	0.48	0.07
Explained variance	3.17	2.46	2.11
Total variance	0.23	0.18	0.15

Note: ACE = Agreeableness, Conscientiousness, and Emotional stability Personality Traits; Low-frequency average = average hearing thresholds at 250, 500 and 1000 Hz; High-frequency average = average hearing thresholds at 2000, 3000 and 4000 Hz.

The resulting factor scores and the three measures executive function, extraversion, and openness to experiences were used as independent variables in a regression analysis to evaluate the influence of the profile measures on the number of consistent preferences obtained by each participant across all pairs of HA settings and environments. The analysis revealed no significant model, suggesting that none of the factors or measures could significantly predict the number of consistent preferences across differences between HA settings and environments (F(6, 45) = 1.66; p = 0.15).

4.5 Discussion

The prevalence of consistent auditory preferences of adults with normal hearing to a moderate sensorineural hearing loss and different audiogram configurations was found to be variable across participants and dependent on the listening environment, the difference between HA settings, and their interaction. Participants obtained more consistent preferences in less complex listening environments, with a consistent preference for, on average, 78% of the comparisons in traffic noise, decreasing systematically to 38% in the dialogue in café noise at 0 dB SNR. Participants obtained more consistent preferences for HA settings differing in intensity (on average 65%), than gain-frequency slope (58%) and directionality (40%). However, this tendency differed across the environments and these overall results were not systematically reflected at the individual level. None of the included psychoacoustic, cognitive and personality profile measures could predict consistency of preference.

Consistency of preference was variable across participants, with only 17% of participants having consistent preferences in 80% or more of the test conditions. Variability was also observed by Keidser et al. (2008) who found some participants having consistent preferences for almost all, and some for only a few conditions, when listening to differences in gain-frequency slope across different environments. This variability across participants may be influenced by their ability to discriminate between different HA settings and the tasks involved in obtaining a consistent preference. Firstly, the influence of discrimination ability on consistency of preference is not uniform. On the one hand, a greater number of participants obtained a consistent preference when listening to settings with large rather than small intensity or gain-frequency slope differences, which was also observed by Keidser et al. (2008) for gain-frequency differences. On the other hand, the discrimination measures obtained in this study were not associated with consistent preferences. It should be noted that the intensity discrimination measure showed participants noticed, on average, differences of 1.2 and 1.3 dB for 500 and 3000 Hz pure tones respectively, with only one participant requiring a difference larger than 3 dB for 3000 Hz. Furthermore, 90% of participants were able to discriminate between responses with an rms difference of 3 dB as they had obtained a consistent preference for small intensity differences for at least one environment (Figure 4-4. However, this did not extend to small gain-frequency differences with the same rms difference, for which a maximum of only 54% of participants obtained a consistent preference. This latter finding is supported by Keidser et al. (2008) who found that 10 of 12 participants with a hearing loss were able to indicate an increasing perceptual difference with increasing rms difference (from 1 to 10 dB) between gain-frequency responses. However, only three of the 10 participants could consistently select a preferred response for most listening conditions. These findings suggest that most participants could likely discriminate between the intensity and gain-frequency slope rms differences of 3 and 6 dB in the paired-comparison task, but some may not have had a preference. Presumably, those without a preference for some or all comparisons simply found a large range of HA settings acceptable, and thus have less need for fine-tuning.

Secondly, the complexity of the tasks involved in obtaining a consistent preference could be another potential reason for the variation in consistent preferences. In each environment, participants not only had to discriminate between the pairs of HA settings, but establish a criterion for their preference, and apply one or more criteria across the different comparisons when pairs of HA settings were presented in a randomised order. A change of criterion used to select a preference (e.g. naturalness, ease of understanding) within the same environment may influence the participant's preference (Keidser, 1995), and consequently the consistency of their responses. In view of the number of preferences to be completed and the unlimited time provided, it is also possible some participants lost motivation or changed their self-chosen criterion part-way through due to boredom and/or fatigue (De Beuckelaer, Kampen, & Van Trijp, 2013). The consistency of preference of participants who did not pass the MoCA screening measure, or those who were non-native speakers of English, did not stand out from other participants, suggesting the tasks necessary to obtain consistent preferences are unaffected by such characteristics.

Consistency of preference was dependent on the environment, suggesting an influence of the complexity of the environment. The change in complexity between environments in this study was multidimensional: as the environment became more complex, the number of target talkers increased, the SNR became poorer, and the noise more fluctuating. For example, more fluctuation was present in the café noise, which comprised multiple speech signals, than in the traffic noise. As speech is a very dynamic signal, the SNR will also fluctuate over time, with greater changes possible from moment to moment in the more fluctuating café noise (e.g. Bentler & Chiou 2006; Edwards et al. 1998). In a given trial, the preferred setting could depend on the actual SNRs and the quality of the target voice heard in each setting, when switching back and forth between settings. If these factors change between settings across trials, then that could influence the participant's ability to obtain consistent preferences. It is expected numerous real-world listening situations, especially those containing speech-in-speech, would contain a similar variation, which means that it is potentially very challenging to select a consistent preference.

Overall, results suggest obtaining a consistent preference for intensity differences was easier than for gain-frequency and directionality differences. Support for this finding can be found in the study by Keidser et al. (2008), in which participants were asked to adjust the volume and gain-frequency slope of a response to reach a preferred setting. Keidser et al. (2008) found that more participants made changes to overall gain than to the slope of the response, suggesting reaching a preferred volume level may be easier than a preferred gain-frequency slope. The lowest number of consistent preferences for directionality compared to intensity and gain-frequency slope differences was expected, because of the smaller perceptual difference between its HA settings, with the same gain-frequency response used for both microphone modes for targets presented at 0° azimuth (Table 4-1).

The significant interaction between environment and difference between HA settings highlights the exceptions to the main findings. Although participants were more likely to have a consistent preference for intensity than for the gain-frequency slope differences, this was only the case for the less complex environments; and although there was a trend for fewer consistent preferences as environments became more complex, this was not the case for directionality (Figure 4-4). The pattern of the consistent preferences for the directionality pair may be influenced by the effectiveness of the directional microphone in improving intelligibility in the different environments. The largest number of consistent preferences for the monologue in traffic noise at 5 dB SNR was expected, as the directional microphone would be most effective in improving the SNR in this situation by decreasing the section of low-frequency dominant traffic noise present behind the participant. The increase in the number of consistent preferences from the dialogue in café noise at 5 dB SNR to the same environment at 0 dB SNR is similar to findings of Walden et al. (2005), who asked 31 participants to select a preference between omnidirectional and hypercardioid responses when listening to sentences presented in speech-shaped noise. When they changed the SNR from 6 to 0 dB, the percentage of preferences for the directional microphone increased from around 55% to 80%. These findings are in line with the expectation of a non-linear relationship between preference for directionality and SNR, with directional microphones being effective in a small range of SNRs, but no more effective than omnidirectional microphones at very large and small SNRs due to the dominance of the target and inability to effectively improve the SNR, respectively (e.g. Walden et al. 2005; Mejia, McLelland, Galloway, Aubreville, & Dillon, under review).

The individual participant profile measures used in this study (psychoacoustic, cognitive, and personality) could not predict who was able to distinguish between HA settings, select a preference, and maintain the same preference criterion throughout the environment, resulting in a consistent preference. This suggests that other factors not evaluated could be better predictors of consistency of preference. It should also be noted that the ACE factor (Agreeableness, Conscientiousness, and Emotional stability Personality Traits) identified in this study may be unique to this test population, or framed by the particular group of profile measures, as the Big Five personality traits examined with the Ten-Item Personality Inventory have been extracted and reported as independent traits unrelated to each other in previous research (John & Srivastava, 1999).

4.5.1 Study Limitations

Some methodological choices may limit the extension of these findings. Despite the aim of simulating real-world test environments, implementations of the speech target and HA amplification resulted in reduced realism of the listening condition. Firstly, although realistic background stimuli and speech signals were used, the speech signals lacked the influence of the background noise on the speaker's voice (Lombard effect) and reverberation, potentially limiting the applicability of the findings to similar real-life situations. The effect of the presence of the Lombard effect and reverberation on consistency of preference are unknown. When listening in background noise, Lombard speech is expected to be more easily understood than speech recorded in quiet (Pichora-Fuller, Goy, & Van Lieshout, 2010),. On the other hand, the inclusion of reverberation in the speech signal could reduce speech understanding (e.g. Helfer & Wilber 1990).

Secondly, the signal processing implemented in the master HA was less complex than what is available in most modern commercial HAs. It is possible additional signal processing could increase the difference between the HA settings beyond the differences of intensity, gain-frequency slope and directionality introduced in this study. This increased difference between the HA settings could increase the number of consistent preferences, as participants obtained more consistent preferences for large rather than small differences.

Thirdly, the amount of low-frequency gain provided was more than what is prescribed for participants with normal and near-normal hearing in the low frequencies. All participants were provided with a minimum amount of gain to ensure the difference between the HA settings was achieved for all participants. However, when clinically fitted, HA users with normal low-frequency hearing and a high-frequency hearing loss would be provided with venting, reducing low-frequency gain and consequently reducing the contrast between the pairs of HA settings. The use of gain and venting matching the low-frequency thresholds is expected to result in fewer consistent preferences, as participants had fewer consistent preferences for small rather than large differences between the pairs of HA settings.

Lastly, when evaluating consistency of preference, comparisons were presented in a randomised order across the different HA settings, contrary to approaches followed when fine-tuning, whether done by the clinician or by the user in their own listening environment, where complaints would be addressed successively. This presentation mode was chosen to reduce a possible order effect, as participants completed 40 to 50 comparisons for each environment. This randomisation within each environment may have resulted in fewer consistent preferences for participants who selected different preference criteria (e.g. comfort, speech perception) for the comparisons of different HA settings (intensity, gain-frequency slope and directionality).

4.5.2 Implications and Future Directions

These findings suggest listeners may not have a consistent preference in all listening situations when choosing between two alternative HA settings. Completing multiple paired-comparisons in the clinic to ensure consistency of preference would be time-consuming, but possible. However, the effectiveness of performing multiple paired-comparisons in the clinic is limited due to the dependency of consistency of preference on the listening environment and the HA settings selected for comparison. The dependency on listening environment is particularly problematic due to difficulties in identifying (Valentine et al., 2011) and recreating (Dreschler et al., 2008) the same, potentially complex, listening environments in the clinic that cause problems in the field. Alternatively, the user may fine-tune the amplification characteristics themselves in their own listening environment. Today, many hearing devices are app controlled (Chasin, 2017), with the app giving the user access to rather sophisticated controls for manipulating the amplification characteristics. Most commonly, the in-situ changes made by the user to the HA setting are temporary, meaning the changes will be undone when the device is next turned off. Permanent fine-tuning is possible by either allowing the user to create an additional listening program for a particular situation, or by providing them with trainable aids.

The relationship between consistency of preference in simulated real-world environments and trainable HA outcomes in the real world remains to be investigated: can those with more consistent preferences in the laboratory make more consistent adjustments to the HA settings, and in the process fine-tune their HAs? In parallel, investigation is required to establish if those with fewer consistent preferences make inconsistent adjustments of trainable devices resulting in undesirable settings, a concern held by 73% of clinicians who reported not to activate training, in response to a survey about their use and perception of trainable HAs (Walravens, Keidser, & Hickson, 2016; Chapter 3).

4.6 Conclusion

Findings from this study showed variability in consistency of preference for adults with hearing ranging from normal to moderate sensorineural hearing loss, depending on the difference between the HA settings, the environment and their interaction. Further, the study showed that some common psychoacoustic and cognitive measures, plus measures of the Big Five personality traits did not predict consistency. These findings challenge the effectiveness of fine-tuning procedures as they are commonly performed in the clinic and suggest that users who are training their own HAs could benefit from counselling to ensure they have realistic expectations of the technology as their effort may be less effective in more complex listening environments.

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Chapter 5 - Activating Training in Hearing Aids: Time-Course, Outcomes, and Prediction of Training

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5.1 Abstract

Objective. To examine the impact of activating training in hearing devices on the time-course of gain changes and outcome measures. Further, to examine the predictive value of consistency of listening preference and profile measures describing hearing, personality and executive function for obtaining trained settings.

Design. Participants were fitted with trainable, remote-controlled receiver-in-the-canal devices following clinical procedures, and asked to make adjustments to settings in the field as needed. Training was level-, frequency- and sound class dependent. After 2 and 6 weeks, participants completed the International Outcome Inventory for Hearing Aids and Client Oriented Scale of Improvement, and logged device information on usage and trained gain changes was retrieved. Consistency of listening preference and profile measures were available from a previous laboratory-based study.

Study sample. Twenty-three participants with mild to moderate sensorineural loss used the devices for 2 weeks; 18 continued to 6 weeks.

Results. After 2 weeks, 50% of participants had obtained trained settings, reaching 61% after 6 weeks. There was no significant difference between outcomes obtained by those who obtained trained settings and those who did not at 6 weeks and obtaining trained settings could not be predicted based on the selected measures.

Conclusions. Activating training following clinical procedures did not introduce adverse effects up to 6 weeks post-fitting. Obtaining trained settings could not be predicted by included measures of consistency of preference, hearing, personality and executive function.

5.2 Introduction

In a clinical setting, HAs are typically fitted based on the user's audiogram applying a generic or proprietary prescription that is based on average preferences. However, not all users are happy with these average settings and request changes to, or fine-tuning of, their HA settings (Valentine et al., 2011). Fine-tuning in the clinic has several limitations, including a reliance on the HA user's recall and description of the acoustic environment in which the prescribed setting is unsatisfactory, and the clinician's knowledge of the myriad of changes that can be made to remedy this complaint

(Nelson, 2001; Valentine et al., 2011). Additionally, true evaluation of the changed HA settings can often not be performed in the clinic as recreating a similar environment may be difficult (Dreschler et al., 2008; Zakis, 2003). Instead, the HA user has to seek out the environment in question in real life to try out the changed settings and then return to the clinic for further changes if necessary. An alternative approach is to fit the user with HAs that include a learning or trainable algorithm, so the user can fine-tune their own HA settings in their own listening environment. Based on consistent user-adjustments to amplification characteristics using the HA controls, the algorithm will gradually fine-tune the HA settings (Dillon et al., 2006).

Trainable HA research has so far focused on evaluating the effect of training when participants were asked to frequently explore different settings in various listening environments. These studies found that most participants can train successfully; that is, the majority prefer their trained response over the prescribed, and obtain responses not negatively affecting their hearing (Keidser & Alamudi, 2013; Zakis et al., 2007). Additionally, Keidser and Alamudi (2013) found that 12 of 19 participants reliably repeated their training, with the remaining participants showing different results during the second trial. The authors noted that although HA use was similar across both trials, fewer adjustments were made during the second trial, which could explain differences in trained settings across trials. The potential reasons raised for the fewer adjustments were study fatigue and the novelty of experimenting with the controls wearing off (Keidser & Alamudi, 2013).

As most research on trainable HAs to date has involved participants being encouraged to make frequent adjustments and explore different HA settings when in different listening environments, little information is available on the time-course of training when participants only make adjustments as needed. In one study, participants were “instructed to adjust gain and treble control according to their preferences as they went about their daily life” (Chalupper et al., 2009). Those researchers found that the average HA response did not change significantly from 1 to 2 weeks, but reported that there were large individual differences. In view of these individual differences, we specifically set out to investigate the time-course of gain changes beyond 2 weeks of HA use. That is, we aimed to examine to what extent HA users would continue to make adjustments up to 6 weeks of use, and if such adjustments resulted in trained gain settings different from those prescribed. Procedures closely resembling clinical practice were used, in contrast with earlier research, in which users were encouraged to make frequent adjustments to the HA controls (e.g. Zakis et al., 2007; Keidser and Alamudi 2013) or the starting response varied from the prescribed to further encourage participants to make frequent adjustments (e.g. Mueller et al., 2008).

A recent survey evaluating the impact of trainable HAs in Australia found that most clinicians (n = 137) were positive about fitting trainable HAs, and most users (n = 15) indicating they had trained their HAs were also positive about their experience (Walravens et al., 2016; Chapter 3). The majority of clinicians (91%) accepted the trained settings their clients had obtained, and only one of the 15 users who had trained reported they were unlikely to train their HAs again. The biggest concern raised by clinicians not activating training was that training could have a negative outcome for the user. In view of this concern from clinicians, we set out to evaluate the outcomes of training after 6 weeks of use.

Successful fine-tuning, be it in the clinic or using trainable HAs, relies on the user having consistent preferences for certain HA settings, so that the resulting HA settings are most likely a reflection of their actual preference. To evaluate the influence of consistency of listening preference on the fine-tuned HA settings when activating training, participants were recruited from those who were part of an earlier laboratory investigation into consistency of listening preference. In that investigation, participants selected their preference between pairs of HA settings differing in intensity, gain-frequency slope, or directionality when listening to four simulated real-world environments (see Chapter 4). Using a two-alternative forced-choice task, selecting the same HA setting nine or 10 times out of 10 was considered to reflect a consistent preference. Consistency of listening preference among the 52 participants with normal hearing to a moderate sensorineural loss was variable and depended on the environment, the difference between the HA settings and their interaction. For each participant, an overall consistency of preference score was obtained, expressed as the number of consistent preferences out of a maximum of 19 different conditions. Also available from that investigation were participants' profile measures, consisting of their performance on a range of hearing, personality and executive function measures. These measures could not predict the overall consistency of preference score in the laboratory, but may be more relevant when self-adjusting HA settings and training in real life; therefore they were included in this study. The ability to predict whether a HA user would be likely to obtain trained settings different from the prescribed would be beneficial in clinical practice. It would allow clinicians to target the fitting of trainable HAs to appropriate clients. To this end, the consistency of preference score and the profile measures were investigated for their predictive value for training, that is, if HA settings were trained to be different to those prescribed.

In summary, this study set out to evaluate: 1) the time-course of training when participants only make adjustments if needed or wanted, in a 6-week period; 2) the outcomes of training at 6 weeks; and 3) whether profile measures (describing hearing, personality and executive function), or a laboratory measure of consistency of listening preference, could predict obtaining trained settings different from the prescribed.

5.3 Materials and Methods

5.3.1 Participants

Participants were recruited from 37 hearing-impaired people who volunteered for an earlier study and for whom an extensive profile was available. In total, 23 adults (9 women) with an average age of 75.9 years (SD = 6.1) accepted the invitation to participate in this study. This sample had a mild to moderate (four-frequency average of 500, 1000, 2000 and 4000 Hz) sensorineural hearing loss (mean = 43.2 dB; SD = 5.7 dB). The hearing losses were symmetrical, with the difference between ears in four-frequency average hearing loss not exceeding 10 dB, and the difference between thresholds at individual frequencies up to 4000 Hz not exceeding 20 dB, with the exception of one participant reaching a difference of 30 dB for one frequency. The majority of participants were experienced HA users; three participants had no prior HA experience.

5.3.2 Devices

Participants were fitted with Signia Pure 7 primax receiver-in-the-canal HAs and an EasyPocket remote control, using Connexx 8.3. These are trainable, multi-channel HAs with an extended high-frequency bandwidth to 12 kHz. Some of the advanced features, including noise reduction, adaptive compression, adaptive directionality and feedback cancellation, were programmed according to the manufacturer's first fit and the trainable algorithm was enabled. Other features, including frequency compression, the tinnitus noise generator and acclimatisation, remained disabled. The HAs automatically classified acoustic scenes into one of six sound classes and assigned corresponding amplification characteristics. The sound classes were speech-in-quiet, speech-in-noise, noise, music, car noise, and quiet.

The onboard HA controls were deactivated. Instead, a remote control was used for any adjustments, providing larger buttons than those onboard the HAs, as well as a visual indicator of which settings were being adjusted. Using the remote control, participants could adjust the volume and sharpness. These adjustments affected gain in four frequency bands with cross-over frequencies of 375, 1375, and 4635 Hz. Changes to volume affected all four frequency bands, whereas changes to sharpness changed the gain in the two highest bands only, with the size of the gain change in the highest band halved in the second-highest band. Participants could adjust the volume and sharpness within a range of 16 dB around the starting response, with the starting response at 50% of the range. Adjustments to the volume and sharpness were instantaneous, but to reduce the impact of a single large change, the trainable algorithm used an averaging technique and implemented the new HA settings incrementally and with a delay. Additionally, a training limit was set to +6 and -9 dB from the starting response, ensuring that no trained settings could reach harmful levels. In summary, the trainable algorithm adjusted the amplification based on consistent adjustments to the volume and sharpness, with reference to the input level of the signal in each of the four frequency channels and the sound class, providing frequency- and environment-dependent training of compression threshold and ratio (Chalupper et al., 2009).

The following logged information was available from the HAs: the number of hours the HAs had been turned on; the percentage of the duration the HAs were turned on in each of the six sound classes; the number of adjustments made to the volume and sharpness; and the change in gain resulting from training in each of the four frequency bands, for input levels of 50, 65 and 80 dB SPL in each of the six sound classes. The number of adjustments and trained change in gain were retrieved from the HAs using a specially developed program. Multiple adjustments made within a 10-second window were considered as one adjustment.

5.3.3 Outcome Measures

Two measures were used to evaluate participant outcomes with the HAs: the Client Oriented Scale of Improvement (COSI) and the International Outcome Inventory for Hearing Aids (IOI-HA). The COSI is a tool to evaluate the outcome of a rehabilitation program, using negotiated and specific listening situations (Dillon, James, & Ginis, 1997). Participants in this study were asked to nominate four listening situations they experienced at least once a week in which it was important for them to be able to hear; these were negotiated to ensure they were realistic. To obtain their COSI result, participants would indicate how much they could hear with the HAs in their COSI listening situations: hardly ever, occasionally, half the time, most of the time or almost always. Values of 1 to 5 are assigned to these responses, with 5 corresponding to “almost always”. Participants’ final ability was calculated by averaging the scores across all goals (Dillon et al., 1997).

The IOI-HA consists of 7 closed-set items that evaluate daily use, benefit, residual activity limitations, satisfaction, residual participation restrictions, impact on others, and quality of life (Cox & Alexander, 2002). Each question is rated on a 5-point Likert scale and scored by assigning values from 1 to 5, with higher scores corresponding to better outcomes.

5.3.4 Consistency of Listening Preference Measures

All participants were part of an earlier study that investigated consistency of listening preference in a laboratory test (Chapter 4). For each participant, an overall consistency of preference score was available, representing the number of conditions (out of 19) for which they had obtained a consistent preference, as well as their profile measures composed of three factor scores and three measures (Chapter 4). The three factors described high-frequency hearing (composed of high-frequency average hearing loss and spectral and temporal resolution at 3000 Hz), low-frequency hearing (low-frequency average hearing loss and spectral and temporal resolution at 500 Hz), and

ACE personality traits (scores on the agreeableness, conscientiousness and emotional stability subscales of the Ten-Item Personality Inventory (Gosling, Rentfrow, & Swann, 2003)). Performance on an executive function task and ratings for the personality traits extraversion and openness to experiences completed these profile measures.

5.3.5 Procedure

Ethical approval for this study was granted by the Australian Hearing Human Research Ethics Committee (AHHREC2017-31) and The University of Queensland's Human Research Ethics Committees A & B (2017001637/XR3.1.2D).

Appointment 1

First, for participants whose audiogram was older than 12 months or who reported a change in their hearing, air-conduction thresholds were obtained at 500, 1000, 2000 and 4000 Hz. If a change of 10 dB or more was present at any of these frequencies, a full audiogram was completed. Next, the four listening situations which would form the COSI evaluation were negotiated between the participant and researcher. Using real-ear gain verification based on the International Speech Test Signal (Holube et al., 2010), the HAs were then fitted to match NAL-NL2 targets (Keidser et al., 2011) as closely as possible for input levels of 50, 65 and 80 dB SPL, resulting in maximal rms differences to target of 6, 3 and 5 dB, respectively. If needed, the overall gain and maximum power output were adjusted, but no other fine-tuning was performed.

After their fitting, participants were instructed on how to use and manage the HAs and remote control following procedures closely resembling clinical practice. Participants were told how to identify the left and right HA, turn the HAs on and off, and insert them, which they practiced until they could insert both HAs successfully. Battery replacement, telephone use and wax removal from domes or moulds were demonstrated, and participants were advised to keep the HAs and remote control away from water. Participants were told that the onboard controls did not work and that they had to use the remote control for any adjustments. They were shown how to lock the remote control keypad to avoid making unintentional changes and how to adjust the volume and the sharpness, and they listened to how the beep accompanying each adjustment changed when the halfway or most extreme settings were reached. Participants who used the telecoil were shown how to access this program. All participants were provided with a one-page user guide for the HAs (with the labels "red-right", "blue-left", and "on/off via battery door") and remote control (with the labels "key lock switch", "louder", "softer", "increase sharpness" and "decrease sharpness"; when a telecoil program was active, the "program change" label was indicated and the programs were listed). Any questions about HA and remote control management were addressed. They were also given the manufacturer's user guide for the HAs and remote control. Participants were then advised that the

HAs would default back to the middle of the available range for both volume and sharpness when turning them off and on, but that the remote control could not be turned off. The remote control had to be changed back to the mid-range for volume and sharpness manually to match the HA settings when turning the HAs off and on.

Lastly, all participants were provided with the same verbal instructions about the field trial, shown in Table 5-1. The corresponding remote control buttons to adjust the volume and sharpness were pointed out again on the one-page user guide during these instructions.

Table 5-1. Verbal instructions provided at the end of Appointment 1.

You are wearing hearing aids with different technologies that work together to amplify speech and reduce noise. I would like to find out how you go using these hearing aids. If you can, it would be great if you could wear them as much as possible, so you can tell me how you went in different situations. The hearing aids will adjust automatically, but you can change the settings if you need or would like to. I explained before that you can change the volume and how sharp the hearing aids will sound. These hearing aids will also try to learn from the changes you make. The hearing aids learn slowly, so they may not sound different from day to day.

Seven participants who needed custom moulds so the prescribed amplification could be provided, attended for an additional appointment to have ear impressions made.

Phone follow-up

Two to 5 days after the HAs were fitted, participants were contacted by phone to check whether anything had prevented them from using the devices: they were asked if the HAs and remote control worked and if the HAs caused any physical discomfort. If participants reported any difficulties, they were invited to return to have these issues addressed. One participant returned to the laboratory to replace a HA that they reported was making intermittent rushing sounds.

Appointment 2

After 2 weeks of HA use, participants returned to report on their experiences and indicated whether they had used the remote control to change the HA settings. Participants completed the IOI-HA, the logged data were downloaded from their HAs, and they completed the COSI. Additional actions were taken or appointments offered for participants depending on their COSI scores and whether they had used the remote control to adjust the HA settings. Firstly, those who had not used the remote control and obtained scores of 4 (“most of the time”) or more for each of their COSI listening situations exited the study after this appointment on the basis that they had no need to make adjustments because they were generally satisfied with the HAs’ performance. Secondly, those who had not used the remote control and obtained a score less than 4 for at least one COSI listening situation were asked if they had tried or considered making adjustments to the HAs to improve that particular situation. If the participant expressed uncertainty about how to make changes, they were reinstructed on the use of the remote control. All other participants continued using the HAs without further instructions.

Appointment 3

After an additional 4 weeks of HA use, the same outcome measures were completed and the logged data were downloaded.

5.3.6 Data Analysis

To achieve the first aim of this study, evaluating the time-course of training, trained gain changes and HA use were compared between 2 and 6 weeks. The data evaluated for this purpose included the logged hours of use, logged percentage of time spent in different sound classes, logged number of adjustments made to volume and sharpness, and the logged gain changes resulting from training, as read from the HA after 2 and 6 weeks. Logged data that were available for both HAs were averaged due to the negligible difference in settings between the left and right aids. The only exception was HA use: three participants with a difference between aids of more than 10% after 2 weeks of use, and one participant for whom this was the case after 2 and 6 weeks of use, were assigned the hours of use of the HA that was used the most, while averaging all other values.

Further, the 72 (six sound classes by four frequency bands by three input levels) logged gain changes were reduced to 24 measures of gain changes by combining information from the different frequency bands and levels. Firstly, for each sound class and input level, values for the two lower and two higher frequency bands were averaged to reduce the number of frequency bands to two; a low-frequency (“LF”) and a high-frequency (“HF”) band. Secondly, the difference in gain for 80 and 50 dB SPL levels was used as a measure of compression ratio (“CR”), maintaining the levels at 65 dB SPL as measures of gain (“gain”) to reduce the number of “levels” to two. The final 24 measures of gain were LF CR, HF CR, LF gain, and HF gain for each of six sound classes. Whether the magnitude of a gain change was sufficiently large to consider the HA trained was determined using criteria introduced by Keidser and Alamudi (2013): 2 dB difference or more for LF and HF gain, or 4 dB difference or more for LF and HF CR. The HA settings were considered trained if any of the extracted 24 measures of gain changes met the applicable criteria. The logged trained gain changes were manually adjusted to 0 dB in the frequency bands affected by venting. The frequency bands affected by venting were those for which insertion gain for a 65 dB SPL input signal was below 0 dB. This adjustment ensured the logged trained gain changes were changes in frequency bands dominated by amplified sound. Differences in participants’ HA use, adjustments and trained gain changes from 2 to 6 weeks were partly evaluated descriptively and partly by using the dependent samples t-test or the Wilcoxon matched pairs test for normally and non-normally distributed data, respectively.

To evaluate the study's second aim, outcome measures obtained at 6 weeks were analysed. Differences in outcome measures between groups of participants who had obtained trained settings and those who had not were evaluated using the independent samples t-test or the Mann-Whitney U-test, for normally and non-normally distributed data, respectively.

To address the study's third aim, the predictive value of the consistency of listening preference and profile measures for training, that is, whether the HA settings were trained to be different from those prescribed, was evaluated using binomial logistic regression. A participant's consistency of preference score was the number of consistent preferences obtained in the laboratory based on 19 measures evaluating intensity, gain-frequency slope and directionality differences in simulated real-world environments (Chapter 4). The profile measures were a consolidation of 9 psychoacoustic, cognitive and personality measures (Chapter 4), represented by 3 factors and three measures: low- and high-frequency hearing, ACE personality traits (agreeableness, conscientiousness and emotional stability subscales of the personality measure), the extraversion and openness to experiences subscales of the personality measure and executive function.

5.4 Results

5.4.1 Time-Course

All 23 participants completed the 2-week trial. At this point, two participants exited the study as they had not made any adjustments to the HAs and had COSI scores of 4 ("most of the time") or greater for all their nominated listening situations. The remaining 21 participants were invited to continue wearing the HAs for another 4 weeks. However, three participants discontinued at or after 2 weeks because of unhappiness with the HAs; time constraints due to their partner's health; and discomfort behind and in the ear caused by the devices and standard domes. Thus, 18 participants used the HAs for 6 weeks, and their data is reported in this section.

According to the logged data, participants wore their HAs on average over 10 hours per day over the first 2 weeks, decreasing significantly to 8 hours per day over the last 4 weeks ($Z = 2.6$; $p = 0.01$). On average, participants wore their HAs the most in situations classified as quiet: 48% of the time in the first 2 weeks and 47% in the last 4 weeks. There was no significant difference in the percentage duration the HAs were used in the different sound classes after 2 and 6 weeks (all $p > 0.1$). After both 2 and 6 weeks of use, participants had made more changes to volume compared to sharpness. Overall, participants made significantly more adjustments per week over the first 2 than over the last 4 weeks (median at 2 weeks = 21.1 adjustments/week compared to median over the last 4 weeks = 8.7 adjustments/week; $Z = 3.5$; $p = 0.0005$). Despite participants both wearing their

HAs for fewer hours per day and making fewer adjustments per week over the last 4 compared to the first 2 weeks, the number of adjustments they made per hour was lower in the last 4 weeks, though not significantly so (median at 2 weeks = 0.3 adjustments/hour compared to the median over the last 4 weeks = 0.2 adjustments/hour; Z = 1.8; p = 0.07).

Different time-courses were evident for the 18 participants who had a need to make adjustments and used the HAs for 6 weeks. After 2 weeks of HA use, one participant reported not using the remote control to make changes to the HA settings but obtained a score less than 4 for at least one COSI listening situation. This person was reminded of the possibility of trying different settings of the device when in situations where difficulty was experienced, and the participant subsequently made (more) adjustments over the next 4 weeks, without obtaining trained settings. Of the remaining 17 participants, six did not obtain trained settings by 2 or 6 weeks, three obtained trained settings by 6 weeks but not by 2 weeks, and eight obtained trained settings by both 2 and 6 weeks.

The extent of training after 2 and 6 weeks of HA use is summarised in Table 5-2, showing that the majority of trained gain changes after 6 weeks were within 2 dB of the prescribed response. While little to no training was achieved for LF gain or LF CR, the proportion of changes of 2 dB or more for HF gain and HF CR doubled from 2 to 6 weeks, showing training for these settings continued beyond 2 weeks of HA use.

Table 5-2. Percentages of measures of trained gain changes (low-frequency gain (LF gain), low-frequency compression (LF CR), high-frequency gain (HF gain), and high-frequency compression (HF CR)) differing from the prescribed by less than 2 dB, from 2 to 4 dB, and from 4 to 6 dB after 2 and 6 weeks of HA use.

Gain change	**2 weeks**			**6 weeks**		
(dB)	**< 2**	**≥ 2 & < 4**	**≥ 4 & < 6**	**< 2**	**≥ 2 & < 4**	**≥ 4 & < 6**
LF gain	100	0	0	99.1	0.9	0
LF CR	99.1	0.9	0	100	0	0
HF gain	86.1	13.0	0.9	72.2	24.1	3.7
HF CR	93.5	6.5	0	85.2	14.8	0
Total	94.7	5.1	0.2	89.1	10.0	0.9

The increase in the proportion of trained gain changes (Table 5-2) was also apparent in the number of sound classes with a trained setting and number of people obtaining trained settings: from 15 sound classes for eight participants after 2 weeks to 30 sound classes for 11 participants after 6 weeks of HA use. Of the eight participants who obtained a trained HA setting after 2 weeks of use, five increased the number of sound classes in which they had trained, whereas three maintained the same number.

The highest proportion of trained gain changes after both 2 and 6 weeks was observed for HF gain (Table 5-2). The average changes made to HF gain between 2 and 6 weeks were small, ranging from 0.2 (SD = 0.4) to 0.7 dB (SD = 1.2) across the different sound classes. Figure 5-1 shows the gain changes between 2 and 6 weeks across the six sound classes, with a change in the same direction shown as a positive change. During this period, a maximal change of 3.6 dB in the same direction and of 1.2 dB in the opposite direction was reached. For 60% of cases, HF gain settings had changed up to 0.5 dB over the last four weeks. For the remaining cases, changes were greater than 0.5 dB, with a third (34%) of HF gain changes continuing to be made in the same direction as during the first 2 weeks, accounted for by 14 participants. Six percent of changes were in the opposite direction, accounted for by six participants.

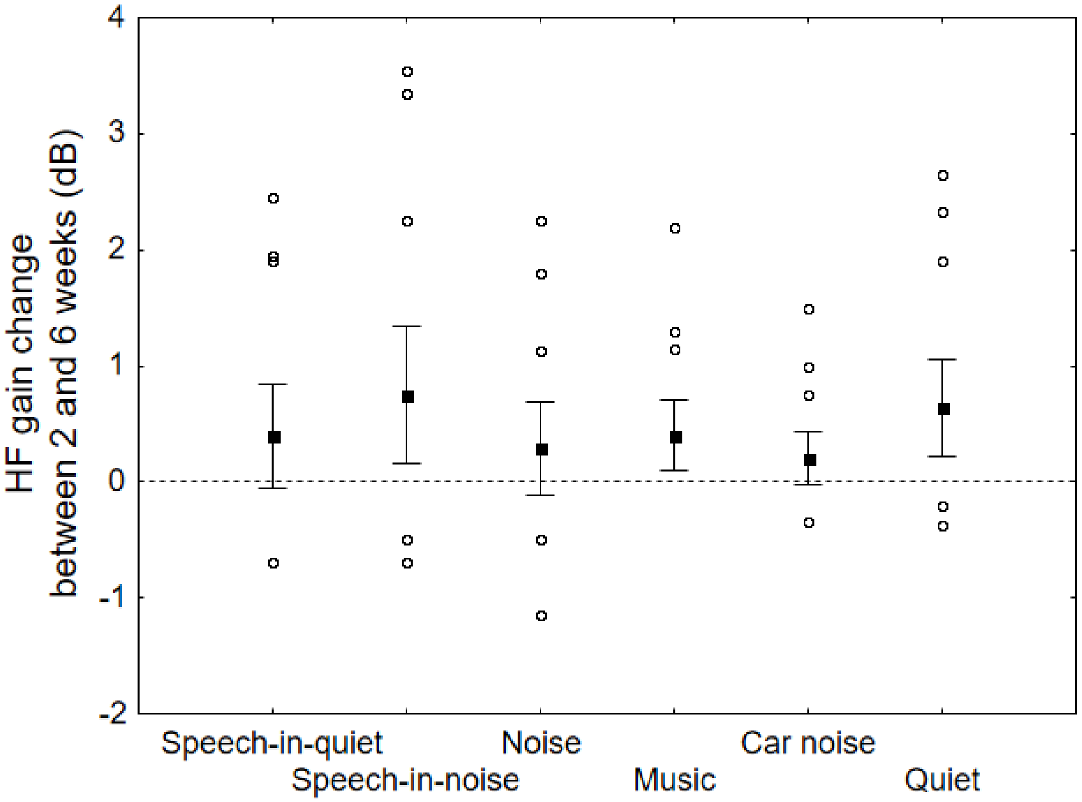

Figure 5-1. Average changes in high-frequency gain (HF gain) between 2 and 6 weeks of HA use. A positive value indicates that gain continued to be changed in the same direction. The whiskers indicate the 95% confidence intervals, with the circles depicting outliers.

After 2 weeks of HA use, 10 of the 20 participants (50%) who had made adjustments had obtained trained settings, increasing to 11 out of 18 (61%) after 6 weeks. Overall, training continued beyond 2 weeks, with settings moving away from the prescribed for both more participants and more sound classes, particularly in the higher frequencies.

5.4.2 Outcomes of Training

The outcome of training was evaluated using the IOI-HA and COSI for the 18 participants who used HAs for 6 weeks. After 6 weeks of use, most participants reported positive outcomes using the

IOI-HA (see Figure 5-2). There was no significant difference between those who had obtained trained settings (n = 11) and those who had not (n = 7) after 6 weeks for any of the IOI-HA items (all p > 0.5).

The final ability COSI score after 6 weeks of HA use, averaging each participant's scores across their listening situations, was also similar for those who had obtained trained settings (n = 11; mean = 4.3) and those who had not (n =7; mean = 4.2; t(16) = -0.3; p = 0.7). The three participants who obtained trained settings by 6 weeks, but not after 2 weeks showed no remarkable change in their COSI or IOI-HA scores. Overall, there was no significant effect of training on outcomes.

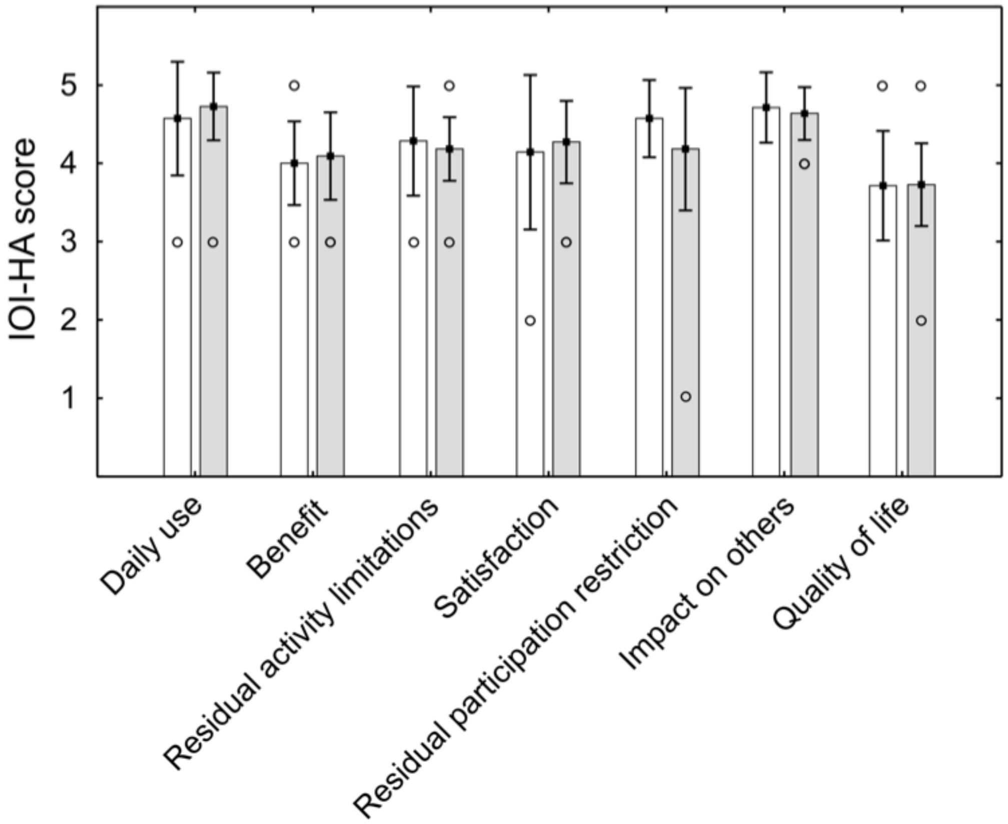

Figure 5-2. Average IOI-HA ratings after 6 weeks of use for those who had obtained trained settings (grey; n = 11) and those who had not (white; n = 7). The whiskers indicate the 95% confidence intervals, with the circles depicting outliers.

5.4.3 Prediction of Obtaining Trained Settings

The profile measures, describing hearing, personality and executive function, and the consistency of preference score obtained in an earlier study were used to evaluate if obtaining trained settings after 6 weeks (n = 18) could be predicted. Neither the profile measures ($\chi^2(6) = 9.5$; p = 0.1) nor the consistency of preference score ($\chi^2(1) = 0.3$; p = 0.6) could predict training, that is, who would be more likely to obtain at least one trained setting after 6 weeks of HA use.

5.5 Discussion

This study set out to evaluate the time-course of training when participants only make adjustments if needed or wanted, the outcomes of training at 6 weeks, and whether a laboratory measure of consistency of listening preference or profile measures (describing hearing, personality and executive function) could predict obtaining trained settings at 6 weeks. Using clinical procedures, half of the participants had obtained trained settings after 2 weeks. Participants continued to make adjustments to 6 weeks, by which time 61% of participants obtained trained settings across more sound classes, without adverse effects on outcome measures. The consistency of preference score and profile measures were unable to predict who obtained trained settings.

Based on logged data, HA use of the study participants after 6 weeks was similar to that observed for a large clinical population (Timmer, Hickson, & Launer, 2017b). HA use in this study was most prevalent in quiet. Although more time was also spent in quiet than in other environments by the population described in Timmer et al. (2017b), their quiet category included both quiet and speech-in-quiet situations, which accounted for 83% of usage time in their study compared to 66% in this study. Some differences may be explained by the different automated classification systems used, and the fact that participants in this study generally constituted a well-functioning group that may have been more outgoing than a typical clinical population. Similarity in the usage data suggests that participants in this study were representative of a clinical population.

Participants made, on average, fewer adjustments per week over the last 4 weeks compared to the first 2 weeks. Although participants in the Keidser and Alamudi (2013) study were encouraged to make frequent adjustments, and participants repeated rather than continued the training, that study found that participants made fewer adjustments during the repeat trial. Their proposed influences of study fatigue and the novelty of experimenting with the controls wearing off (Keidser & Alamudi, 2013) may also have played a part in this study. An additional potential influence in this study may have been a reduced need to make adjustments over time, as participants became used to the HA settings and/or the trained gain changes for particular sound classes reached or approached the participants' preferred settings. Participants further obtained, on average, small trained gain changes over the last 4 weeks (Figure 5-1). Despite participants both making fewer adjustments per week and obtaining small trained gain changes over the last 4 weeks, more participants obtained trained settings after 6 weeks of HA use. This finding suggests that not all HA users had reached their trained response(s) after 2 weeks of HA use. Similarly, Chalupper et al. (2009) found that, averaged across participants, the change in trained settings between 1 and 2 weeks was less than 1 dB. However, they concluded that therefore, training "mostly finished after 1 week". It is possible the average change between week 1 and week 2 may have been small for participants in the Chalupper et al. (2009) study, however, it cannot be excluded that some of those participants may have continued training and then obtained larger differences from the prescribed settings in time. As training is sound class specific and implemented gradually, it is possible that some participants needed more time in particular environments in order to make enough adjustments to obtain trained settings. It is unknown for how long HA users would continue to make adjustments and for how long those adjustments would result in further changes to their trained gain.

The majority of participants in the present study made adjustments even when they were instructed to make adjustments only if needed or wanted. They had a need to make adjustments but obtained fewer trained changes and smaller trained changes than previously reported (Keidser & Alamudi, 2013; Zakis et al., 2007). The proportion of participants who obtained trained settings after 6 weeks of use was lower compared to earlier studies with 11 of 18 participants (61%) obtaining at least one trained setting. This number may have reached 14 out of 21 participants (66%), if three participants had not discontinued the trial, as two had already obtained trained settings by 2 weeks. This proportion of participants is smaller than in the Keidser and Alamudi (2013) study where 24 of 26 participants (92%) trained in around 3 to 7 weeks, using similar criteria to obtain trained settings. The trained changes in HF gain in this study were also of lower magnitude than in previous studies (Keidser & Alamudi, 2013; Zakis et al., 2007). For example, 18 participants in the Zakis et al. (2007) study obtained average trained HF gain changes in 1 to 4 weeks of -4.1 dB, and participants in the Keidser and Alamudi (2013) study obtained average changes to HF gain from -0.7 to -2.6 dB on average, across six sound classes. These findings suggest that encouraging adjustments to be made, which was the approach of the Zakis et al. (2007) and Keidser and Alamudi (2013) studies, results in more extensive training than was observed in this study. Those earlier studies may therefore overestimate the proportion of people who will benefit from trainable HAs.

Two of the findings on training deserve further scrutiny. Firstly, it is notable that most of the trained gain changes after 6 weeks of use were for HF gain. This finding was expected due to the impact of venting: both low-frequency bands were affected for 14 of the 18 participants who used HAs for 6 weeks. It suggests that training may be less effective for those with milder hearing loss in the low frequencies who tend to be fitted with open domes or large vents. Secondly, the limited amount of change to the compression ratio values may have been situational. Participants used their HAs, on average, almost half of their time using HAs in situations classified as quiet, potentially reducing the opportunity to make adjustments at higher levels to impact the compression ratio. Furthermore, the 4 dB cut-off introduced by Keidser and Alamudi (2013) to measure the difference between 40 and 90 dB input levels may have been conservative when evaluating the difference between 50 and 80 dB as in this study.

With 89% of participants indicating a final ability score of 4 (“most of the time”) or more when rating their listening situations using the COSI at 6 weeks, and the average rating across all items of IOI-HA reaching 4.3, outcome measures showed similar findings to earlier studies of outcomes with conventional HAs (Dillon, Birtles, & Lovegrove, 1999; Hickson, Clutterbuck, & Khan, 2010). Furthermore, obtaining trained settings did not result in outcomes significantly different from those of participants who stayed with the prescribed setting. This suggests that activating training in HAs did not impact outcomes, however this needs to be considered alongside the relatively small difference between the prescribed and trained settings at 6 weeks for the majority of participants. Some of the trained changes were small and/or limited to one sound class. This might have a limited effect on listening experiences as reflected in the HA outcome measures, especially if trained settings were obtained for a sound class which did not occur very often.

The laboratory measure of consistency of listening preference and profile measures (describing hearing, personality and executive function), did not predict who obtained trained settings. This finding suggests that a different combination of measures may be needed for this purpose. A prediction of who obtain trained settings would be helpful, because it would allow for targeting to users who are more likely to need extensive fine-tuning. However, as findings showed that training had no impact on outcome measures at 6 weeks, training could potentially be activated for all users at the time of fitting, with the effect reviewed at a follow-up appointment within the first 6 weeks of usage. A review of the effect of training at some early point in the rehabilitation process is necessary because, Keidser and Alamudi (2013) found that two of 26 participants obtained trained settings they did not prefer by 3 to 7 weeks after the fitting. Participants in that study were encouraged to make adjustments and try different HA settings in different listening environments. The authors raised the possibility that those instructions may have negatively influenced the outcome for these two participants. It is possible that they had difficulty distinguishing between the settings and were unable to revert to the originally prescribed settings that they may have been perfectly happy with. As suggested by Keidser and Alamudi (2013), clients who can immediately be excluded from training include those who cannot manage the user controls to make adjustments to the HA setting, and those with low cognitive function.

5.5.1 Limitations

With 23 participants taking part up to 2 weeks and 18 up to 6 weeks, the number of participants who enrolled in the study was relatively small. Participants were recruited from a pool of 37 who had a hearing loss that could benefit from HAs, for whom a comprehensive set of profile measures were available that could be evaluated alongside their trained settings. No new participants were recruited as time constraints on this study did not allow for the completion of the same battery of profile measures; especially the consistency of preference score.

The choice of using the remote control to adjust the HAs may have reduced the motivation to make adjustments for some participants. Firstly, participants needed to have the remote control within reach to be able to make adjustments, and therefore had to remember to take it with them when out and about. Secondly, using the remote control requires time to retrieve and unlock it before using it, potentially creating a higher threshold of need before the user is motivated to make adjustments. Also, this may make it more difficult to make adjustments when the duration of a sound is short. Lastly, some may have felt stigmatised by the visibility of using a remote control to make adjustments when in the presence of others, as this may have drawn attention to them wearing HAs (David & Werner, 2016). Such issues were investigated in the present study and are described in Chapter 6.

Some of the logged information was sound class specific: the percentage use and trained gain changes were available for each of the six sound classes, however, the number of adjustments (volume and sharpness) was not. This meant that it was not possible to tie a trained change of a HA setting in a given sound class to an actual number of adjustments to volume and/or sharpness in that class. Such data could have provided interesting information about the efficiency of training in each sound class, that is the number of adjustments required by each individual to obtain a change in gain of, for example, 1 dB.

5.5.2 Implications and Future Directions

Findings in this study suggest that HA users can utilise a training algorithm to fine-tune their devices when away from the clinic. Data showed that training continued for at least 6 weeks, and did not at that point influence outcome measures. These results suggest that most adults who can physically and mentally manage the technology can have training activated, provided progress and outcomes are reviewed within 6 weeks of fitting.

Participants in this study continued to make adjustments over 6 weeks with the number of trained gain changes increasing during the entire period. This raises the question of how long participants would have continued to make adjustments and whether more would have obtained trained settings over time. Future research into trainable HAs should aim to evaluate the long-term effect of having training activated, while monitoring the influence on outcome measures. Investigation of participants’ motivation and strategy of making adjustments could provide information about who may be more likely to obtain trained settings.

5.6 Conclusion

This study showed that when activating training in HAs using clinical protocols, adults who prefer a change to their prescribed setting and who can manage making adjustments can use a trainable algorithm to fine-tune their HA settings in the medium term (up to 6 weeks) without adversely affecting outcomes. The likelihood of obtaining trained settings could not be predicted from measures of consistency of listening preference, hearing, personality and executive function. The findings suggest that training can be activated for clients who can manage user controls and a review of progress and the effects of training is recommended within the first 6 weeks post-fitting.

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Chapter 6 - Barriers and Facilitators to User-Driven Fine-Tuning

This chapter is in preparation for submission with the following author list: Walravens, E., Hickson, L. & Keidser, G.

6.1 Abstract

Objectives. An increasing number of hearing devices allow the user to modify the amplification settings after the initial fitting, or to perform user-driven fine-tuning. Although fine-tuning is common in standard clinical practice, it is unknown how users go about making adjustments to the amplification settings of their devices in their own listening environments.

Design. Twenty-three adults with binaural mild to moderate sensorineural hearing loss participated. Following procedures close to clinical practice, participants were fitted with trainable or learning hearing aids, which permanently fine-tune the settings by taking into account the consistency of the user-adjustments to the hearing aid controls. Participants were asked to wear the devices as much as possible and were provided with a remote control to make adjustments to the settings if needed or wanted. Participants were advised that the devices would try to learn from the adjustments they made. After 2 weeks, participants were interviewed about their experiences with the devices and remote control and were asked about their thoughts on the concept of training. Participants also completed the Client Oriented Scale of Improvement, and the logged device settings were retrieved. Two participants exited the study as they had made no adjustments and were satisfied with the devices' performance. The remaining 21 participants were invited to continue using the devices for another 4 weeks, however three participants discontinued the study before the 6-week follow-up, when the 2-week measures were repeated. The transcribed semi-structured interviews were evaluated using template analysis.

Results. The themes of barriers and facilitators to making adjustments emerged from the analysis, each with three subthemes about the perceived need for making adjustments, the remote control, and difficulty with, or ease of, making adjustments. Time to learn was an additional facilitator subtheme. The main barrier to making adjustments was that the hearing aids worked well so there was no perceived need to make adjustments. Reported strategies to make adjustments varied, with some participants notably making adjustments in anticipation of a particular listening environment.

Conclusion. Participants reported both barriers and facilitators to making adjustments. Findings suggest that most barriers could be reduced by additional instruction, modifications to the equipment for making adjustments and providing a choice of how adjustments are made. Trainable hearing aid users could benefit from counselling about the training process, including the advice to make adjustments in the moment.

6.2 Introduction

Fine-tuning, or the adjustment of the amplification characteristics of a hearing device after the initial fitting, is common practice in hearing rehabilitation (J. A. Nelson, 2001; Valentine et al., 2011). This can be undertaken by the clinician using the manufacturer's fitting software and involves making adjustments based on the reports of the person with hearing loss about their experiences outside the clinic. Other platforms for fine-tuning, such as dedicated remote controls and mobile device apps, which are controlled by the person with hearing loss, are available for performing fine-tuning in real-life situations (Keidser & Convery, 2016). This is referred to as user-driven fine-tuning, a concept that has gained attention recently, for example when used in the laboratory to adjust simulated HAs as part of a user-driven fitting procedure (Boothroyd & Mackersie, 2017; P. B. Nelson, Perry, Gregan, & Van Tasell, 2018).

User-driven fine-tuning can vary in its implementation, differing for example in the platform used to make adjustments, which features can be adjusted, and how long the fine-tuned settings last. The platform chosen to make adjustments (onboard controls, remote control, or smartphone) may influence the ease and frequency of use. If onboard controls are available and the user can manage them, these can be used to change, for example, the volume. Onboard controls are readily accessible, however the number of features that can be adjusted is limited. A remote control provides larger buttons and potentially a visual indication of adjustments that are being made and could allow for more features to be changed than onboard controls, as well as more complex features. Using a smartphone app to make adjustments provides a visual display of the available features, could provide access to a larger number of features, and its use may be less conspicuous than a remote control as smartphone usage is more widespread. Additionally, fine-tuning apps can provide more information about the features and their settings due to access to a large screen and finer resolution. Fine-tuning apps are increasingly available, including for non-traditional amplification devices. In view of the lower cost of non-traditional devices (e.g. Keidser & Convery 2016), and performance of some of these matching that of traditional HAs (Keidser & Convery, 2018; Reed, Betz, Kendig, Korczak, & Lin, 2017), the number of users with access to more advanced features for user-driven fine-tuning is expected to increase (Keidser & Convery, 2016).

Concerning how long the fine-tuned settings last, setting changes can be temporary (i.e. the default setting is provided next time the device is turned on), or permanent (i.e. the device retains the fine-tuned settings, even after it has been turned off). Retention of the settings may be immediate, for example by creating a new listening program for a specific situation, or can take place over time, for example by using a trainable or learning device, which incrementally alters amplification settings based on consistent changes made and the listening environment in which they were made (Dillon et al., 2006).

Outcomes from user-driven fine-tuning in real-world environments when made permanent through applied training have shown that, for the majority of users, the fine-tuned settings are repeatable (Keidser & Alamudi, 2013) and generally preferred over the prescribed response (Keidser & Alamudi, 2013; Zakis et al., 2007). Despite these encouraging outcomes, it is unknown why some users obtain settings they do not prefer (Keidser & Alamudi, 2013). As a trainable algorithm requires consistent user-adjustments for the amplification settings to be altered incrementally, some users must repeatedly make adjustments resulting in settings they do not prefer. This raises the important question, which has not been investigated to date, as to how users go about making adjustments to their hearing devices in their own listening environments.

This study set out to use qualitative research to evaluate how adults with hearing loss fine-tune HAs in their own listening environments after being fitted with trainable HAs following procedures similar to those used in clinical practice. HAs with a trainable algorithm were chosen because they record not only the number of adjustments made, but also a measure of how consistent the adjustments are in the form of changes to the HA amplification. To reduce variability across the group, all participants made adjustments using a remote control, which provided visual indicators and larger buttons than the onboard controls and eliminated the necessity of using and being familiar with a smartphone. Participants could make adjustments to the gain and frequency response which resulted in permanent changes, implemented gradually over time if the adjustments were consistent. Additionally, participants were asked about their opinion on the fact that the HAs could learn their preferred settings from their fine-tuning activities.

6.3 Materials and Methods

6.3.1 Participants

Twenty-three adults aged 65 to 89 years with mild to moderate bilateral sensorineural hearing loss (mean = 43.2 dB HL; SD = 5.7 dB HL; 500, 1000, 2000 and 4000 Hz) participated. Participants were a subset from an earlier study (see Chapter 4) and were recruited from the National Acoustic Laboratories and Australian Hearing client database. The study was approved by the Australian Hearing Human Research Ethics Committee (AHHREC2017-31) and The University of Queensland Human Research Ethics Committees A & B (2017001637). Twenty participants had previously worn HAs (Table 6-1).

Table 6-1. Description of the participants, with an asterisk indicating participation in trainable hearing aid research in the last five years.

				Adjustments made		**Trained measures after 6 weeks**					
Participant	**Age**	**Gender**	**Prior hearing aid experience**	**After 2 weeks**	**After 6 weeks**	**Speech in quiet**	**Speech in noise**	**Noise**	**Music**	**Car Noise**	**Quiet**
1	67	Male	Yes	No - Exit	-	-					
2	80	Female	Yes	No - Exit	-	-					
3	75	Female	Yes	No - Reinstructed	Yes						
4	80	Male	Yes	Yes	Yes						
5	80	Female	Yes*	Yes	Yes	Yes	Yes		Yes	Yes	Yes
6	71	Male	Yes	Yes	Discontinued	Discontinued					
7	89	Male	Yes*	Yes	Yes	Yes	Yes	Yes			
8	76	Male	Yes	Yes	Yes						
9	77	Male	Yes	Yes	Yes	Yes	Yes		Yes		
10	84	Female	No	Yes	Yes	Yes		Yes			
11	74	Female	Yes	Yes	Discontinued	Discontinued					
12	73	Female	Yes	Yes	Yes						
13	71	Male	Yes	Yes	Yes						
14	76	Female	Yes	Yes	Yes						
15	78	Male	No	Yes	Yes						
16	68	Male	Yes	Yes	Yes		Yes		Yes		Yes
17	73	Male	Yes	Yes	Yes	Yes	Yes	Yes			
18	80	Male	Yes	Yes	Yes		Yes				

			Prior			**Trained measures after 6 weeks**					
			hearing aid	**Adjustments made**		**Speech-**	**Speech-**			**Car**	
Participant	**Age**	**Gender**	**experience**	**After 2 weeks**	**After 6 weeks**	**in-quiet**	**in-noise**	**Noise**	**Music**	**Noise**	**Quiet**
19	78	Male	No	Yes	Yes	Yes	Yes	Yes			Yes
20	71	Male	Yes	Yes	Yes	Yes					Yes
21	65	Female	Yes	Yes	Discontinued	Discontinued					
22	87	Male	Yes	Yes	Yes	Yes	Yes				Yes
23	72	Female	Yes	Yes	Yes			Yes			

6.3.2 Devices and Fitting

Participants were fitted with Signia Pure 7 primax receiver-in-the-canal HAs and an EasyPocket remote control (Sivantos Pte. Ltd., Erlangen, Germany). The HAs are multi-channel, environmentally adaptive, trainable devices. The fitting software default setting was used for the advanced features such as noise reduction, adaptive compression, adaptive directionality and feedback cancellation, and the trainable algorithm was enabled and limited to +6 and -9 dB from the starting response. The HAs were fitted to match NAL-NL2 targets (Keidser et al., 2011) for the International Speech Test Signal (Holube et al., 2010) at 50, 65 and 80 dB SPL, and verified using real-ear measurements. The onboard HA controls were deactivated and the remote control was needed to make any adjustments to the volume and sharpness, both limited to a range of 16 dB. Most participants were fitted with a single program, but those who used a telecoil were provided with a second program to access this feature.

These HAs modified the amplification settings depending on the sound class of the environment. The six sound classes were speech-in-quiet, speech-in-noise, noise, music, car noise and quiet. Adjustments affected amplification across four bands with cut-off frequencies 375, 1375, and 4635 Hz: volume affected gain across all four bands; sharpness modified the gain in the two highest frequency bands, with the gain halved in the second-highest band. The training algorithm took the sound class and the level in each of the four bands into account, providing sound class specific compression training.

The following logged gain settings were available for each device: the gain change made for each input level of 50, 65 and 80 dB SPL across the four frequency bands and six sound classes. Values were averaged across the left and right devices due to their negligible difference, and the values in the frequency band(s) affected by venting were set to 0 to ensure that only changes from frequency bands dominated by amplified sound were taken into account. Based on criteria proposed by Keidser and Alamudi (2013), the number of trained values was reduced by averaging the gain change values across the two low-frequency and the two high-frequency bands and by creating a difference measure for the gain change for 80 and 50 dB input levels. In total, 24 measures of change to trained gain were evaluated: the change for two input levels (65 dB and the difference measure for 80 and 50 dB SPL), for two frequency regions (the average for the low- and high frequency bands) and this for each of the six sound classes. A measure was considered to be trained if the change was 2 dB or more for values for 65 dB input signals or 4 dB or more for the difference measure. Table 6-1 shows for which of the six sound classes a trained measure was obtained by each participant who used the HAs for 6 weeks.

6.3.3 Procedure: Appointment Structure

All participants attended a fitting appointment. Participants and the researcher negotiated four goals using the COSI (Dillon et al., 1997) a tool to evaluate the outcome of a rehabilitation program. The selected goals represented listening situations in which it was important to be able to hear, and which were experienced at least weekly.

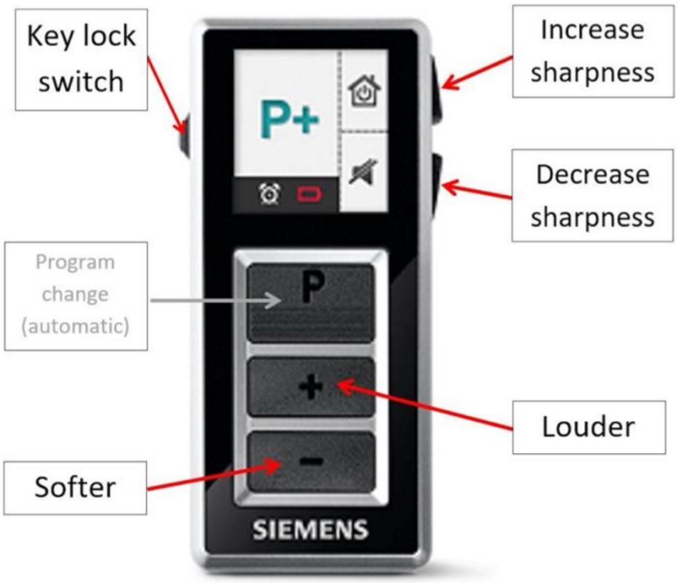

Figure 6-1. One-page user guide for the remote control for those not using a telecoil (Sivantos Pte. Ltd.).

After the HA fitting, participants were instructed on how to use the remote control to make adjustments to the HA settings and provided with a one-page user guide (see Figure 6-1). The remote control was always active, but a keypad lock could be used to avoid unintentionally pushing buttons. Under the screen of the remote control were three buttons of which two, marked “+” and “-”, could be used to increase and decrease the volume, and those who elected to use a telecoil program were advised that they could access this by pushing the button marked *“P”*. On the side of the remote control, to the right side of the screen, were two buttons to adjust the sharpness, labelled “Increase sharpness” and “Decrease sharpness” on the one-page user guide (Figure 6-1). Their function was indicated by three bars on the right of the remote control screen (Figure 6-2): an increase in sharpness showed the third bar to be higher (top button), whereas a decrease in sharpness was depicted by a lower third bar (lower button). The main display changed when increasing or decreasing volume, by showing a scale (left of Figure 6-2) so participants had a visual indication of the level. When pushing either of the sharpness buttons, its symbol would appear in the middle of the screen, to indicate whether sharpness was being increased (middle of Figure 6-2) or decreased (right of Figure 6-2), but no visual scale was available. Both volume and sharpness adjustments were accompanied by an indicator beep; the change to a series of warning beeps when reaching the extremes, or a series of different beeps to indicate they had reached the middle of the available range of adjustments were demonstrated. Participants were instructed to use the HAs as much as possible, and to use the remote control to change the HA settings if they needed or wanted to. They were also advised that the HAs would try to learn from the changes they made. The instructions provided verbatim at the end of the fitting appointment are included in Table 6-2.

Table 6-2. Verbal instructions provided at the end of the fitting appointment.

You are wearing hearing aids with different technologies that work together to amplify speech and reduce noise. I would like to find out how you go using these hearing aids. If you can, it would be great if you could wear them as much as possible, so you can tell me how you went in different situations. The hearing aids will adjust automatically, but you can change the settings if you need or would like to. I explained before that you can change the volume and how sharp the hearing aids will sound. These hearing aids will also try to learn from the changes you make. The hearing aids learn slowly, so they may not sound different from day to day.

Figure 6-2. Representation of the remote control display when changing the volume (left), increasing the sharpness (middle) and decreasing the sharpness (right).

Two weeks after the fitting, participants returned for an appointment in which they completed the COSI, indicated whether they had used the remote control to make changes to the HA settings, and were interviewed. The researcher also downloaded data on changes made to the HAs. The COSI was scored by assigning the values 1 (hardly ever) to 5 (almost always) to the final ability question (how often were you able to hear in that situation with your hearing aids). Two participants, who reported that they had not used the remote control to make changes to the HA settings and obtained a score of 4 or higher on all their COSI listening situations, did not continue in the study after this appointment, as they were presumed to be satisfied with the HAs' performance and not in need of fine-tuning (participants 1 and 2 in Table 6-1). Participant 3 reported that they had not made adjustments and obtained a COSI score below 4 for one of their goals; this participant was reminded that they could make adjustments and continued in the study. Of the 20 participants who had made adjustments, 10 obtained at least one measure considered to be trained. The 21 participants remaining in the study were invited to continue wearing the HAs for another 4 weeks, however three discontinued before this time: participant 6 was unhappy with the sound quality of the HAs, participant 11 had no more time to volunteer because of their partner’s worsening health and participant 21 found the devices and standard domes had become too uncomfortable in and behind the ear. Four weeks later, the remaining 18 participants completed the same evaluations and were interviewed again. All 18 participants had made adjustments, 11 of them obtaining trained settings (the sound classes for which they obtained trained settings are shown in Table 6-1). Information on the fine-tuned settings that participants obtained, and additional outcome measures they completed can be found in Chapter 5.

6.3.4 Procedure: Interviews

Participants were interviewed about their experiences with the HAs and remote control using a topic guide (see Table 6-3 and Table 6-4). These semi-structured interviews were conducted by the first author, probing participants’ experiences with the HAs and how they made adjustments. Any unsolicited comments participants provided during the follow-up appointments which were relevant to the research question were also noted and brought up during the interview, as well as their reported performance in listening situations they had selected for their COSI evaluation. Interviews were conducted after 2 and 6 weeks of HA use. Interviews ranged from just under 6 to just over 42 minutes, were audio-recorded and sent de-identified and securely to Rev.com (San Francisco, CA, USA) for transcription. A total of 41 interviews were available: all 23 participants were interviewed after 2 weeks of HA use, and 18 were interviewed after 6 weeks of use.

During the 2-week interview, all but one participant were asked an additional direct question: *“I mentioned the HAs will try to learn from the changes you make to the remote control. Do you remember? What do you think about that?”* If they did not remember or were unsure, the original instructions from the fitting appointment were provided: *These hearing aids will also try to learn from the changes you make. The hearing aids learn slowly, so they may not sound different from day to day* (Table 6-2).

6.3.5 Analysis

Template analysis, as described by Brooks, McCluskey, Turley, and King (2015), was used to analyse the semi-structured interviews. This structured approach to thematic analysis was chosen for the flexibility in its coding structure and for its iterative nature of using and reviewing the coding template. Analysis is guided by the data and includes the possibility to use both descriptive and interpretative themes. Interviews from six participants were selected for preliminary coding based on their self-reported remote control use: all three participants who indicated that they did not make adjustments after 2 weeks of HA use (1, 2, 3), and three participants who did (12, 16, 20). Meaning units relevant to the research question were identified initially in the transcribed text. These were then coded, and an initial thematic template was developed by the first and second authors, which was subsequently applied to the remainder of the participants' interviews. All meaning units were coded by the first author and reviewed by the second author, and any disagreements were reviewed until agreement was reached. When new codes relevant to the research question were identified and did not fit the template, the template was modified upon agreement of all authors.

Table 6-3. Two-week interview topic guide.

Tell me about how you have been going with the HAs.

When participants mention remote control use, adjusting the HA settings, managing the HA or remote control, experience of performance with the HAs in different environments and the experience of making adjustments, they will be prompted to provide additional information.

If the participant has not mentioned the topics listed above and the main question has been exhausted, the following questions will be used to probe more specific areas:

- What was it like to use the remote control?
- How did you go about changing the HA settings? What did you think about the result when you changed the HA settings?
- Where have you been wearing the hearing aids? How did you go?
- Final: Is there anything else you'd like to tell me about how you think you've been going with the HAs?

I mentioned the HAs will try to learn from the changes you make to the remote control. Do you remember? (If not, repeat "These hearing aids will also try to learn from the changes you make. The hearing aids learn slowly, so they may not sound different from day to day.") What do you think about that?

Table 6-4. Six-week interview topic guide.

Has anything changed in how you feel you have been going with the HAs since I saw you last?

When participants mention any adjustments made to the HA settings (stopped, continued, decreased, or increased number of changes) and why, they will be prompted to provide additional information.

If the participant has not mentioned making adjustments to the HA settings, the following questions will be used to probe for further information:

- Since we spoke last, did you feel the need to change how the HAs were sounding? Why/why not?
- Do you think you have been making the same number of changes to the HA settings since the last time I saw you?

6.4 Results

In response to the semi-structured interviews investigating how participants made adjustments to their HA settings, the themes of barriers and facilitators to making adjustments emerged. Four subthemes of facilitators (see Table 6-5) and three subthemes of barriers (see Table 6-6) were identified; categories were also evident for some subthemes. Example quotes are provided in the tables and additional examples are included in the sections below with quotes displayed in italics along with the participant number and whether they were expressed during the interview after 2 or 6 weeks.

6.4.1 Facilitators to Making Adjustments

Perceived need for making adjustments, the ease of using the remote control, ease of making adjustments and time to learn were mentioned as facilitators (Table 6-5). Most participants who had made adjustments expressed the need to do so, either in general or for specific situations: *"When these great big double lorries roared past, I put it down softer"* (10 – 2 weeks). Participants reported on the ease of using the remote control, and a similar ease of making adjustments with the remote control, leading to a positive result from making adjustments: *"each time I got it to where I wanted it to be"* (16 – 2 weeks).

Responses varied in relation to which strategy for making adjustments participants had used. Some participants commented that they were experimenting with making adjustments; others recounted specific approaches, such as anticipating the settings that would suit the most, before reaching their intended listening situation, sometimes by using the visual display of the volume setting as a reference: *"I learned, say, if I knew I was going to see somebody on a one-to-one I knew I would have to use the volume here and I could set it beforehand because I knew exactly where I should have it for talking one-to-one"* (5 – 6 weeks). Notably, not all participants were able to describe in detail how they went about making adjustments, only mentioning *"I fiddled around with that"* (16 – 2 weeks).

A final facilitator sub-theme that emerged from the interviews was that it took time to learn. Some participants indicated that it took time to learn to use the remote control, but more often participants expressed that they had to learn what adjustments do, for example mentioning that they were becoming more efficient when making adjustments over time: *"only using it once per change instead of having to do four or five checks to get it right"* (13 – 6 weeks), or learning *"when it can adjust and when it can't"* (13 – 6 weeks).

6.4.2 Barriers to Making Adjustments

Subthemes for the theme of barriers to making adjustments were: no perceived need for making adjustments, remote control issues and difficulty with making adjustments (Table 6-6). All participants mentioned experiencing some barriers, most commonly that there was no perceived need for making adjustments in some or all situations, mainly because the HAs were performing well. This led some participants to expect no further need to make adjustments and decide that *"Most times I don't have the remote control on me, I leave it at home"* (19 – 6 weeks). The two participants who had not made any adjustments and obtained high COSI scores for all their nominated listening situations unsurprisingly reported the HAs to be performing well and therefore had no perceived need to make adjustments. Some participants also found an alternative strategy which reduced their need to make adjustments, such as reducing the source of the noise, avoiding going to particular places or just putting up with the listening environment.

A range of remote control issues also prevented some participants from making (more) adjustments, with categories either related to the physical presence of the remote control (forgetting the remote control, burden of extra equipment, and visibility of using the remote control) or its use (uncertainty about the remote control, visual indicators unclear, and dexterity problems). Participants reported forgetting the remote control, which included forgetting to use it and forgetting to take it with them. The burden of extra equipment was also mentioned as a barrier, caused by the need to have the remote control available to make adjustments, with some participants indicating they preferred *"adjusting them on the aids themselves"* (14 – 2 weeks). The visibility of using a remote control prevented some participants from making (enough) adjustments because of *"all the intervention in the situation"* (12 – 2 weeks) or because they could not *"leave the light [of the remote control screen] on in a darkened theatre long enough to play around"* (5 – 2 weeks). The remaining categories of remote control issues were more related to its use. Participants expressed uncertainty about the remote control, such as *"I really didn't know which one was sharp and which wasn't"* (19 – 6 weeks). Some participants found the meaning of visual indicators unclear, especially how sharpness was depicted (see Figure 6-2), reporting that *"It would be much smarter if they used those two symbols with words under, you can then know which one you're using"* (15 – 6 weeks). Another visual indicator causing confusion was the lack of a visual scale for the sharpness adjustments, as was available for the volume. Lastly, one participant mentioned dexterity problems, saying *"older hands are just, they don't look clumsy, but they are"* (5 – 6 weeks).

The final barrier sub-theme concerned participants' difficulty with making adjustments to the HA settings (Table 6-6), including four categories. Most often participants commented on the impact of adjustments, that sharpness adjustments were not noticeable or that adjustments were not effective. Examples of this ineffectiveness were mainly reported as not reducing the background noise enough, an insufficient available range to make adjustments (*"the change that I had anticipated from changing the tone wasn't as significant as I was planning"*; 18 – 2 weeks), or due to the tradeoff in sound quality associated with making particular adjustments. Participants also indicated that in some situations adjusting was too hard, for example because the duration of the sound was too short, or because it was impractical to make adjustments, for example while singing. A few participants expressed concern about making the sound worse, suggesting that *“my input's likely to put them in the wrong direction”* (2 – 2 weeks).

6.4.3 Opinions on Trainable Hearing Aids

Participants were advised at the end of the fitting appointment that *“*these hearing aids will also try to learn from the changes you make. The hearing aids learn slowly, so they may not sound different from day to day,*”* see Table 6-2. When participants were asked 2 weeks later what they thought about the HAs learning, their responses indicated that some participants understood this concept, and some potentially did not. One participant seemed to interpret the question about HAs learning as getting used to the HAs: *I think that's true, of the car, particularly. I'm not hearing as much noise as I'm driving as I did the first week. For me, it's sort of quietened down a bit. It's not as dramatic. Turning the gear stick and stuff, that's the sort of thing that was loud as it did. I think my brain has adjusted to it.”* (19 – 2 weeks).

Those who did understand the concept showed a range of opinions on the topic and most of them seemed to consider their experiences over the last 2 weeks and evaluate whether they had noticed the training. One participant indicated that learning meant having to make fewer adjustments over time, with the back-up of making adjustments if the learned setting was unsuitable: *“I thought that was a terrific idea. 'Cause if you've got this [remote control], you can still change it back if – but instead of having to worry all the time about having that, no, I thought that was a marvellous idea”* (10 – 2 weeks). Another participant deduced that learning must be situation and level-dependent: *“I mean, it was generally better all over, so whether they remembered because of the change, I mean, I guess I'd have to be in the same situation with that amount of noise for it to adjust again”* (12 – 2 weeks). Another expressed their frustration as the HAs did not seem to be learning, as they had to keep making changes: *“it certainly didn't seem like it was learning much (laughs). You know every so often I used to think, ‘Oh I have to change this again’, because it's not delivering what I feel I should be getting”* (11 – 2 weeks). One participant explained the difficulty in trying to notice if their HAs were learning: *“Did I perceive a change? Not really, but I'm not sure how much it learned and how much it changed. Plus, it probably was small increments, which I wouldn't notice. It's like if you see somebody every day, you don't notice the change as if you see them every three months. Maybe, I guess a comment I could make, I did notice in the second week I was using the remote less. Now, whether that's I've got used to it or I've found the settings, I don't know. That's just a, observation.”* (13 – 2 weeks).

Table 6-5. Theme of facilitators to making adjustments: subthemes, categories and example quotes. Participant number and appointment interview are shown in brackets after each quote.

Subtheme	**Category**	**Example quotes**
Perceived need for making adjustments	/	In certain circumstances you know I've had to change the volume. Either bring it down or pick it up a little bit. (20 – 2 weeks) Well, it's the traffic noise that's the main, but in a club, if there's a lot of people and there's a lot of talking going on, then that can become difficult and that's when I've got to fiddle around with the little remote. (18 – 2 weeks)
Ease of using the remote control	/	I like the idea of the controller in some ways, it's very easy and effective. (8 – 2 weeks) It's pretty easy. I think a two-year-old kid could work it [remote control] (16 – 2 weeks).
Ease of making adjustments	Positive result from making adjustments	And I found by lowering the volume when there's background noise, it's much easier. (20 – 2 weeks) And it worked in the concert, again, I was able to adjust it, adjust the hearing aids to better hear the instruments. (8 – 2 weeks)
	Strategy for making adjustments	I'd rather keep persevering with it and try and figure out how it's going to work better for me. (16 – 2 weeks) When I'm going to a group situation, I put it louder before I get there, before I see them. (21 – 2 weeks)

Subtheme	Category	Example quotes
Time to learn	Learn what adjustments do	Maybe before that I didn't think of it, but the longer I had them, the more often I'd understand that these circumstances I can use the remote. (23 – 6 weeks) Volume was easy you know with that, the sharpness I got to say I'm still learning. … Like with volume I *"*oh yeah that needs two,*"* bang, done. But with sharpness, it was *"*hm, no*"* still up and down a bit. I'm still not confident. (13 – 6 weeks)
	Learn to use the remote control	So I guess that's a big, as I keep going back, that's the biggest thing is I've learned how to do it, because with my hearing aid, I don't have that convenience. (13 – 6 weeks) There's a bit of learning involved and habituation required for the other symbols [sharpness] on the remote. (5 – 2 weeks)

Note: "/" indicates there are no categories identified under the sub-theme

Table 6-6. Theme of barriers to making adjustments: subthemes, categories and example quotes. Participant number and appointment interview are shown in brackets after each quote.

Subtheme	Category	Example quotes
No perceived need for making adjustments	Aid performing well	Well, I've been going very well with the hearing aids. They do sort of make some things much clearer, especially television, which I can now watch with much lower volume. (1 – 2 weeks) I went to the school spectacular, which had thousands of kids in it, and I didn't find I was having any trouble at all hearing what they were saying. … And that was just easy to listen to, really was. (2 – 2 weeks)
	Alternative strategy	I've got to turn the level of air conditioning down so it's not so loud. (19 – 6 weeks) Sometimes I put up with the way it is and don't worry about it. (16 – 6 weeks)

Subtheme	**Category**	**Example quotes**
Remote control issues	Forgetting remote control	Yeah, sometimes I did, but I forgot to use the remote control. (3 – 2 weeks) I tried it several times and sometimes I forgot and left it [remote control] at home, but- (7 – 6 weeks)
	Burden of extra equipment	I just found that it was annoying to have to carry something new in my bag. And also fishing it out and then turning it on and then changing it, it was too cumbersome. I'd much rather just twiddle a knob on the hearing aids itself. (11 – 2 weeks) I found the remote a bit of a nuisance because I, one extra thing to carry in the handbag, basically. (14 – 6 weeks)
	Visibility of using remote control	It's just that I found it a little bit embarrassing when you try to do that while everybody's around you looking at you. (21 – 2 weeks) And especially the fact that I couldn't actually physically - what's the word I'm looking for, I think it's - unobtrusively adjust it This was fairly obvious. (11 – 2 weeks)
	Uncertainty about remote control	What's this [sharpness buttons] supposed to do? (17 – 2 weeks) So I don't know whether the remote would be able to identify that. Bear in mind the remote is in my pocket, and it's not hearing, it wouldn't be hearing the same volume as I can in the area. (23 – 2 weeks)
	Visual indicators unclear	You don't see the result of what changes you've made so you don't know whether you've successfully changed anything. (15 – 6 weeks) But when you reduce the sharpness, it [visual display] doesn't change. It stays- (9 – 6 weeks)
	Dexterity problems	It then became a manipulation issue due to age, perhaps. But the number of variables wouldn't alter at what age you were on there. But older hands are just, they don't look clumsy but they are. (5 – 6 weeks)

Subtheme	Category	Example quotes
Difficulty with making adjustments	Sharpness adjustments not noticeable	I honestly have used it [sharpness buttons] a number of times and I cannot tell the difference so I haven't used it. (23 – 6 weeks) I can't find any variation with moving the treble and with moving the bass. I can't find any variation in it at all. I hear the beep beep [indicator tone]. But nothing's changing. (20 – 2 weeks)
	Adjustments not effective	And it did work, but at times I, even adjusting it, I couldn't adjust far enough to get it right. (13 – 6 weeks) I turned it down. Tried to adjust it, but it didn't seem to make much difference. The big background noise was more overpowering than the actual person talking, and that should not be the case. (3 – 6 weeks)
	Adjusting was too hard	Often, the situation has passed, the moment has passed. (5 – 2 weeks) It's there and it's gone. I didn't worry about it. It was just, *"Ah, yeah."* And that's [it]. If I was, say, around my grandkids and they were squealing and yelling, yes, I'd be adjusting it down. For a minor, small amount of time, they're not worth it. (13 – 2 weeks)
	Concern about making sound worse	So I didn't want to adjust them in case I couldn't put it back again. The way you set it when I was here last, that's how I left it. (2 – 2 weeks) Then I thought, well I won't hear what everybody's saying otherwise [on turning down the volume]. (3 – 2 weeks)

6.5 Discussion

Participant interviews about how they fine-tuned their HAs revealed the themes of barriers and facilitators to making adjustments. With the exception of the facilitator sub-theme of time to learn, the barriers and facilitators to making adjustments were opposite sides of the same issues, touching on the perceived need to make adjustments, the platform used to make adjustments and the difficulty or ease of making adjustments. Additionally, some participants indicated that time to learn impacted the latter two subthemes. Not all participants understood the concept of learning HAs, and those who did showed a range of attitudes towards the concept.

Most participants described situations when they had a perceived need to make or not to make adjustments. As expected, a need to make adjustments was most often reported when describing situations of listening to speech in background noise, whereas when the HAs were considered to be performing well, participants did not see the need to make adjustments. The finding that only two participants indicated no need to fine-tune their HA settings suggests that the majority of HA users have a need for fine-tuning and that HA devices should therefore allow adjustments to be made.

Although many participants reported that the remote control was easy to use and they experienced a positive result from making adjustments, a number had difficulties with its use or physical presence. Some of the difficulties could be addressed by providing additional or alternative information to the user, by making technical or design modifications to the remote control, or by providing a different platform to make adjustments. Providing additional or alternative information could improve the reported uncertainty about the remote control. In the present study, which was designed to reflect a typical clinical encounter, instructions to participants about the remote control were relatively brief (demonstration with verbal instructions, and a review using the one-page user guide as reference, see Figure 6-1). In view of the brief instructions and the known variability in HA management (Bennett et al., 2018), it is not surprising that some participants had difficulty managing the remote control. To address this in future, further information could be provided in video format, an approach which has been shown to improve management skills for first-time HA users in clinical practice (Ferguson, Brandreth, Brassington, Leighton, & Wharrad, 2016) and experienced and inexperienced HA users participating in research (Convery, Keidser, Hickson, & Meyer, 2018). Additionally, this information may have sped up the learning process for participants who initially experienced some difficulty but reported that they had learned over time to use the remote control and what adjustments do.

Technical as well as design modifications could be made to the remote control or HAs to help reduce some of the barriers. Comments about sharpness adjustments not being noticeable and the adjustments not being effective suggest that it may be beneficial to increase the available range of adjustments. This modification is restricted by the available dynamic range in the HAs, due to gain limitations of the device, and venting and feedback effects. Furthermore, it seems that some of the issues with unclear visual indicators for the sharpness adjustments on the remote control could be remedied by having a similar visual scale for sharpness as was available for volume. Although participants reported better understanding about how to use the remote control over time, for example *"There's a bit of learning involved and habituation required"* (5 – 2 weeks), reducing any uncertainty about the platform used for making adjustments seems particularly important in the first days and weeks of using new HAs to reduce the potential impact on sound quality. This finding of the need for early and timely support for older adults to use HAs most effectively is supported by Solheim, Gay, and Hickson (2018) who found that new HA users who reported more issues with their HAsin the first 6 months used their HAs less.

Providing an alternative platform to make adjustments could reduce further remote control issues such as forgetting the remote control, the burden of extra equipment, the visibility of using a remote control, and dexterity problems. The option of making adjustments on board the HAs or using a mobile phone app would reduce or eliminate the problem of forgetting the remote control and the burden of extra equipment, as adjustments would be made with devices already available. Although only a handful of participants reported not making adjustments because of the visibility of the remote control, it is expected that some participants may have made fewer or no adjustments in particular situations, for example when in a group, due to the stigma associated with HA use (David & Werner, 2016). The barrier of visibility of the remote control and dexterity problems is likely to be reduced by allowing the user to select their preferred platform to make adjustments.

An interesting aspect of the findings of this study related to the strategies that participants used to make adjustments. Some reported making adjustments before or after rather than during the event for which the adjustments were intended. A few participants mentioned anticipating which adjustments may be needed, and then making the adjustments before entering the environment because this was more convenient or because they did not want to be seen using the remote control. At the other extreme, one participant reported making adjustments in quiet, when trying to improve the sound of creaking floorboards after walking on them. This finding is of particular importance when user-driven fine-tuning is used to create permanent changes to the HA settings over time, especially when training is dependent on the sound class. Making adjustments in a different sound class to the one intended, may lead to no or ineffective training in the situation and sound class where it is intended and thus frustration because of the ongoing need to make adjustments for that situation. Furthermore, if the strategy is used consistently, the HAs are inadvertently, and possibly inappropriately, trained in a sound class where changes may not be needed. As there is no need to make adjustments to HA settings in quiet, the changes made before or after the event they were intended for explain the finding that some participants obtained trained settings for situations classified by the HAs as quiet (Table 6-1). These data suggest that when activating training, users need to be carefully educated about how training works, and the importance of making adjustments in the moment.

Some participants did not understand the concept of trainable HAs, and those who did showed a range of attitudes towards the concept. Although the brief information provided about the HAs trying to learn may have been insufficient for some participants, earlier reports by Keidser et al., (2007) also showed that some HA users struggled with this idea, despite the provision of written information about the features of a trainable HA and how it differed from a traditional HA. Even if alternative ways of introducing the concept are used, it may remain difficult to grasp for some. Earlier evaluations showed that most of the potential users had a positive attitude towards the concept of trainable HAs (Keidser et al., 2007; Walravens et al., 2016, Chapter 3), although fewer thought that they would benefit personally from the technology (Keidser et al., 2007). Findings from this study highlight the difference between mostly positive opinions when evaluating a theoretical concept and more nuanced views based on practical experience with trainable HAs. Most participants who understood the concept seemed to evaluate whether they had noticed if the HAs were learning. Noticing the influence of training after 2 weeks of HA use may have been difficult because of a combination of reasons: the trainable algorithm makes gradual changes to the HA settings, which occur independently across six sound classes, and participants were getting used to potentially different amplification settings from their own HAs. Consequently, using perceived differences in HA settings to evaluate training may have resulted in more neutral and negative opinions on trainable HAs than reported in previous surveys.

6.5.1 Limitations

We set out to use methods as they are used in clinical practice, however, two choices were not in line with this approach. Firstly, the participants had a range of experience in volunteering for research and as such may not be considered representative of typical clients. Secondly, participants were not provided a choice on how to make adjustments; they were only offered the remote control to ensure homogeneity. As is known from an earlier survey (Keidser et al., 2007) and reports from the participants in this study, HA users may have a preference for other options such as onboard controls. This methodological choice may have increased reported problems with making adjustments in the present study.

6.5.2 Implications and Future Directions

Findings show the need for most participants to make adjustments to the HA settings, and the need to evaluate with the user which platform for making adjustments is most suitable for them. Furthermore, participant reports confirm the importance of following up on the management of the chosen platform for making adjustments. HA users fitted with an active trainable algorithm should be instructed about how training works and to make adjustments in the listening situation for which the adjustments are intended. Future research could evaluate the outcome of interventions designed to reduce barriers to making adjustments, such as providing additional instructions in video format, and the impact of instructions on how to train HAs.

6.6 Conclusion

This study set out to evaluate how adults with hearing loss fine-tune their HA settings, when fitted with trainable HAs following procedures similar to those used in clinical practice and adjusting the HA settings using a dedicated remote control. Analysis of their interviews revealed the themes of barriers and facilitators to making adjustments, each covering subthemes about the perceived need for making adjustments, the platform for making the adjustments, and the difficulty or ease of making adjustments. Additionally, time to learn was a facilitator to making adjustments.

The reported barriers suggest that the platform for user-driven fine-tuning should be discussed with clients and thoroughly demonstrated, and the effectiveness of adjustments evaluated. Future platforms could probably be improved by involving users in the design phase. If the devices are trainable, informational counselling about the aim and effect of fine-tuning is highly desirable.

6.7 References

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Chapter 7 - Conclusion

The overall aim of this thesis was to examine the impact and application of trainable HAs and to achieve this three studies were conducted:

a) a survey evaluating the impact of trainable HAs in clinical practice by asking clinicians about their use of and experience with trainable HAs and asking adults with a hearing loss about their expectations for and experiences with trainable HAs (Chapter 3);
b) a laboratory study investigating the consistency of preference for HA settings and whether consistency of preference could be predicted based on psychoacoustic, cognitive and personality measures (Chapter 4); and
c) a mixed methods study using procedures closely resembling clinical practice, looking into the time-course and outcomes of training, the prediction of training based on measures from the laboratory study (Chapter 5), and how users went about making adjustments to their HA settings in their own listening environments (Chapter 6).

7.1 Summary of Findings

The survey included responses from 259 clinicians and 104 adults with a hearing loss of whom 81 indicated that they were HA users. Of the HA users, 15 reported that had experience training HAs. Responses indicated that the majority of clinicians and HA users with experience using trainable HAs reported positive experiences with trainable HAs. Further, the majority of HA candidates were interested in trainable HAs. However, the overall number of clients with training activated in their HAs is expected to be low, as this feature is not available in HAs from all manufacturers, nor in all HA models, and not all clinicians knew whether HAs they fitted were trainable. Additionally, most clinicians activated this feature selectively, reporting the most common reasons for not activating training were that the HA controls were already disabled for management purposes, and that they were concerned their client might not understand the concept. Clinician reports on when they activated training suggested that the impact of trainable HAs in Australian clinical practice was limited.

The laboratory study into consistency of preference for HA settings was conducted because of the importance of consistent preferences for obtaining trained HA settings different from the prescribed. For the trainable algorithm to modify the HA settings, the user needs to make adjustments to the HA controls that result in consistent preferred settings for a particular situation, such that the algorithm will modify the HA settings to reach that preferred setting over time. Consistency of preference was evaluated in 52 adults with hearing ranging from normal to a mild to moderate sensorineural loss. Using a two-alternative forced-choice task, participants selected a preference for HA settings differing in intensity, gain-frequency slope and directionality presented in four simulated real-world environments. Consistency of preference was variable and depended on the environment, the difference between the HA settings and their interaction. Preferences were more consistent for larger differences between settings and for less complex environments. The selected psychoacoustic, cognitive and personality measures could not predict who was more likely to obtain more consistent preferences. Findings from this study questioned the effectiveness of fine-tuning in clinical practice and suggested the need to counsel trainable HA users about the likely effectiveness of training, especially in more complex environments, to ensure appropriate expectations.

In the mixed methods study, 23 participants who had also taken part in the consistency of preference study were fitted with trainable HAs following clinical procedures. Half of the participants who had made adjustments to the HA settings obtained trained settings different from the prescribed settings after 2 weeks, increasing to 61% after 6 weeks. There was no difference in scores for the IOI-HA (Cox & Alexander, 2002) and COSI (Dillon et al., 1997) between those who had obtained trained settings different from the prescribed after 6 weeks and those who had not. Furthermore, measures from the laboratory study could not predict who was likely to obtain trained settings different from the prescribed. Findings suggested that most adults who can make adjustments to their HA settings could use trainable HAs to fine-tune their HA settings up to 6 weeks, without adverse effects on outcome measures. However, as adverse results from training have been reported previously (Keidser & Alamudi, 2013), users should be followed up to evaluate their outcome measures and trained HA settings.

Interviews with the same 23 participants were conducted to evaluate how they went about using the controls to adjust their HA settings in their own listening environments. Analysis revealed the themes of barriers and facilitators to making adjustments to their HA settings. Both barriers and facilitators concerned the perceived need for fine-tuning, the platform used to make adjustments and the ease or difficulty of making adjustments. Additionally, time to learn emerged as a facilitator. Results suggested that additional or alternative instructions and design or technical modifications to the equipment (in this research a remote control was used) could reduce the majority of reported barriers. Reported strategies for fine-tuning the HA settings indicated that those using trainable HAs require clear instructions on how the trainable algorithm works; especially on the importance of adjusting the HAs in the intended situation. Where the quantitative component of the mixed methods study indicated the importance of following up on outcome measures and trained HA settings, qualitative findings demonstrated the need to also evaluate the management of the platform and the strategies used to adjust the HAs.

7.1.1 Comparison Between Survey and Mixed Methods Study

Parallels could be drawn between the findings from the survey and mixed methods study regarding the need for fine-tuning, concern about outcomes, changes to HA settings and reported advantages experienced. Both the survey and mixed methods study demonstrated that HA users have a need to fine-tune their HAs and can train their HAs to obtain settings that differ from the prescribed settings. In the survey, training was observed by clinicians, while in the mixed methods study, trained gain changes were seen in the logged data.

The surveyed clinicians who did not provide trainable HAs (n = 122) were most concerned about users obtaining a negative outcome (73% of them). However, this was much less of a concern for the 15 survey respondents who had used trainable HAs, with only one of the 15 expressing this concern. In the mixed methods study, a few participants also raised concerns about making the sound worse, but on balance it seemed to be less worrisome for the older adults with hearing loss than it was for clinicians.

On average, changes to HA settings resulting from training were relatively small, which was both reported by clinicians in the survey and observed in the mixed methods study. In the survey, the majority of the 137 clinicians who indicated that they provided trainable HAs reported that most of the time they accepted the trained settings. One third of those clinicians reported that the trained settings were similar to those programmed at the fitting. In the mixed methods study, 89% of gain measures were within 2 dB of the prescribed settings after 6 weeks of HA use, with one third of participants obtaining settings similar to the prescribed. Although the trained changes were relatively small, greater trained gain measures were seen for some participants. Additionally, other studies have demonstrated that when comparing trained and prescribed settings, HA users showed a reliable preference for their trained settings (Keidser & Alamudi, 2013; Zakis et al., 2007).

Furthermore, additional advantages to training HAs were also reported in the survey and were reflected in findings from the mixed methods study. The majority of users in the survey (13/15) reported that the trainable HAs were easy to train, echoed by participants from the mixed methods study reporting the ease of using the remote control and ease of making adjustments to their HA settings. Half of the surveyed users (8/15) reported that they had obtained personalised settings, although this was not verified, and 61% of participants in the mixed methods study obtained at least one trained setting. Only one third (5/15) of trainable HA users in the survey indicated that they made fewer adjustments to the HA controls over time, compared to the majority (16/18) of participants from the mixed methods study who made fewer adjustments per week over the last 4 weeks compared to the first 2 weeks. This difference may have occurred because the survey was a self-reported reflection about changes over time, whereas in the mixed methods study the changes over time were quantified by evaluating logged data from the HAs. One advantage reported by users in the survey (i.e., ‘I felt more involved with my hearing care’) did not arise in the mixed methods interviews. This is perhaps not surprising as in the mixed methods study participants’ involvement was time-limited and research-based.

7.1.2 Qualitative Findings Informing Quantitative Results of the Mixed Methods study

Chapter 5 and 6 were part of a mixed methods study which used a concurrent nested design (Robson & McCartan, 2015). The qualitative approach was composed of interviews, which were nested within the quantitative approach, which included obtaining outcome measures and logged data from the HAs. Mixed method studies provide additional benefits to using a single approach by combining qualitative and qualitative data. Benefits include, for example, enhancing the validity of the findings reflected in both data sets (referred to as triangulation), and explaining data obtained using one approach with data obtained using another approach (referred to as complementarity; Greene, Caracelli, & Graham, 1989; Robson & McCartan, 2015). Examples of both of these benefits were found in the mixed method study. In relation to triangulation, for example, most participants recounted in the interviews that they had a need to fine-tune their HAs, and such fine-tuning was evident in the logged number of adjustments they had made to volume and sharpness controls during the field trial.

In relation to complementarity, the description of some participants’ strategy of how they made adjustments to their HA settings provided insight into why some participants obtained trained measures for the quiet sound class. The quantitative data suggested that some participants, on average, trained their HAs to provide less gain in quiet environments, which seems odd as in quiet listening situations there would not be any noise or loud events. The likely reason why some participants consistently turned gain down in quiet was provided during the interviews. Some participants reported to reduce gain in anticipation of, or after, a particular listening event, such as entering a noisy restaurant. It is possible that the sound class before an expected loud listening event was quiet, and that when gain was reduced in anticipation of entering the louder environment, this was done consistently, resulting in a trained lower gain setting in the quiet sound class.

7.2 Limitations and Future Directions

Study-specific limitations are included throughout the thesis in sections 3.6.1, 4.5.1, 5.5.1 and 6.5.1, and more general limitations are listed below.

Participants in the laboratory and mixed method studies were older adults and most had a mild to moderate sensorineural hearing loss. Their findings may not be applicable to younger adults or those with different degrees of hearing loss. Further research is necessary with a clinical population varying for example in terms of age, degrees of hearing loss, hearing loss configuration, and motivation for HA use.

Response rates for the survey were low (5 to 11% of clinicians and 14 to 44% of hearing-impaired adults responded), and participant numbers were low for the mixed methods study (n = 23), the latter because potential participants were selected amongst those who had already taken part in the laboratory study. This approach meant that information collected during the laboratory study could be evaluated alongside the findings from the mixed methods study, but it also reduced the statistical power. No additional participants were recruited for the mixed methods study due to the time involved in also obtaining all measures from the laboratory study.

The findings from the mixed methods study were, to some extent, influenced by the devices used, more specifically the implementation of the trainable algorithm, the lack of choice of the platform to make adjustments (remote control only) and the technical limitations of this platform. Conducting a study on training in clinical practice would include providing participants the choice between different platforms for adjusting their HAs and could include devices from different manufacturers who present different proprietary training algorithms. Furthermore, future research could explore the impact of providing additional instructions on the management of the platform chosen for fine-tuning and more explicit instructions on how training works.

The investigation into how users approached fine-tuning of their HA settings was conducted using interviews. This provided rich initial information and suggested the need for additional work investigating users' motivation to fine-tune their HAs in their everyday environments and the strategies they employ. The interviews relied on participants recalling how they changed the settings of their HAs and why they did so. A real-time approach would reduce the need for participants to rely on their memory and allow for evaluation of multiple and varied listening situations, looking into their strategies and whether their adjustments are effective in improving their listening experience. This is particularly relevant for environments that are experienced less frequently. A potential approach for this evaluation is ecological momentary assessment, which has been shown to provide valid in-the-moment information on the acoustic environment and HA users' experiences (Timmer, Hickson, & Launer, 2017a). Such research might identify factors that predict training (none of those included in the present study were predictive), how to introduce new HA features that are trainable (e.g., directionality), and might ultimately lead to clinical practices that reduce the need for follow up fine-tuning appointments.

Further research into training HA settings has the potential to optimise client outcomes. Training or fine-tuning by the user in their own listening environment increases the user's involvement in the self-management of their hearing loss, which is known to improve outcomes in other chronic conditions (Bodenheimer, Lorig, Holman, & Grumbach, 2002).

7.3 Clinical Implications

The mixed methods study found that there was a need for most participants to make adjustments to their HAs, suggesting that they had a need to fine-tune their devices, which could be achieved using trainable HAs. However, the survey highlighted that some clinicians were unaware that HAs they fitted had a trainable feature. As clinicians are the ones who are likely to introduce this feature to their clients, it is important that clinicians are made aware of the availability and implementation of training in the HAs they provide. Trainability could be one of the HA features highlighted when manufacturers introduce clinicians to new HAs.

The laboratory study showed that consistency of listening preference was variable, questioning the effectiveness of fine-tuning procedures as they are often used in clinical practice. This finding indicated that those in need of extensive fine-tuning may benefit from the use of trainable HAs, allowing the user to make multiple adjustments to reach their preferred HA settings in their own listening environments. Such fine-tuning eliminates the need for the user to remember and describe the listening problem and environment for which they would like improved HA settings to their clinician. It also removes the requirement for the clinician to interpret and translate the user's listening problem to changes of one or more settings.

Furthermore, findings indicated that those who will be permanently fine-tuning or training their HAs should be counselled about the limitations of fine-tuning settings in particularly complex listening environments, as few participants obtained consistent preferences in complex simulated real-world environments, such as listening to speech in a noisy café.

7.3.1 Suggestions for Managing Trainable Hearing Aids in Clinical Practice

Based on the findings in this study, in particular Chapter 6, and work by Keidser and Alamudi (2013) and Bentler et al. (2016) summarised in 2.2.5 (p. 23), suggestions for managing adults' use of trainable HAs can be updated.

Training could be activated for those who can physically manage user controls and have no cognitive problems (Keidser & Alamudi, 2013). Evaluate with the client if they would be willing to make adjustments in their listening environments (Bentler et al., 2016), what their preferred platform is for making adjustments, and explain the concept of trainable HAs.

During the fitting appointment, ensure that the client notices adjustments made to the features that can be user controlled (e.g. while playing some music), and increase the step size of the adjustments if needed. Explain the function of all controls and the anticipated impact of varying the controls.

Remind the client of the process of training and the need to adjust their HAs in the moment when fine-tuning is needed.

About 2 weeks after the fitting, evaluate the client's progress and evaluate training progress based on their satisfaction with the HA performance, outcome measures, whether adjustments were made, and the trained change to the HA settings. A summary of the evaluation and recommended course of action is provided in Table 7-1. For example, if the client has made few adjustments and is dissatisfied with how their HAs perform, evaluate if they had difficulty managing the controls to make adjustments and reinstruct if needed. Check if they noticed a difference when making adjustments and ask them to provide an example of when this was not the case. Clarify the function of the controls and set expectations about their limitations if needed (e.g. when the client reports adjusting gain for the high frequencies when listening to a sound most likely dominated by low frequencies). Ask the client if, when they did make adjustments, they were able to improve the performance of the HAs. If this was not the case, ask them for an example. Evaluate the client's strategy and instruct if needed. Encourage them to make adjustments and review their progress.

7.4 Conclusion

This project set out to evaluate the impact and application of trainable HAs. In terms of impact, the findings indicate that both clinicians and users with experience of trainable aids were mostly positive about them, however many clinicians were not activating training. Thus, there is scope to increase the impact of trainable HAs and some core issues warrant further investigation. Evaluation of consistency of listening preference in the laboratory revealed that there was considerable variability across participants and that consistency was influenced by the difference between HA settings and the acoustic environment. Factors that might predict which participants were more consistent were not identified. The application of trainable HAs using procedures closely resembling clinical practice demonstrated that there was a need for fine-tuning and that those who can make adjustments to their HA settings could train their HAs and achieve good outcomes. In view of the need for fine-tuning, the potential for more effective user-driven fine-tuning for some, the positive reports from those with trainable HA experience, and outcomes using trainable HAs, there is an opportunity to increase the impact of trainable HAs in clinical practice, improving the fine-tuning process for clinicians and users. The development of evidence-based clinical guidelines for candidacy and management of trainable HA users would assist towards this goal.

Table 7-1. Summary of the proposed follow-up management of trainable hearing aid users.

User-adjustments made	**Outcomes**	**Settings different to prescribed settings**	**Clinician course of action**
None to few	Positive	Not applicable	Deactivate.
	Poor	Not applicable	• Evaluate: management, adjustments noticeable, adjustments effective, strategy; • Reinstruct if needed; • Encourage to make adjustments; • Review.
Yes	Positive	Yes	Continue.
		No	Evaluate need for adjustments: Yes ○ evaluate: adjustments effective, strategy, ○ reinstruct if needed, ○ evaluate if like to continue training: if yes: review; if no: deactivate No Deactivate.
	Poor	Yes	• Evaluate: adjustments noticeable, adjustments effective, strategy; • Reinstruct if needed; • Reprogram prescribed settings; • Evaluate if like to restart training.
		No	• Evaluate: adjustments noticeable, adjustments effective, strategy; • Reinstruct if needed; • Advise settings are similar to prescribed settings and evaluate if like to continue training.

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Appendices

Appendix A - Questions From Surveys Described in Chapter 3

A.1 Clinician Survey

Thank you for taking the time to share your thoughts with us on trainable hearing aids in adult hearing aid fitting.
This multiple choice survey will take up to 20 minutes to complete.

Your responses will be recorded anonymously, so please give us your honest opinion.

This survey has received ethical approval from the Australian Hearing Human Research Ethics Committee and the Behavioural & Social Sciences Ethical Review Committee of the University of Queensland.

[Instructions, participant information]

A.1.1 [Qualifying items]

Item	Response options
Firstly, please provide us with some information about yourself, so we can check if this survey is suitable for you.	
Please indicate if you practice as:	☐ an audiologist ☐ an audiometrist ☐ neither of the above => *excluded*
Which category describes your current workload? Select all that apply	☐ Academic research ☐ Academic teaching ☐ CI rehabilitation ☐ **Clinical support** ☐ Community education ☐ Diagnostic ☐ **Hearing aids and rehabilitation – adult** ☐ Hearing aids and rehabilitation – paediatric ☐ Industrial ☐ Management ☐ **Product training and sales – Hearing aids** ☐ Policy making => *exclude those not selecting one of the bolded options*
Select whether the following statement applies: In the last month, I have discussed rehabilitation options, including hearing aid selection with adult clients, clinicians or students in training:	☐ Yes ☐ No => *excluded*
Exclusion message: Sorry, you do not qualify to take this survey, as we are looking for clinicians who fit hearing aids to adult clients. Thank you for your time.	

A.1.2 [Contingency items]

A trainable, learning or self-learning feature is a hearing aid feature that can be activated to let the client fine-tune their own hearing aid settings after the fitting. A trainable feature learns and anticipates user preferences by combining user-selected hearing aid settings with acoustic information from the environment the settings were selected in. Training requires that the aid settings can be adjusted by the user. It can involve overall volume learning, noise management, or compression and volume learning in different sound classes (e.g. speech in noise, music).

	Item	Response options	Go to
1	Can you order hearing aids that have a trainable feature?	☐ No	[C. Passive Non-Providers] p.
		☐ Yes	Item 1a
		☐ I don’t know	[C. Passive Non-Providers] p.
1a	Thinking about the last 6 months, approximately what percentage of hearing aids you fitted had a trainable feature available?	0%	[C. Passive Non-Providers] p.
		Less than 10% 10 to 25% 25 to 50 % 50 to 75% 75 to 90% >90% ... of the hearing aids I fitted had a trainable feature	Item 2
2	Have you activated the trainable feature when it was available?	☐ No, I make sure training is not activated	[B. Active Non-Providers] p.
		☐ Yes, I sometimes activate the trainable feature (even if only very rarely)	[A. Providers] p. 134
		☐ Yes, I always activate the trainable feature	[A. Providers] p. 134
		☐ I don’t know if the trainable feature was activated or not.	[C. Passive Non-Providers] p. 144

A.1.3 [Evaluation of experience or expectations]

[A. Providers]

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>3</td><td>Where did you first find out about a trainable feature in hearing aids?</td><td>☐ At a product launch OR from a sales rep
☐ At a conference
☐ As part of a continuous education program
☐ During my audiology training
☐ Other:</td></tr>
<tr><td>4</td><td>Condition: if selecting “Yes, I sometimes activate the trainable feature” on <i>item 2</i>.
How often would you estimate that you have activated a trainable feature?</td><td>☐ When it was available, I have activated the trainable feature for about 25% of clients.
☐ When it was available, I have activated the trainable feature for about 50% of clients.
☐ When it was available, I have activated the trainable feature for about 75% of clients.</td></tr>
<tr><td>5</td><td>Condition: if selecting “Yes, I sometimes activate the trainable feature” on <i>item 2</i>.
Based on your experience, which client information do you consider before activating the trainable feature?
Select all that apply</td><td>☐ Audiometric information
☐ Cognitive status
☐ Distance to the clinic
☐ Diverse listening needs
☐ Finger dexterity
☐ Hearing aid experience
☐ Interest in feature
☐ Personality: very particular about settings
☐ Use of assistive listening technology
☐ Vision
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these items were in your decision to activate the trainable feature</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>6</td><td>Did you activate a trainable feature based on:</td><td>☐ your own initiative
☐ the client’s initiative
☐ both</td></tr>
</table>

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>6b</td><td>What made you decide to activate the trainable feature when it was available?
Select all that apply</td><td>☐ I believe it could benefit my clients
☐ I wanted to find out how it affected outcomes for my clients
☐ I was told to
☐ I just did, I hadn’t thought about why
☐ other:</td></tr>
<tr><td>6c</td><td>Condition: response to item 6b is “I believe it could benefit my clients”:
In what way do you believe the feature could benefit your clients? Please add your responses in the box(es) below.</td><td></td></tr>
<tr><td>7</td><td>Condition: response to item 2 is “Yes, I sometimes activate the trainable feature”
When you did not activate the trainable feature, what were the reasons?
Select all that apply</td><td>☐ I didn’t think the client would understand the concept (e.g. poor cognition)
☐ I didn’t think the client would be able to train successfully (e.g. obtaining poorer settings)
☐ I didn’t think the client had enough hearing aid experience to use a trainable feature
☐ Hearing aid controls were already deactivated for management reasons (e.g. dexterity, vision problems) or client preference (e.g. prefer aids to be ‘automatic’)
☐ I didn’t think clients were in need of fine-tuning when both the clients and I were happy with the hearing aid settings at the fitting
☐ <i>I offered, but the client declined</i>
☐ <i>I have stopped using the trainable feature</i>
☐ other:</td></tr>
<tr><td></td><td>Rate how important these items were in your decision not to activate the trainable feature
(omits the items in italics)</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
</table>

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>7a</td><td>Condition: if response to item 7 is “I offered, but the client declined”
What were reasons clients gave for declining the trainable feature? Select all that apply</td><td>☐ Poor cognition
☐ Poor dexterity
☐ No/limited hearing aid experience
☐ Lack of motivation
☐ Poor vision
☐ Other:</td></tr>
<tr><td rowspan="2">7b</td><td>Condition: if response to item 7 is ”I have stopped using the trainable feature”
Why did you stop using trainable features? Select all that apply</td><td>☐ I still needed to fine-tune settings
☐ I didn’t see much overall benefit to the client: trained settings were very similar to the original settings
☐ Clients obtained poorer outcomes: clients obtained settings inappropriate for their hearing loss, e.g. too soft.
☐ I didn’t feel I knew enough about how the trainable feature was impacting settings.
☐ I prefer manual fine-tuning relying on the client’s descriptions
☐ I was advised to do so by my manager/clinical educator
☐ Other:</td></tr>
<tr><td>Rate how important the items were in your decision to stop using the trainable feature</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>8</td><td>Did you evaluate if the trained settings were appropriate for the client’s hearing loss and/or if the client was happy with the settings?</td><td>☐ Yes
☐ No</td></tr>
<tr><td>8a</td><td>Condition: if response to item 8 is “ Yes”
How did you evaluate the outcome of hearing aid training? Select all the techniques you have used:</td><td>☐ I measured the insertion/coupler gain of the trained response and compared them to the initial responses
☐ I downloaded the trained hearing aid settings and compared them to the initial settings
☐ I obtained a subjective report from the client
☐ I evaluated the outcome of the training as part of the hearing aid fitting (e.g. COSI, aided speech assessment, satisfaction questionnaire)
☐ other:</td></tr>
</table>

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>8b</td><td>What was generally the outcome of the training?</td><td>☐ (Most of the time) the trained settings were kept
☐ (Most of the time) the trained settings were kept, and they were similar to the original settings
☐ (Most of the time) the trained settings were kept, but I did further fine-tuning
☐ (Most of the time) the settings were reset to the initial prescription/manufacturer’s settings
☐ Other:</td></tr>
<tr><td>9</td><td>Have trainable features changed your fitting and follow-up procedure?</td><td>☐ Not at all
☐ Slightly
☐ Moderately
☐ Very
☐ Extremely
☐ Comment:</td></tr>
<tr><td>10</td><td>Based on your experience, which of the following statements about the potential advantage to you/your practice of activating a trainable feature do you agree with?
Select all that apply</td><td>☐ More cost-effective: less additional follow-up appointments needed
☐ Time-saving: more time available in the follow-up appointment(s) to discuss other rehabilitation aspects (e.g. communication tips, assistive listening devices)
☐ Increased client retention: improved client outcomes/satisfaction due to personal fine-tuning
☐ Simpler fine-tuning process: no/less need to rely on client report for fine-tuning
☐ No advantage: I don’t think there are any advantages to me/my practice using the trainable feature
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these advantages are to you/your practice</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>11</td><td>Based on your experience, which of the following statements about the potential advantage to clients of activating a trainable feature do you agree with?
Select all that apply</td><td>☐ Convenience: fewer visits to the clinic after fitting or adjustment
☐ Psychological ownership: clients feel more involved with/ in control of their rehabilitation
☐ Improved outcome: clients are more satisfied as they obtained highly personalised settings
☐ On-going adjustments: clients can fine-tune their settings at any time in response to changes to their hearing, listening situation or preference
☐ No advantage: I don’t think there are any advantages to clients in using the trainable feature
☐ other:</td></tr>
<tr><td></td><td>Rate how important these advantages are to your clients</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>12</td><td>Based on your experience, which of the statements about the potential disadvantage to you/your practice of activating a trainable feature do you agree with?
Select all that apply</td><td>☐ Less cost effective: additional time needed to explain the training concept during device selection and/or fitting
☐ Time consuming: after obtaining inappropriate hearing aid settings, they are reset and an additional trial period started
☐ Creates a bad image: the clients think the hearing aid is doing all the fine-tuning because I can’t
☐ Reduces the need for hearing care in the long term: clients can adjust their own hearing aids when their hearing changes
☐ No disadvantage: I don’t think there were any disadvantages to me/ my practice using the trainable feature
☐ other:</td></tr>
<tr><td></td><td>Rate how important these disadvantages are to you/your practice</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>13</td><td>Based on your experience, which of the statements about the potential disadvantage to **clients** of activating a trainable feature do you agree with?
Select all that apply</td><td>☐ Time consuming: clients have to spend extra time to train their hearing aids
☐ Negative outcome: clients dislike hearing aids because they obtained inappropriate settings
☐ Extra appointment: if training was initially unsuccessful, clients need to trial the devices longer and return to the clinic
☐ Feeling of personal failure: clients return confused about the training concept
☐ Masks slowly developing problems: if training is used long-term without follow-up, inappropriate settings or hearing changes go unnoticed
☐ No disadvantage: I don’t think there were any disadvantages to clients in using the trainable feature
☐ other:</td></tr>
<tr><td></td><td>Rate how important these disadvantages are to your **clients**</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
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[B. Active Non-Providers]

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>3</td><td>Where did you first find out about a trainable feature in hearing aids?</td><td>☐ at a product launch OR from a sales rep
☐ at a conference
☐ as part of a continuous education program
☐ during my audiology training
☐ other:</td></tr>
<tr><td rowspan="2">4</td><td>What was your motivation not to activate a trainable feature? Select all that apply</td><td>☐ I didn’t think the client would understand the concept (e.g. poor cognition)
☐ I didn’t think the client would be able to train successfully (e.g. obtaining poorer settings)
☐ I didn’t think the client had enough hearing aid experience to use a trainable feature
☐ Hearing aid controls were already deactivated for management reasons (e.g. dexterity, vision problems) or client preference (e.g. prefer aids to be ‘automatic’)
☐ I thought clients were not in need of fine-tuning when both the clients and I were happy with the hearing aid settings at the fitting
☐ *I offered, but the client declined*
☐ I prefer manual fine-tuning relying on the client’s descriptions
☐ I didn’t feel I knew enough about how the trainable feature would impact settings
☐ I have been advised not to by my manager/clinical educator.
☐ other:</td></tr>
<tr><td>Rate how important these items were in your decision not to activate the trainable feature
(omits the ones in italics)</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>5</td><td>Condition: If not “prefer manual fine-tuning”
If some/most of your considerations could be overcome, would you consider using a trainable feature?
Please indicate on the scale from 1 (very unlikely) to 5 (very likely).</td><td>1. Very unlikely
2. Unlikely
3. Neutral
4. Likely
5. Very likely
Comment:</td></tr>
<tr><td rowspan="2">6</td><td>Which of the advantages of using a trainable feature listed below do you think could be relevant to you/your practice?
Select all that apply</td><td>☐ Could be more cost-effective: less additional follow-up appointments needed
☐ Could be time-saving: more time available in the follow-up appointment(s) to discuss other rehabilitation aspects (e.g. communication tips, assistive listening devices)
☐ Could increase client retention: improved client outcomes/satisfaction due to personal fine-tuning
☐ Could be a simpler fine-tuning process: no/less need to rely on client report for fine-tuning
☐ No advantage: I don’t think the there are any advantages to me/my practice using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these advantages would be to you/your practice</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>7</td><td>Which of the client-related advantages of using a trainable feature listed below do you think could be relevant?
Select all that apply</td><td>☐ Could be convenient: fewer visits to the clinic after fitting or adjustment
☐ Could increase psychological ownership: clients feel more involved with/ in control of their rehabilitation
☐ Could improve outcome: clients are more satisfied as they obtained highly personalised settings
☐ Could allow for on-going adjustments: clients can fine-tune their settings at any time in response to changes to their hearing, listening situation or preference.
☐ No advantage: I don’t think there are any advantages to clients in using the trainable feature
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these advantages would be to your clients</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>8</td><td>Which of the statements about the potential disadvantage to you/your practice of activating a trainable feature do you think could be relevant?
Select all that apply</td><td>☐ Could be less cost effective: additional time needed to explain the training concept during device selection and/or fitting
☐ Could be time consuming: after obtaining inappropriate hearing aid settings, they are reset and an additional trial period started
☐ Could create a bad image: the clients might think the hearing aid is doing all the fine-tuning because I can’t
☐ Could reduce the need for hearing care in the long term: clients can adjust their own hearing aids when their hearing changes
☐ No disadvantage: I don’t think there are any disadvantages to me/ my practice using the trainable feature
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these disadvantages would be to you/your practice</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td rowspan="2">9</td><td>Which of the statements about the potential disadvantage to clients of activating a trainable feature do you think could be relevant?
Select all that apply</td><td>☐ Could be time consuming: clients have to spend extra time to train their hearing aids
☐ Could have a negative outcome: clients dislike hearing aids because they obtained inappropriate settings
☐ Could need extra appointments: if training was initially unsuccessful, clients need to trial the devices longer and return to the clinic
☐ Could create a feeling of personal failure: clients return confused about the training concept
☐ Could mask slowly developing problems: if training is used long-term without follow-up, inappropriate settings or hearing changes might go unnoticed
☐ No disadvantage: I don’t think there are any disadvantages to the client using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these disadvantages would be to your clients</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
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[C. Passive Non-Providers]

	Item	Response options
3	Where did you first find out about a trainable feature in hearing aids?	☐ At a product launch OR from a sales rep ☐ At a conference ☐ As part of a continuous education program ☐ During my audiology training ☐ Other:
4a	Condition: if response to *item 1* is “No” (trainable HAs unavailable) or if response to *item 1a* is “0%” (trainable HAs available but not fitted) Would you use the trainable feature if it were available? Please indicate on the scale from 1 very unlikely to 5 very likely.	1. Very unlikely 2. Unlikely 3. Neutral 4. Likely 5. Very likely Comment:
4b	Condition: if response to *item 1* is “Don’t know” (if available for fitting) Would you use the trainable feature if it were available? Please indicate on the scale from 1 very unlikely to 5 very likely.	1. Very unlikely 2. Unlikely 3. Neutral 4. Likely 5. Very likely Comment:
4c	Condition: if response to *item 2* is “Don’t know” (if training was activated) If the fitting software would ask for your choice, would you use the trainable feature? Please indicate on the scale from 1 very unlikely to 5 very likely.	1. Very unlikely 2. Unlikely 3. Neutral 4. Likely 5. Very likely Comment:

<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td>5a</td><td>Condition: if response to <i>item 4</i> is <3
Why do you consider it unlikely you would use the trainable feature?
Select all that apply</td><td>☐ I don’t think clients would understand the concept (e.g. poor cognition)
☐ I don’t think clients would be able to train successfully (e.g. obtaining poorer settings)
☐ I don’t think clients had enough hearing aid experience to use a trainable feature
☐ I think clients are not in need of fine-tuning when both the clients and I are happy with the hearing aid settings at the fitting
☐ I often deactivate hearing aid controls for management reasons (e.g. dexterity, vision problems) or client preference (e.g. prefer aids to be 'automatic')
☐ I prefer manual fine-tuning relying on the client’s descriptions
☐ I don’t feel I know enough about how the trainable feature would impact settings.
☐ I have been advised not to by my manager/clinical educator.
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these items are in your decision</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>5b</td><td>Condition: if response to <i>item 4</i> is ≥ 3 (more likely than unlikely to use if available)
Which client information would you consider before using the trainable feature?
Select all that apply</td><td>☐ Audiometric information
☐ Cognitive status
☐ Distance to the clinic
☐ Diverse listening needs
☐ Finger dexterity
☐ Hearing aid experience
☐ Interest in feature
☐ Personality: very particular about settings
☐ Use of assistive listening technology
☐ Vision
☐ Other:</td></tr>
<tr><td></td><td>Rate how important these items would be in your decision to use the trainable feature</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
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<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td rowspan="2">6</td><td>Which of the advantages of using a trainable feature listed below do you think could be relevant to you/your practice?
Select all that apply</td><td>☐ Could be more cost-effective: less additional follow-up appointments needed
☐ Could be time-saving: more time available in the follow-up appointment(s) to discuss other rehabilitation aspects (e.g. communication tips, assistive listening devices)
☐ Could increase client retention: improved client outcomes/satisfaction due to personal fine-tuning
☐ Could be a simpler fine-tuning process: no/less need to rely on client report for fine-tuning
☐ No advantage: I don’t think the there are any advantages to me/my practice using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these advantages would be to you/your practice</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td rowspan="2">7</td><td>Which of the client-related advantages of using a trainable feature listed below do you think could be relevant?
Select all that apply</td><td>☐ Could be convenient: fewer visits to the clinic after fitting or adjustment
☐ Could increase psychological ownership: clients feel more involved with/ in control of their rehabilitation
☐ Could improve outcome: clients are more satisfied as they obtained highly personalised settings
☐ Could allow for on-going adjustments: clients can fine-tune their settings at any time in response to changes to their hearing, listening situation or preference.
☐ No advantage: I don’t think there are any advantages to the client using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these advantages would be to your clients</td><td><table><tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td></tr>
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<table>
<tr><th></th><th>Item</th><th>Response options</th></tr>
<tr><td rowspan="2">8</td><td>Which of the statements about the potential disadvantage to you/your practice of activating a trainable feature do you think could be relevant?
Select all that apply</td><td>☐ Could be less cost effective: additional time needed to explain the training concept during device selection and/or fitting
☐ Could be time consuming: after obtaining inappropriate hearing aid settings, they are reset and an additional trial period started
☐ Could create a bad image: the clients might think the hearing aid is doing all the fine-tuning because I can’t
☐ Could reduce the need for hearing care in the long term: clients can adjust their own hearing aids when their hearing changes
☐ No disadvantage: I don’t think there are any disadvantages to me/ my practice using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these disadvantages would be to you/your practice</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
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</table></td></tr>
<tr><td rowspan="2">9</td><td>Which of the statements about the potential disadvantage to clients of activating a trainable feature do you think could be relevant?
Select all that apply</td><td>☐ Could be time consuming: clients have to spend extra time to train their hearing aids
☐ Could have a negative outcome: clients dislike hearing aids because they obtained inappropriate settings
☐ Could need extra appointments: if training was initially unsuccessful, clients need to trial the devices longer and return to the clinic
☐ Could create a feeling of personal failure: clients return confused about the training concept
☐ Could mask slowly developing problems: if training is used long-term without follow-up, inappropriate settings or hearing changes might go unnoticed
☐ No disadvantage: I don’t think there are any disadvantages to the client using the trainable feature
☐ Other:</td></tr>
<tr><td>Rate how important these disadvantages would be to your clients</td><td><table>
<tr><th></th><th>Slightly important</th><th>Moderately Important</th><th>Very important</th><th>Extremely important</th></tr>
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A.1.4 [Demographic items]

Item	Response options
The hearing aids listed below have a trainable/learning feature you can turn on/off. Please tick the hearing aids you have fitted. Hearing aids are listed by manufacturer in alphabetic order.	Manufacturer Aid family
Finally, please provide some more information about yourself and your professional experience, this information will show whether we have captured responses from a range of professionals. Remember, all your answers are anonymous and confidential.	
Please select your age category	☐ Younger than 25 y ☐ 25 to 30 y ☐ 31 to 40 y ☐ 41 to 50 y ☐ 51 to 60 y ☐ older than 60 y
Please indicate which gender you identify with	☐ female ☐ male ☐ Indeterminate/Intersex/Unspecified
In which setting(s) do you work as an audiologist/audiometrist:	☐ Commonwealth government ☐ private practice ☐ private practice – independent ☐ private hospital ☐ private medical practice ☐ Community health ☐ State/territory government (incl hospital, Local Area Health) ☐ University ☐ Manufacturer ☐ Not-for-profit practice ☐ Other:
How many years you have been practising as an audiologist/audiometrist:	☐ Less than 1 y ☐ 1 to 5 y ☐ 6 to 10 y ☐ 11 to 20 y ☐ 21 to 30 y ☐ 31 to 40 y ☐ Over 40 y
How many years have you been fitting hearing aids:	☐ Less than 1 y ☐ 1 to 5 y ☐ 6 to 10 y ☐ 11 to 20 y ☐ 21 to 30 y ☐ 31 to 40 y ☐ Over 40 y
Select the professional organisation you are a member of:	☐ Audiology Australia ☐ Australian College of Audiology ☐ Hearing Aid Audiometrist Society of Australia

Item	Response options
If you like, you can add more information about your thoughts on trainable features in the space below:	
You have completed the survey. Thank you very much for your participation.	

A.2 Survey for Adults With Hearing Loss

Thank you for taking the time to complete this survey. We would like the view of adults who have a hearing impairment. This includes those with and without hearing aid experience.

Please provide us with your honest opinion, you will not be able to be identified from the information you provide.

The survey uses the term “hearing aid/s”, this refers to either one or two hearing aids, as is or would be applicable to you.

[Changing the font size, instructions, participant information]

A.2.1 [Qualifying and contingency items]

Item	Response options
Firstly, please provide us with some information about yourself, so we can check if this survey is suitable for you.	
q1. Please select your age	☐ Younger than 18 y => *excluded (1)* ☐ 18 to 30 y ☐ 31 to 40 y ☐ 41 to 50 y ☐ 51 to 60 y ☐ 61 to 70 y ☐ 71 to 80 y ☐ 81 to 90 y ☐ older than 90 y
q2. Have you used hearing device/s in the last 10 years?	☐ Yes, only hearing aid/s ☐ Yes, only implantable device/s => *excluded (2)* ☐ Yes, a combination of hearing aid/s and implantable device/s => *excluded (2)* ☐ No
q3. Overall, how much difficulty do you have hearing (**without** hearing aid/s if you have them)?	1. No difficulty => *Excluded if "No" chosen for q2 (3)* 2. Slight difficulty 3. Moderate difficulty 4. Quite a lot of difficulty 5. Very much difficulty
Exclusion messages	As you are under 18 years of age, your contribution ends here. Thank you for your time. Sorry, you do not qualify to take this survey, as we are looking for people with hearing aid experience only. Thank you for your time. As you do not report any difficulty with your hearing, your contribution ends here. Thank you for your time.

Hearing aid users are directed to "[Contingency items for hearing aid users]*"* (p. 152)
Unaided adults with a hearing impairment are directed to "[C. Unaided adults with hearing impairment]*"* (p. 156).

A.2.2 [Contingency items for hearing aid users]

Item	Response options
1. Have you heard about trainable or learning hearing aids?	☐ Yes ☐ I might have heard about it, but I’m not sure ☐ No
1b. Condition: if response to *item 1* is “Yes”: How did you find out about this?	☐ I heard about it from my hearing aid provider when I chose my current hearing aid/s ☐ I found out about it online, researching hearing aid/s ☐ I heard about it from a friend/family member ☐ I read about it in a newsletter (for example from a hearing support group) ☐ Other:
2. Please read the description below. When you get new hearing aids, they are set for your hearing loss. Sometimes these settings do not work well in all situations. Now there are hearing aids you can optimize yourself by using the buttons on the hearing aid or on a remote control. As you change the settings to what you like, your hearing aids learn your preference for different situations. These hearing aids are called trainable because you train them in how you like to listen.	
3. Have you trained your hearing aid/s?	☐ Yes => *directed to “*[A. Experience with trainable hearing aids]*”*, p. 153. ☐ No => *directed to “*[B. Experience with hearing aids, not trainable]*”*, p. 155.

A.2.3 [Evaluation of experience or expectations]

[A. Experience with trainable hearing aids]

Item	Response options
4. How long did you train your hearing aid/s for?	☐ One week or less ☐ 1 to 2 weeks ☐ to 3 weeks ☐ to 4 weeks ☐ More than 4 weeks ☐ Ongoing: I can/ could continue to train my hearing aid/s
5. How did you make most of the changes to your hearing aid/s during the training period?	☐ Using hearing aid buttons ☐ Using a hearing aid remote control ☐ Using both
6a. How easy did you find training your hearing aid/s?	1 Very difficult 2 Difficult 3 Neither 4 Easy 5 Very easy Comments:
6b. How did training your hearing aids change the sound quality?	6 Much worse 7 Worse 8 Stayed the same 9 Better 10 Much better Comments:
7a. What were the advantages you experienced because you trained your hearing aid/s? Select all that apply	☐ Personalisation: the settings are better in some listening situations ☐ Convenience: fewer visits to the hearing centre ☐ Involvement: I felt more involved with my hearing care ☐ Fewer changes: after training the hearing aid/s, I made fewer changes to my hearing aid/s ☐ No advantage: I did not experience any advantages training my hearing aid/s ☐ Other:

Item	Response options
7b. What were the disadvantages you experienced because you trained your hearing aid/s? Select all that apply.	☐ Time consuming: I had to spend extra time to train my hearing aid/s ☐ Worse sound quality: I didn’t like the settings I obtained ☐ Confusing: I found the process of training my hearing aid/s confusing ☐ No disadvantage: I did not experience any disadvantages training my hearing aid/s ☐ Other:
8. If you needed new hearings aid/s and they could be trained, how likely is it that you would train your hearing aid/s again?	11 Very unlikely 12 Unlikely 13 Neutral 14 Likely 15 Very likely Comments:

[B. Experience with hearing aids, not trainable]

Item	Response options
4. Here is the same description again. When you get new hearing aids, they are set for your hearing loss. Sometimes these settings do not work well in all situations. Now there are hearing aids you can optimize yourself by using the buttons on the hearing aid or on a remote control. As you change the settings to what you like, your hearing aids learn your preference for different situations. These hearing aids are called trainable because you train them in how you like to listen.	
4a. Based on this brief description, would you like to train your hearing aid/s?	☐ Yes ☐ No
4b. Condition: if “Yes” on *item 4a*: Why would you like to train your hearing aid/s? Select all that apply	☐ I would be able to personalise my hearing aid settings for different situations ☐ I would need fewer appointments to have my hearing aid/s adjusted ☐ I would feel more involved with my hearing care ☐ I would make fewer changes to my hearing aid/s over time ☐ Other:
4c. Condition: if “No” on *item 4a*: Why would you prefer not to train your hearing aid/s? Select all that apply	☐ I don’t have enough experience with hearing aid/s ☐ I am not good with technology ☐ I don’t want to or can’t use hearing aid controls ☐ I don’t want to spend the time training my hearing aid/s ☐ I don’t want to be seen fiddling with the hearing aid/s when I’m out in company ☐ The potential extra cost of the hearing aid/s ☐ I’m afraid the hearing aids would sound worse than the original ☐ I prefer the professionals to set my hearing aid/s ☐ I’m not sure, I would need more information ☐ Other:

[C. Unaided adults with hearing impairment]

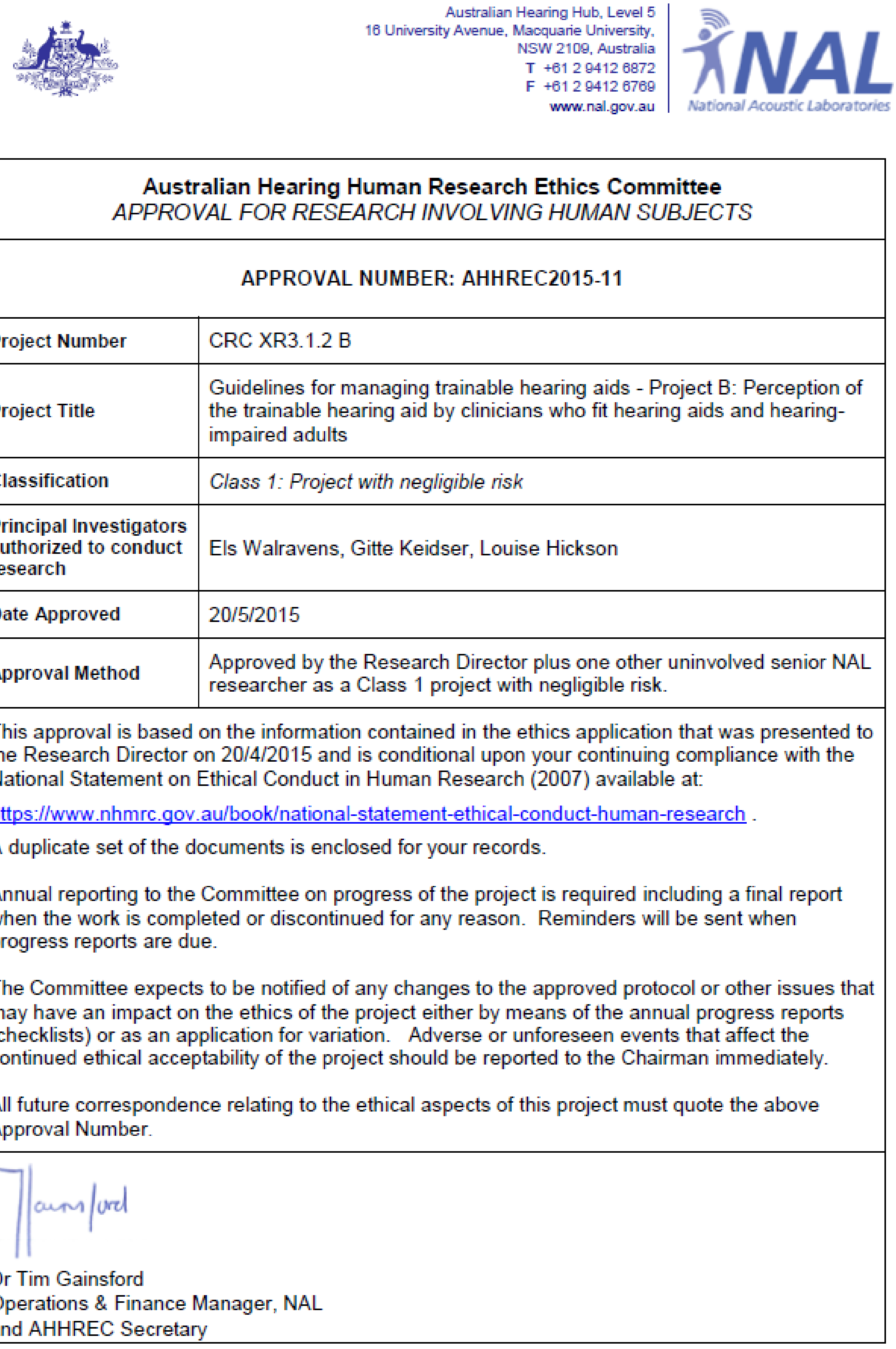
Item	Response options
0. Which of the following statements best describes your view of your current hearing status?	☐ I think I have a hearing problem. However, I am not yet ready to take any action to solve the problem, but I might do so in the future. ☐ I know I have a hearing problem, and I intend to take action to solve it soon. ☐ I know I have a hearing problem, and I am ready to take action to solve it now.
1. Please read the description below. When you get new hearing aids, they are set for your hearing loss. Sometimes these settings do not work well in all situations. Now there are hearing aids you can optimize yourself by using the buttons on the hearing aid or on a remote control. As you change the settings to what you like, your hearing aids learn your preference for different situations. These hearing aids are called trainable because you train them in how you like to listen.	
2. Based on this brief description, if/when you decided to try hearing aid/s, would you like the option of training your hearing aid/s?	☐ Yes ☐ No
2a. Condition: if “Yes” on *item 2*: Why would you like to train hearing aid/s? Select all that apply	☐ I would be able to personalise my hearing aid settings for different situations ☐ I would need fewer appointments to have my hearing aid/s adjusted ☐ I would feel more involved with my hearing care ☐ I would make fewer changes to my hearing aid/s over time ☐ Other:

Item	Response options
2b. Condition: if “No” on *item 2*: Why would you prefer not to train hearing aid/s? Select all that apply	☐ I don’t have any experience with hearing aid/s ☐ I am not good with technology ☐ I don’t want to or couldn’t use hearing aid controls ☐ I wouldn’t want to spend time training my hearing aid/s ☐ I wouldn’t want to be seen fiddling with the hearing aid/s when I’m out in company ☐ The potential extra cost of the hearing aid/s ☐ I’m afraid the hearing aids would sound worse than the original ☐ I would prefer the professionals to set my hearing aid/s ☐ I’m not sure, I would need more information ☐ Other:
3. Knowing hearing aids can be trained, do you now feel more ready to obtain a hearing aid?	☐ Yes ☐ Maybe ☐ No ☐ Don’t know

A.2.4 [Demographic items]

Item	Response options
Finally, please provide some details about yourself, this information will show whether we have received opinions from a range of people. Remember, all your answers are anonymous and confidential.	
What is your gender?	☐ Female ☐ Male ☐ Indeterminate/Intersex/Unspecified
What is the highest level of education you have completed?	☐ primary ☐ year 10 ☐ high school – year 12 ☐ TAFE/ technical college ☐ university
What is your current employment status?	☐ student; apprentice ☐ employed full-time ☐ employed part-time ☐ house duties (stay at home parent) ☐ unemployed ☐ retiree
For how long do you feel you've had a problem with your hearing?	☐ Less than 1 y ☐ 1 to 5 y ☐ to 10 y ☐ 10 to 20 y ☐ 20 to 30 y ☐ 30 to 40 y ☐ Over 40 y
Which organisation invited you to participate in the survey?	☐ Australian Hearing ☐ National Acoustic Laboratories volunteer database ☐ Neurosensory
Do you have any further comments or thoughts about trainable hearing aids?	
Only for those with experience with hearing aids: Think about how much you used your present hearing aid/s over the past two weeks. On an average day, how many hours did you use the hearing aid/s?	☐ None ☐ less than 1 hour a day ☐ 1 to 4 hours a day ☐ 4 to 8 hours ☐ more than 8 hours a day
You have completed the survey. Thank you very much for sharing your thoughts with us. Please note trainable hearing aid/s usually carry an extra cost. If you have any queries about your hearing aid/s and their features, please contact your hearing care provider. A list of hearing care providers can be found here: http://www.audiology.asn.au/index.cfm/consumers/audiology-services-directories/	

Appendix B - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 3



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Australian Hearing Human Research Ethics Committee
APPROVAL FOR RESEARCH INVOLVING HUMAN SUBJECTS

APPROVAL NUMBER: AHHREC2015-11

Project Number	CRC XR3.1.2 B
Project Title	Guidelines for managing trainable hearing aids - Project B: Perception of the trainable hearing aid by clinicians who fit hearing aids and hearing-impaired adults
Classification	*Class 1: Project with negligible risk*
Principal Investigators authorized to conduct research	Els Walravens, Gitte Keidser, Louise Hickson
Date Approved	20/5/2015
Approval Method	Approved by the Research Director plus one other uninvolved senior NAL researcher as a Class 1 project with negligible risk.

This approval is based on the information contained in the ethics application that was presented to the Research Director on 20/4/2015 and is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007) available at:

https://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research .

A duplicate set of the documents is enclosed for your records.

Annual reporting to the Committee on progress of the project is required including a final report when the work is completed or discontinued for any reason. Reminders will be sent when progress reports are due.

The Committee expects to be notified of any changes to the approved protocol or other issues that may have an impact on the ethics of the project either by means of the annual progress reports (checklists) or as an application for variation. Adverse or unforeseen events that affect the continued ethical acceptability of the project should be reported to the Chairman immediately.

All future correspondence relating to the ethical aspects of this project must quote the above Approval Number.

Dr Tim Gainsford
Operations & Finance Manager, NAL
and AHHREC Secretary

Appendix C - Ethical Approval From the University of Queensland Behavioural & Social Sciences Ethical Review Committee for the Study Described in Chapter 3

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	Improving Clinical Pathways For Hearing Rehabilitation - 23/06/2015 - AMENDMENT
Chief Investigator:	Prof Louise Hickson
Supervisor:	None
Co-Investigator(s):	Dr Nerina Scarinci, Els Walravens, Caitlin Grenness, Andrea Caposecco, Dr Carly Meyer, Dr Adrian Fuente, Dr Katie Ekberg, Karen Pedley, Robert Cowan, Barbra Timmer, Dr Teresa Ching, Akmaliza Ali, Anna O'Brien, Jill Snell, Dr Jane Black, A/Prof Catherine McMahon, Laura Vaccari, Dr Valerie Looi, Dr Christopher Lind, Dr Gitte Keidser
School(s):	School of Health and Rehabilitation Sciences
Approval Number:	2011000857
Granting Agency/Degree:	The Hearing Cooperative Research Centre; The Defence Health Foundation
Duration:	31st December 2021

Comments/Conditions:

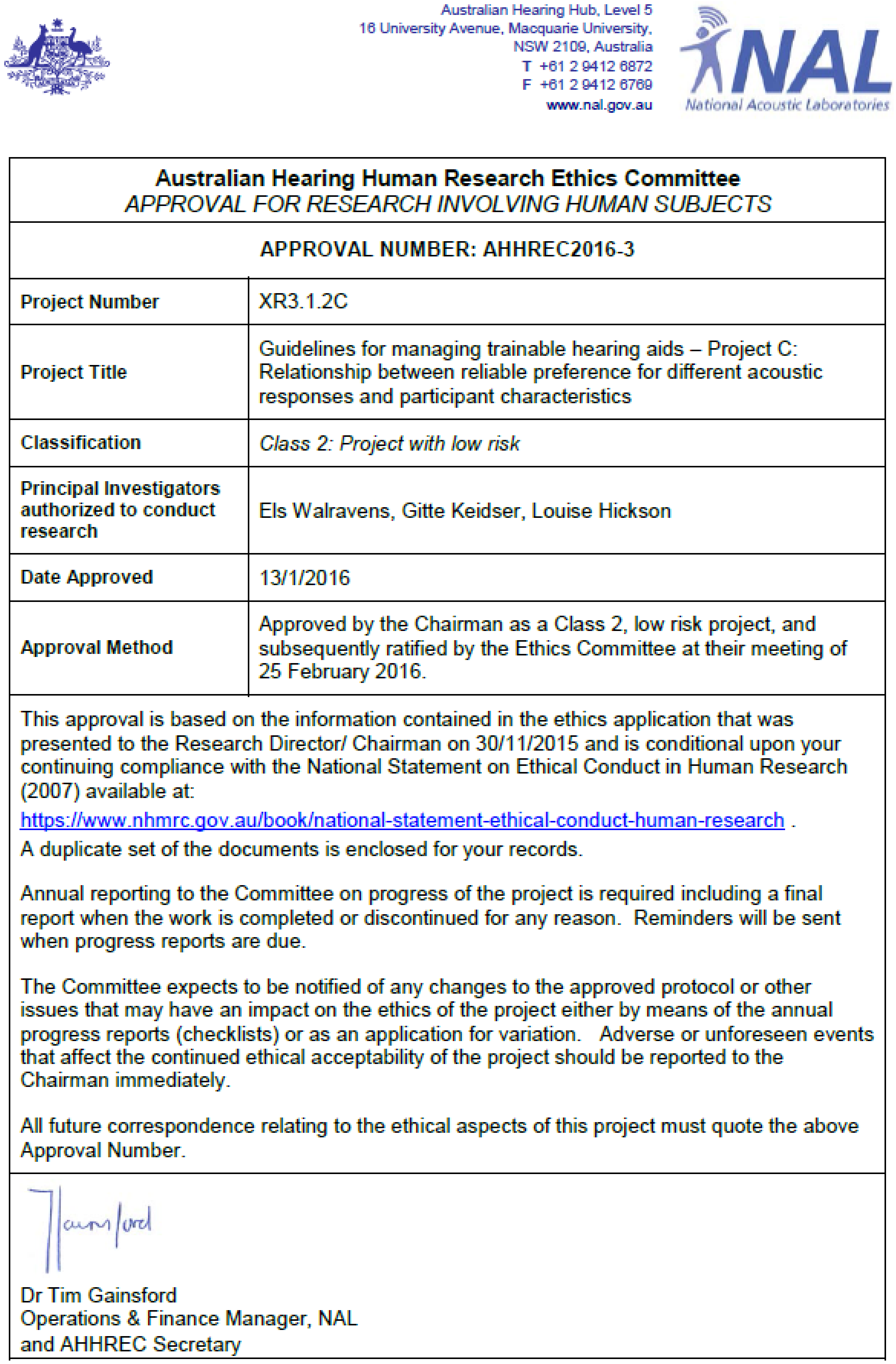
Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
Behavioural & Social Sciences Ethical Review Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Associate Professor John McLean
Chairperson
Behavioural & Social Sciences Ethical Review Committee

Signature ____________ Date 29/6/2015

Appendix D - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 4 and 5



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National Acoustic Laboratories

Australian Hearing Human Research Ethics Committee
APPROVAL FOR RESEARCH INVOLVING HUMAN SUBJECTS

APPROVAL NUMBER: AHHREC2016-3

Project Number	XR3.1.2C
Project Title	Guidelines for managing trainable hearing aids – Project C: Relationship between reliable preference for different acoustic responses and participant characteristics
Classification	*Class 2: Project with low risk*
Principal Investigators authorized to conduct research	Els Walravens, Gitte Keidser, Louise Hickson
Date Approved	13/1/2016
Approval Method	Approved by the Chairman as a Class 2, low risk project, and subsequently ratified by the Ethics Committee at their meeting of 25 February 2016.

This approval is based on the information contained in the ethics application that was presented to the Research Director/ Chairman on 30/11/2015 and is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007) available at:
https://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research .
A duplicate set of the documents is enclosed for your records.

Annual reporting to the Committee on progress of the project is required including a final report when the work is completed or discontinued for any reason. Reminders will be sent when progress reports are due.

The Committee expects to be notified of any changes to the approved protocol or other issues that may have an impact on the ethics of the project either by means of the annual progress reports (checklists) or as an application for variation. Adverse or unforeseen events that affect the continued ethical acceptability of the project should be reported to the Chairman immediately.

All future correspondence relating to the ethical aspects of this project must quote the above Approval Number.

Dr Tim Gainsford
Operations & Finance Manager, NAL
and AHHREC Secretary

Appendix E - Ethical Approval From the University of Queensland Behavioural & Social Sciences Ethical Review Committee for the Study Described in Chapter 4 and 5

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	Improving Clinical Pathways For Hearing Rehabilitation - 02/03/2016 - AMENDMENT
Chief Investigator:	Prof Louise Hickson
Supervisor:	None
Co-Investigator(s):	Dr Nerina Scarinci, Els Walravens, Dr Caitlin Grenness, Dr Anne Hill, Dr Carly Meyer, Dr Adrian Fuente, Dr Katie Ekberg, Karen Pedley, Prof Robert Cowan, Prof Trevor Russell, Prof Deborah Theodoros, Barbra Timmer, Dr Teresa Ching, Akmaliza Ali, Dr Jane Black, Dr Gitte Keidser, Dr Monique Wait
School(s):	School of Health and Rehabilitation Sciences
Approval Number:	2011000857
Granting Agency/Degree:	The Hearing Cooperative Research Centre
Duration:	31st December 2021

Comments/Conditions:

Sub-Study: Guidelines for Managing Trainable Hearing Aids - Project C: Relationship Between Reliable Preference for Different Acoustic Responses and Participant Characteristics

Approval from the Australian Hearing HREC, dated 13/01/2016 AHHREC2016-3

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
Behavioural & Social Sciences Ethical Review Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Associate Professor Elizabeth MacKinlay
Acting Chairperson
Behavioural & Social Sciences Ethical Review Committee

Signature Liz MacKinlay

Date 14/4/16 ~~[illegible]~~

Appendix F - Ethical Approval From the Australian Hearing Human Research Ethics Committee for the Study Described in Chapter 5 and 6

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Australian Hearing Human Research Ethics Committee [EC00109]

APPROVAL FOR RESEARCH INVOLVING HUMAN SUBJECTS

APPROVAL NUMBER: AHHREC2017-31

Project Number	XR3.1.2D
Project Title	Guidelines for managing trainable hearing aids - Project D: Qualitative evaluation of trainable hearing aids
Classification	*Class 2: Project involving low risk.*
Principal Investigators authorized to conduct research	Els Walravens, Gitte Keidser, Louise Hickson (University of Queensland)
Date Approved	14/10/2017
Approval Method	Approved by the Chairman as a Class 2, low risk project, and ratified by the Ethics Committee at their meeting of 28/11/2017.

This approval is based on the information contained in the ethics application that was presented to the Chairman on 22/09/2017 and is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007) available at:

https://www.nhmrc.gov.au/book/national-statement-ethical-conduct-human-research .

A duplicate set of the documents is enclosed for your records.

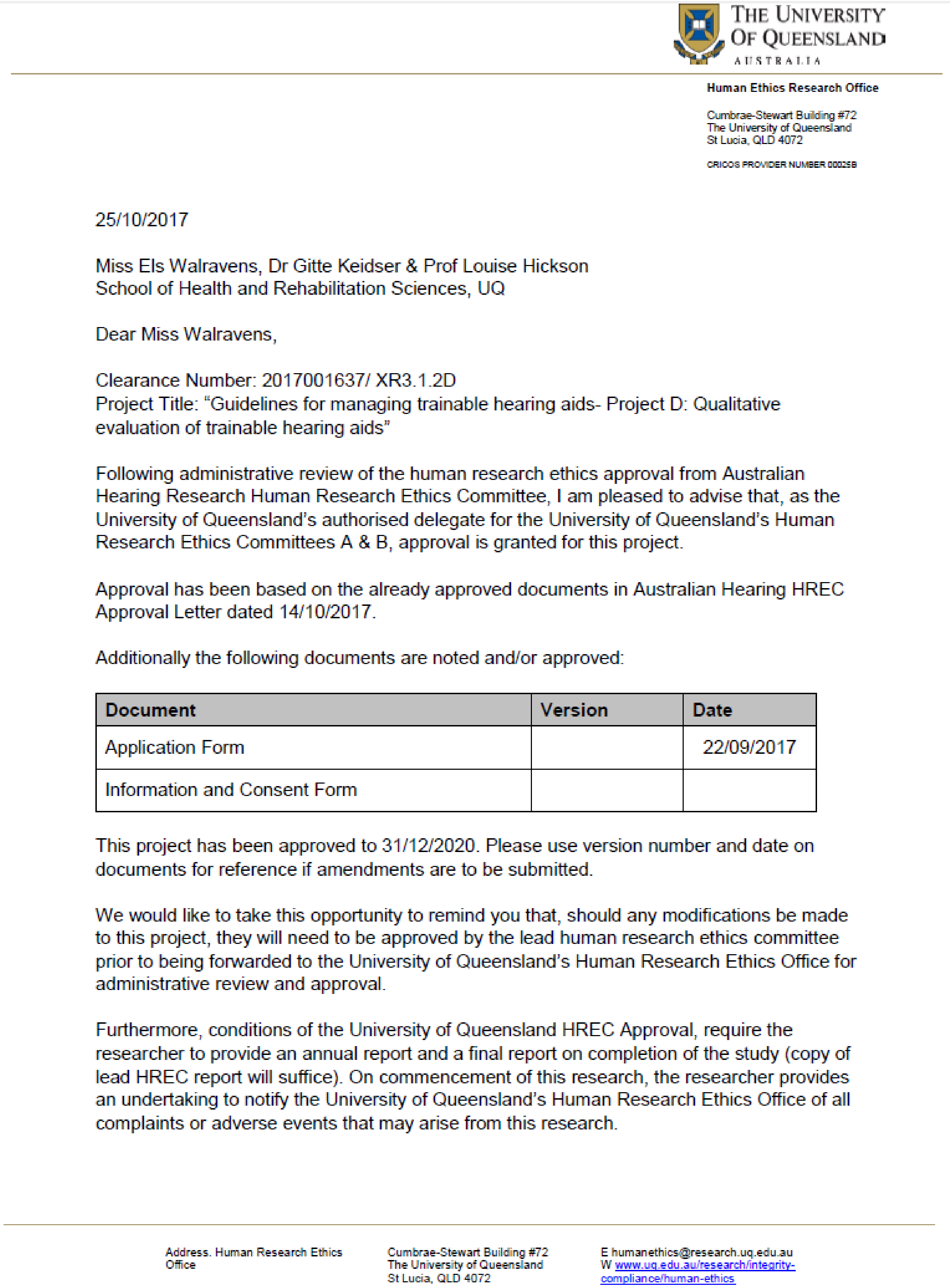
Annual reporting to the Committee on progress of the project is required including a final report when the work is completed or discontinued for any reason. Reminders will be sent when progress reports are due.

The Committee expects to be notified of any changes to the approved protocol or other issues that may have an impact on the ethics of the project either by means of the annual progress reports (checklists) or as an application for variation. Adverse or unforeseen events that affect the continued ethical acceptability of the project should be reported to the Chairman immediately.

All future correspondence relating to the ethical aspects of this project must quote the above Approval Number.

Dr Tim Gainsford
Operations & Finance Manager, NAL
and AHHREC Secretary

Appendix G - Ethical Approval From the University of Queensland Human Research Ethics Committees A & B for the Study Described in Chapter 5 and 6



THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Human Ethics Research Office

Cumbrae-Stewart Building #72
The University of Queensland
St Lucia, QLD 4072

CRICOS PROVIDER NUMBER 00025B

25/10/2017

Miss Els Walravens, Dr Gitte Keidser & Prof Louise Hickson
School of Health and Rehabilitation Sciences, UQ

Dear Miss Walravens,

Clearance Number: 2017001637/ XR3.1.2D
Project Title: “Guidelines for managing trainable hearing aids- Project D: Qualitative evaluation of trainable hearing aids”

Following administrative review of the human research ethics approval from Australian Hearing Research Human Research Ethics Committee, I am pleased to advise that, as the University of Queensland’s authorised delegate for the University of Queensland’s Human Research Ethics Committees A & B, approval is granted for this project.

Approval has been based on the already approved documents in Australian Hearing HREC Approval Letter dated 14/10/2017.

Additionally the following documents are noted and/or approved:

Document	Version	Date
Application Form		22/09/2017
Information and Consent Form		

This project has been approved to 31/12/2020. Please use version number and date on documents for reference if amendments are to be submitted.

We would like to take this opportunity to remind you that, should any modifications be made to this project, they will need to be approved by the lead human research ethics committee prior to being forwarded to the University of Queensland’s Human Research Ethics Office for administrative review and approval.

Furthermore, conditions of the University of Queensland HREC Approval, require the researcher to provide an annual report and a final report on completion of the study (copy of lead HREC report will suffice). On commencement of this research, the researcher provides an undertaking to notify the University of Queensland’s Human Research Ethics Office of all complaints or adverse events that may arise from this research.

Address. Human Research Ethics Office

Cumbrae-Stewart Building #72
The University of Queensland
St Lucia, QLD 4072

E humanethics@research.uq.edu.au
W www.uq.edu.au/research/integrity-compliance/human-ethics

Please keep a copy of this document for your records.

Kind regards,

Chris Ro'Mey

Chris Rose'Meyer
Governance Officer
Office of Research Ethics
The University of Queensland

Appendix H - Raw Data of Profile Measures (Chapter 4)

	Intensity discrimination		Comfortable dynamic range	Spectral resolution		Temporal resolution	
	500 Hz	3000 Hz		500 Hz	3000 Hz	500 Hz	3000 Hz
202	0.788	0.735	6	11.981	3.713	6.075	0.675
203	0.866	0.680	12	8.522	18.309	5.119	5.316
204	1.102	0.754	9	12.572	10.041	8.859	9.872
206	1.120	0.797	9	10.884	2.700	5.063	-1.181
207	0.851	3.888	4.5	5.400	6.919	-2.953	1.688
208	1.290	0.901	9	6.497	-0.338	-1.688	-4.894
209	2.626	0.876	6	16.200	-0.759	6.947	-1.603
210	1.197	0.812	9	6.581	12.741	-0.084	1.013
211	0.680	0.621	6	8.016	2.447	12.403	-2.700
212	1.351	0.964	6	9.872	18.394	15.356	7.003
214	0.706	0.958	12	9.366	-0.169	9.619	-2.025
215	0.850	3.888	15	9.787	-2.869	9.197	-2.109
216	0.639	0.656	9	11.644	17.634	7.847	9.197
217	0.766	1.169	12	11.728	18.309	7.509	11.559
218	0.953	0.981	9	9.450	6.413	9.028	-1.772
219	1.568	1.440	9	10.716	7.088	5.316	-0.506
220	0.966	3.888	9	7.931	4.894	8.606	-1.013
221	1.167	3.888	12	9.872	4.387	1.013	-0.506
223	1.266	1.243	6	5.569	7.172	-0.506	-2.194
224	1.348	1.117	6	10.463	3.459	4.388	-0.169
225	1.003	1.843	6	9.788	8.016	2.531	-1.434
226	1.256	0.786	9	8.944	2.531	2.953	-1.519
227	1.495	3.888	6	11.559	5.822	7.088	-0.591
228	1.292	1.207	9	12.656	17.381	1.181	0.225
229	1.194	1.152	9	11.897	3.291	18.731	-2.278
230	0.950	1.464	15	9.113	4.472	3.375	0.591
231	0.964	1.373	6	7.425	10.884	6.581	-0.169
232	1.031	2.596	9	7.678	8.944	6.497	1.519
233	1.274	1.735	6	8.606	1.181	5.822	-2.784
234	1.015	2.235	12	6.666	4.894	10.547	1.013

	Intensity discrimination		Comfortable dynamic range	Spectral resolution		Temporal resolution	
	500 Hz	3000 Hz		500 Hz	3000 Hz	500 Hz	3000 Hz
235	1.249	1.547	12	11.559	-2.869	1.434	-4.894
236	1.753	1.481	15	12.319	8.100	6.750	1.350
237	1.165	3.888	9	11.053	-2.869	8.944	-4.894
238	1.023	0.962	9	9.619	10.884	11.138	3.712
239	1.266	1.065	15	11.306	16.284	10.969	-1.181
240	1.019	0.843	12	10.884	19.322	7.341	2.109
241	1.503	1.164	9	10.463	5.063	3.881	-2.616
242	1.984	1.137	27	6.919	18.900	1.772	2.616
243	0.900	1.337	9	9.956	15.019	7.594	6.666
244	1.086	0.810	12	8.691	15.272	9.534	2.700
245	1.406	1.119	6	10.800	7.847	10.378	0.928
247	1.067	1.098	9	12.994	3.122	8.184	2.700
248	1.956	2.339	12	13.078	3.713	17.213	-2.953
249	1.489	1.512	15	10.378	-2.869	8.184	-4.894
250	1.701	1.217	9	10.800	5.147	4.753	-1.856
251	0.945	1.306	9	9.450	10.294	5.063	2.869
252	1.905	0.885	12	14.428	19.069	14.934	7.425
253	0.888	0.897	9	9.703	1.350	9.028	-3.881
254	0.995	2.542	9	10.631	8.100	14.006	-1.856
255	0.918	1.355	12	11.475	0.675	4.641	0.591
256	0.988	1.113	15	10.969	9.956	6.412	-0.759
257	1.358	1.075	6	12.234	7.256	5.259	-3.713

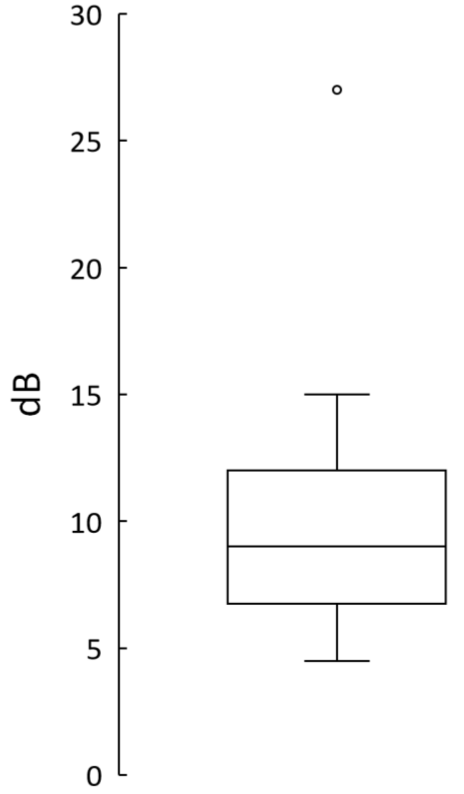
	Extraversion	Agreeableness	Conscien-tiousness	Emotional Stability	Openness to experiences	Consistent preferences
202	4	7	7	6.5	7	9
203	4.5	6.5	6	5.5	6.5	12
204	4.5	6	7	5	6.5	16
206	3.5	6.5	6.5	6	2.5	9
207	4.5	7	6.5	4.5	6.5	12
208	6	5.5	6.5	5	7	12
209	2	6	5	7	5.5	8
210	3.5	3.5	6	4	3	9
211	2.5	6.5	7	7	3.5	16
212	5	3	4.5	3.5	4.5	10
214	3	5.5	5	3.5	4	14
215	1.5	4.5	4.5	4.5	4.5	8
216	1.5	6.5	7	6	4.5	16
217	5	3	7	4.5	5	10
218	6	6.5	6.5	6.5	6.5	14
219	4.5	6.5	7	7	6.5	17
220	4.5	7	5.5	4.5	3.5	7
221	5.5	3	6	4.5	4	14
223	3.5	6	5	3	4.5	8
224	4.5	6	5	6	7	16
225	5.5	6.5	7	5	5	9
226	4	5.5	7	6.5	5	17
227	7	6	6	5	4	12
228	6.5	4	3.5	2	3.5	11
229	6.5	4.5	7	6	3.5	3
230	5.5	3.5	4.5	6	6.5	6
231	3.5	7	6	4.5	6.5	17
232	2	6	6	4.5	3.5	12
233	3.5	2.5	5	5.5	4	12
234	6	6.5	6.5	6.5	3.5	11
235	3.5	5.5	6	7	4.5	9
236	5	3.5	6.5	4	4	6

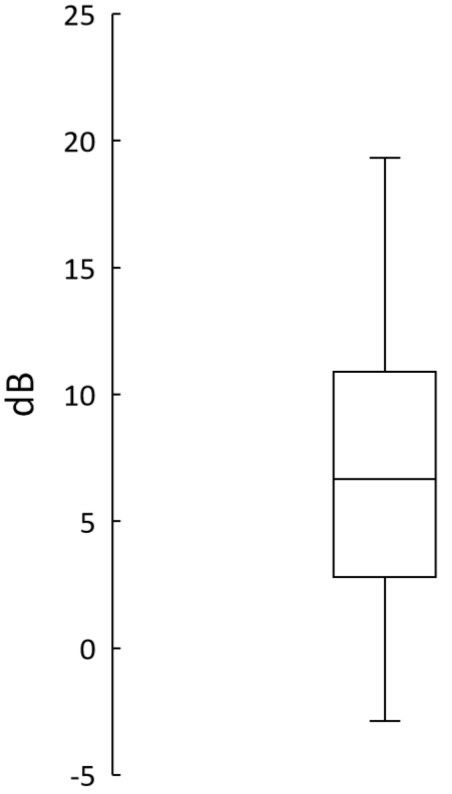
	Extraversion	Agreeableness	Conscien-tiousness	Emotional Stability	Openness to experiences	Consistent preferences
237	2.5	3.5	5.5	5	4.5	11
238	6	6.5	6	2	5.5	16
239	6	6	4.5	6	5.5	16
240	3	4	5	2.5	4.5	6
241	4.5	6.5	4	5	4.5	11
242	6	4.5	4	3.5	5.5	11
243	1.5	4	6.5	4	6	13
244	5	6.5	6	7	5.5	10
245	3.5	7	6.5	5.5	3.5	6
247	3.5	5.5	6.5	7	4	13
248	2	4.5	4.5	4.5	3.5	15
249	4	5	6	3.5	5	9
250	6	5.5	7	7	6.5	13
251	1.5	6.5	6	2.5	3.5	14
252	4.5	7	7	6.5	6.5	11
253	6.5	7	6.5	7	6.5	7
254	5.5	5	3	6	5	7
255	2.5	5.5	5.5	6.5	3.5	13
256	4.5	5	5	5.5	5.5	3
257	4	7	4.5	3.5	4.5	7

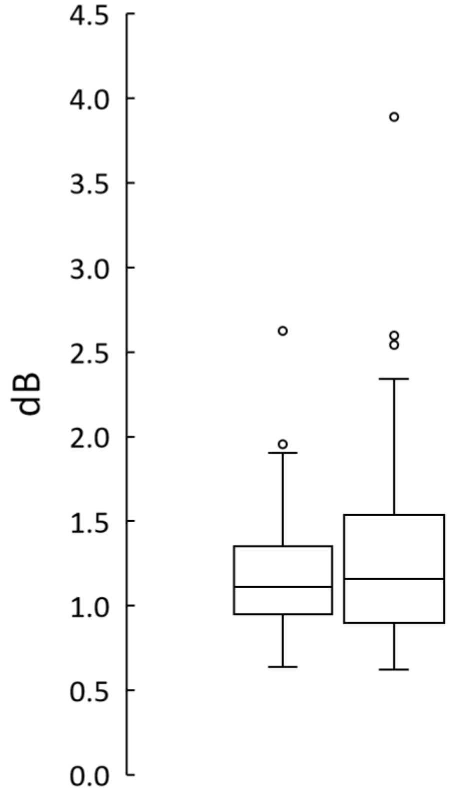
	MoCA	Working memory recall (%)	Executive function (ms)	Working memory updating (%)
202	27	0.667	938	0.854
203	29	0.542	992	0.833
204	29	0.875	818	0.813
206	27	0.583	835	0.771
207	28	0.292	893	0.958
208	24	0.625	693	0.896
209	28	0.333	722	0.813
210	23	0.292	1095	0.604
211	19	0.500	1040	0.479
212	27	0.667	851	0.979
214	28	0.667	922	0.813
215	29	0.292	1150	0.896
216	30	0.833	811	0.792
217	25	0.583	1016	0.792
218	26	0.458	842	0.771
219	26	0.417	813	0.646
220	27	0.417	727	0.688
221	28	0.667	803	0.833
223	27	0.333	944	0.750
224	23	0.375	794	0.792
225	28	0.583	761	0.792
226	24	0.417	926	0.688
227	27	0.625	554	0.771
228	29	0.542	926	0.729
229	26	0.500	946	0.688
230	27	0.458	598	0.917
231	29	0.625	574	0.688
232	27	0.333	1009	0.750
233	25	0.500	861	0.875
234	27	0.583	897	0.750
235	27	0.417	795	0.896
236	26	0.667	707	0.813

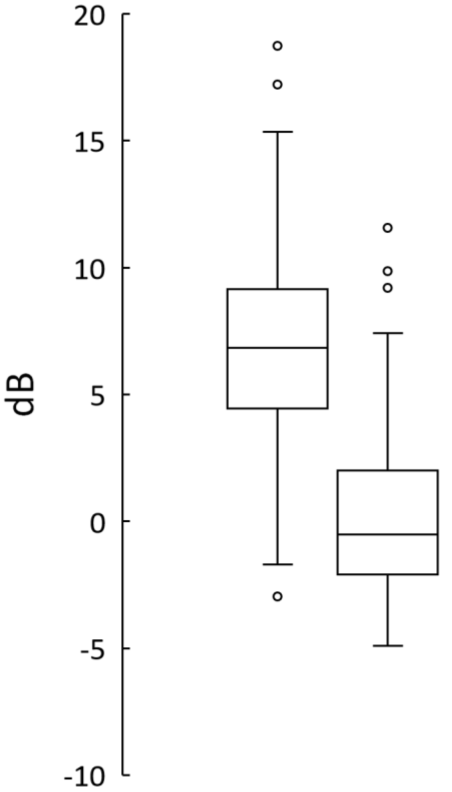
	MoCA	Working memory recall (%)	Executive function (ms)	Working memory updating (%)
237	24	0.458	871	0.813
238	29	0.667	653	0.813
239	27	0.542	845	0.792
240	27	0.708	779	0.792
241	28	0.542	852	0.750
242	26	0.542	1065	0.813
243	25	0.417	649	0.917
244	26	0.500	950	0.646
245	28	0.667	895	0.813
247	28	0.500	851	0.521
248	24	0.500	789	0.729
249	29	0.542	700	0.938
250	27	0.583	709	0.792
251	26	0.667	686	0.813
252	28	0.542	957	0.813
253	28	0.667	1001	0.833
254	30	0.583	921	0.875
255	27	0.542	1035	0.813
256	22	0.583	783	0.729
257	27	0.458	862	0.875

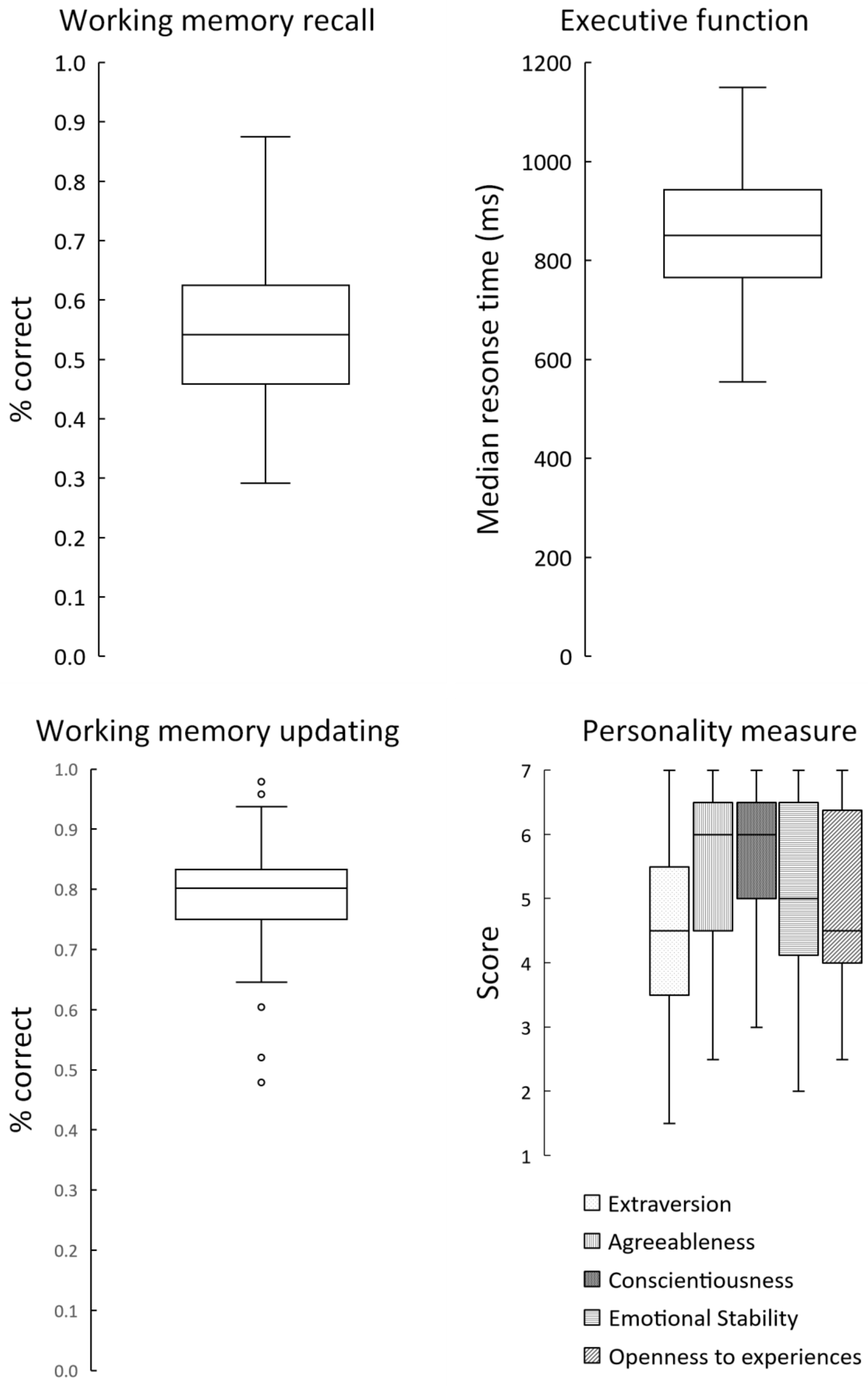
Appendix I - Performance on profile measures (Chapter 4)


Comfortable dynamic range


Spectral resolution


Intensity discrimination


Temporal resolution


Working memory recall
% correct
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Executive function
Median resonse time (ms)
1200
1000
800
600
400
200
0
Working memory updating
% correct
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Personality measure
Score
7
6
5
4
3
2
1
Extraversion
Agreeableness
Conscientiousness
Emotional Stability
Openness to experiences