AUDITORY ACCLIMATIZATION IN NEW ADULT HEARING AID USERS: A SYSTEMATIC REVIEW

by

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ETHICS STATEMENT

The author, whose name appears on the title page of this dissertation, has obtained, for the research described in this work, the applicable research ethics approval. The author declares that she has observed the ethical standards required in terms of the University of Pretoria's Code of ethics for researcher's and the Policy guidelines for responsible research.

FORMATTING

American Psychological Association (APA) 7th edition referencing style was used in this dissertation.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABR: Auditory Brainstem Response
AD: Audiologist-driven fitting
ALLRs: Auditory Late Latency Responses
ANOVA: Analysis of Variance
APA: American Psychological Association
APHAB: Abbreviated Profile of Hearing Aid Benefit
ARTs: Acoustic Reflex Tests
AV: Aversiveness
BN: Background Noise
CAEPs: Cortical Auditory Evoked Potentials
CEBM: Oxford Centre for Evidence-Based Medicine
CHL: Conductive Hearing Loss
COSI: Client Oriented Scale of Improvement
CST: Connected Speech Test
dB HL: Decibels Hearing Level
dB SL: Decibels Sensation Level
dB SPL: Decibels Sound Pressure Level
DDT: Dichotic Digits Test
EC: Ease of Communication
ERPs: Event-Related Potentials
EQ-5D: EuroQol-5-dimensions Instrument
FAAF: Four Alternative Auditory Feature Test
fMRI: Functional Magnetic Resonance Imaging
FFR: Frequency Following Response
GHABP: Glasgow Hearing Aid Benefit Profile
GDS: Geriatric Depression Scale
HA: Hearing Aids
HAPQ: Hearing Aid Performance Questionnaire
HASS: Hearing Aid Satisfaction Survey
HDABI: Hearing Aid Disability and Benefit Inventory
HHIE: Hearing Handicap Inventory for the Elderly
HHDI: Handicap and Disability Inventory
HINT: Hearing in Noise Test
HL: Hearing Loss
HPI: Hearing Performance Inventory
hrs/day: Hours Per Day
IOI-HA: International Outcome Inventory for Hearing Aids
LA: Linear Amplification
LDHQ: Localization Disabilities and Handicaps Questionnaire
NIH: National Institute of Health
NRA: Noise Reduction Algorithms
NST: Nonsense Syllable Test
PISR: Percentage Index of Speech Recognition
PD: Patient-driven fitting group
PICOST: Population Intervention Comparison Outcome Study Design Timeline
PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews
PROSPERO: International Prospective Register of Systematic Reviews
QDS: Quantified Denver Scale of Communication Function
RCT: Randomized Controlled Trial
RGDT: Random Gap Detection Test
RV: Reverberation
SADL: Satisfaction with Amplification in Daily Life
SECAP: Simplified Evaluation of Central Auditory Processing
SIN: Speech in Noise
SNHL: Sensorineural Hearing Loss
SPAC: Speech Pattern Contrast
SPIN: Speech Perception in Noise Test
SPMSQ: Short Portable Mental Status Questionnaire
SRPRN: Speech Recognition Percentages in Noise
SRT: Speech Recognition Threshold
SRTN: Speech Recognition Thresholds in Noise
SSQ: Speech, Spatial and Qualities of Hearing Scale
SSQ-D: Speech, Spatial and Qualities of Hearing Scale—Difference Version
SSRT-N: Subjective SRT-N
STT: Set-to-target groups
ULL: Uncomfortable Loudness Level Tests
WDRC: Wide Dynamic Range Compression
WIN: Words in Noise Test
WRS: Word Recognition Scores

ABSTRACT

Background: Auditory acclimatization refers to gradual improvements in auditory performance over time, driven by changes in acoustic input from hearing aids, independent of task familiarity or training effects. This review explored auditory acclimatization through behavioural, self-reported, and electrophysiological measures encompassing studies including bilateral and unilateral hearing aid users from controlled and uncontrolled studies.

Objectives: The primary aim of this systematic review was to investigate the presence and extent of acclimatization phenomena following hearing aid intervention, while also examining the factors that influenced this process.

Methods: A systematic search of CINAHL, PubMed, and Web of Science databases was conducted in March 2024. The review protocol was registered on PROSPERO and conducted in accordance with PRISMA 2020 guidelines. Eligible studies focused on behavioural outcomes (such as speech recognition in various environments), self-reported benefits and satisfaction, and electrophysiological measures.

Results: Forty-four included studies were reviewed: 32 on speech recognition, 23 on self-reported outcomes, and 9 on electrophysiological measures, with 18 reporting multiple outcome types. All studies used longitudinal designs. Among those with control groups, 53% found evidence of acclimatization in speech recognition, while others showed mixed or no effects. Self-reported outcomes were similarly varied, with 29% reporting improvements in hearing disability, communication, and satisfaction. For electrophysiological measures, 57% indicated neural adaptation. When acclimatization was observed, changes were typically small to moderate, with early gains in self-reported outcomes stabilizing over time. Consistent hearing aid use, hearing loss severity, and device features may influence acclimatization, while cognitive abilities and age did not appear to.

Conclusion: Auditory acclimatization appeared to have limited clinical relevance, with studies showing variable and modest effects making it an inconsistent predictor of hearing aid success. To improve patient outcomes, efforts should focus more on overcoming barriers to hearing aid adoption and encourage consistent use. Effective strategies should include educating patients on the benefits of long-term use, alongside ongoing support and counselling. Prioritizing these factors may enhance hearing aid effectiveness and improve the overall quality of life for individuals with hearing loss.

KEYWORDS

Hearing aids, Amplification, Acclimatization, Adaptation, Perceptual learning, Changes over time, Improvements over time.

CHAPTER 1: INTRODUCTION

1.1 Background

Over 1.5 billion people globally experience hearing loss, with at least 430 million requiring rehabilitation (World Health Organization, 2021). Hearing loss has risen from the 11th to the 3rd leading cause of disability between 2010 and 2019 (Haile et al., 2021). It can result from various factors, including genetic conditions, chronic diseases, and age-related changes (World Health Organization, 2024). Hearing loss affects socioeconomic status, mental and physical health, education, and employment (Chen et al., 2014; Emmett & Francis, 2015; Gopinath et al., 2012; Li et al., 2014; Mener et al., 2013). Rehabilitation, including amplification devices, aural rehabilitation, and speech therapy, is crucial for improving functioning and participation in education, work, and social activities (World Health Organization, 2024).

Many individuals with hearing loss could benefit from amplification devices like hearing aids (Ferguson et al., 2017), yet usage remains low. Lin et al. (2011) found that only 3% of those with mild hearing loss use hearing aids, compared to 41% and 76.6% for moderate and severe cases, respectively. Jayakody et al. (2018) linked untreated hearing loss with significant depression, stress, and anxiety, while Peelle and Wingfield (2016) noted its impact on cognitive systems for speech comprehension. Despite these issues, hearing aid uptake remains low (Saunders et al., 2012). More recently, national data revealed a 45.5% increase in hearing aid use among adults aged 65 and older between 2011 and 2022, with the greatest increases seen in metropolitan areas and higher-income groups. However, hearing aid use declined by 15.2% among low-income individuals in nonmetropolitan areas, reflecting persistent disparities in access to care (Bessen et al., 2024).

Various factors contribute to the suboptimal uptake and use of hearing aids. A systematic review by Knoetze et al. (2023) examined studies from 2011 to 2022 and identified both audiological and non-audiological factors influencing hearing aid adoption among adults with hearing loss. Significant determinants include the severity of hearing loss, self-reported hearing disability, and availability of financial support. Access to financial support—whether through income, pensions, health insurance, or third-party funding—was consistently linked to increased hearing aid uptake. In six studies, higher household income and applications for subsidized or government-funded hearing services were positively associated with hearing aid adoption, further underscoring the importance of financial accessibility in addressing this critical barrier. The review also highlighted emerging influences such as cognitive anxiety and urban residency. Other barriers encompass high costs, limited access to hearing healthcare services, lack of awareness, negative perceptions of hearing aids, and concerns regarding their effectiveness (Goggins & Day, 2009; McCormack & Fortnum, 2013; McPherson, 2018; Orji et al., 2020).

In another systematic review, Knudsen et al. (2010) examined factors influencing patients' decisions to seek help, hearing aid uptake, and satisfaction, focusing on the period following hearing aid fitting up to approximately one year. This review analysed how factors such as lifetime experience with hearing aids, daily living activities, major life events, medication, and the cosmetic appearance of hearing aids, as well as longitudinal changes over time, impacted post-fitting outcomes.

1.2 Acclimatization to hearing aids

Time or longitudinal change can also be defined as acclimatization or an adaptation period. This process involves perceptual learning, where an individual gradually learns to use the change in acoustic information provided by the hearing aid. Acclimatization leads to improved performance, which cannot be explained solely by task familiarity, procedural adjustments, or training effects (Arlinger et al., 1996). It is a critical aspect following the period of hearing aid fitting. Auditory acclimatization periods are frequently incorporated into research studies and have been of interest to many researchers. Gatehouse (1992) was among the pioneers in conceptualizing acclimatization, underscoring its importance in understanding users' experiences.

Effective adaptation to hearing aids is important for user satisfaction and overall experience (Glick & Sharma, 2020). This adaptation includes improving speech comprehension in noisy environments (Wright & Gagné, 2021) and acclimating to new sounds, which requires overcoming initial discomfort and creating new neural pathways (Karawani et al., 2018a; Munro, 2008). Integrating acclimatization periods into research and clinical practice is essential for optimizing hearing aid outcomes and ensuring users receive the maximum benefit from their devices. Functional changes in auditory ability can result from acclimatization (improvement) or deprivation (decline). This study emphasizes acclimatization, which reflects improved performance over time with hearing aid use. The research on auditory acclimatization in new hearing aid users have been contradictory (Dawes & Munro, 2017). Several studies have found evidence of an acclimatization effect (Gatehouse, 1992, Yund et al., 2006), while others have not supported the presence of a noticeable acclimatization effect following hearing aid use (Bentler et al., 1993; Dawes et al., 2014a; Humes & Wilson, 2003 and Saunders & Cienkowski, 1997). Acclimatization has been assessed using various methods, including speech recognition, self-reports, and electrophysiological measures (Karawani et al., 2018b; Philibert et al., 2005; Vestergaard, 2006), each capturing different aspects of the acclimatization process. These areas of investigating acclimatization to hearing aids are considered below.

1.2.1 Behavioural outcomes

Speech recognition tests assess individuals' ability to understand and repeat spoken words or sentences in various conditions (American Speech-Language-Hearing Association [ASHA], 1988). These tests are typically conducted in quiet, as a percentage correct (Lavie et al., 2015), and in noise, either as a percentage correct or a signal-to-noise ratio (Habicht et al., 2018; Wright & Gagné, 2021). Common measures include the Speech Perception in Noise Test (SPIN) (Bilger et al., 1984), Connected Speech Test (CST) (Cox et al., 1988), Nonsense Syllable Test (NST) (Levitt & Resnick, 1978), and Four Alternative Auditory Feature Test (FAAF) (Foster & Haggard, 1979). Researchers have examined the effects of acclimatization on speech recognition with hearing aids over varying durations. Gatehouse (1992) reported improvements after 12 weeks of use, a finding consistent with Munro and Lutman (2003), who also examined a 12-week period. Wright and Gagné (2021) observed similar trends over a longer duration of 10 months. However, some studies, such as Dawes et al. (2014a), which also examined a 12-week period, and Saunders and Cienkowski (1997), who assessed acclimatization over 3 months, found no significant effects. Similarly, Humes and Wilson (2003) conducted a long-term study over 3 years but reported no evidence of acclimatization.

1.2.2 Self-reported outcomes

Self-reported measures have been used in studies on auditory acclimatization (Megha & Maruthy, 2019; Munro & Lutman, 2004; Reber & Kompis, 2005) to assess the utilization, benefits, satisfaction, and impact of hearing aids. These measures evaluate aspects such as disability level, daily challenges, speech comprehension, and overall satisfaction (Cox & Alexander, 1999; Gatehouse, 1999, 2001; Gatehouse & Noble, 2004). While some studies report positive changes in new users over time (Chang et al., 2016; Dawes et al., 2014a; Laperuta & Fiorini, 2012; Mulrow et al., 1992; Vestergaard, 2006) other studies find no evidence of acclimatization (Cox & Alexander, 1992; Horwitz & Turner, 1997; Humes et al., 2002a; Yund et al., 2006). Notably, Humes et al. (2002a) observed declines in satisfaction ratings over time. These outcomes highlight the complexities of measuring acclimatization, as individual experiences and self-reports are subject to variability. Furthermore, the reliability of self-reported measures is influenced by inherent limitations such as social desirability, memory constraints, and individual differences in interpretation (Rosenman et al., 2011).

1.2.3 Electrophysiological outcomes

In the Eriksholm workshop on acclimatization in the mid-1990s, it was recommended to use electrophysiological measurements alongside perceptual measures to study anatomical changes during hearing aid acclimatization (Arlinger et al., 1996). Subsequent studies have tracked these changes by investigating auditory Event-Related Potentials (ERPs), including both cortical (Habicht et al., 2018; Karawani et al., 2018a, 2022) and subcortical measures (Dawes et al., 2013; Karawani et al., 2018b; Philibert et al., 2005). Subcortical ERPs, such as Auditory Brainstem Response (ABR) and Frequency Following Response (FFR), occur within 10 milliseconds of the stimulus and reflect auditory nerve and brainstem activity (Bidelman, 2015; Calcus et al., 2022; Carcagno & Plack, 2022). Cortical ERPs, like Cortical Auditory Evoked Potentials (CAEPs), appear up to 300 milliseconds after the stimulus and reflect higher-level cognitive functions from thalamic and cortical sources (Näätänen & Picton, 1987; Picton et al., 1999; Scherg et al., 1989). Similar to studies on speech recognition and self-reported measures, some studies have reported improvements in acclimatization over time, such as those by Karawani et al. (2022) and Philibert et al. (2005). However, other studies, like Dawes et al. (2013), did not present findings indicating acclimatization.

1.3 Overview of previous evidence on acclimatization

While some studies have reported evidence of acclimatization (Cox et al., 1996; Gatehouse, 1992; Munro & Lutman, 2003; Yund et al., 2006), others report no significant changes in aided speech perception, self-reported outcomes, or electrophysiological measures among new hearing aid users (Bentler et al., 1993; Dawes et al., 2014a; Humes & Wilson, 2003; Humes et al., 2002; Saunders & Cienkowski, 1997; Taylor, 1993). This discrepancy might have stemmed, in part, from an incomplete understanding of auditory acclimatization. Dawes and Munro (2017) suggested that the apparent mismatch between research findings and the experiences of clinicians and new hearing aid users arose from inaccuracies or gaps in the conceptualization of auditory acclimatization at the time. Furthermore, variations in outcome measures used across studies exacerbated this issue. Differences in the types of assessments—such as speech perception tasks, self-reported questionnaires, and electrophysiological measures—produced inconsistent results, particularly when protocols and test conditions were not standardized. Additionally, factors like hearing aid fitting parameters, usage levels, signal processing algorithms, age, initial hearing loss, test materials, and uncontrolled learning effects (Palmer et al., 1998) introduced further variability, complicating the interpretation of acclimatization outcomes.

Notable earlier reviews by researchers such as Arlinger et al. (1996), Byrne & Dirks (1996), Palmer et al. (1998), Turner et al. (1996), Munro (2008), and Mueller & Powers (2001) were conducted some time ago. Arlinger et al. (1996) highlighted the Eriksholm Workshop's standardized definitions for auditory deprivation and acclimatization, noting that acclimatization effects with linear hearing aids resulted in a 0-10% improvement in speech identification. They emphasized the need for further research due to inconsistent outcome measures. Byrne and Dirks (1996) reviewed non-speech auditory abilities, finding evidence of acclimatization in intensity discrimination, binaural masking, and localization. They noted that some changes in loudness discomfort might stem from procedural factors rather than actual auditory changes.

Turner et al. (1996) reviewed 12 studies on hearing aid benefits over time, finding mixed results in group-level improvement but significant individual variation, making it difficult to predict outcomes. Palmer et al. (1998) focused on functional and physiological changes related to auditory acclimatization, highlighting variability in results due to factors like initial hearing loss and inconsistent study designs. They noted that learning might continue up to 18 weeks post-fitting, with relearning lasting up to two years in cases of auditory deprivation. Mueller and Powers (2001) emphasized that hearing aid users often need to adjust to amplification changes and suggested incorporating acclimatization into patient counselling. Munro's (2008) review found that hearing aids can stimulate perceptual and physiological changes in the auditory system, although the extent and significance of these effects remain debated. More recently, Lavie et al. (2022) conducted a systematic review to explore the impact of hearing aid use on speech perception among older adults over time, the study reports evidence of amplification-induced auditory plasticity in older adults, with caution due to the modest improvements and moderate study quality.

1.4 Study rationale

This systematic review aimed to provide a comprehensive evaluation of the acclimatization phenomenon for hearing aids. The primary objective was to determine whether an acclimatization period existed for hearing aid users, evaluate its magnitude, and assess its clinical relevance. The review rigorously evaluated studies to expand the current knowledge base, address inconsistencies, and offer valuable insights into the auditory experiences of hearing aid users. By comparing controlled and uncontrolled study designs, the review sought to distinguish true acclimatization effects from other influences, such as practice effects.

CHAPTER 2: METHODOLOGY

2.1 Research aim

The main aim of this systematic review was to ascertain whether there is evidence for an auditory acclimatization effect following the use of hearing aids and to evaluate its magnitude if present.

2.2 Research design

This study used a systematic review design, which aimed to identify, assess, and summarize evidence from studies conducted internationally, across multiple countries and regions, to confirm existing practices, address inconsistencies, explore conflicting findings, develop actionable recommendations for decision-making, and highlight priorities for future research (Munn et al., 2018). The review included both controlled and uncontrolled study designs to provide a comprehensive overview of the evidence. Controlled studies, which employed comparison groups, were analyzed to evaluate causal relationships more rigorously, while uncontrolled studies were reviewed to capture broader trends and insights where experimental control was not feasible. By analyzing these designs separately, the review aimed to compare and contrast their findings, providing a nuanced understanding of evidence for acclimatization. The research questions guiding the review were as follows: Was there evidence of systematic improvements in behavioral, self-reported, and electrophysiological measures consistent with acclimatization following hearing aid use, particularly from studies employing a controlled design? What was the magnitude of any reported changes, and were they clinically relevant? What was the time course for these changes to stabilize? Lastly, were factors such as the duration and severity of hearing loss, or the length of hearing aid use, associated with systematic changes in these outcomes?

2.3 Ethical considerations

Ethical guidelines are established in research to maintain standards within the framework of good clinical practice and to protect participants' rights and welfare and the integrity of research (Beecher, 1966; Kim, 2012). This study entailed a systematic review, thus involving research on previously published literature. Since it did not involve human subjects, ethical principles directly related to human research were deemed irrelevant. However, ethical clearance was obtained from the Research and Ethics Committee of the Faculty of

Humanities, University of Pretoria, highlighting the study's commitment to ethical principles (Appendix A). The study focused on ensuring adherence to ethical standards regarding data integrity and transparency. The review protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) website with the protocol ID: 258723 (CRD42021258723).

Plagiarism

Throughout the research process, strict adherence to ethical standards regarding plagiarism was maintained. Helgesson and Eriksson (2015) suggest that plagiarism should be understood as "using someone else’s intellectual product (such as texts, ideas, or results), thereby implying that it is their own." Plagiarism, defined as the unauthorized use or close imitation of the language and thoughts of another author, was diligently avoided. All sources contributing to the study were acknowledged to ensure proper crediting of original authors and to prevent any form of academic misconduct. The study and written report were the researcher’s original work, with the American Psychological Association (APA) 7th edition referencing style used to accurately acknowledge all sources utilized.

Data Storage

In accordance with ethical principles and university regulations, the data obtained from the study were securely stored electronically on UP Repository, also known as FigShare. This platform was chosen for its reliability and compliance with data storage standards. The data will remain accessible and preserved for a minimum of 10 years, ensuring transparency and accountability in research practices.

Publication Bias

To mitigate bias and include all relevant research findings, a comprehensive search strategy was employed across multiple databases using diverse methods. This approach involved using databases like PubMed, Scopus, and Web of Science to capture studies from various disciplines and regions. Techniques such as keyword searches, Boolean operators, and citation tracking were implemented, along with manual searches of reference lists from relevant articles and reviews. The search covered a wide time frame, including both historical and contemporary studies, to capture the evolution of research findings and avoid time-related bias. By employing this rigorous and inclusive strategy, the study aimed to uphold impartiality and completeness in reporting research outcomes, providing a more accurate and comprehensive representation of the evidence.

2.4 Selection Criteria for Research Material

The population Intervention Comparison Outcome Study Design Timeline (PICOST) framework was used to select the eligibility criteria for this study.

Exclusion Criteria

The exclusion criteria for this study were defined to ensure the clarity and specificity of the research focus. Excluded from consideration were studies involving children (≤ 17 years old) and those focusing on animal research. Interventions utilizing advanced feature hearing aids, such as, frequency lowering technology, were excluded to maintain the focus on the acclimatization process with standard hearing aids. These advanced features could alter the hearing aid experience, potentially influencing the acclimatization process in ways that are distinct from typical adjustments to conventional hearing aids. By excluding these, we ensured that the study focused on the more common user experience and enabled comparisons between studies without the confounding effects of these specialized features. Non-commercial hearing aids and surgical implants, such as cochlear implants or bone-anchored hearing aids, were also excluded, as they differ fundamentally from conventional hearing aids in terms of technology and their impact on hearing and acclimatization. Additionally, studies where participants received auditory training or aural rehabilitation were excluded to eliminate external factors that could influence acclimatization independently of the hearing aids themselves. Conditions other than sensorineural hearing loss (SNHL) were excluded, such as those with conductive hearing loss (CHL). Moreover, experienced users and individuals without hearing impairment were not included as the experimental group (only as control group).

Inclusion Criteria

Included in the study were new hearing aid users aged 18 and above, utilizing digital air conduction hearing aids either unilaterally or bilaterally. Studies focusing on individuals with

SNHL who at the time of the reporting study acquired hearing aids, were included. Various types of comparators were considered, including control groups without amplification, experienced hearing aid users as controls, and pre- vs. post-hearing aid fitting comparisons. The outcomes of interest included behavioural outcomes such as speech recognition in different environments, self-reported outcomes related to hearing disability and satisfaction, as well as electrophysiological outcomes including subcortical and cortical measures. Only peer-reviewed journal publications were included, and studies with at least two data points taken within the same condition to observe changes over time were considered eligible. There were no restrictions based on publication dates for the eligible literature, and studies needed to be available in English to be included in the analysis.

2.5 Information source and search strategy

A systematic literature search was conducted through three databases CINAHL, PubMed, and Web of Science. There were no date restrictions on publications, and only English articles were extracted. The search terms for two key concepts as listed in the following table (Table 2.1) were used in the search process. The search terms were used as keywords with Boolean operators.

Table 2.1 Key concepts and keywords for database search

Concept 1		**Concept 2**
(hearing aid) OR (hearing device) OR (amplification)	**AND**	(acclimat*) OR (acclimatization) OR (acclimatization period) OR (acclimatization effect) OR (perceptual learning) OR (plasticity) OR (benefit over time) OR (adaptation) OR (longitudinal change)

All relevant articles were identified and screened independently by the researcher (CW) and one supervisor (FMA). Full-text copies of articles identified by the search and considered to meet inclusion criteria were obtained for data synthesis. Further searches were conducted before the completion of the systematic review to assess for any additional studies. Additional information was manually identified through snowballing of the reference lists from included studies as well as the screening of related articles that may not have been returned by the initial database searches. Studies, if found through this exercise, were included. Unpublished data as well as data from non-peer-reviewed publications were excluded. The protocol for Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) was followed (Figure 3.1).

2.6 Data Collection Procedures (Selection and Coding)

The literature search findings were imported into Rayyan software, where duplicate articles were identified and removed. Subsequently, the remaining articles were transferred to an Excel spreadsheet for further review. Titles and abstracts underwent screening, and full texts were examined when required. Records that passed the initial screening were then assessed for eligibility. Data extraction was conducted by the primary reviewer (CW), with verification by the second reviewer (FMA). The inter-reviewer discrepancy rate was 7%, mainly concerning special hearing aid features and factors such as rehabilitation and training. These discrepancies were resolved through discussions with additional team members, VM and DWS.

For each study, relevant data based on the aim were extracted (Appendix B). The extracted data from each study encompassed details such as reference, country, population demographics, sample size, study design, mean age, gender distribution, description of hearing loss, comparators, and duration between initial and final measurements. Additionally, data were collected on the impacts of hearing aid acclimatization on behavioural outcomes (e.g., speech recognition), self-reported measures, and electrophysiological responses in adults with hearing loss. Studies were categorized based on their primary focus areas, including aided and unaided speech testing, latency, and amplitude testing. Efforts were made to retrieve any missing data by contacting study authors when necessary.

Strategy for Data Synthesis

Narrative Synthesis: In line with the approaches outlined by Campbell et al. (2020) and Popay et al. (2006), a formal narrative synthesis was conducted. This involved analysing studies separately based on their uncontrolled and controlled designs, providing a comprehensive overview of the evidence.

Quantitative Synthesis (Meta-analysis)

A meta-analysis was attempted using Comprehensive Meta-Analysis software version 3, employing an inverse variance weighting approach and a random effects model (Borenstein et al., 2005), to assess the impact on three outcome domains by comparing the standardized mean difference over time between new hearing aid users and a control group. This analysis extracted means and standard deviations from 11 studies, excluding uncontrolled studies, but a quantitative analysis was not performed. The challenge of calculating standard deviations over time, due to the interdependence of data points, hindered further analysis. Although the method by Borenstein et al. (2021) was considered to adjust for correlations between intra-group effect sizes, it required unavailable individual participant data. Without this critical correlation data, the composite effect size and standard deviation could not be accurately computed, preventing the completion of the meta-analysis.

2.7 Reliability and Validity

Reliability and validity are concepts used to evaluate the quality of research. Validity concerns what an instrument measures, and how accurate it is. The confidence one can have in data obtained through the use of an instrument is known as reliability (Mohajan, 2017). The PRISMA guidelines was followed to ensure the validity and reliability of the study.

2.8 Study Quality Appraisal

The quality of the included studies was evaluated using the National Institute of Health (NIH) Quality Assessment Tools (2021), which are designed specifically for assessing individual research studies. These tools provide a structured framework for evaluating key elements, such as study methodology, risk of bias, and reporting quality. Studies were assigned scores based on specific questions and criteria, categorizing them as 'good,' 'fair,' or 'poor' depending on their study design. For cohort and controlled interventional studies, a 14-question tool was used, with scores of 11–14 considered 'good,' 6–10 as 'fair,' and 0–5 as 'poor.' Before-After (Pre-Post) studies without a control group with scores of 9–12 categorized as 'good,' 5–8 as 'fair,' and 0–4 as 'poor' (Oliaei et al. 2021). In this assessment, 'Yes' was scored as 1 point, while 'No,' 'Cannot Determine,' 'Not Reported,' and 'Not Applicable' were scored as 0 points. The total score reflected the number of affirmative responses (Appendix C).

The level of evidence for the included studies was determined using the Oxford Centre for Evidence-Based Medicine (CEBM) Levels of Evidence (2011), which ranks evidence hierarchically based on quality and relevance to clinical practice. Evidence was grouped into five levels (1–5), with Levels 1 and 2 representing the highest quality (Appendix D). The assessment was conducted independently by the primary reviewer (CW).

CHAPTER 3: RESEARCH ARTICLE

Title: Auditory acclimatization in new adult hearing aid users: A registered systematic review of magnitude, key variables, and clinical relevance

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3.1 Abstract

Objectives: Auditory acclimatization is a systematic change in auditory performance over time linked to alterations in acoustic information provided by hearing aids, involving an improvement in performance that cannot be attributed solely to task, procedural, or training effects. This pre-registered systematic review aimed to comprehensively examine the presence of auditory acclimatization among new adult hearing aid users, quantify its magnitude when observed, and explore the factors that may influence acclimatization.

Design: A systematic literature search was conducted across the CINAHL, PubMed, and Web of Science databases in March 2024. The selected reports for the study focused on behavioural (such as speech recognition in quiet and noise), self-reported (e.g., hearing aid benefits/ satisfaction), and electrophysiological outcomes. The review protocol was registered on PROSPERO and followed PRISMA 2020 reporting guidelines. A meta-analysis was attempted but excluded due to large missing data.

Results: The systematic review identified 44 studies on auditory acclimatization following hearing aid use. Of these, 32 focused on behavioural speech recognition outcomes: 19 had control groups (10 reported acclimatization, 2 mixed results, 7 no acclimatization) and 13 did not (6 reported acclimatization, 3 mixed, 4 no acclimatization). For self-reported outcomes, 23 studies were reviewed: 7 with control groups (2 reported acclimatization, 4 mixed, 1 none) and 16 without (5 reported acclimatization, 3 mixed, 8 none). Of the 9 studies on electrophysiological outcomes, 7 had control groups (4 reported acclimatization, 3 did not) and 2 lacked control groups (mixed results). Evidence suggests that consistent hearing aid

use, hearing loss severity, and device features may influence acclimatization. Cognitive abilities and age did not appear to be related to acclimatization.

Conclusion: This review offers a broader scope by including 44 studies, covering both bilateral and unilateral hearing aid users, as well as controlled and uncontrolled studies—some of which were not included in earlier reviews. While there is evidence supporting the existence of acclimatization, its magnitude in new adult hearing aid users is generally minimal and inconsistently replicated across studies. Although new users do need time to adjust, the clinical relevance of acclimatization appears limited. Amplification benefits can be reliably measured during routine follow-ups, typically 2-6 weeks post-fitting. As a result, prioritizing acclimatization in clinical practice for adults with age-related hearing loss may not be necessary. Instead, it may be more beneficial for clinicians and researchers to focus on addressing more significant factors, such as barriers to hearing aid uptake as well as support needed to facilitate hearing aid handling skills that could promote hearing aid use.

3.2 Introduction

Auditory acclimatization is conceptualised as the benefit from perceptual learning in which individuals gradually adapt over time to the changes in acoustic information provided by their hearing aids (Arlinger et al., 1996). This performance improvement cannot be solely attributed to task, procedural, or training effects (Arlinger et al., 1996). To measure auditory acclimatization, there is a need to: (i) assess baseline performance, (ii) then track changes over time, and (iii) compare with a control group to isolate acclimatization effects. Functional changes in hearing following hearing aid use may stem from either improvement in the aided ear (i.e. an acclimatization effect) or worsening performance in the unaided ear (i.e., an effect of auditory deprivation) (Silman et al., 1984).

Over the past three decades, numerous studies have been performed to investigate the presence and potential impact of auditory acclimatization. Study findings on acclimatization have however been inconsistent. Some studies have reported evidence suggesting an acclimatization effect (Glick & Sharma, 2020; Karawani et al., 2022; Munro & Lutman, 2003), while others have not (Choi et al., 2011; Dawes et al., 2013; Saunders & Cienkowski, 1997). There is ongoing uncertainty about the presence and significance of auditory acclimatization, which underscores the need for this updated and comprehensive review. The last review on this topic was conducted by Lavie et al. in 2022 and focused exclusively on speech perception outcomes. Acclimatization studies have however focussed on three main outcome domains including (a) behavioural (i.e., accuracy of aided speech recognition), (b) self-reported changes such as hearing aid benefit and/or satisfaction, and (c) electrophysiological measures.

With respect to behavioural outcomes, accuracy of aided speech recognition is typically assessed in terms of percentage correct (Horwitz & Turner, 1997; Taylor, 1993), either in quiet or in noise, or as signal-to-noise ratio (SNR in decibels) for a given criterion performance, such as 50% correct (Habicht et al., 2018). For example, in a study conducted by Gatehouse (1992), who introduced the concept of "acclimatization," four participants received hearing aids in one ear. Speech recognition was measured in both the aided and unaided conditions of the fitted ear at the outset and after a 12-week period. Over the 12-week period, speech recognition improved in the aided listening condition compared to a decline observed in the unaided listening condition for the fitted ear. There were no changes or only slight declines in the performance in the non-fitted ear. Gatehouse (1992) interpreted this pattern of findings to support the presence of an acclimatization effect for aided listening. Other studies have also noted improvements in aided listening for new hearing aid users. Munro and Lutman (2003) found that the fitted ear improved over time, while the non-fitted ear declined. Wright and Gagné (2021) observed a 2 decibels (dB) improvement in SNR for new users over four weeks, whereas experienced users showed no change. However, several studies (Dawes et al., 2014a; Humes & Wilson, 2003; Petry et al., 2010; Saunders & Cienkowski, 1997) did not find improvements in speech recognition. Various factors could explain inconsistent results across studies, including acclimatization effects being small on average and hard to detect without large study samples, insufficient experimental design to control the effects of repeated testing, degree of hearing loss, personal traits (e.g., personality, motivation, expectations), acoustic environments, and differences in acclimatization related to age, cognitive status, and hearing aid use (Dawes et al., 2014a; Horwitz & Turner, 1997; Palmer, 1998; Petry et al., 2010).

Self-reported measures have been used to assess subjective changes in aided listening among new hearing aid users in relation to auditory acclimatization. These measures typically include utilization, perceived benefits, satisfaction, and the impact of hearing aids on quality of life [e.g., the Hearing Handicap Inventory for the Elderly (HHIE), the Glasgow Hearing Aid Benefit Profile (GHABP), and the Abbreviated Profile of Hearing Aid Benefit (APHAB)]. However, a potential limitation of self-report measures is the bias that can arise from factors such as social desirability, recall bias, expectations, memory constraints, emotional state, and individual differences in interpretation (Rosenman et al., 2011). Given that self-reports are subjective, it can be challenging to determine whether perceived improvements are due to auditory acclimatization, general adjustment to hearing aids, or other psychological factors.

Some studies have shown positive changes in self-reported outcomes among new hearing aid users over time (Chang et al., 2016; Dawes et al., 2014a; Laperuta & Fiorini, 2012; Mulrow et al., 1992; Vestergaard, 2006). For instance, in a study by Dawes et al. (2014a), participants completed the Speech, Spatial and Qualities of Hearing Scale—Difference version (SSQ-D; Gatehouse & Noble 2004) and reported positive changes at 12 weeks compared to baseline. There were improvements in both new bilateral and unilateral hearing aid user groups, while there were no changes among the experienced hearing aid user group. However, other studies found no change in self-reported outcomes consistent with an acclimatization effect (Cox & Alexander, 1992; Horwitz & Turner, 1997; Humes et al., 2002a; Yund et al., 2006). Humes et al. (2002a) reported a *decline* in satisfaction ratings over time in both the Hearing Aid Satisfaction Survey (HASS) and the GHABP measures within a single group of new hearing aid users. At the 1-year and 2-years' time points, satisfaction ratings were lower compared to earlier time points (1-month and 6-months).

Researchers have also examined auditory Event-Related Potentials (ERPs) in relation to hearing aid acclimatization. ERPs include both cortical (Habicht et al., 2018; Karawani et al., 2018a, 2022) and subcortical (Dawes et al., 2013; Karawani et al., 2018b; Philibert et al., 2005) measures, with studies reporting mixed findings regarding acclimatization effects. Philibert et al. (2005) found a reduction in wave V latency in the right ear of a single group of new bilateral hearing aid users after 6 months, though wave I and III latencies and amplitudes remained unchanged. Dawes et al. (2013) reported no changes in ABR wave V latency or amplitude in new unilateral and bilateral users and a control group of experienced users after three months. Karawani et al. (2022) observed increased N1 amplitudes to speech syllables presented in quiet after two weeks among new hearing aid users. P2 amplitudes in quiet also increased but only after six weeks. In contrast, the control group exhibited no changes in the amplitudes and latencies of P1, N1, and P2 peaks between the baseline session and 24 weeks.

Previous reviews have examined auditory acclimatization, observing changes in adult performance over time. Arlinger et al. (1996) reported from the Eriksholm Workshop, which provided standardized definitions for auditory deprivation and acclimatization, summarized existing knowledge, and identified research gaps. They found that linear hearing aids were associated with acclimatization and deprivation effects, with studies showing a 0-10% improvement in speech identification, although acclimatization could take months. They highlighted the need for research on participant expectations and reliable outcome measures due to inconsistencies in assessments. Byrne and Dirks (1996) focused on non-speech abilities like intensity discrimination, binaural masking, and sound localization, finding acclimatization or deprivation effects in these areas. They suggested these effects should be considered in research and clinical practice, particularly in hearing aid fitting.

Turner et al. (1996) reviewed 12 studies on hearing aid benefit over time, analysing both objective (e.g., speech recognition) and subjective (e.g., questionnaires) measures. While some studies showed increased benefit, others showed no change, with significant individual variation. Of these 12 studies, our review included 9, excluding those with prior hearing aid users. Palmer et al. (1998) reviewed 19 studies on functional and physiological auditory changes, noting variability due to factors like initial hearing loss and inconsistent control groups. They found learning continued up to 18 weeks post-fitting, with some relearning lasting up to two years.

Mueller and Powers (2001) noted that hearing aid users often adjust to changes in amplification, influenced by loudness levels and environmental sounds. They recommended incorporating acclimatization into patient counselling and fitting procedures. Munro (2008) reviewed 12 studies and found that hearing aids can lead to both perceptual and physiological changes, including improvements in speech perception and intensity discrimination, though the rate and significance of acclimatization vary. Lavie et al. (2022) found amplification-induced plasticity in older adults, improving speech perception, though overall gains were small and study quality moderate.

Overall, previous reviews highlight that auditory acclimatization typically results in perceptual improvements, such as better speech recognition and intensity discrimination, but the extent and timeline of these changes can vary widely among individuals (Arlinger et al., 1996; Byrne & Dirks, 1996; Munro, 2008). The reviews underscore the need for consistent research methodologies and long-term studies to better understand and predict acclimatization effects and enhance hearing aid fitting practices (Palmer et al., 1998; Mueller & Powers, 2001). The inconsistency of research findings prompts consideration of the clinical relevance of acclimatization. If notable effects were present, they would likely be consistently observed across studies (Turner et al., 1996).

The aim of this review was to systematically evaluate auditory acclimatization in new hearing aid users in an up-to-date synthesis of research. Many previous studies that reported acclimatization lacked a control group, meaning that it was not possible to attribute changes in aided listening to acclimatization effects rather than to effects related to training effect due to repeated testing. We therefore aimed to directly compare the results of controlled versus uncontrolled studies. We aimed to examine the magnitude and time course of acclimatization effects and their clinical relevance, while exploring factors that may influence acclimatization. We hypothesized that greater hearing loss, consistent hearing aid use, and advanced device features would lead to faster and more pronounced acclimatization, particularly in cognitively able individuals.

The specific research questions were:

1. Is there evidence of systematic improvement in behavioural, self-reported, and electrophysiological measures consistent with acclimatization following hearing aid use from studies that utilised a controlled design?
2. If changes were reported, what is their magnitude and are they likely to be clinically relevant?
3. If changes were reported, what is the time course to reach asymptote?
4. Are factors such as the duration and severity of hearing loss, or the length of hearing aid use, associated with systematic changes in these outcomes?

3.3 Materials and methods

The review protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) website [protocol ID: 258723 (CRD42021258723)]. The review was performed and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021).

Information Sources and Search Strategy

A systematic literature search was conducted across three databases: CINAHL, PubMed, and Web of Science. The selection of these databases was based on their comprehensive coverage of relevant literature in the field of audiology. The databases were searched using their respective platforms: CINAHL via EBSCOhost, PubMed via NCBI, and Web of Science via Clarivate Analytics. The initial search was performed on February 8, 2023, and was updated on March 16, 2024, to capture any newly published articles. The search strategy was collaboratively developed by the primary author (CW) and co-authors (VM, DS, FMA), and executed by CW, who performed the search. The search strategy utilized a combination of text words and controlled terms, focusing on two primary domains. All search terms used included: "hearing aid" OR "hearing device" OR "amplification" AND "acclimat*" OR "acclimatization" OR "acclimatization period" OR "acclimatization effect" OR "perceptual learning" OR "plasticity" OR "benefit over time" OR "adaptation" OR "longitudinal change."

Eligibility Criteria

The Population, Intervention, Comparison, Outcome, Study Design, and Timeline (PICOST) framework was utilized to determine the eligibility criteria for this study. Note that the PICOST eligibility criteria table included additional items, such as condition and language (Table 3.1).

Table 3.1: Eligibility Criteria

	Inclusion	Exclusion
Population	New hearing aid users aged 18 and above.	Children (≤ 17 years old), animal research
Intervention	Digital air conduction hearing aids (Unilateral & Bilateral)	Advanced feature hearing aids (e.g., frequency lowering), non-commercial hearing aids, surgical implants (e.g., cochlear implant, bone-anchored hearing aid), and when training was received (auditory training & aural rehabilitation).
Condition	Individuals with sensorineural Hearing Loss (SNHL) with new hearing aids.	No hearing impairment, conductive hearing loss (CHL), and experienced users as the experimental group.

Comparator	Any comparator to new hearing aid users (e.g., those with hearing loss with no amplification as a control group; experienced hearing aid users control group; normal hearing individuals as control group, pre- vs post-hearing aid fitting; aided ear versus unaided ear as the control in unilateral fittings).	None
Outcomes	• Behavioural outcomes (i.e., speech recognition in quiet and/or noisy environments) • Self-reported outcomes (e.g., hearing disability, hearing aid benefit and/or satisfaction) •Electrophysiological outcomes, including subcortical measures such as Auditory Brainstem Response (ABR) testing and Frequency Following Response (FFR), and cortical measures such as Cortical Auditory Evoked Potentials (CAEPs).	No reported outcomes, acoustic reflex tests (ARTs), discrimination-limen measures, uncomfortable loudness level tests (ULL), and Functional Magnetic Resonance Imaging (fMRI) tests.
Study Design	Peer-reviewed journal publications.	Unpublished studies, non-peer-reviewed publications, thesis/dissertations, systematic reviews, and case reports.
Timing	At least two data points measures taken within the same condition to observe changes over time, such as baseline vs. 3 weeks. No publication date restrictions apply to the eligible literature.	No post-intervention follow-up period.
Language	English	Non- English

Selection Process

All articles retrieved from electronic searches were first identified and extracted by the primary author (CW) and then cross-checked by the second reviewer (FMA). Both reviewers independently screened the articles to ensure thoroughness and accuracy. Duplicates were identified and removed using Rayyan software. The remaining articles were managed in an Excel spreadsheet. The selection process involved an initial review of titles. Articles that appeared relevant based on their titles were then assessed by reading their abstracts. Full-text articles were subsequently reviewed to determine eligibility for inclusion in the data synthesis. Additional articles were manually identified through reference lists and related articles that met the eligibility criteria. Both reviewers reached consensus on the included studies. The inter-reviewer discrepancy rate was 7%, primarily related to special hearing aid features and factors such as rehabilitation and training. Discrepancies were resolved through discussions with additional team members (VM and DWS). The PRISMA protocol was followed.

Data Extraction

Following the completion of the selection process, data extraction was meticulously carried out to ensure both accuracy and comprehensiveness by the primary author (CW). Data were extracted from each included study, encompassing several key variables. These included reference, country, population, sample size, study design, mean age, gender ratios, description of hearing loss, comparators, and length between the first and last measurement. Additionally, data were collected on the effects of hearing aid acclimatization on behavioural (e.g., speech recognition), self-reported, and electrophysiological measures in adults with hearing loss.

Quality (Risk of Bias) Assessment and Determination of Level of Evidence

The quality of the included studies was assessed using the National Institute of Health (2021) (NIH) Quality Assessment Tools, tailored for evaluating individual research studies. These tools offered a structured framework for evaluating key aspects such as methodology, risk of bias, and reporting quality. They utilized specific questions and criteria to assign a score to each study, categorizing them as 'good,' 'fair,' or 'poor' based on study design. For cohort and controlled interventional studies, the 14-question tool assigned scores of 11–14 as 'good,' 6–10 as 'fair,' and 0–5 as 'poor.' Additionally, for Before-After (Pre-Post) studies without a control group also followed the scoring methodology outlined by Oliaei et al. (2021), with scores of 9–12 categorized as 'good,' 5–8 as 'fair,' and 0–4 as 'poor. In this assessment, 'Yes' was scored as 1 point, while 'No,' 'Cannot Determine,' 'Not Reported,' and 'Not Applicable' were scored as 0 points. Thus, the total score represents the number of affirmative responses. The level of evidence for the included studies was determined using the Oxford Centre for Evidence-Based Medicine (CEBM) Levels of Evidence (2011), offering a hierarchical method for ranking evidence based on quality and relevance to clinical practice. It categorizes evidence into five levels (1–5). Levels 1 and 2 represent the highest quality of evidence. The assessment and determination were conducted independently by the primary reviewer (CW), with discrepancies resolved by a second reviewer (FMA).

Data Synthesis

Narrative Synthesis: A formal narrative synthesis was undertaken as described by Campbell et al. (2020) and Popay et al. (2006). The examination of the studies involved conducting a separate analysis based on uncontrolled and controlled designs. The narrative synthesis aimed to integrate findings from different study designs, providing a comprehensive overview of the evidence base. This approach allowed for a detailed examination of the effects of hearing aid acclimatization, highlighting differences and commonalities across studies with varying methodologies.

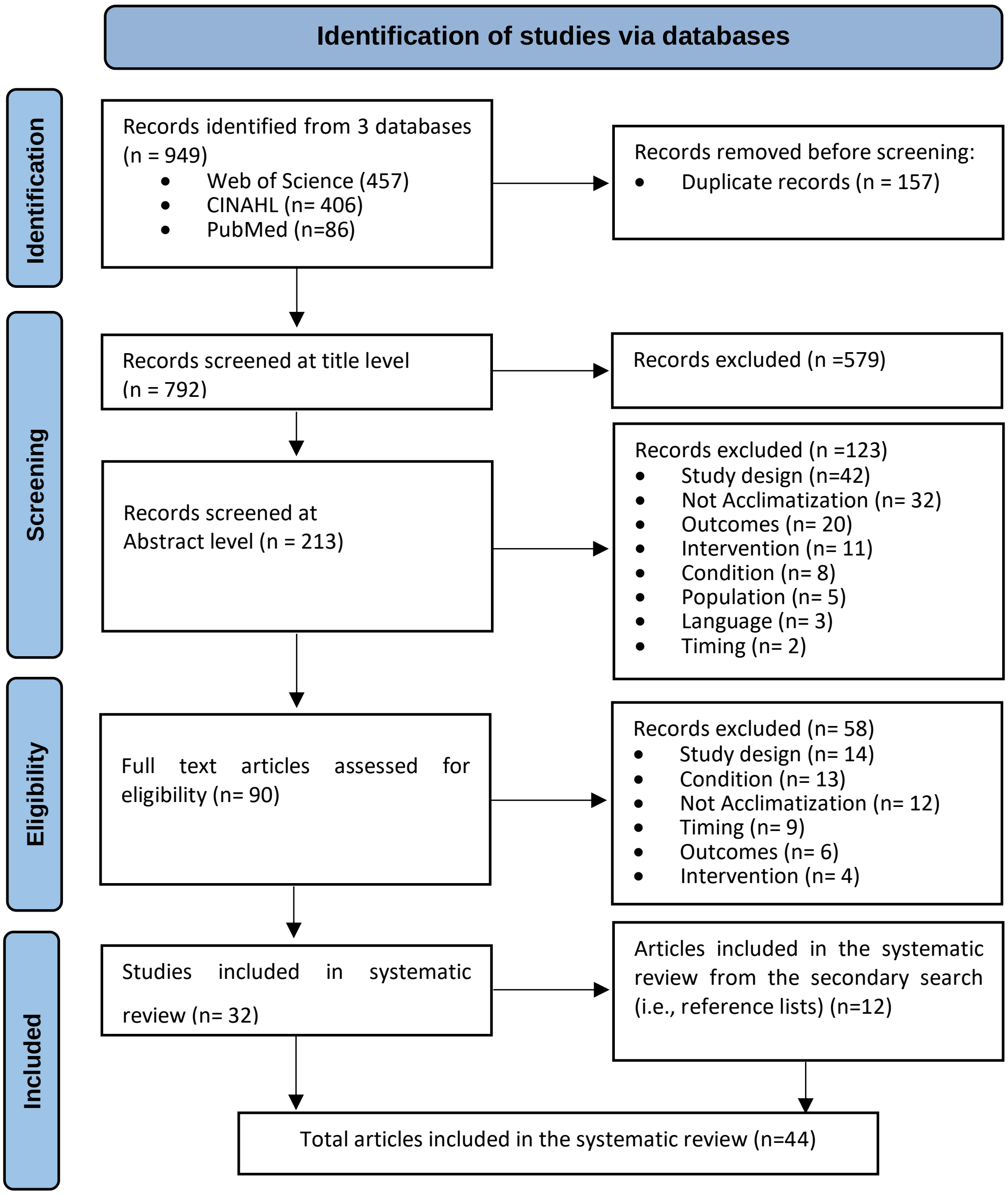
Quantitative synthesis: A meta-analysis was attempted using Comprehensive Meta-Analysis software version 4, employing an inverse variance weighting approach and a random effects model (Borenstein et al., 2005), to assess the impact on three outcome domains by comparing the standardized mean difference over time between new hearing aid users and a control group. This analysis extracted means and standard deviations from 11 studies, excluding uncontrolled studies. Despite these efforts, the challenge of calculating standard deviations for each group over time—due to the interdependence of data points across time points—hindered further qualitative analysis. The Borenstein et al. (2021) method, which adjusts for correlations between a study's intra-group effect sizes, was considered. However, this method required individual participant data that was unavailable. Without this critical correlation data, the composite effect size and its standard deviation could not be accurately computed, preventing the completion of the meta-analysis despite initial efforts.

3.4 Results

Search and Study Selection

A database search conducted in February 2023 and repeated in March 2024 identified 949 records. After removing duplicates, 792 records were screened by title and, excluding 579 based on titles and 123 based on abstracts. The full texts of 90 articles were then reviewed, with 32 meeting the inclusion criteria. Reviewing the references of these 32 articles revealed 12 additional relevant studies, resulting in a total of 44 articles for the systematic review, as shown in Figure 1. This number exceeds that of previous reviews, indicating that new research has emerged since the last review and supporting the need for this updated systematic review.

Figure 3.1. PRISMA flow diagram



Study Characteristics

Table 3.2 summarizes the key characteristics of the 44 studies included in the review: 32 focused on speech recognition, 23 on self-reported outcomes, and 9 on electrophysiological outcomes. Among these, 18 studies reported on multiple outcomes across two or three domains. All 44 studies were included in the systematic review, with 11 studies selected for the attempted meta-analysis. The 33 studies that were not considered for meta-analysis were excluded due to the absence of a control group or insufficient reporting on means and standard deviations. Almost half of the studies were conducted in North America (43%), while close to a quarter were conducted in Europe (30%). All studies used a longitudinal design, assessing scores at multiple time points post-hearing aid intervention. The study designs included true experimental (n=4) and quasi-experimental (n=22) studies. Additionally, there were pre-experimental studies (n=17), which consisted of within-subject designs (n=4), where participants with unilateral fittings acted as their own control, and single-group pretest-post-test designs (n=13), where one group was assessed at various time points over a given period. Finally, there was one cohort observational study (n=1). 25 studies that included a control group are denoted with an asterisk next to the author(s) and year in table 3.3, 3.4 and 3.5. Control groups included experienced hearing aid users, normal hearing individuals, matched participants with hearing loss, and the non-fitted ear in unilateral fittings. Study durations ranged from 3 weeks to 3 years, with the most common duration being 6 months. Sample sizes ranged from 4 to over 200 participants. Among the studies, 18% involved unilateral hearing aid users, 46% involved bilateral hearing aid users, and 36% included both types.

Tables 3.3 to 3.5 detail each study's behavioural (speech recognition), self-reported, and electrophysiological outcomes, respectively. Studies measured various factors hypothesized to impact acclimatization, including listening conditions (aided and unaided), stimulus levels in different environments, and ear comparisons. Additionally, research explored the effects of hearing aid features, fitting protocols, usage duration, degree of hearing loss, age, fitting type (bilateral or unilateral), and cognitive factors. The following sections will outline study outcomes in three main outcome domains.

Table 3.2: Key characteristics of included studies (n= 44)

Authors (year)	*Country*	*Study Design*	*Participants & sample size (n=)*	*Control*	*Examined components (Longitudinally)*	*Description of HL*	*Hearing Aid fitting type*		*Outcome domain*		
							Uni	*Bil*	*B*	*SR*	*AEP*
Gatehouse (1992)	Scotland	Pre-experimental (within-subject design)	New unilateral HA users (n=4)	Yes (non-fitted ear)	Free field vs headphones to fitted ear vs headphones to non-fitted ear (control) & in both listening conditions.	Bilateral Moderate SNHL	✓		✓		
Mulrow et al. (1992)	US	Pre-experimental (single group pretest–post-test design)	New Unilateral HA users (n=192)	No	Baseline vs Post fitting timepoints only	Bilateral SNHL (97 %) and Mixed HL (3%)	✓			✓	
Silman et al. (1993)	US	Quasi experimental	New unilateral HA users (n=19) New bilateral HA users (n=28) Control-Normal (n=19)	Yes (non-fitted ear & normal non-HA users)	Fitted vs non-fitted ear & new users vs normal participants (control) (do not say which listening condition tested in)	Bilateral symmetrical SNHL	✓	✓	✓		
Taylor (1993)	US	Pre-experimental (single group pretest–post-test design)	New Unilateral HA users (n=37) New Bilateral HA users (n=21)	No	Unilateral & bilaterally aided combined, thus no control condition. Baseline vs Post fitting timepoints only	Bilateral high f SNHL	✓	✓	✓	✓	
Bentler et al. (1993a)	US	Quasi experimental	Sample (n=65): New (n=26), Experienced (n=39) Unilateral (n=55) Bilateral (n=10)	Yes (experienced HA users)	New vs experienced, Degree of HL, configuration, quiet vs noise, circuit type & wear time (all measures taken in aided condition)	Mild- moderate SNHL	✓	✓	✓		
Bentler et al. (1993b)	US	Quasi experimental	Sample (n=65): New (n=26), Experienced (n=39) Unilateral (n=55) Bilateral (n=10)	No	New vs experienced, Degree of HL, Configuration, Circuit type & wear time. (Only provide results for experimental group)	Mild-moderate SNHL	✓	✓		✓	
Cox et al. (1996)	US	Quasi experimental	New Unilateral HA users (n=22), Experienced Unilateral HA users (n=5)	Yes (experienced HA users)	New vs experienced, aided vs unaided listening conditions & Different HAs	Bilateral sloping mild-moderate or moderately severe	✓		✓		
Humes et al. (1996)	US	Quasi experimental	New HA users (n=10), Experienced HA users (n=10) (groups combined during testing)	No	Aided vs unaided listening condition, Subjective vs objective, amount of wear time (groups combined during testing)	Bilateral, symmetrical SNHL	✓	✓	✓	✓	
Horwitz et al. (1997)	US	Quasi experimental	New Unilateral HA users (n=13) Experienced Unilateral HA users (n=13)	Yes (experienced HA users)	New vs experienced, aided vs unaided listening condition, Gain: fixed initial vs daily adjusted.	Moderately- severe SNHL sloping in high f	✓		✓	✓	
Suanders & Cienkowski (1997)	US	Quasi experimental	New Bilateral HA users (n=24) Experienced Bilateral HA users (n=24)	Yes (experienced HA users)	New vs experienced, aided vs unaided listening condition, different combinations of frequency response & method of output limiting	Mild to moderate symmetrical SNHL		✓	✓		
Arlinger & Billermark (1999)	Sweden	Cohort observational	New Bilateral HA users (n=15) New Unilateral HA users (n=14)	No	Aided vs unaided listening conditions for self-reported measures, Analog vs digital (groups tested together)	Unilateral & Bilateral HL	✓	✓	✓	✓	
Humes et al. (2002a)	US	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=134) in year one and (n=49) in year two.	No	Post fitting timepoints only	Bilateral flat or gently sloping SNHL		✓		✓	
Humes et al. (2002b)	US	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=134) in year one and (n=49) in year two.	No	Aided vs unaided listening condition	Bilateral flat or gently sloping SNHL		✓	✓	✓	
Munro & Lutman (2003)	UK	Pre-experimental (within-subject design)	*New Unilateral HA users (n=16)	Yes (non-fitted ear)	Fitted ear vs non fitted ear & aided vs unaided listening condition	Bilateral, symmetrical, mild-moderate, sloping, high f SNHL.	✓		✓		
Humes & Wilson (2003)	US	Pre-experimental (single group	New Bilateral HA users (n=9)	No	Aided vs unaided listening condition	Bilateral flat or gently sloping SNHL	✓	✓	✓	✓	

		pretest–post-test design)									
Munro & Lutman (2004)	UK	Quasi experimental	New Unilateral HA users (n=32) Group M: Comparing status to when pt last visited the lab. Group F: Comparing status to the first time using HAs.	No	Moving Group vs Fixed Group	Mild-moderate, sloping, high f SNHL.	✓			✓	
Philibert et al. (2005)	France	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=8)	No	LE vs RE (All measures taken in the unaided listening condition)	Bilateral HL		✓			✓
Reber & Kompis (2005)	Switzer-land	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=23) 3 groups: AD: Audiologist driven. PD: Patient driven. STT: Set to target.	No	Aided vs unaided listening conditions & Fitting protocols	Bilateral SNHL		✓	✓		
Vestergaard (2006)	Denmark	Quasi experimental	New Bilateral HA users (n=20) Experienced Bilateral HA users (n=5)	Yes (experienced HA users)	New vs experienced, Wear time	Bilateral steeply sloping HL		✓		✓	
Prates & Iório. (2006)	Brazil	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=16)	No	Baseline vs Post fitting timepoints only	Bilateral, slight to moderately severe HL.		✓	✓	✓	
Yund et al. (2006)	US	Quasi experimental	New Bilateral HA users (n=39) 2 types of fittings: linear and WDRC	No	WDRC vs Linear amplification over time	Bilateral, sloping, symmetrical, moderate low f to severe high f		✓	✓	✓	
Amorim & Almeida (2007)	Brazil	Pre-experimental (within-subject design)	New Bilateral HA users (n=8) New Unilateral HA users (n=8)	Yes (non-fitted ear: only for behavioural)	Fitted ear vs non fitted ear, aided vs unaided listening condition & LE vs RE	Bilateral symmetric moderate to severe mixed or SNHL	✓	✓	✓	✓	
Metselaar et al. (2009)	Netherlands	True experimental (Double blind RCT)	Sample size in total: (n=254) New HA users (n=113) Experienced HA users (n=196) Prescriptive method (n= 190) Comparative (n=119)	Yes (experienced HA users)	New vs experienced, Comparative vs prescriptive fittings Three strata of maximum speech intelligibility.	SNHL and mixed HL	✓	✓		✓	
Petry et al. (2010)	Brazil	Quasi experimental	New Bilateral HA users Group A: Adults (n=13) Group I: Elderly Group (n=27)	No	Adults' vs elderly (Age) (all measures taken in aided condition)	Bilateral HL		✓	✓		
Choi et al. (2011)	Korea	Quasi experimental	New Bilateral HA users (n=18) Non-users (Control): (n=11)	Yes (non-HA users)	New HA users vs non HA users, Cognitive aspects	Bilateral SNHL		✓	✓		
Song et al. (2011)	US	Pre-experimental (within-subject design)	New Unilateral HA users (n=66)	Yes (non-fitted ear)	Fitted ear vs non fitted ear (All measures taken in unaided listening condition)	Bilateral HL	✓		✓		
Pinheiro et al. (2012)	Brazil	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=60)	No	LE and RE ears over time	Bilateral, symmetrical moderate to-severe SNHL		✓	✓		
Laperuta & Fiorini (2012)	Brazil	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=22)	No	Post fitting timepoints only	Bilateral, symmetrical SNHL (40- and 70-dB HL)		✓		✓	
Dawes et al. (2013)	UK	Quasi experimental	*New Unilateral (n=8), New Bilateral (n=10), Experienced Unilateral (n=3), Experienced Bilateral (n=3)	Yes (non-fitted ear & experienced HA users)	Fitted ear vs non fitted ear, new vs experienced HA users	Bilateral symmetrical, mild-to-moderate, sloping high f SNHL	✓	✓			✓
Dawes et al. (2014a)	UK	Quasi experimental	*New Unilateral (n=16) New Bilateral (n=16) Experienced Unilateral (n=9) Experienced Bilateral (n=8)	Yes (non-fitted ear & experienced HA users)	Fitted vs non fitted ear, new vs experienced, aided vs unaided listening conditions, unilateral vs bilateral fittings & LE vs RE	Bilateral, symmetrical, mild-to-moderate, sloping high-f SNHL	✓	✓	✓	✓	
Dawes et al. (2014b)	UK	Quasi-experimental	*New Unilateral (n=11) New Bilateral (n=13) Experienced Unilateral (n=6) Experienced Bilateral (n=7)	Yes (non-fitted ear & experienced HA users)	Fitted vs non fitted ear, new vs experienced, aided vs unaided listening conditions, unilateral vs bilateral fittings & LE vs RE	Bilateral, mild-to-moderate, sloping high f SNHL	✓	✓	✓		✓

Lavie et al. (2015)	Israel	Quasi-experimental	New HA users- Bilateral & Unilateral (n= 36), Non-users Bilateral (n=11)	Yes (non-HA users)	New HA users vs non HA users, Dominant vs non-dominant ear & Unilateral vs bilateral (All measures taken in unaided listening condition)	Bilateral, flat, or moderately sloping audiograms	✓	✓	✓		
Chang et al. (2016)	Korea	Quasi-experimental	New Unilateral (n=145) New Bilateral (n=11) Experienced Unilateral (n=27) Experienced Bilateral (n=25)	No (WRS) Yes (self-reported: experienced HA users)	New vs experienced, unilateral vs bilateral & HA type	Conductive:2 Sensorineural: 175 Mixed: 31	✓	✓	✓	✓	
Dawes & Munro (2017)	UK	Quasi experimental	*New Bilateral HA users (n=35) Experienced Bilateral HA users (n=20)	Yes (experienced HA users)	New vs experienced, specific degree of HL and HA use & cognition (All measures taken in the aided condition)	Bilateral, symmetrical, mild-to-moderate		✓	✓	✓	
Habicht et al. (2018)	Germany	Quasi experimental	New Bilateral HA user (n=16) Experienced Bilateral HA users (n=14)	Yes (experienced HA users)	New vs experienced, Low vs high linguistic complexity & Processing time.	Bilateral HL		✓	✓		✓
Karawani et al. (2018a)	US	True experimental (RCT)	*HA users (n=18) Non-HA users (control) = (n=14)	Yes (non-HA users)	New HA users vs non HA users. Aided vs unaided listening conditions, quiet vs noise stimulus	Bilateral symmetrical mild-severe SNHL		✓			✓
Karawani et al. (2018b)	US	True experimental (RCT)	*New HA users (n=20) Non-HA users (n=15)	Yes (non-HA users)	New HA users vs non-users. Aided vs unaided listening conditions.	Moderate ARHL		✓	✓	✓	✓
Megha & Maruthy (2019a)	India	Pre-experimental (single group pretest–post-test design)	*New Unilateral HA users (n=30)	No	Good vs poor performers, ALLRs were recorded in the unaided condition.	Bilateral, mild-moderate SNHL	✓			✓	✓
Megha & Maruthy (2019b)	India	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=26)	No	Quiet vs noise stimulus, Cognitive factors	Bilateral, mild-moderate SNHL		✓	✓	✓	
Megha & Maruthy (2020)	India	Quasi experimental	New Bilateral HA users (n=30) Normal non-HA users (n=17)	Yes (non-HA users; normal)	New HA users vs normal hearing individuals.	Bilateral, mild-moderate SNHL	✓	✓	✓		✓
Glick & Sharma (2020)	US	Quasi experimental	New Bilateral HA users (n=28) Normal non-HA users (n=13)	Yes (SIN: non-HA users; normal) No (self-reported)	New HA users vs normal hearing individuals (all measures taken in aided condition) (Self-reported results only on HA users)	Bilateral, mild-moderate sloping HL		✓	✓	✓	
Wright & Gagné (2021)	Canada	True experimental (double blind RCT)	*New Bilateral HA users (n=32) Experienced Bilateral HA users (n=15)	Yes (experienced HA users)	New vs experienced, NRA on vs off, HA use, age, the severity of HL, gender, speed of processing perceived handicap, working memory & wear time (all measures taken in aided condition)	Bilateral, mild to moderately severe SNHL		✓	✓		
Karawani et al. (2022)	US	Quasi experimental	New Bilateral HA users (n=17) Non-HA users (n=14)	Yes (non-HA users)	New HA users vs non-HA users, cortical changes: quiet vs noise, wear time	Bilateral symmetrical SNHL		✓			✓
Ito et al. (2023)	Japan	Pre-experimental (single group pretest–post-test design)	New Bilateral HA users (n=9) New Unilateral HA users (n=32)	No	Pre vs post fitting measures (all in unaided listening conditions)	Bilateral symmetrical SNHL	✓	✓	✓		

Note: AEP= Auditory electrophysiological potentials, ALLRs= Auditory Late Latency Responses, ARHL= Age-Related Hearing Loss, B= Behavioural, bil= bilateral, f= frequency, HA= Hearing aids, HL= Hearing loss, LE= Left ear, NRA=Noise reduction algorithms, RCT=Randomized controlled trial, RE= Right ear, SIN: Speech in Noise, SNHL: Sensorineural hearing loss, SR= Self-reported, UK= United Kingdom, uni= unilateral, US= United States, vs= verses and WDRC= Wide Dynamic Range Compression.

***The asterisks in the participants & sample size column indicate which studies conducted a sample size estimation or power analysis.**

Summary of Studies Focusing on Behavioural Outcomes (i.e. Speech Recognition)

This systematic review analysed 32 studies on speech recognition, with 15 focusing on recognition in noisy environments, 5 in quiet, and 12 in both conditions (Appendix F). Among the 32 studies, 19 included control groups, and 13 did not. Of the 19 studies with control groups, 10 (53%) reported evidence of auditory acclimatization, while two studies (10%), such as Lavie et al. (2015), showed mixed results—evidence of acclimatization in Dichotic and Speech-in-Noise (SIN) measures but not in monosyllabic word identification in quiet. Seven (37%) studies found no evidence of acclimatization. Among the 13 studies without control groups, 6 (46%) reported acclimatization, 3 (23%) had mixed results, and 4 (31%) showed no evidence of acclimatization (All outcomes described in Table 3.3).

Aided Speech Recognition in Quiet

Evidence for changes in aided speech recognition in quiet was mixed. Silman et al. (1993) reported improved speech performance in the fitted ear of a monaurally aided group, with a slight decline in the non-fitted ear. The control group of non-hearing aid users showed no differences over time, suggesting an acclimatization effect for new monaural hearing aid users. Reber and Kompis (2005) observed an average improvement of 31 percentage points in speech recognition at 50 dB SPL between 2 weeks and 6 months for the audiologist-driven (AD) fitting and set-to-target (STT) groups, while no change was noted in the patient-driven (PD) fitting group. Prates & Iório (2006) found improvements in the Percentage Index of Speech Recognition (PISR) within the first three months post-fitting. Pinheiro et al. (2012) noted an increase in mean speech recognition scores from 69.6% to 73.6% after 3-10 months of hearing aid use among new bilateral users, though this study lacked a control group. Similarly, Chang et al. (2016) reported improvements in aided word recognition scores at 1- and 3-months post-fitting for new hearing aid users, but also without a control group for the word recognition scores.

In contrast, Taylor (1993) found no changes in aided word recognition scores in either quiet or noise over the course of a year among newly fitted unilateral and bilateral hearing aid users, with no control condition. Similarly, Bentler et al. (1993a) reported no time effect or influencing factors on the Nonsense Syllable Test (NST) in a quiet background, showing minimal changes (<5%) across test sessions over a year, indicating no substantial acclimatization. Humes et al. (1996) observed increases in aided NST scores among new and experienced users (combined during testing), but found no effect related to post-fitting interval or test ear. Saunders and Cienkowski (1997) reported no differences in changes in speech recognition measures in quiet over three months between new and experienced users. Humes et al. (2002b) similarly found no change in Connected Speech Test (CST) aided speech recognition scores over the first two years of hearing aid use among new bilateral users, with no control group. Additionally, Amorim and Almeida (2007), along with Petry et al. (2010), found no differences in aided speech recognition scores over time among new bilateral and unilateral hearing aid users.

Aided Speech Recognition in Noise

Gatehouse (1992) reported that among new unilateral hearing aid users, aided speech recognition improved in the fitted ear over 12 weeks, while the non-fitted ear showed no change. Silman et al. (1993) found that while overall Speech Perception in Noise (SPIN) scores remained stable, speech performance in noise improved in the aided ear but worsened in the unaided ear. Cox et al. (1996) observed that new unilateral users improved CST scores by 4-5%, with noise benefit doubling from 4% to 8% after regular use, unlike the control group, which showed no improvement. Additionally, Speech Pattern Contrast (SPAC) test results indicated improved aided performance between 6- and 9-weeks post-fitting, with no changes in the control group. Horwitz et al. (1997) noted an increase in benefit from 7 to 14 rau among new unilateral users over five follow-up visits, while long-term users saw a slight decrease from 10 to 9 rau over 18 weeks. Arlinger and Billermark (1999) demonstrated a 1.4 dB improvement in the speech-to-noise ratio at 60 dB and a 0.65 dB improvement at 75 dB with DigiFocus hearing aids after one year, whereas analog aids only showed a 0.8 dB improvement at 75 dB and none at 60 dB. Munro and Lutman (2003) confirmed acclimatization, with aided scores improving by 1.0%, 2.6%, and 3.6% at 55-, 62-, and 69-dB SPL in the newly fitted ear, while the control ear consistently showed around -2.0% changes. Prates and Iório (2006) reported improved SRT measures in new bilateral users, particularly during the first three months. Yund et al. (2006) observed a 4.6% improvement in syllable recognition improved by 4.6% in new bilateral users with wide dynamic range multichannel compression (WDRMCC) fittings within the first 8 weeks. Choi et al. (2011) found that new bilateral users showed improvement in the WIN test, with scores increasing from 11.7 to 13.1 after 6 months, while the control group remained unchanged. Dawes and Munro (2017) reported a 3 dB SIN score improvement after 30 days among new bilateral users with moderate hearing loss who consistently used their hearing aids, with no improvement in experienced users. Megha and Maruthy (2019b, 2020) also observed improvements in speech-in-noise performance over two months in bilateral hearing aid users. Glick and Sharma (2020) found a 3.5 dB SNR enhancement in QuickSIN scores after 6 months in new bilateral users, while non-users showed no change. Wright and Gagné (2021) reported a 2 dB SNR improvement over 4 weeks in new bilateral users, with no change in experienced users.

Several studies did not find evidence of acclimatization. Taylor (1993) reported no changes in speech recognition in noise over a year in both unilateral and bilateral hearing aid users. Humes et al. (2002b) found mixed results: CST scores at 65 dB (+8 dB SNR) improved from 1 to 6 months post-fitting, but NST scores declined from 1 to 6 months before improving again at 1 year. Over two years, NST scores declined from 1 month to 2 years post-fitting in bilateral users. Humes and Wilson (2003) observed limited acclimatization over three years in 9 elderly participants. Reber and Kompis (2005) reported no change in aided SRT in noise over 6 months, with scores remaining consistent (3.0 dB compared to the initial 3.4 dB) and no differences between bilateral groups. Yund et al. (2006) found no consistent gains in those with bilateral LA fittings, likely due to consistent sound encoding in WDRMCC processing. Petry et al. (2010) found no differences in speech recognition thresholds in noise (SRTN) or speech recognition percentages in noise (SRPRN) after 14 and 90 days of hearing aid use, indicating the duration of use did not impact benefits. Dawes et al. (2014a) observed a statistically significant improvement in speech recognition over 12 weeks in new bilateral and unilateral hearing aid users, as well as in a control group of experienced users, likely due to a general practice effect rather than acclimatization. Habicht et al. (2018) found no differences in SRT80s between new and experienced hearing aid users, with only a marginal preference for low linguistic complexity sentences after 24 weeks. Karawani et al. (2018b) reported improved QuickSIN scores in both aided and unaided conditions for the experimental group and in the control group's unaided condition, but no main effects of time or group were observed, suggesting the improvements were due to practice effects rather than hearing aid use.

Unaided Speech Recognition in Quiet

Some studies reported improvements in unaided speech recognition in quiet conditions. Reber and Kompis (2005) observed a statistically significant increase in unaided scores between 2 weeks and 6 months across all three groups (AD, STT, PD) at 50 dB SPL. Ito et al. (2023) found that individuals with a flat-type audiogram showed improvement in unaided speech discrimination, with over half of the participants achieving a 10% or greater increase. On the other hand, several studies did not observe improvements. Humes et al. (1996) found that NST unaided scores remained stable over time, with only 8.3% of scores falling outside the 95% boundary. Similarly, Saunders and Cienkowski (1997) reported no differences in unaided listening across visits. Humes et al. (2002b) even noted a decrease in unaided CST performance from 1 month to 1 year. Song et al. (2011) reported that unaided Word Recognition Scores (WRS) generally stayed the same or decreased over time, while Lavie et al. (2015) found no changes in unaided monosyllabic word identification in quiet over a 14-week period.

Unaided Speech Recognition in Noise

In unaided speech recognition in noise, most studies reported no changes over time or slight performance declines. Gatehouse (1992) found a decline in the fitted ear over 12 weeks, with no changes in the non-fitted ear. Cox et al. (1996) observed no difference in unaided CST scores between baseline and 12 weeks for both the study and control groups. Humes et al. (1996) reported stable unaided NST scores, with only 8.3% outside the 95% boundary. Saunders and Cienkowski (1997) found no differences in unaided listening across visits.

Humes et al. (2002b) noted a decline in unaided CST and NST performance from 1 month to 1 year. Munro and Lutman (2003) found a slight, non-significant decrease in mean unaided speech recognition scores over time. Lavie et al. (2015) reported improvement in unaided speech recognition for new hearing aid users over 14 weeks, with no gains in the control group. Karawani et al. (2018b) observed improved QuickSIN scores in unaided conditions for both experimental and control groups, likely due to a practice effect rather than acclimatization.

Table 3.3: Summary of studies focusing on behavioural outcomes (n=32)

Study	***Duration of study***	***Time points measured***	***HA Use (mean)***	***How HA use was measured***	***Assessment measures***	***Speech in Quiet /Noise***	***HA Acclima-tization***	***Outcomes***
Gatehouse (1992)*	12 weeks	Baseline, 1w, 2w, 3w, 4w, 5w, 6w, 8w, 10w, 12w	Not reported	-	WRS & FAAF	WRS: Q FAAF: N	Yes	• Over 12 weeks, the fitted ear showed speech recognition improvement in aided FAAF conditions, with a decline in unaided conditions. • In contrast, the non-fitted ear showed no changes in either unaided or aided conditions.
Silman et al. (1993)*	+- 1 year	1: Between 6- & 12-weeks post fitting, 2: 1 year following initial test	At least 4hrs/day	Self-reported (subjects indicated usage)	SRT, W-22, SIN & NST	SRT, NST, W-22: Q SIN: N	Yes	• Monaurally aided group: The W-22, NST, and SPIN tests showed enhanced speech performance in the fitted ear and a slight decline in the non-fitted ear. • Binaurally aided group: A trend toward improvement in most ear and speech measures. • Control group: No differences were found over time.
Taylor (1993)	1 year	Baseline, 3w, 3mo, 6mo & 1yr	Not reported	-	SRT, WRS	WRS: Q+N	No	• Audiometric measurements showed no significant changes over the course of the investigation ($p < 0.05$).
Bentler et al, (1993a)*	1 year	Baseline, 1mo, 3mo, 6mo, 12mo post fitting	Part-time: <4hrs/day Full time: 9.3hrs/day	Self-reported (questionnaire)	NST & SPIN	NST: Q/N SPIN: N	No	• No time effect observed for High Predictability items in the experimental group. For Low Predictability items, a quadratic trend emerged among part-time users. • In the NST, a linear trend was noted for new users in quiet backgrounds. Conversely, noise conditions suggested a more complex third-degree polynomial fit across various factors, possibly influenced by experience and configuration, yet no significant interactions were observed. • Score changes stayed below 5%, with greater variances in challenging conditions indicating stable performance.
Cox et al. (1996)*	12 weeks	Baseline, 3w, 6w, 9w, 12w post fitting	Week 1: 5hrs/day Week 3-12: 8hrs/day or more	Self-reported	CST & SPAC	N	Yes	• CST: In the study group, there was no difference between the 0- and 12-week unaided scores, but aided scores improved, with a 4-5% increase and noise benefit doubling from 4% to 8% after regular use. The control group showed no improvement. • SPAC: In the study group, unaided listening showed no differences across sessions, but aided did, with improved performance between 6- and 9-weeks post-fitting. The control group exhibited no changes in both listening conditions.
Humes et al. (1996)	6 months	Baseline, 7, 15, 30-, 60-, 90- and 180-days post fitting	6-7hrs/day	Objective (datalogging feature)	NST & HINT	NST: Q HINT: N	No	• NST: Unaided and aided scores remained stable over time. • HINT: Aided HINT scores remained stable, with 8.7% of data points exceeding the critical differences boundaries, which was not significantly different from chance alone.
Horwitz et al. (1997)*	18 weeks	Baseline, 3w, 6w, 10w, 14w, 18w post fitting	Not reported	-	NST	N	Yes	• Fixed initial gain NST: Statistical analysis showed a significant time effect on benefit for new users, but no significant change for long-standing users over the 18 weeks. • Daily adjusted gain NST: Significant time effect for new users, not for long-standing users.
Suanders & Cienkowski (1997)*	3 months	day 0, 1mo, 2mo & 3mo post fitting.	Not reported	-	SRT-Q, PSRT-N, and SSRT-N.	SRT-Q PSRT-N SSRT-N	No	• ANOVA revealed non-significant differences across visits for unaided listening on all measures. Aided advantages did not differ between new and experienced users on any test, and there were no significant interactions between user status and test session.
Arlinger & Billermark (1999)	1 year	1 month & 1 year	Initially: 6hr/day. 1yr later: 11hr/day	Self-reported	SRT	N	Yes	• DigiFocus users saw a 1.4 dB SNR increase at 60 dB and 0.65 dB at 75 dB after one year. • In contrast, analogue hearing aids showed only a 0.8 dB improvement at 75 dB ($p < 0.05$), with a tendency for poorer speech recognition at 60 dB.
Humes et al. (2002b)	2 years	1mo, 6mo, 12mo and 49 pts returned at 24mo (2yr)	Required at least 6hrs/day.	Self- reported (diary)	NST & CST	NST: N CST: Q+N	Aided CST & NST 6mo- 1yr: Yes 1yr-2yrs: No	• 1-year dataset: CST at 50 dB in quiet showed a notable increase in aided performance from 6 to 12 months post-fit ($F(2, 250) = 4.77$, $p = .009$). At 65 dB (+8 dB SNR), there was improvement in aided performance from 1 to 6 months post-fit ($F(2, 250) = 8.83$, $p < .001$). Unaided performance decreased from 1 to 12 months ($F(1, 123) = 7.49$, $p = .007$). NST aided performance declined from 1 to 6 months but improved from 6 to 12 months ($F(2, 246) = 5.69$, $p = .004$). Unaided performance on the NST declined from 1 to 12 months ($F(1, 123) = 4.06$, $p = .046$). • 2-year dataset: Statistical power was low (< .66) for CST measures but exceeded .89 for NST. Significant effects were observed only for aided NST performance ($F(3, 126) = 2.75$, $p = .046$), with a decline from 1 month to 2 years ($p = .037$). • Combined data: Limited evidence of significant acclimatization effects in the first 2 years of HA use.

Munro & Lutman (2003)*	12 weeks	Baseline (some as late as 7 days after fitting), 6w, 12w post fitting.	Required at least 6-8 hrs/day.	Self-reported	FAAF for quiet, normal, and raised speech levels	N	Yes	• The aided scores improved in the fitted ear across all presentation levels: approximately 1.0%, 2.6%, and 3.6% at 55-, 62-, and 69-dB SPL, respectively. Conversely, the control ear saw consistent negative changes, typically around -2.0%. • Average unaided hearing scores were around 61 initially, with performance starting at about 55% for speech at 55 dB SPL and 71% for speech at 69 dB SPL, and although there was a slight, non-significant decline in these scores over time, the overall trend indicated stable hearing ability post-fitting.
Humes & Wilson (2003)	3 years	1mo, 6mo, 1yr, 2yr, 3yr post fitting	9 subjects Y1: 9.8 hrs/day (no data for years 2 and 3)	Self-reported	NST & CST	NST: N CST: Q+N	No	• For CST in quiet, evidence of HA acclimatization was limited: 11.1% of scores improved, while 2.8% worsened. In noise, 13.9% of the data points showed a decline, while 25% improved after the 1-month post-fit interval. However, participants who initially showed improvement often reverted to non-significant differences at later intervals. • For NST, 5.6% of scores improved and 22.2% worsened over time. Although the focus was on improvements in aided performance, unaided performance remained stable. This suggests that initial measures taken after one month of HA use may have underestimated the effects of acclimatization.
Reber & Kompis (2005)	6 months	2 weeks & 6 months post fitting	Between 5 & 10 hrs/day	Self-reported	SRT (German ''Freiburger'' word-test & the German ''Basler'' sentence test)	SRT: Q+N	Noise: No Quiet: Yes	• Basler: Aided SRT in noise remained consistent at an average of 3.0 dB, compared to the initial 3.4 dB. • In quiet: Unaided scores increased for all groups. Aided conditions showed a notable 31% increase at 50 dB SPL for all groups, with significance seen in AD and STT groups but not PD group.
Prates & Iório (2006)	3 months	Baseline, 1mo, 2mo, 3mo post fitting	Not reported	-	PISR & SRT	PISR: Q SRT: N	Yes	• PISR and SRT measures demonstrated an improvement over time. The most improvements happened within the first three months.
Yund et al. (2006)	40 weeks	0, 1, 2, 4, 8, 16,32 weeks & 32, 33, 34, 36, and 40-weeks post-fitting.	Not reported	-	NST	N	WDRMCC: Yes LA: No	• Syllable recognition improved by 4.6% for users of WDRMCC hearing aids over 8 weeks, compared to a 2.2% improvement for LA users within 2 to 4 weeks. WDRMCC users benefited more from aided stimuli and improved their consonant identification, while LA users mainly altered their response biases. Overall, WDRMCC users showed evidence of acclimatization, unlike LA users.
Amorim & Almeida (2007)*	18 weeks	Baseline, 4w, 16/18 w post fit	Not reported	-	Speech discrimination	Q	No	• Unilateral users experienced improved speech recognition in the aided ear and a decline in the non-aided ear, but without statistical significance.
Petry et al. (2010)	90 days	14 days & 90 days post fitting	Not reported	-	SRTS, SRTN, SRPRS & SRPRN	SRTS: Q SRTN: N	No	• The study found no differences in speech recognition thresholds in quiet (SRTS) and noise (SRTN) measures after 14 and 90 days of HA use in both Group A and Group I. Similarly, there were no differences in speech recognition percentages in quiet (SRPRS) and noise (SRPRN) between the 14th and 90th days in both groups. • The duration of HA use did not impact the benefits, as measured by these tests.
Choi et al. (2011)*	6 months	Baseline & 6m post fitting	Not reported	-	WIN	N	Yes	• Comparison of recognition scores between the study and control groups showed that after 6 months, the study group improved, from 11.7±1.9 to 13.1±1.5 (P<0.05), while the control group's score stayed the same.
Song et al. (2011)*	Between 5 mo & 12yrs	Baseline vs post-fit value ranged between 5mo & 12yrs	Not reported	-	WRS	Q	No	• When aiding the better WRS ear, 17 out of 21 experienced a decrease, and 2 improved. For those with worse WRS, 12 out of 23 saw a decrease in control ear scores. In patients with equal WRS in both ears, control ears mostly declined (15 out of 22), while aided ears remained stable or improved in only 2 out of 22 cases. Overall, regardless of which ear was aided, WRS generally stayed the same or decreased.
Pinheiro et al. (2012)	10 months	Pre-fitting & between 3-10 months post fitting	9.1 hrs/day	Not reported	PISR & DDT	Q	Yes	• The percentage of speech recognition on the PISR: before (mean 69.6%) and after (mean 73.6%) the use of HAs. No correlation was found between the performance of the elderly on cognitive tests and the percentage of speech recognition in a monoaural task. • High standard deviation values were observed for the DDT, indicating variability in results for both ears compared to the mean values. Analysis re-evaluation showed an improvement in digit recognition in dichotic listening, with more evident improvement in the left ear.
Dawes et al. (2014a)*	12 weeks	Baseline & 12w post fitting	7.5 hrs/day	Objective (datalogging feature)	FAAF	N	No	• A small, statistically significant improvement was observed in the study group as well as in the control group, likely due to a general practice effect. This underscores the importance of using a control group to avoid misinterpreting improvements as acclimatization effects. • No interaction between time and group, stimulus intensity, or ear of aiding was observed. • Unilateral and bilateral fitting yielded no differences in improvement. • No change in error patterns or group-level acclimatization was found.

								• No notable improvements in speech recognition at higher stimulus intensities, contradicting the "stimulus novelty" hypothesis from prior studies
Dawes et al. (2014b)*	12 weeks	Baseline & 12 weeks	Required at least 6hrs/day. Mean= 10 hrs/day	Objective (datalogging feature)	FAAF	N	No	• No interactions or correlations were found between time, level, group (new users versus control group), speech recognition changes, and N1/P2 latency or amplitude, age, average hearing loss, or HA use (Pearson's $\|r\|$ between 0.03 and 0.44; all $p > 0.05$).
Lavie et al. (2015)*	14 weeks	Baseline, 4w, 8w, 14w post fitting	Not reported	-	Dichotic Tests, SIN, Monosyllabic Word Identification in Quiet	Dichotic & SIN: N Mono syllabic: Q	Dichotic & SIN: Yes Mono syllabic: No	• Dichotic test: Improvements in less dominant ear, with no changes for the dominant ear, and no changes were observed in the control group. • SIN: Enhancements were noted, while no such gains were seen in the control group. • Mono syllabic-quiet: No significant changes, & also for the control group.
Chang et al. (2016)	3 months	Pre fit & 1mo, 3mo post fit	Not reported	-	WRS	Q	Yes	• New HA users experienced an improvement in their WRS scores at both 1- and 3-months post-fitting.
Dawes & Munro (2017)*	1 month	Baseline, 1-, 7-, 14- and 30-day post fitting.	Subgroup (>6 hrs/day)	Objective (datalogging feature)	SIN	N	Subset: Yes	• New users did not significantly improve compared to experienced users. • However, a subset of new users with moderate hearing loss, using their HAs for at least 6 hours daily, showed a SIN improvement of around 3 dB SNR when compared to experienced users.
Habicht et al. (2018)*	24 weeks	Baseline, 12w, 24w post fitting	At 24 weeks= New: 8.2 hrs/day. Ex: 10.7 hrs/day	NovHA: datalogging ExpHA: self-reported	Processing times & SRT	SRT: N	Processing times: Yes SRT: No	• Novice users improved processing times by 30%, showing HA benefits for speech comprehension. Experienced users saw no changes. • SRT80s were similar across sentence types and user groups, with no significant differences.
Karawani et al. (2018b)*	6 months	Baseline, 6mo post fit	Required to wear 8hrs/day	Objective (datalogging feature)	QuickSIN	N	No	• QuickSIN scores improved in both aided and unaided conditions for the experimental group and in the control group's unaided condition. However, there were no main effects of time or group observed ($p > 0.08$). The improvement in both groups likely reflects a practice effect rather than a true change due to HA use.
Megha & Maruthy (2019b)	2 months	Baseline, 1mo, 2mo post fitting	8 hrs/day	Objective (datalogging feature)	Sentence Recognition scores	N	Yes	• Over 2 months of HA use, a mean SNR gain of 3.19 dB was observed, indicating that consistent HA usage can lead to improved speech understanding for new HA users.
Megha & Maruthy (2020)*	2 months	Initial, 1mo, 2mo post fitting. Control: recorded twice, 2 months apart.	8.1 hrs/day	Objective (datalogging feature)	SIN	N	Yes	• An improvement in SIN scores for HA users after 2 months. • The control group showed no statistically significant changes in SIN. • Enhanced ALLRs do not guarantee automatic improvements in speech perception in noise.
Glick & Sharma. (2020)*	6 months	Baseline & 6mo post fit	9,84 hrs/day	Objective (datalogging feature)	QuickSIN,	N	Yes	• New HA users showed a 3.5 dB SNR improvement in QuickSIN scores after 6 months. Non-users' scores remained stable with no notable changes during the study.
Wright & Gagné (2021)*	10 months	Baseline, 2w, 4w, 6w, 8w, 14w, 22w, 38w post fit.	12hrs/day	Objective (datalogging feature)	HINT	N	Yes	• Over a 4-week period, new HA users experienced a notable improvement in speech recognition in noisy environments, with an average gain of approximately 2 dB in SNR. • In contrast, experienced HA users showed no change in their performance.
Ito et al. (2023)	1 or 2 years	1 mo post-fit, then every 3 months for the first year, followed by annual assessments.	>8 hrs/day	Self-reported	Speech Discrimination: Japanese Monosyllabic List	Q	Yes	• Improvement in unaided speech discrimination was only evident in the flat-type audiogram group, with over half showing a 10% or greater increase. Factors like age, sex, and fitting details showed no notable impact on improvement.

Note: AD= audiologist driven fitting, ALLR= Auditory Late Latency Responses, ANOVA= Analysis of Variance, CST= Connected Speech Test, DDT= Dichotic Digits Test, dB HL= decibels hearing level, dB SPL= decibels sound pressure level, dB SL= decibels sensation level, HA= hearing aids, HINT= Hearing in Noise Test, hrs/day= hours per day, LA= linear amplification, mo= month, NST= Nonsense Syllable Test, PD= patient driven fitting, PISR= Percentage Index of Speech Recognition, PSRT-N= Performance SRT-N, SRT= Speech recognition threshold, SPAC= Speech Pattern Contrast, SPIN= Speech Perception in Noise, STT= set-to-target, SSRT-N= Subjective SRT-N, w= weeks, WIN= Words in noise , WRS= Word Recognition Score and WDRMCC= wide dynamic range multichannel compression.

* Studies that included a control group are denoted with an asterisk next to the author(s) and year*

Summary of Studies Focusing on Self-reported Outcomes

The study utilized various self-reported measurements to evaluate hearing and communication, including examples such as HHIE and the SSQ for hearing disability; the Quantified Denver Scale of Communication Function (QDS) for communication abilities; and the Profile of Hearing Aid Benefit (PHAB) and the APHAB for hearing aid benefit. Satisfaction was assessed with the HASS and the International Outcome Inventory for Hearing Aids (IOI-HA), while mental health was evaluated using the Geriatric Depression Scale (GDS). Additionally, quality of life was measured with the EuroQol-5-dimensions instrument (EQ-5D). These examples illustrate the range of assessments used, with many more included in the study.

A total of 23 studies included self-reported outcomes, with seven using control groups. Among the studies with control groups, two (29%) reported evidence of acclimatization, four (57%) had mixed results, and one (14%) no evidence. Of the 16 studies without control groups, five (31%) reported acclimatization, three (19%) had mixed outcomes, and eight (50%) reported no evidence (All outcomes described in Table 3.4).

The self-reported outcomes across studies investigating hearing aid acclimatization revealed varied results. Studies showing improvement included those by Mulrow et al. (1992), improvements were noted across social, emotional, and communication aspects from baseline to 4 months post-hearing aid fitting, as evidenced by changes in HHIE, QDS, and GDS scores. These improvements remained stable throughout the 12-month period. Horwitz et al. (1997) found a decrease in problems reported by new hearing aid users over an 18-week period, with no changes observed for long-standing users. Laperuta and Fiorini (2012) reported that Satisfaction with Amplification in Daily Life (SADL) scores improved over six months, reflecting enhanced communication skills, sound localization, and psychological well-being, alongside increased daily hearing aid use. Dawes et al. (2014a) observed mean SSQ-D scores improving for new unilateral and bilateral hearing aid users over 12 weeks, though experienced users showed no significant change. Megha and Maruthy (2019a) noted improvements in SSQ scores related to speech and spatial hearing over two months, while Megha and Maruthy (2019b) reported progressive gains in perceived benefits from hearing aid use across all SSQ domains over the same period. Finally, Glick and Sharma (2020) found high levels of improvement in hearing aid benefit and satisfaction after six months, with participants rating their ability to hear effectively in important situations highly on the COSI, achieving a mean improvement score of 4.09 and a final rating of 4.49 out of 5. The IOI-HA and SADL scores also indicated perceived benefit and satisfaction, with scores surpassing the 80th percentile for similar hearing loss levels.

Studies with mixed outcomes include Arlinger and Billermark (1999), who found improvements in speech understanding but not in other subscales of the APHAB such as ease of communication, reverberation, and aversiveness of sounds; Vestergaard (2006), who observed improvement in GHABP and IOI-HA for users with more than 4 hours of daily usage but no changes in other measures like the SADL and HAPQ; and Metselaar et al. (2008), who noted improvements in specific measures like HHDI and APHAB for new users, but no impact on general health or depression scores. Similarly, Karawani et al. (2018b), who observed improvements in APHAB subscales over 6 months, but not for SSQ measurement. These mixed outcomes highlight that acclimatization may be domain-specific, with some aspects of hearing and daily life improving more than others.

Studies showing no improvement include those by Taylor (1993), reported the total HHIE scores declined at 6 months and 1 year, these differences were not significantly different from the 3-week or 3-month means; Bentler et al. (1993b), who found no changes in satisfaction or hearing performance over 1 year; Humes et al. (1996, 2002a, 2002b), who across various studies, reported little to no acclimatization effects over periods ranging from 6 months to 2 years; Humes and Wilson (2003), who found no evidence of acclimatization over 3 years; Munro and Lutman (2004), who noted in Group M, participants compared their current hearing aid satisfaction to their last lab visit, with satisfaction dropping from 70% to 50% over 12-15 weeks, indicating adjustment over time. In Group F, participants compared satisfaction to their first hearing aid use, consistently rating it high (60-80%) with little change, suggesting no clear adjustment. The study notes that self-reported satisfaction can be unreliable due to and questioned the efficacy of self-report methods; Prates and Iório (2006), who observed no changes in IOI-HA scores over 3 months; Yund et al. (2006), who found stable subjective performance with no acclimatization over 40 weeks; Amorim and Almeida (2007), who reported no changes in HHIE scores after HA usage; and Dawes and Munro (2017), who observed no changes in self-reported annoyance or distraction ratings and no association with improved speech-in-noise performance.

Table 3.4: Summary of studies focusing on self-reported outcomes (n=23)

Study	Duration of study	Time points measured	HA Use	How HA use was measured	Assessment measures	HA Acclima tization	Outcomes
Mulrow et al., (1992)	1 year	Baseline, 4mo, 8mo, 12 mo post fitting	4mo: 90% used HAs >4 hrs/day; at 8 & 12mo: dropped to 83% and 76%.	Self-reported	HHIE, QDS, GDS, SPMSQ	Yes	• Significant improvements ($p < 0.05$) were observed in all measures from baseline to 4 months post-hearing aid fitting, particularly in social, emotional, and communication benefits (HHIE: t (186) = 9.9, $p < 0.0001$; QDS: t(186) = 6.7, $p < 0.0001$; GDS: t (186) = 2.2, $p = 0.03$). • These improvements remained stable at 4, 8, and 12 months ($p > 0.10$). • However, while cognition improvements assessed by the SPMSQ were statistically significant from baseline to the 4-month follow-up (t (186) = X, $p < 0.05$), they regressed to baseline levels at the 8- and 12-month follow-up assessments ($p < 0.05$).
Taylor, (1993)	1 year	Pre fit, 3w, 3mo, 6mo, 1yr post fitting	Not reported	-	HHIE	No	• The study found an initial decrease in perceived handicap after 3 weeks of hearing aid use (Pre fit vs Post fit) However, by 3 months, perceived handicap increased before stabilizing at 6 months and 1 year. • Though total HHIE scores declined at 6 months and 1 year, these differences were not different from the 3-week or 3-month means. Significant differences were observed in the means of the social/situational and emotional scales of the HHIE (F's 4, 288 = 6.21 and 7.10, respectively; p's < 0.01).
Bentler et al, (1993b)	1 year	Initial fitting, 6mo, 12mo post fitting	Part-time: 2.57 hr/day. Full time: 10.61 hrs/day	Self-reported	HPI, Expectation Checklist, Qualitative Judgments & Satisfaction Questionnaire	No	• HPI: score remained stable over time. However, items related to communication ability in a quiet background showed reduced difficulties over the year. • Expectation Checklist: no changes in the overall scores. But when looking at cohesive items separately, self-perceived communication performance exceeded expectations over time. • Qualitative judgments and the Satisfaction Questionnaire: no changes over time.
Humes et al, (1996)	6 months	Initial fitting, 7, 15, 30-, 60-, 90- and 180-days post fitting	6-7hrs/day	Objective (datalogging feature)	HHIE, HAPI & satisfaction ratings	HHIE & HAPI: No Satisfaction : Yes	• The study found no significant differences in HHIE scores over a 6-month period, indicating no acclimatization effect. HAPI subscales also remained stable. Repeated-measures ANOVAs revealed no impact of post-fit interval on HAPI subscale performance. • Hearing-aid satisfaction tended to increase, particularly in the first 30 days, implying initial low satisfaction improved over time. Notably, post-fit interval no longer significantly affected hearing-aid satisfaction when data from 7 days post-fit were excluded.
Horwitz et al., (1997)*	18 weeks	Initial fitting, 3w, 6w, 10w, 14w, 18w post fitting	Not reported	-	PHAB	Yes	• A decrease in aided frequency of problems over five visits for new users, while no change for long-standing users. • The unaided results for both groups showed stable frequencies of problems over time. • While subjective benefit improvement (unaided minus aided conditions) was not significant, there was an improvement over time in the aided condition for new hearing aid users.
Arlinger & Billermark, (1999)	1 year	1 month & 1 year	Initially: 6hr/day. 1yr: 11hr/day	Self-reported	APHAB & Gothenburg Profile	APHAB: No Gothenbur g: Mixed	• APHAB: no categories reached statistical significance, indicating no significant acclimatization effect. • Gothenburg Profile measures: After one year of HA use, there was a substantial improvement in speech understanding, lower impairment. However, no statistically significant differences were observed for localizing sounds, effects on relations with others, and effects on reactions.
Humes et al., (2002a)	2 years	1mo, 6mo, 12mo and 49 pts returned at 24mo (2yr)	After 1yr: 8.65hr/day (reported in diaries)	Self-reported (diary)	HASS, GHABP & HDABI	No	• HASS: participants reported high satisfaction scores, averaging around 4, with no significant changes over time. • GHABP: satisfaction ratings averaged between 3.0 and 3.5, pointing to stable satisfaction levels. • While an apparent increase in HDABI usage ratings was observed, it's essential to remember that HDABI scores are inversely proportional to usage.
Humes et al., (2002b)	2 years	1mo, 6mo, 12mo and 49 pts returned at 24mo (2yr)	Required at least 6hrs/day.	Self-reported (diary)	HAPI & HHIE	No	• HAPI showed significant effects on speech-in-noise and speech-with-reduced-cues subscales for both 1-year and 2-year datasets, but not for speech-in-quiet or nonspeech subscales. Notably, changes were limited to the first year of hearing-aid use. • For HHIE, a significant effect was observed in the 1-year dataset, but not in the 2-year dataset.
Humes & Wilson, (2003)	3 years	1mo, 6mo, 1yr, 2yr, 3yr post fitting	9 subjects Y1: 9.8 hrs/day (no data for years 2 and 3)	Self-reported	HAPI & HHIE	No	• HAPI: Little evidence of acclimatization. Among 144 possible paired comparisons, only 17.4% displayed changes, with 11.1% declining and 6.3% improving. • HHIE: 8.3% of participants experienced declines, while 2.8% showed improvements.
Munro & Lutman, (2004)	24 weeks	Group M: 3,6,9,12,15,18,21, 24 weeks post fitting. Group F: 4,8,12,16,20,24 weeks post fitting	Group M: 90% > 4hrs/day, 80% > 8hrs/day. Group F: 100% > 4hrs/day, 80% > 8hrs/day.	Self-reported (diary)	GHABP	Group M: Yes Group F: No	• Group M subjects rated their current benefit compared to the previous visit. Median scores decreased from 70% at 3 weeks to 50% by weeks 12-15, stabilizing around 9-12 weeks post-fitting, with significant changes. • In Group F, subjects referenced their initial fitting. Benefit and satisfaction consistently scored higher than after fitting, with median scores between 60% and 80%, but no significant changes were observed.
Vestergaard, (2006)*	13 weeks	1w, 4w, 13w post fitting	First-time HA users (>4 hrs/day) Experienced users (<4 hrs/day)	Not reported	GHABP, IOI-HA, HAPQ & SADL	GHABP & IOI-HA: Yes SADL & HAPQ: No	• First-time HA users showed better outcomes over time than those with prior HA experience or <4 hours of daily HA use, reflected in GHABP and IOI-HA scales. Conversely, no such trend was observed in SADL and HAPQ scales.

Prates & Iório., (2006)	3 months	Day one, 1mo, 2mo, 3mo post fitting	Not reported	-	IOI-HA	No	• IOI-HA: No changes in the first and third months of HA adaptation. • Despite positive adaptation trends with high scores overall, no dissatisfaction with questionnaire items was observed throughout the study. • However, authors remained cautious, noting the potential influence of free HA provision on patient satisfaction.
Yund et al, (2006)	40 weeks	2, 8, 32 weeks post fitting.	Not reported	-	PHAB & HAPI	No	• HAPI maintained stable subjective performance, while PHAB showed a slight decrease in benefit over time. • Friedman's tests found no differences across weeks 2 to 32 for both questionnaires and their subtests in LA and WDRMCC user groups, combined.
Amorim & Almeida., (2007)	18 weeks	pre-fit, 4w, 16/18 w post fit	Not reported	-	AHPAB, HHIE	No	• AHPAB scores were higher without HAs before fitting compared to after fitting. After 4 weeks and 16/18 weeks of HA usage, only the Aversiveness subscale showed a significant difference. • Similarly, in the HHIE inventory, scores without HAs were significantly higher than with HAs after fitting, but no significant differences were observed after 4 weeks and 16/18 weeks of HA usage.
Metselaar et al (2009)*	12 months	Baseline, 2wk, 6wks, 12wks, 6mo, 12 months post fitting.	Not reported	-	HHDI, APHAB, GDS, EQ-5D	HHDI, APHAB= Yes GDS, EQ-5D= No	• HHDI: New HA users showed improvements post-fitting, reporting lower withdrawal and greater HA benefit compared to experienced users. • APHAB: Benefits were reported in most subscales, except for aversiveness, which remained consistent at the 26-week follow-up. • GDS: The study found consistently low depression prevalence, unchanged over a year. • EQ-5D: HA fitting had no substantial impact on self-reported general health.
Laperuta & Fiorini., (2012)	6 months	1mo, 3mo, 6mo post fitting	1mo= 6.3 hrs/day 3mo= 6.7 hrs/day 6mo= 6.8 hrs/day	Self-reported	SADL	Yes	• SADL scores showed improvements over the initial six months, indicating enhanced communication skills, sound localization, sound quality, psychological well-being, and fewer issues in noisy environments, feedback, and telephone use.
Dawes et al., (2014a)*	12 weeks	Baseline & 12w post fitting	7.5 hrs/day	Objective (datalogging feature)	SSQ	Yes	• The mean SSQ-D scores improved over time for new unilateral and bilateral users, while experienced users showed no change. Additionally, no correlations were found between SSQ-D scores and aided performance changes on the FAAF for any listening condition among new users.
Chang et al., (2016)*	3 months	HHIE: Pre fit & 1mo, 3mo. IOI-HA: 1mo & 3mo post fit	Not reported	-	HHIE & IOH-HA	HHIE: Yes IOI-HA: No	• HHIE scores decreased from pre-fitting (54.07 ± 27.35) to 1 month (43.25 ± 27.87) and 3 months (37.79 ± 27.07), with statistically significant differences between pre-fitting and both 1-month and 3-month scores. • Comparison of IOI-HA scores at 1 month and 3 months showed no statistically significant difference. The control group also showed no change over time.
Dawes & Munro., (2017)*	1 month	Initial vs day 30	Required at least 6hrs/day	Objective (datalogging feature)	IOI-HA & questionnaire: "annoyance"	No	• No changes were noted in self-reported annoyance or distraction ratings of background noise during the task. Experienced users found the noise more bothersome and distracting than new users, despite no age or hearing differences.
Karawani et al. (2018b)*	6 months	Pre vs 6mo post	Required to wear 8hrs/day	Objective (datalogging feature)	APHAB & SSQ	APHAB: Yes SSQ: No	• APHAB: Improvements were seen in EC, RV, and BN subscales, but AV to sounds increased. • SSQ: The experimental group showed improved speech subscale scores, but significance was lost after multiple comparison correction. No differences in the control group's scores.
Megha & Maruthy (2019a)	2 months	M1 (immediately), M(1-mo), M3 (2-mo)	8.1 hrs/day	Objective (datalogging feature)	SSQ	Yes	• The study observed improvements in SSQ scores over 2 months of HA use, encompassing better speech hearing, spatial hearing, and hearing qualities.
Megha & Maruthy, (2019b)	2 months	Baseline, 1mo, 2mo post fitting	8 hrs/day	Objective (datalogging feature)	SSQ	Yes	• SSQ: Perceived benefits with HA acclimatization improved across all domains, with scores increasing progressively from baseline to the 2-month session.
Glick & Sharma., (2020)	6 months	Baseline & 6mo post fit	9,84 hrs/day	Objective (datalogging feature)	COSI, IOI-HA, SADL	Yes	• COSI: Average improvement with hearing aids was rated at 4.09, with a final ability rating of 4.49 out of 5, indicating that participants felt they could hear most of the time (>75%) in their important listening situations. • IOI-HA: The average improvement score was 4.33, showing benefit from hearing aid use. • SADL: Scoring 5.68, with positive sub-scores including service satisfaction and positive self-image, indicating high levels of perceived benefit and satisfaction from hearing aids, surpassing the 80th percentile for adults with similar degrees of hearing loss.

Note: AV= Aversiveness, BN= Background Noise, COSI= Client Oriented Scale of Improvement, EC= Ease of Communication, EQ-5D= EuroQol-5-dimensions instrument, GDS= Geriatric Depression Scale, GHABP= Glasgow Hearing Aid Benefit Profile, HAPQ= Hearing Aid Performance Questionnaire, HASS= Hearing Aid Satisfaction Survey, HDABI= Hearing Aid Disability and Benefit Inventory, HHDI= Handicap and Disability Inventory, HHIE= Hearing Handicap Inventory for the Elderly, hrs/day= Hours per day, HPI= Hearing Performance Inventory, IOI-HA= International Outcome Inventory for Hearing Aids, LA= Linear Amplification, LDHQ= Localization Disabilities and Handicaps Questionnaire, mo= Month, PHAB= Profile of Hearing Aid Benefit, QDS= Quantified Denver Scale of Communication Function, RGDT= Random Gap Detection Test, RV= Reverberation, SADL= Satisfaction with Amplification in Daily Life, SECAP= Simplified Evaluation of Central Auditory, SPMSQ= Short Portable Mental Status Questionnaire, SSQ= Speech, Spatial and Qualities of Hearing Scale, WDRMCC= Wide Dynamic Range Multichannel Compression and yr.= year.

* Studies that included a control group are denoted with an asterisk next to the author(s) and year*

Summary of Studies Focusing on Electrophysiological Outcomes

Nine studies examined electrophysiological outcomes, specifically ABR, CAEPs, and late ERPs, to assess the effects of hearing aid use on neural adaptation and auditory processing over varying time frames. Of these, seven studies included control groups, while two did not. Among the controlled studies, four (57%) provided evidence supporting acclimatization, whereas three (43%) did not find such effects. In the uncontrolled studies, one demonstrated evidence of acclimatization, while the other reported mixed results, with latency measurements showing improvement over time, but no corresponding change in amplitude (All outcomes described in Table 3.5).

All studies assessed both latency and amplitude values to determine whether acclimatization occurred over time, except for the study by Karawani et al. (2018a). In this study, only the amplitudes of the CAEP P1, N1, and P2 peaks were measured. Overall, the findings varied depending on the type of electrophysiological measure and the presence of a control group. For ABR, studies like Philibert et al. (2005) observed a reduction in wave V latency over time, indicating functional plasticity, while Dawes et al. (2013, 2014b) found no significant changes in latency or amplitude, suggesting a lack of measurable neural adaptation in this measure.

CAEPs provided more evidence of hearing aid-induced changes. For instance, Karawani et al. (2018a, 2018b, 2022) demonstrated increased amplitudes in N1 and P2 components over time, particularly under quiet conditions, with earlier changes noted in N1 compared to P2. These results suggest that hearing aids may enhance auditory signal processing and cognitive function. Similarly, Megha and Maruthy (2019a, 2020) reported reduced latencies in P1 and N1, indicating possible acclimatization effects, though P2 latencies remained stable. In contrast, studies focusing on late ERPs (Habicht et al., 2018) showed no changes in latencies or amplitudes over time.

Table 3.5: Summary of studies focusing on electrophysiological outcomes (n=9)

Study	Duration of study	Time points measured	HA Use	How HA use was measured	Assessment measures	Assessing	HA Acclimatization	Outcomes
Philibert et al., (2005)	6 months	Baseline, 3mo, 6mo post fit	At least 8hrs/day	The exact duration not measured, but all wore HAs ≥8 hrs/day per questionnaire	ABR (click stimulation)	Amplitude and Latency: Wave I, III, V	Yes	• The statistical analysis revealed no significant effect for amplitude or latency of wave I or III. However, a statistically significant interaction was found between the 'time' and 'ear' factors for wave V latency ($F(2,8) = 7.9$, $p = 0.013$), indicating a shortening of wave V latency over the time-course in the right ear. These findings suggest that hearing aid fitting induces functional plasticity at the peripheral level of the auditory system.
Dawes et al., (2013)*	3 months	Baseline vs 3 months	Required at least 6hrs/day	Objective (datalogging feature)	ABR (click stimulation)	Latency and Amplitude: Wave V	No	• No latency changes were observed over time in the aided ears of new user groups, with high reliability indicated by the high correlation between T1 and T2 latency. • There were no differences between T1 and T2 in mean amplitude for any group, suggesting lower reliability as indicated by the low correlation between T1 and T2 amplitude. • In summary, the study found no changes in either the latency or amplitude of ABR wave V in the aided ears of both groups after 3 months of hearing aid usage.
Dawes et al., (2014b)*	12 weeks	Baseline & 12 weeks	Required at least 6hrs/day. Mean= 10 hrs/day	Objective (datalogging feature)	CAEP's	Latency and Amplitude: N1 and P2	No	• In both new unilateral and bilateral user groups, N1 and P2 latencies were influenced by sound level, while N1 and P2 amplitudes were affected by both sound level and ear. Similar effects were observed in the experienced user group. However, no changes were found over time in N1 or P2 for either group.
Habicht et al., (2018)*	24 weeks	Baseline, 12w, 24w post fitting	New: 8.2 hrs/day. Ex: 10.7 hrs/day	NovHA: datalogging ExpHA: self-reported	Late ERPs	Latency and Amplitude: N1, P2, N2, P3	No	• The study detected no changes in ERP measurements over time for both new and experienced hearing aid users. Latencies of the N2 and P3 components remained consistent across groups, with no differences or changes observed in P3 amplitudes between the two groups.
Karawani et al. (2018a)*	6 months	Baseline & 6mo post fit	Required to wear 8hrs/day	Objective (datalogging feature)	CAEP's	Amplitude: P1, N1, P2.	Yes	• The experimental group showed increased N1 and P2 amplitudes. In quiet conditions, a interaction between time, amplification, and group was observed, with amplified N1 peak amplitudes in the experimental group. No changes were found in noise conditions. Additionally, P2 amplitudes increased in aided conditions for both quiet and noise, but not without hearing aids. However, no interaction was found for time and group. No changes were observed in the control group. • Overall, these findings suggest hearing aids may enhance auditory signals and cognitive function.
Karawani et al. (2018b)*	6 months	Baseline & 6mo post fit	Required to wear 8hrs/day	Objective (datalogging feature)	FFR	Peak Latency and Amplitude: Transition and steady-state regions of the response	Yes	• Latencies remained consistent in the experimental group post-six months; they were delayed in the control group. Physiological changes, including reduced F0 magnitude, were seen in the experimental group but not in controls. The study suggests hearing aids can affect subcortical processing and mitigate neural timing delays, with implications for further research on cortical changes and cognitive processing effects.
Megha & Maruthy (2019a)	2 months	M1 (initial fit), M2 (1 mo), M3 (2 mo)	8.1 hrs/day	Objective (datalogging feature)	CAEP's	Latency and Amplitude: P1, N1, P2	Latency: Yes Amplitude: No	• Median latencies decreased from M1 to M3 for P1 and N1 but not for P2. However, in P2, latencies increased. A significant session effect was found for P1 and N1, but not for P2. • Median amplitudes showed minimal change from M1 to M3. No significant session effect was observed on P1-N1 and N1-P2 amplitude of ALLRs.
Megha & Maruthy, (2020)*	2 months	Baseline, 1mo, 2mo. Control: Recorded twice (2mo interval).	8.1 hrs/day	Objective (datalogging feature)	CAEP's	Latency and Amplitude: P1, N1, P2	Yes	• The clinical group displayed reduced latency for P1 and N1 while P2 remained stable with the Friedman's test indicating a significant main effect of session on the peak latency of P1 and N1, but not in P2. • The amplitude also increased in P1 and N1 in ALLRs over three sessions, while P2 latency remained stable. • In contrast, the control group indicated no differences between the first and third session.
Karawani et al. (2022)*	6 months	Baseline,2w, 6w, 12w, 18w, 24w	9,31hrs/day	Objective (datalogging feature)	CAEP's	Latency and Amplitude: P1, N1, P2	Yes	• Neural changes were noticeable after 2 weeks, with increases in N1 amplitude. It took 6 weeks for similar changes in P2 amplitude. An increase in P2 amplitudes in noise was observed after 24 weeks, but N1 amplitudes in noise did not change. This suggests earlier neuroplasticity in N1 amplitudes (2 weeks after fitting) compared to P2 (6 weeks after fitting). • In contrast, the control group showed no changes in P1, N1, and P2 peaks between sessions 1 and 6 in both quiet and noise conditions.

Note: ABR= Auditory Brainstem Response, ALLRs= Auditory Late Latency Responses, CAEP's= Cortical Auditory Evoked Potentials, ERPs= Event-Related Potentials, FFR= Frequency Following Response, HAs= Hearing Aids, hrs/day= hours per day, mo= month, M1= Month 1, M2= Month 2 and M3= Month 3.

* Studies that included a control group are denoted with an asterisk next to the author(s) and year*

Factors Influencing Acclimatization

Various studies have explored factors potentially influencing acclimatization to hearing aids, including hearing aid use, degree of hearing loss, cognition, age, device characteristics, and presentation levels (Table 3.6). Evidence suggests that consistent hearing aid use, particularly among new users with severe hearing loss, is associated with improved speech recognition (Dawes & Munro, 2017). However, other studies found no correlation between hearing aid use and changes in speech recognition performance (Dawes et al., 2014a; Dawes et al., 2014b). Similarly, while more severe hearing loss has been linked to greater improvements in speech perception in noise (Wright & Gagne, 2021), other studies found no significant association between hearing loss severity and changes in either speech recognition or self-reported outcomes (Bentler, 1993b; Metselaar, 2009). Cognitive abilities and age consistently showed no relationship with acclimatization outcomes (Dawes et al., 2014a; Wright & Gagne, 2021). Device features, such as digital processing and WDRMCC fittings, were associated with greater performance gains over time (Arlinger & Billermark, 1999; Yund et al., 2006). Additionally, presentation levels influenced acclimatization, with higher speech levels showing greater improvements over time, while lower levels showed no changes (Munro & Lutman, 2003).

Table 3.6: Factors Influencing Acclimatization

Factors		***Influence on acclimatization***
Hearing aid use	Speech Recognition	Bentler et al. (1993a) found no difference in speech recognition improvements between part-time (<4 hours/day) and full-time (>4 hours/day) hearing aid users. Dawes et al. (2014a) and Dawes et al. (2014b) found no correlation between hearing aid use and changes in speech recognition performance. Dawes & Munro (2017) showed that new users with severe hearing loss and consistent use improved speech recognition by 4.1 dB in 30 days, while experienced users improved by 0.8 dB. No improvement was seen for new users with milder loss or inconsistent use. Wright & Gagne (2021) found no link between hearing aid use and the acclimatization period, likely because all participants used their aids for at least 9 hours/day.
	Self-reported Outcomes	Vestergaard (2006) found that first-time users wearing hearing aids for over 4 hours daily had better benefit and satisfaction over time, but the study couldn't confirm a direct cause-and-effect relationship between usage and long-term outcomes. Bentler et al. (1993b) found a correlation between daily hearing aid use and satisfaction ratings ($r = .37$, $p < .02$).
	Electrophysiological Measures	Dawes et al. (2014b) found no correlations between changes in N1/P2 amplitude or amount of hearing aid use.

Degree of hearing loss	Speech Recognition	Bentler (1993a) found no change in speech recognition performance over time, despite participants having mild to moderate hearing loss. Dawes et al. (2014a) and Dawes et al. (2014b) found no correlation between hearing loss severity and changes in speech recognition performance. Dawes & Munro (2017) found that new hearing aid users with severe hearing loss and consistent use showed improvement in Speech-in-Noise performance over time ($F(3,22) = 7.21$, $p < 0.01$). Wright & Gagne (2021) found that more severe hearing loss was associated with greater improvement in speech perception in noise.
	Self-reported Measures	Bentler (1993b) found no change in the HPI-38 total score over time, regardless of hearing loss severity, suggesting that hearing loss severity did not impact self-reported outcomes. Metselaar (2009) found that while the degree of hearing loss affected HHDI scores, it did not correlate with the perceived benefit from hearing aids (APHAB scores). This indicates that different levels of hearing loss might lead to similar benefits from proper hearing aid fitting.
	Electrophysiological Measures	Dawes et al.(2014b) found no correlation between changes in N1/P2 amplitude or latency and average hearing loss levels for new hearing aid users
Cognition		Dawes et al. (2014a) and Dawes & Munro (2017) found no correlation between cognitive factors (reaction time, working memory) and changes in speech recognition or acclimatization outcomes. They suggested that acclimatization shifts attention, making background sounds noticeable. As acclimatization advances, these sounds are ignored, reducing masking, improving speech recognition, and enhancing background noise tolerance. Megha & Maruthy (2019b) and Wright & Gagne (2021) also found no correlations between working memory, processing speed, and acclimatization.
Age		Dawes et al. (2014b) found no correlations between age and changes in speech recognition, N1/P2 latency, or amplitude. Wright & Gagne (2021) found no correlation between age (63-75 years, M=70.2) and the extent of acclimatization over 22 weeks.
Hearing aids	Device Type	Arlinger & Billermark (1999) found that digital hearing aids (DigiFocus) showed improvements in speech recognition over time, especially at higher speech levels, while analogue aids showed only modest improvements and poorer recognition at lower speech levels.
	Device features	Yund et al. (2006) found that new HA users with WDRMCC fittings showed 45% performance gains within 8 weeks, while those with LA fittings lacked consistent gains, likely due to the more uniform sound encoding in WDRMCC processing.
Presentation levels		Munro & Lutman (2003) found that acclimatization to hearing aids occurs at higher speech levels, leading to greater improvements, while lower levels showed no changes. Dawes et al. (2014a) reported no improvements at higher stimulus intensities.

Quality (Risk of Bias) Assessment and Level of Evidence for the Systematic Review

Quality ratings, detailed in Appendix G, revealed that the studies assessed with the 12-question NIH quality assessment tool had an average score of 8.15 (68%), while those assessed with the 14-question tool had an average score of 8.28 (59%), both corresponding to a 'Fair' quality rating on the NIH Quality Assessment Scale. Among the studies reviewed, 10 (23%) were deemed good quality, 33 (75%) received a fair quality rating, and one (2%) was assessed as poor quality. Factors contributing to lower quality included a lack of randomization, absence of blinding in group assessments, and inadequate reporting on sample size considerations for detecting significant differences in main outcomes with sufficient statistical power. Regarding the OCEBM levels of evidence, where level 1 represents the highest quality of evidence and level 5 represents the lowest, out of the 44 studies analysed, 13 (30%) were classified as level 4, 27 (61%) as level 3, and four (9%) as level 2, representing true experimental studies (Appendix G).

3.5 Discussion

Is there high-quality evidence of systematic improvements outcome measures consistent with acclimatization following hearing aid use?

Despite the extensive scope of this review, which spans over 30 years of research, the findings align with previous reviews, indicating that evidence for auditory acclimatization is generally inconsistent and, when observed, tends to be small in magnitude. This conclusion is consistent with the observations of Turner and Bentler (1998), who, in their letter on hearing aid acclimatization, indicated that current evidence does not support a significant acclimatization effect. They emphasized that across many studies, observed improvements in speech recognition were minimal and often difficult to differentiate from task-specific learning or natural variability.

The current review adds to previous reviews on this topic by providing an up-to-date synthesis of the literature and by making the important distinction between those studies that included a controlled design and those that did not. The comparison between controlled and uncontrolled studies on auditory acclimatization following hearing aid use warrants careful interpretation. Among studies focused on speech recognition outcomes, controlled studies showed a slight tendency toward reporting acclimatization (10 acclimatization vs. 7 no acclimatization), whereas uncontrolled studies exhibited a more balanced distribution (6 acclimatization vs. 4 no acclimatization). For self-reported outcomes, studies without control groups leaned more toward not observing acclimatization (5 acclimatization vs. 8 none), while those with control groups mostly observed acclimatization (2 acclimatization vs. 1 none). In terms of electrophysiological outcomes, 7 out of 9 studies had control groups (4 acclimatization vs. 3 no acclimatization), while the 2 uncontrolled studies yielded mixed results.

It is important to note that the number of studies available, particularly in the electrophysiological category, may not be sufficient to allow for robust comparisons between controlled and uncontrolled designs. Therefore, while there is a trend indicating that more studies report acclimatization rather than no acclimatization, the evidence remains inconsistent and lacks robustness across different study designs and outcome measures.

The absence of controlled experimental settings in some studies complicates the interpretation of observed changes, making it difficult to attribute them definitively to acclimatization rather than other factors such as repeated testing or the natural course of adaptation. Consequently, future research should prioritize studies with rigorous control groups and focus on accurately quantifying the magnitude of changes attributable to acclimatization. This approach is crucial for understanding the variability across studies and underscores the need for caution when assessing the clinical relevance of acclimatization.

If changes were reported, what is their magnitude and are they likely to be clinically relevant?

Changes in auditory performance with hearing aids generally range from small to moderate. For instance, Cox et al. (1996) noted a 4-5% increase in speech recognition and a 4-8% improvement in noisy environments over 12 weeks. Bentler et al. (1993a) and Munro and Lutman (2003) reported changes of 1.0% to 3.6%, while Pinheiro et al. (2012) observed a 4% increase, and Yund et al. (2006) recorded a 4.6% improvement over 8 weeks.

Self-reported outcomes show large initial improvements that stabilize into smaller or moderate gains over time, as seen in studies like Mulrow et al. (1992) and Taylor (1993), with some reports of small declines (e.g., Yund et al., 2006). Electrophysiological measures also show moderate changes, with Karawani et al. (2018a, 2018b) noting moderate to large effect sizes in N1 and P2 amplitudes and latencies, and Megha and Maruthy (2020) reporting medium to large effects in P1 and N1 latencies.

Overall, acclimatization effects result in small to moderate auditory performance improvements, with significant early gains in self-reported outcomes that tend to stabilize over time. Electrophysiological responses show moderate changes, particularly in early cortical components.

While perceptual learning is a well-established phenomenon, evidence for auditory acclimatization in new adult hearing aid users remains inconsistent, with only small- moderate effects reported across the 44 studies. If acclimatization were clinically significant, we would expect more consistent and robust outcomes across studies. Instead, the variability and modest magnitude of change raise doubts about its clinical relevance.

Given these findings, it appears that while new users need some time to adjust to hearing aids, the benefits of amplification do not rely on an extended acclimatization period. Clinicians can therefore effectively assess the benefits of hearing aids at routine follow-up appointments, typically 2-6 weeks after fitting, without waiting for potential acclimatization. Future efforts may be better directed at addressing barriers to hearing aid uptake and use, which likely have a more significant impact on patient outcomes than the less consistently observed effects of acclimatization.

If changes occur, what is the time course?

Study lengths varied from 3 weeks to 3 years, reflecting the overall duration of data collection. Hearing aid acclimatization improvements for speech recognition generally occurred within the first few months, with gains often seen between six and twelve weeks (Gatehouse, 1992; Cox et al., 1996). Benefits continued over several months, with gradual improvements up to a year (Horwitz et al., 1997; Arlinger & Billermark, 1999; Humes et al., 2002b), though most enhancements were noted within the initial three months, emphasizing this period for maximizing hearing aid benefits (Prates & Iório, 2006).

Electrophysiological studies showed significant improvements as early as 2 weeks post-fitting, with increased N1 amplitude (Karawani et al., 2022) and further increases in P2 amplitude after 6 weeks (Karawani et al., 2022). Mid-term benefits, including reduced latency and increased P1 and N1 amplitudes, were observed at 3 to 6 months (Maruthy, 2019; Megha & Maruthy, 2020). Long-term changes continued beyond 6 months, with differences in peak latencies and P2 amplitudes in noise (Karawani et al., 2018b), reflecting neuroplastic changes from auditory stimulation.

Self-reported outcomes generally showed improvements in communication, satisfaction, and perceived benefits within the first few months, stabilizing over time (Humes & Wilson, 2003; Munro & Lutman, 2004; Taylor, 1993). However, the duration and consistency of these benefits varied, with some studies indicating a regression in specific areas after initial gains (Mulrow et al., 1992).

The clinical implications for audiology patients and clinicians regarding the time course emphasize the importance of the first 2 to 6 weeks after fitting hearing aids. This period is likely to witness the most significant changes in patient performance, making regular assessments during this time essential for tracking progress and providing timely feedback. It is crucial to set realistic expectations through comprehensive counselling, reassuring patients that while improvements may be noticeable early on, additional benefits could develop over the following months.

Effective acclimatization may depend on interventions that mirror real-life experiences, as repeated exposure to relevant sounds can enhance adaptation. Prioritizing approaches that reflect daily auditory situations during these initial weeks may lead to better acclimatization, improving patient satisfaction and outcomes. Additionally, encouraging consistent use of hearing aids during this period can enhance long-term benefits and contribute to overall success.

Are factors such as the duration and severity of hearing loss, or the length of hearing aid use, associated with systematic changes in outcomes?

The factors influencing auditory acclimatization among hearing aid users are complex and present a range of perspectives across studies. For instance, the duration of hearing aid use has been examined with mixed results. Studies by Bentler et al. (1993a) and Dawes et al. (2014a, 2014b) found no significant correlation between the duration of hearing aid use and improvements in speech recognition. However, Dawes and Munro (2017) observed that consistent use among new users with severe hearing loss led to notable gains in speech recognition, suggesting that regular use might play a crucial role in acclimatization, particularly for those with more severe impairments.

The degree of hearing loss similarly yielded contrasting findings. While Bentler (1993a) and Dawes (2014a, 2014b) reported no significant relationship between the severity of hearing loss and changes in speech recognition, Dawes and Munro (2017) identified improvements in users with severe hearing loss, indicating that the extent of hearing impairment might influence the acclimatization process in certain cases.

Cognitive factors, often considered in rehabilitation contexts, appeared to have no significant impact on acclimatization outcomes (Dawes et al., 2014a; Dawes & Munro, 2017). Additionally, age did not emerge as a significant factor influencing acclimatization (Dawes et al., 2014b; Wright & Gagne, 2021), suggesting that the acclimatization process might be relatively independent of these variables.

The type of hearing aid and its features also showed some influence on acclimatization. For example, digital hearing aids were associated with greater improvements in speech recognition compared to analog devices (Arlinger & Billermark, 1999; Yund et al., 2006), highlighting the potential role of advanced technology in facilitating acclimatization.

Future Directions

While the existing research on auditory acclimatization is extensive, there are still opportunities for improving study designs and consistent reporting of outcomes. Increasing the rigor of study as well as consistent reporting in several areas including study design, ensuring interventions reflect real-life experiences, ensuring adequate sample sizes, and improving measurement practices as outlined in Table 3.7 could help future studies.

Table 3.7: Recommendations for designing and reporting of future studies on hearing aid acclimatization

Area of recommendation	Suggestions for Future Clinical Trials
Study Design	• Utilize longitudinal designs with at least 6 months duration for extended monitoring. • Include control groups to differentiate hearing aid effects from natural adaptation. • Prioritize randomization allocation of participants to different groups.
Testing Relevance	• Effective acclimatization occurs with interventions closely resembling real-life experiences. Optimal adaptation may be achieved through repeated exposure to relevant stimuli. In hearing aid studies, mirroring daily auditory experiences may enhance adaptation. • Ensure hearing aid usage of at least 8 hours a day.
Sample Size	• Ensure study sample is appropriate for statistical power. Only 9 out of 44 reviewed studies performed sample size estimation or power analysis.
Outcomes	• Include different domains of outcomes such as self-reported, behavioural and electrophysiological. • Use standardized outcome measures that have been commonly used in hearing aid studies. • Collect data on various factors (e.g., hearing aid fitting quality, daily usage patterns, and device compliance) to examine factors influencing auditory acclimatization.
Time Points & baseline measurements	• Take frequent measurements: baseline, 1 month, 3 months, 6 months, and 12 months. • Avoid delays in baseline measurements to prevent underestimating treatment effects. • Ensure follow-up assessments are long enough to observe initial improvements and long-term stabilization.
Additional Factors	• Investigate impact of hearing aid fitting quality and daily use on acclimatization outcomes. • Examine effects of poorly fitted devices and low compliance on auditory, cortical, and cognitive improvements.

	• Explore the influence of rehabilitation, auditory training, and advanced hearing aid features (e.g., directional microphones, noise reduction algorithms) on acclimatization outcomes.
Acclimatization Yes/No	• Ensure clarity in terminology to distinguish benefit or training effect from acclimatization. • Differentiate acclimatization by observing group improvements. • Experimental group improvement without control group changes indicates acclimatization. • Both groups improving may suggest a practice effect, not acclimatization. • No change or decreased performance in both groups suggests acclimatization absence.

Limitations

A key limitation of this study was the inability to complete the meta-analysis due to missing data required for the meta-analysis. Additionally, variability in the timing and type of outcome measures across studies complicated the comparison and integration of findings.

3.6 Conclusions

While auditory acclimatization may contribute to the adjustment process for some new hearing aid users, its overall clinical relevance appears to be limited. The variability and modest effects observed across numerous studies suggest that acclimatization is not a primary determinant of hearing aid success. Therefore, the emphasis in clinical practice and research should shift toward more impactful areas, such as overcoming barriers to hearing aid adoption, fostering consistent use, and tailoring interventions to individual patient needs. These factors are likely to have a more substantial and predictable influence on patient outcomes than the less consistently observed phenomenon of acclimatization. Moving forward, focusing on these critical aspects will better support patients in achieving optimal hearing outcomes and satisfaction with their hearing aids.

3.7 References

Amorim, R. M. D. C., & Almeida, K. D. (2007). Study of benefit and of acclimatization in recent users of hearing aids. *Pró-Fono Revista de Atualização Científica, 19*, 39-48.

Arlinger, S., & Billermark, E. (1999). One year follow-up of users of a digital hearing aid. *British journal of audiology, 33*(4), 223-232.

Arlinger, S., Gatehouse, S., Bentler, R., Byrne, D., Cox, R., Dirks, D., Humes, L., Neuman, A., Ponton, C., & Robinson, K. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and hearing*, *17*(3), 87S.

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993a). Longitudinal study of hearing aid effectiveness. I: Objective measures. *Journal of Speech, Language, and Hearing Research, 36*(4), 808-819.

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993b). Longitudinal study of hearing aid effectiveness. II: Subjective measures. *Journal of Speech, Language, and Hearing Research, 36*(4), 820-831.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). Introduction to meta-analysis. John Wiley & Sons.

Borenstein, M., Rothstein, D., & Cohen, J. (2005). Comprehensive meta-analysis: A computer program for research synthesis [Computer software]. Englewood, NJ: Biostat

Byrne, D. (1996). Implications of acclimatization for hearing aid fitting practices and research. *Ear and Hearing*, 17(3 Suppl), 25S-26S.

Campbell, M., McKenzie, J. E., Sowden, A., Katikireddi, S. V., Brennan, S. E., Ellis, S., ... & Thomson, H. (2020). Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline. *bmj, 368*.

Chang, Y. S., Choi, J., Moon, I. J., Hong, S. H., Chung, W. H., & Cho, Y. S. (2016). Factors associated with self-reported outcome in adaptation of hearing aid. *Acta oto-laryngologica, 136*(9), 905-911.

Choi, A. Y., Shim, H. J., Lee, S. H., Yoon, S. W., & Joo, E. J. (2011). Is cognitive function in adults with hearing impairment improved by the use of hearing aids?. *Clinical and experimental otorhinolaryngology, 4*(2), 72.

Cox, R. M., Alexander, G., Taylor, I. M., & Gray, G. A. (1996). Benefit acclimatization in elderly hearing aid users. *JOURNAL-AMERICAN ACADEMY OF AUDIOLOGY*, *7*, 428-441.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2013). Brainstem processing following unilateral and bilateral hearing-aid amplification. *Neuroreport*, *24*(6), 271-275.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014a). Acclimatization to hearing aids. *Ear and hearing, 35*(2), 203-212.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014b). Auditory acclimatization and hearing aids: Late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. The Journal of the Acoustical Society of America, 135(6), 3560-3569.

Dawes, P., & Munro, K. J. (2017). Auditory distraction and acclimatization to hearing aids. *Ear and hearing, 38*(2), 174-183.

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *The Journal of the Acoustical Society of America, 76*(1), 87-96.

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: Evidence from monaural fitting of hearing aids. *The Journal of the Acoustical Society of America, 92*(3), 1258-1268.

Gatehouse, S. (1993). Role of perceptual acclimatization in the selection of frequency responses for hearing aids. *Journal of the American Academy of Audiology, 4*(5), 296-306.

Gatehouse, S. (1995). Acclimatisation to monaural hearing aid fitting-effects on loudness function and preliminary evidence for parallel electrophysiological and behavioural effects. P*sychoacoustics, speech and hearing aids.*

Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*, 43, 85–99

Glick, H. A., & Sharma, A. (2020). Cortical neuroplasticity and cognitive function in early-stage, mild-moderate hearing loss: evidence of neurocognitive benefit from hearing aid use. *Frontiers in Neuroscience, 93*.

Habicht, J., Finke, M., & Neher, T. (2018). Auditory acclimatization to bilateral hearing aids: Effects on sentence-in-noise processing times and speech-evoked potentials. *Ear and hearing, 39*(1), 161-171.

Horwitz, A. R., & Turner, C. W. (1997). The time course of hearing aid benefit. *Ear and Hearing, 18*(1), 1-11.

Humes, L. E., Halling, D., & Coughlin, M. (1996). Reliability and stability of various hearing-aid outcome measures in a group of elderly hearing-aid wearers. *Journal of Speech, Language, and Hearing Research, 39*(5), 923-935.

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B., & Amos, N. (2002a). Longitudinal changes in hearing aid satisfaction and usage in the elderly over a period of one or two years after hearing aid delivery. *Ear and Hearing*, 23(5), 428-438.

Humes, L. E., Wilson, D. L., Barlow, N. N., & Garner, C. (2002b). Changes in hearing-aid benefit following 1 or 2 years of hearing-aid use by older adults. *Age (years),* 72, 73-0.

Humes, L. E., & Wilson, D. L. (2003). An examination of changes in hearing-aid performance and benefit in the elderly over a 3-year period of hearing-aid use.

Ito, A., Fukuda, S., Shimozawa, M., Abe, K., Kumada, J., & Nakaya, M. (2023). Benefits of amplification for unaided speech discrimination in age-related hearing loss with flat type audiogram. *Auris Nasus Larynx*, *50*(1), 62-69.

Karawani, H., Jenkins, K., & Anderson, S. (2018a). Restoration of sensory input may improve cognitive and neural function. *Neuropsychologia, 114*, 203-213.

Karawani, H., Jenkins, K. A., & Anderson, S. (2018b). Neural and behavioral changes after the use of hearing aids. Clinical *Neurophysiology, 129*(6), 1254-1267.

Karawani, H., Jenkins, K., & Anderson, S. (2022). Neural Plasticity Induced by Hearing Aid Use. *Frontiers in Aging Neuroscience*, *14*, 1-12. https://doi.org/10.3389/fnagi.2022.884917

Laperuta, E. B., & Fiorini, A. C. (2012). Satisfaction of elderly individuals with hearing aids in the first six months of use. *Jornal da Sociedade Brasileira de Fonoaudiologia, 24*, 316-321.

Lavie, L., Banai, K., Karni, A., & Attias, J. (2015). Hearing aid–induced plasticity in the auditory system of older adults: evidence from speech perception. *Journal of Speech, Language, and Hearing Research, 58*(5), 1601-1610.

Lavie, L., Shechter Shvartzman, L., & Banai, K. (2022). Plastic changes in speech perception in older adults with hearing impairment following hearing aid use: a systematic review. *International journal of audiology, 61*(12), 975-983.

Megha, & Maruthy, S. (2019a). Consequences of hearing aid acclimatization on ALLRs and its relationship with perceived benefit and speech perception abilities. *European Archives of Oto-Rhino-Laryngology, 276*, 1001-1010.

Megha, N., & Maruthy, S. (2019b). Auditory and cognitive attributes of hearing aid acclimatization in individuals with sensorineural hearing loss. *American Journal of Audiology, 28*(2S), 460-470.

Megha, & Maruthy, S. (2020). Effect of hearing aid acclimatization on speech-in-noise perception and its relationship with changes in auditory long latency responses. *American Journal of Audiology, 29*(4), 774-784.

Metselaar, M., Maat, B., Krijnen, P., Verschuure, H., Dreschler, W. A., & Feenstra, L. (2009). Self-reported disability and handicap after hearing-aid fitting and benefit of hearing aids: comparison of fitting procedures, degree of hearing loss, experience with hearing aids and uni-and bilateral fittings. *European Archives of Oto-Rhino-Laryngology, 266*, 907-917.

Mueller, H. G., & Powers, T. A. (2001). Consideration of auditory acclimatization in the prescriptive fitting of hearing aids. In *Seminars in Hearing* (Vol. 22, No. 02, pp. 103-124).

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech, Language, and Hearing Research, 35*(6), 1402-1405.

Munro, K. J. (2008). Reorganization of the adult auditory system: Perceptual and physiological evidence from monaural fitting of hearing aids. *Trends in amplification, 12*(2), 85-102.

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *The Journal of the Acoustical Society of America*, *114*(1), 484-495.

Munro, K. J., & Lutman, M. E. (2004). Self-reported outcome in new hearing aid users over a 24-week post-fitting period. *International Journal of Audiology, 43*(10), 555-562.

National Institute of Health. (2021). Study Quality Assessment Tools | National Heart, Lung, and Blood Institute (NHLBI). Nih.gov. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools

Oliaei, S., SeyedAlinaghi, S., Mehrtak, M., Karimi, A., Noori, T., Mirzapour, P., ... & Dadras, O. (2021). The effects of hyperbaric oxygen therapy (HBOT) on coronavirus disease-2019 (COVID-19): a systematic review. *European journal of medical research, 26*, 1-12.

Oxford Centre for Evidence-Based Medicine Levels of Evidence. (2011). https://www.cebm.net/wp-content/uploads/2014/06/CEBM-Levels-of-Evidence-2.1.pdf

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Bmj, 372*.

Palmer, C. V., Nelson, C. T., & Lindley IV, G. A. (1998). The functionally and physiologically plastic adult auditory system. *The Journal of the Acoustical Society of America, 103*(4), 1705-1721.

Petry, T., dos Santos, S. N., & Costa, M. J. (2010). Speech recognition according to the length of hearing aid use. *Brazilian journal of otorhinolaryngology, 76*(4), 462-468.

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2005). The auditory acclimatization effect in sensorineural hearing-impaired listeners: evidence for functional plasticity. *Hearing Research, 205*(1-2), 131-142.

Pinheiro, M. M. C., Iório, M. C. M., Miranda, E. C., Dias, K. Z., & Pereira, L. D. (2012). The influence of cognitive aspects and auditory processes on the hearing aid acclimatization in the elderly. *Jornal Da Sociedade Brasileira De Fonoaudiologia, 24*, 309-315.

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., ... & Duffy, S. (2006). Guidance on the conduct of narrative synthesis in systematic reviews. *A product from the ESRC methods programme Version, 1*(1), b92.

Prates, L. P. C. S., & Iório, M. C. M. (2006). Acclimatization: speech recognition in hearing aid users. *Pró-Fono Revista de Atualização Científica, 18*, 259-266.

Reber, M. B., & Kompis, M. (2005). Acclimatization in first-time hearing aid users using three different fitting protocols. *Auris Nasus Larynx, 32*(4), 345-351.

Robinson, K., & Summerfield, Q. A. (1996). Adult auditory learning and training. *Ear and Hearing, 17*(3), 51S-65S.

Rosenman, R., Tennekoon, V., & Hill, L. G. (2011). Measuring bias in self-reported data. *International Journal of Behavioural and Healthcare Research*, *2*(4), 320-332.

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139.

Silman, S., Gelfand, S. A., & Silverman, C. A. (1984). Late-onset auditory deprivation: effects of monaural versus binaural hearing aids. *The Journal of the Acoustical Society of America*, *76*(5), 1357-1362.

Silman, S., Silverman, C. A., Emmer, M. B., & Gelfand, S. A. (1993). Effects of prolonged lack of amplification on speech-recognition performance: preliminary findings. *Journal of rehabilitation research and development, 30*(3), 326.

Song, J. E., Tanaka, S. M., Pinto, J. M., Rasmussen, B., Ferro, L. M., & Saadia-Redleaf, M. I. (2011). Long-term effects of hearing aids on word recognition scores. *Annals of Otology, Rhinology & Laryngology, 120*(5), 314-319.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. E*ar and hearing, 14*(6), 390-394.

Turner, C. W., & Bentler, R. A. (1998). Does hearing aid benefit increase over time?. T*he Journal of the Acoustical Society of America, 104*(6), 3673-3674.

Turner, C. W., Humes, L. E., Bentler, R. A., & Cox, R. M. (1996). A review of past research on changes in hearing aid benefit over time. *Ear and hearing, 17*(3), 14S-28S.

Vestergaard, M. D. (2006). Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. *International journal of audiology, 45*(7), 382-392.

Wright, D., & Gagné, J. P. (2021). Acclimatization to hearing aids by older adults. *Ear and Hearing, 42*(1), 193-205.

Yund, E. W., Roup, C. M., Simon, H. J., & Bowman, G. A. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *Journal of Rehabilitation Research and Development, 43*(4), 517.

CHAPTER 4: DISCUSSION AND CONCLUSIONS

4.1 Summary of results

Despite a growing body of research, this review found that the evidence for auditory acclimatization remains inconsistent, aligning with previous conclusions that acclimatization effects are either negligible or difficult to measure due to small-to-moderate change sizes and variability (Turner & Bentler, 1998). Although some well-controlled studies demonstrate acclimatization, the relatively modest magnitude of these changes raises concerns about their clinical significance, particularly in the context of hearing aid fitting and follow-up practices. This suggests that while acclimatization may occur, its impact on long-term outcomes may not be as substantial as once thought.

When interpreting findings of this current review it is important to note that observed improvements over time may not solely reflect acclimatization. Control groups are crucial in research to differentiate these effects. For instance, studies by Dawes et al. (2014a & 2014b) and Karawani et al. (2018b) noted speech recognition enhancements over time in both study and control groups, suggesting general practice effects rather than specific acclimatization to hearing aids. Distinguishing studies with and without control groups is vital, as the absence of controls can confound the interpretation of temporal improvements. The systematic review included studies with and without control groups. Out of the 32 studies on behavioural speech recognition outcomes, 19 (59.38%) made use of control groups in their studies. For self-reported outcomes, 7 out of 23 studies (30.43%) made use of control groups. Of the 9 studies on electrophysiological outcomes, 7 (77.78%) made use of control groups. The following section discusses the specific research questions in detail.

4.1.1 Evidence for auditory acclimatization following hearing aid use

Based on the studies reviewed, auditory acclimatization might have occurred in new adult hearing aid users across behavioural, self-reported, and electrophysiological measures; however, the magnitude of this effect remained uncertain, and its clinical relevance was yet to be confirmed. While some studies showed specific changes in these areas, the overall findings were mixed and sometimes contradictory. This variability could have resulted from factors such as differing research designs, participant characteristics, and the variety of outcome measures used. The lack of consistent time points across studies made comparisons difficult, and the absence of controlled settings in some research might have introduced confounding variables, obscuring the true effects of acclimatization. Individual variability, including differences in motivation and fatigue, further complicated the reliability of outcomes. These challenges, along with the heterogeneity of study designs and measures, rendered a meta-analysis unfeasible. This underscored the need for more standardized methodologies, control groups, and careful consideration of variables in future research to gain clearer insights into auditory acclimatization.

The inconsistency in evidence raises an important question: Does this suggest that acclimatization might not occur, or are the challenges in measuring it obscuring its presence? The mixed results could imply that if acclimatization does occur, its effects may be minimal and difficult to detect. Alternatively, these findings may reflect the challenges of identifying subtle changes that require sensitive assessments. Variations in hearing aid use, testing methods, and individual differences may also impact the results, and self-reported outcomes may be influenced by participant expectations rather than actual changes. Despite these challenges, the evidence does combine to suggest that if acclimatization effects exist, they are likely subtle and may not have significant clinical implications.

4.1.2 Time course and magnitude of acclimatization

If auditory acclimatization exists, the time to reach an asymptote reflects how long it takes individuals to fully adapt and achieve stable enhanced auditory performance. This duration varies based on factors such as hearing aid usage (hours per day), severity of hearing loss, and individual differences in auditory processing and adaptation, as well as the specific outcome domains considered. To understand this time course, it is important to distinguish between becoming accustomed to hearing aids and true auditory acclimatization, as discussed by Dawes, Maslin, and Munro (2014), who explored the process of getting used to hearing aids from the adult perspective. Becoming accustomed to hearing aids involves the initial phase of adapting to their physical presence, overcoming stigma, and managing practical aspects like fitting and maintenance (Brooks, 1989; Hétu, 1996). This process includes accepting hearing loss, adjusting to amplified sound, and addressing emotional challenges (Brooks, 1985; Palmer et al., 2006). In contrast, true auditory acclimatization is a process where individuals refine auditory perception, interpret, and distinguish sounds, and make ongoing adjustments to optimize hearing aid performance. While the initial phase involves practical adjustments and acceptance, auditory acclimatization focuses on the gradual development of auditory skills or performance over weeks, months, or even years. For example, Gatehouse (1992) and Prates & Iório (2006) observed notable gains within three months, while other studies, such as those by Mulrow et al. (1992) and Taylor (1993), noted continued adaptation for up to a year. Karawani et al. (2022) found neural changes within two weeks, with further adaptation over six weeks. AEPs may be a more reliable measure of acclimatization than self-reports, as they can objectively capture these subtle changes more accurately. Overall, while acclimatization can vary among individuals, it generally progresses gradually in the early months, with potential ongoing adjustments extending beyond this period.

The magnitude of these improvements in auditory performance with hearing aids ranged from small to moderate. Speech recognition measures showed variability, with Cox et al. (1996) reporting a 4-5% increase in scores and a 4-8% improvement in noisy environments over 12 weeks. Bentler et al. (1993a) and Munro and Lutman (2003) observed minimal changes of 1.0% to 3.6%. Self-reported benefits also vary widely, with significant drops in HHIE scores observed by Chang et al. (2016) and high satisfaction reported by Glick and Sharma (2020), although other studies like Humes and Wilson (2003) found minimal acclimatization over time. Changes in electrophysiological measures ranged from minimal to moderate, with significant findings in some studies, such as shortened wave V latency (Philibert et al., 2005) and increased N1 and P2 amplitudes (Karawani et al., 2018a). Overall, acclimatization effects were small to moderate, indicating gradual but not always substantial improvements.

4.1.3 Factors influencing acclimatization

There was some evidence to suggest that consistent hearing aid use, hearing loss severity, and device features may influence acclimatization, but results were not conclusive. For instance, Dawes & Munro (2017) observed significant gains in new users who consistently used their aids, and other studies reported improvements in speech-in-noise performance among those with more severe hearing loss (Dawes & Munro, 2017; Wright & Gagne, 2021). However, other research (Bentler et al., 1993a; Dawes, 2014a, 2014b) found no significant link between these factors and speech recognition outcomes. Additionally, cognitive abilities and age were found to be unrelated to the acclimatization process, with no significant correlations between these variables and changes in speech recognition or electrophysiological measures (Dawes et al., 2014a; Dawes & Munro, 2017; Megha & Maruthy, 2019b; Wright & Gagne, 2021).

4.2 Clinical implications

The findings from this project emphasises the importance of personalized counselling and tailored intervention strategies that account for individual differences in acclimatization processes. While perceptual learning is a well-established phenomenon, the evidence for acclimatization remains inconsistent, indicating only small to moderate effects when reported. If acclimatization were clinically significant, one would expect to see more consistent and robust outcomes across studies; however, new users need time to adjust to their hearing aids and the altered auditory experience, the benefits of amplification do not seem to require an extended acclimatization period.

Moving forward, it may be more beneficial for clinicians and researchers to prioritize addressing barriers to hearing aid uptake and use, as these factors likely have a more significant impact on patient outcomes than the inconsistently observed effects of auditory acclimatization. Below are potential areas where clinicians can intervene to optimize patient care:

Expectation Management

Setting realistic expectations about the benefits of hearing aids from the outset is essential. Clinicians should explain that while some users may experience perceptual changes over time, most improvements are likely to happen relatively quickly, with the potential for further, more gradual changes over the long term. This transparency helps prevent disappointment, fosters trust, and reassures patients, ultimately increasing their confidence in the performance and effectiveness of their hearing aids.

Device-Related Factors

Fine-tuning hearing aid settings to match individual needs may have a more significant impact than waiting for potential acclimatization. Ensuring the correct fitting and optimizing device features like noise reduction, directional microphones, and frequency response can improve speech recognition and overall satisfaction. Regular follow-up appointments to make these adjustments are essential for maximizing benefit.

Troubleshooting and Support

Early issues with hearing aids, such as discomfort or problems with sound quality, may lead to discontinuation if left unresolved. Proactively addressing these concerns with patients through troubleshooting can help prevent negative experiences that are sometimes mistakenly attributed to the need for acclimatization.

Counseling on Consistent Use

Encouraging consistent hearing aid use is likely more important than relying on acclimatization alone. Clinicians should counsel patients on the importance of wearing their hearing aids for most of the day, as regular use may drive better outcomes.

Personalized Interventions

Given the variability in individual outcomes, personalized strategies remain key. Clinicians should take into account patient-specific factors, including the degree of hearing loss, lifestyle, and psychological readiness, when recommending hearing aids and follow-up care. Tailored interventions, rather than a one-size-fits-all approach, can help users adapt more effectively.

Focus on Psychosocial Barriers

Factors such as stigma, frustration, or denial about hearing loss can hinder successful hearing aid use. Clinicians should address these psychological aspects, offering counseling and support to help patients overcome emotional barriers and stay motivated to use their hearing aids regularly.

In summary, the focus should be on immediate, practical interventions, such as fine-tuning devices and managing patient expectations, while acknowledging that acclimatization may still be relevant for some users. Rather than depending solely on acclimatization, clinicians can proactively address factors that have a more immediate and measurable impact on patient outcomes. By emphasizing these actionable strategies, clinicians can ensure timely improvements, enhance patient satisfaction, and ultimately contribute to better long-term quality of life for hearing aid users.

4.3 Critical evaluation

Strengths of the study

Protocol Registration & Adherence to PRISMA Guidelines: The review was registered with PROSPERO to adhere to systematic review standards. Additionally, following the PRISMA 2020 guidelines ensured that the review was conducted systematically and reported comprehensively, providing a clear framework.

Comprehensive Search Strategy: Utilizing multiple reputable databases (CINAHL, PubMed, and Web of Science) ensured a thorough search of the literature, minimized the risk of publication bias, and enhanced the comprehensiveness of the evidence base.

Collaborative Design: Involving co-authors in developing the search strategy contributed to diverse perspectives and enhanced expertise, which improved the quality and relevance of the search terms used. Moreover, having reputable authors review the work ensured its reliability and rigor throughout the review process.

Clear Eligibility Criteria: The use of the PICOST framework for determining eligibility criteria was systematic and structured, ensuring that the studies included in the review were relevant and comparable.

Independent Screening Process: The dual-reviewer approach for article screening, along with the use of Rayyan software for managing duplicates, enhanced the rigor and reliability of the selection process.

Quality Assessment Tools: Utilizing the NIH Quality Assessment Tools and the Oxford Centre for Evidence-Based Medicine Levels of Evidence provided a robust framework for evaluating the quality of included studies.

Extensive Inclusion of Studies: By identifying a total of 44 articles for the systematic review, the study presented a substantial evidence base that contributed to the understanding of hearing aid acclimatization effects in new users.

Study limitations

Incomplete Meta-Analysis: An attempt was made to quantitatively synthesize findings using meta-analysis, employing a random effects model to assess the impact of acclimatization across behavioral, self-reported, and electrophysiological measures. However, the meta-analysis could not be completed due to the absence of crucial correlation data between effect sizes across time points. Although it was possible to calculate mean changes, the interdependence of data points over time made it challenging to accurately compute standard deviations without detailed correlation data, which would require individual participant information. Without this data, it was not feasible to calculate the composite effect size and its corresponding standard deviation. This limitation significantly hindered the ability to quantitatively assess the magnitude of acclimatization effects and derive more robust conclusions about its impact over time.

4.4 Future research

Study Design Considerations

To enhance the robustness of future research, several methodological recommendations should be considered. Longitudinal study designs are essential for monitoring changes over extended periods and should include control groups to differentiate between the effects of hearing aid use and natural auditory adaptation. Additionally, larger sample sizes will improve the generalizability and statistical power of findings, accounting for individual variability in acclimatization rates and outcomes. Frequent measurements at multiple time points, particularly in the early stages of intervention, are crucial for accurately capturing the dynamic process of acclimatization.

Objective Measures

Future studies should prioritize the use of AEPs to provide an objective measure of auditory change over time. AEPs offer precise evaluations of neural changes related to acclimatization, minimizing the influence of subjective factors found in self-reported or behavioural outcomes. This approach enhances the detection of subtle auditory improvements and clarifies the time course of acclimatization.

Real-World Relevance

Studies should incorporate designs that closely mirror real-life experiences to optimize the acclimatization process. Acclimatization is most effective when interventions resemble individuals' daily auditory environments. Research on hearing aids shows participants adapt better when the interventions reflect their typical experiences. Interventions lacking real-world relevance may not produce significant acclimatization effects, as participants may struggle to adjust to controlled lab conditions. For instance, Gatehouse's (1992) and Munro & Lutman's (2003) studies highlighted how hearing aids enhance aided listening but can impair unaided listening.

Timing of Baseline Measurements

Researchers should consider the timing of baseline measurements to accurately capture the effects of acclimatization and minimize potential confounding factors. Delayed baseline measurements may obscure the true magnitude of change occurring over time, potentially underestimating treatment effects or leading to misinterpretation of findings. Therefore, it is critical to consider baseline timing carefully to minimize the influence of acclimatization on outcomes.

Meta-Analysis for Quantifying Change

Conducting a meta-analysis will reliably quantify changes in performance by comparing study groups to control groups over time. To successfully carry out a meta-analysis on auditory acclimatization, obtaining individual raw data from study authors is essential. Once collected, appropriate statistical methods that account for correlations between effect sizes should be applied to compute the composite effect size and variance.

Rehabilitation and Advanced Hearing Aid Features

Future research should explore the impact of rehabilitation, auditory training, and advanced hearing aid features, such as directional microphones and noise reduction algorithms, on acclimatization outcomes. Clear terminology is essential to differentiate between acclimatization and benefit, ensuring studies assess physiological changes over time rather than merely reporting immediate improvements. By addressing these factors, researchers can enhance the relevance of their findings to real-life situations.

4.5 Conclusions

In conclusion, while perceptual learning and auditory acclimatization are recognized phenomena, the extent of acclimatization among new adult hearing aid users appears to be minimal and lacks consistent replication in research. The variability reported across studies suggests that acclimatization is neither universal nor reliably significant in determining hearing aid success. Factors such as personal expectations, the quality of hearing aid fittings, and individual differences in auditory processing likely play a role in the acclimatization process. Although it is acknowledged that new users need time to adjust to their hearing aids and the accompanying listening experiences, the importance of acclimatization and its effects on perceived benefits over time do not seem to justify prioritization in clinical practice. Instead, attention should be directed toward more impactful factors, such as reducing barriers to hearing aid adoption—including misconceptions, financial constraints, and limited access to audiological services—and encouraging consistent hearing aid use. Interventions that educate patients on the benefits of sustained use, coupled with ongoing support and counselling, can significantly enhance the effectiveness of hearing aids. By focusing on these consistently impactful factors, audiologists and researchers can improve patient outcomes and enhance the overall quality of life for individuals with hearing loss, leading to more evidence-based practices that effectively meet patient needs.

5. REFERENCES

American Speech-Language-Hearing Association. (1988). Guidelines for determining threshold level for speech. *ASHA*, *30*, 85-88.

Arlinger, S., Gatehouse, S., Bentler, R., Byrne, D., Cox, R., Dirks, D., Humes, L., Neuman, A., Ponton, C., & Robinson, K. (1996). Report of the Eriksholm Workshop on auditory deprivation and acclimatization. *Ear and Hearing*, *17*(3), 87S.

Beecher, H. K. (1966). Ethics and clinical research. *New England Journal of Medicine*, *274*(24), 1354–1360. https://dx.doi.org/10.1056/NEJM196606162742405

Bentler, R. A., Niebuhr, D. P., Getta, J. P., & Anderson, C. V. (1993a). Longitudinal study of hearing aid effectiveness. I: Objective measures. *Journal of Speech, Language, and Hearing Research*, *36*(4), 808-819.

Bessen, S. Y., Zhang, W., Garcia-Morales, E., Deal, J. A., & Reed, N. S. (2024). Hearing Aid Use Trends Among Older Adults by Income and Metropolitan vs Nonmetropolitan Residence. *JAMA Network Open,* *7*(9), e2436140-e2436140. https://dx.doi.org/10.1001/jamanetworkopen.2024.36140

Bidelman, G. M. (2015). Towards an optimal paradigm for simultaneously recording cortical and brainstem auditory evoked potentials. *Journal of Neuroscience Methods*, *241*, 94-100. https://dx.doi.org/10.1016/j.jneumeth.2014.12.019

Bilger, R. C., Nuetzel, J. M., Rabinowitz, W. M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech, Language, and Hearing Research*, *27*(1), 32-48.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). *Introduction to meta-analysis*. John Wiley & Sons.

Borenstein, M., Rothstein, D., & Cohen, J. (2005). *Comprehensive meta-analysis: A computer program for research synthesis* [Computer software]. Biostat.

Brooks, D. N. (1985). Factors relating to the under-use of postaural hearing aids. *British Journal of Audiology*, *19*(3), 211-217.

Brooks, D. N. (Ed.). (1989). *Adult aural rehabilitation*. Chapman and Hall.

Byrne, D. (1996). Implications of acclimatization for hearing aid fitting practices and research. *Ear and Hearing*, *17*(3 Suppl), 25S-26S.

Calcus, A., Undurraga, J. A., & Vickers, D. (2022). Simultaneous subcortical and cortical electrophysiological recordings of spectro-temporal processing in humans [Original Research]. *Frontiers in Neurology*, *13*. https://doi.org/10.3389/fneur.2022.928158

Campbell, M., McKenzie, J. E., Sowden, A., Katikireddi, S. V., Brennan, S. E., Ellis, S., ... & Thomson, H. (2020). Synthesis without meta-analysis (SWiM) in systematic reviews: Reporting guideline. *BMJ*, *368*. https://dx.doi.org/10.1136/bmj.l6890

Carcagno, S., & Plack, C. J. (2022). Relations between speech-reception, psychophysical temporal processing, and subcortical electrophysiological measures of auditory function in humans. *Hearing Research*, *417*, 108456. https://dx.doi.org/10.1016/j.heares.2022.108456

Chang, Y. S., Choi, J., Moon, I. J., Hong, S. H., Chung, W. H., & Cho, Y. S. (2016). Factors associated with self-reported outcome in adaptation of hearing aid. *Acta Oto-Laryngologica*, *136*(9), 905-911. https://dx.doi.org/10.3109/00016489.2016.1170201

Chen, D. S., Genther, D. J., Betz, J., & Lin, F. R. (2014). Association between hearing impairment and self-reported difficulty in physical functioning. *Journal of the American Geriatrics Society*, *62*(5), 850-856. https://dx.doi.org/10.1111/jgs.12800

Cox, R. M., & Alexander, G. C. (1992). Maturation of hearing aid benefit: Objective and subjective measurements. *Ear and Hearing*, *13*(3), 131-141.

Cox, R. M., & Alexander, G. C. (1999). Measuring satisfaction with amplification in daily life: The SADL scale. *Ear and Hearing*, *20*(4), 306-320.

Cox, R. M., Alexander, G. C., Gilmore, C., & Pusakulich, K. M. (1988). Use of the Connected Speech Test (CST) with hearing-impaired listeners. *Ear and Hearing*, *9*(4), 198-207.

Cox, R. M., Alexander, G. C., Taylor, I. M., & Gray, G. A. (1996). Benefit acclimatization in elderly hearing aid users. *Journal of the American Academy of Audiology*, *7*, 428-441.

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2013). Brainstem processing following unilateral and bilateral hearing-aid amplification. *Neuroreport*, *24*(6), 271-275. https://dx.doi.org/10.1097/WNR.0b013e32835f8b30

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014a). Acclimatization to hearing aids. *Ear and Hearing*, *35*(2), 203-212. https://dx.doi.org/10.1097/AUD.0b013e3182a8eda4

Dawes, P., Munro, K. J., Kalluri, S., & Edwards, B. (2014b). Auditory acclimatization and hearing aids: Late auditory evoked potentials and speech recognition following unilateral and bilateral amplification. *The Journal of the Acoustical Society of America*, *135*(6), 3560-3569. https://dx.doi.org/10.1121/1.4874629

Dawes, P., Maslin, M., & Munro, K. J. (2014). 'Getting used to' hearing aids from the perspective of adult hearing-aid users. *International Journal of Audiology*, *53*(12), 861-870. https://dx.doi.org/10.3109/14992027.2014.938782

Emmett, S. D., & Francis, H. W. (2015). The socioeconomic impact of hearing loss in US adults. *Otology & Neurotology*, *36*(3), 545. https://dx.doi.org/10.1097/MAO.0000000000000562

Ferguson, M. A., Kitterick, P. T., Chong, L. Y., Edmondson-Jones, M., Barker, F., & Hoare, D. J. (2017). Hearing aids for mild to moderate hearing loss in adults. *Cochrane Database of Systematic Reviews (9)*. https://dx.doi.org/10.1002/14651858.CD012023.pub2

Foster, J., & Haggard, M. (1979). FAAF–An efficient analytical test of speech perception. *Proceedings of the Institute of Acoustics*, *3*, 9-12.

Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*, *43*, 85-99. https://dx.doi.org/10.1080/14992020400050014

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: Evidence from monaural fitting of hearing aids. *The Journal of the Acoustical Society of America*, *92*(3), 1258-1268. https://dx.doi.org/10.1121/1.403921

Gatehouse, S. (1999). Glasgow Hearing Aid Benefit Profile: Derivation and validation of a client-centered outcome measure for hearing aid services. *Journal of the American Academy of Audiology*, *10*(02), 80-103.

Glick, H. A., & Sharma, A. (2020). Cortical neuroplasticity and cognitive function in early-stage, mild-moderate hearing loss: Evidence of neurocognitive benefit from hearing aid use. *Frontiers in Neuroscience*, *93*. https://dx.doi.org/10.3389/fnins.2020.00093

Goggins, S., & Day, J. (2009). Pilot study: Efficacy of recalling adult hearing-aid users for reassessment after three years within a publicly-funded audiology service. *International Journal of Audiology*, *48*(4), 204-210. https://dx.doi.org/10.1080/14992020802575687

Gopinath, B., Schneider, J., Hickson, L., McMahon, C. M., Burlutsky, G., Leeder, S. R., & Mitchell, P. (2012). Hearing handicap, rather than measured hearing impairment, predicts poorer quality of life over 10 years in older adults. *Maturitas*, *72*(2), 146-151. https://dx.doi.org/10.1016/j.maturitas.2012.03.010

Habicht, J., Finke, M., & Neher, T. (2018). Auditory acclimatization to bilateral hearing aids: Effects on sentence-in-noise processing times and speech-evoked potentials. *Ear and Hearing*, *39*(1), 161-171. DOI: 10.1097/AUD.0000000000000476

Haile, L. M., Kamenov, K., Briant, P. S., Orji, A. U., Steinmetz, J. D., Abdoli, A., Abdollahi, M., Abu-Gharbieh, E., Afshin, A., & Ahmed, H. (2021). Hearing loss prevalence and years lived with disability, 1990–2019: Findings from the Global Burden of Disease Study 2019. *The Lancet*, *397*(10278), 996-1009.

Helgesson, G., & Eriksson, S. (2015). Plagiarism in research. *Medicine, Health Care and Philosophy*, *18*, 91-101. https://dx.doi.org/10.1007/s11019-014-9583-8

Hétu, R. (1996). The stigma attached to hearing impairment. *Scandinavian Audiology. Supplementum*, *43*, 12-24.

Horwitz, A. R., & Turner, C. W. (1997). The time course of hearing aid benefit. *Ear and Hearing*, *18*(1), 1-11.

Humes, L. E., & Wilson, D. L. (2003). An examination of changes in hearing-aid performance and benefit in the elderly over a 3-year period of hearing-aid use. *Ear and Hearing*, *23*(5), 428-438.

Humes, L. E., Wilson, D. L., Barlow, N. N., Garner, C. B., & Amos, N. (2002). Longitudinal changes in hearing aid satisfaction and usage in the elderly over a period of one or two years after hearing aid delivery. *Ear and Hearing*, *23*(5), 428-438.

Jayakody, D. M., Friedland, P. L., Eikelboom, R. H., Martins, R. N., & Sohrabi, H. R. (2018). A novel study on association between untreated hearing loss and cognitive functions of older adults: Baseline non-verbal cognitive assessment results. *Clinical Otolaryngology*, *43*(1), 182-191. https://dx.doi.org/10.1111/coa.12937

Karawani, H., Jenkins, K., & Anderson, S. (2022). Neural plasticity induced by hearing aid use. *Frontiers in Aging Neuroscience*, *14*, 1-12. https://doi.org/10.3389/fnagi.2022.884917

Karawani, H., Jenkins, K. A., & Anderson, S. (2018). Neural and behavioral changes after the use of hearing aids. *Clinical Neurophysiology*, *129*(6), 1254-1267. https://dx.doi.org/10.1016/j.clinph.2018.03.024

Karawani, H., Jenkins, K., & Anderson, S. (2018). Restoration of sensory input may improve cognitive and neural function. *Neuropsychologia*, *114*, 203-213. https://dx.doi.org/10.1016/j.neuropsychologia.2018.04.041

Kim, W. O. (2012). Institutional review board (IRB) and ethical issues in clinical research. *Korean Journal of Anesthesiology*, *62*(1), 3-12. https://dx.doi.org/10.4097/kjae.2012.62.1.3

Knoetze, M., Manchaiah, V., Mothemela, B., & Swanepoel, D. W. (2023). Factors influencing hearing help-seeking and hearing aid uptake in adults: A systematic review of the past decade. *Trends in Hearing*, *27*. https://dx.doi.org/10.1177/23312165231157255

Knudsen, L., Öberg, M., Nielsen, C., Naylor, G., & Kramer, S. E. (2010). Factors influencing help seeking, hearing aid uptake, hearing aid use and satisfaction with hearing aids: A review of the literature. *Trends in Amplification*, *14*(3), 127-154. https://dx.doi.org/10.1177/1084713810385712

Laperuta, E. B., & Fiorini, A. C. (2012). Satisfaction of elderly individuals with hearing aids in the first six months of use. *Jornal da Sociedade Brasileira de Fonoaudiologia*, *24*, 316-321.

Lavie, L., Shechter Shvartzman, L., & Banai, K. (2022). Plastic changes in speech perception in older adults with hearing impairment following hearing aid use: A systematic review. *International Journal of Audiology*, *61*(12), 975-983. https://dx.doi.org/10.1080/14992027.2021.2014073

Lavie, L., Banai, K., Karni, A., & Attias, J. (2015). Hearing aid–induced plasticity in the auditory system of older adults: Evidence from speech perception. *Journal of Speech, Language, and Hearing Research*, *58*(5), 1601-1610. https://dx.doi.org/10.1044/2015_JSLHR-H-14-0225

Levitt, H., & Resnick, S. (1978). Speech reception by the hearing-impaired: Methods of testing and the development of new tests. *Scandinavian Audiology. Supplementum*, *6*, 107-130.

Li, C.-M., Zhang, X., Hoffman, H. J., Cotch, M. F., Themann, C. L., & Wilson, M. R. (2014). Hearing impairment associated with depression in US adults, National Health and Nutrition Examination Survey 2005-2010. *JAMA Otolaryngology–Head & Neck Surgery*, *140*(4), 293-302.

Lin, F. R., Thorpe, R., Gordon-Salant, S., & Ferrucci, L. (2011). Hearing loss prevalence and risk factors among older adults in the United States. *Journals of Gerontology: Biological Sciences and Medical Sciences*, *66*, 582-590.

McCormack, A., & Fortnum, H. (2013). Why do people fitted with hearing aids not wear them? *International Journal of Audiology, 52*(5), 360-368. https://dx.doi.org/10.3109/14992027.2013.769066

McPherson, B. (2018). Hearing aid systems in low-resource settings. *Community Ear and Hearing Health, 15*(19), 1-1.

Megha, & Maruthy, S. (2019a). Consequences of hearing aid acclimatization on ALLRs and its relationship with perceived benefit and speech perception abilities. *European Archives of Oto-Rhino-Laryngology, 276*, 1001-1010. https://dx.doi.org/10.1007/s00405-019-05303-0

Mener, D. J., Betz, J., Genther, D. J., Chen, D., & Lin, F. R. (2013). Hearing loss and depression in older adults. *Journal of the American Geriatrics Society, 61*(9), 1627. https://dx.doi.org/10.1111/jgs.12429

Mohajan, H. (2017). Two criteria for good measurements in research: Validity and reliability. *Annals of Spiru Haret University Economics Series*(4).

Mueller, H. G., & Powers, T. A. (2001). Consideration of auditory acclimatization in the prescriptive fitting of hearing aids. In *Seminars in Hearing (Vol. 22, No. 02, pp. 103-124)*. https://dx.doi.org/10.1055/s-2001-14976

Mulrow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech, Language, and Hearing Research, 35*(6), 1402-1405.

Munn, Z., Peters, M. D., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology, 18*(1), 1-7. https://dx.doi.org/10.1186/s12874-018-0611-x

Munro, K. J. (2008). Reorganization of the adult auditory system: Perceptual and physiological evidence from monaural fitting of hearing aids. *Trends in Amplification, 12*(2), 85-102. https://dx.doi.org/10.1177/1084713808316173

Munro, K. J., & Lutman, M. E. (2003). The effect of speech presentation level on measurement of auditory acclimatization to amplified speech. *The Journal of the Acoustical Society of America, 114*(1), 484-495. https://dx.doi.org/10.1121/1.1577556

Näätänen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*(4), 375-425. https://dx.doi.org/10.1111/j.1469-8986.1987.tb00311.x

National Institute of Health. (2021). Study quality assessment tools | National Heart, Lung, and Blood Institute (NHLBI). *NIH.gov*. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools

Oliaei, S., SeyedAlinaghi, S., Mehrtak, M., Karimi, A., Noori, T., Mirzapour, P., ... & Dadras, O. (2021). The effects of hyperbaric oxygen therapy (HBOT) on coronavirus disease-2019 (COVID-19): A systematic review. *European Journal of Medical Research, 26*, 1-12. https://dx.doi.org/10.1186/s40001-021-00570-2

Orji, A., Kamenov, K., Dirac, M., Davis, A., Chadha, S., & Vos, T. (2020). Global and regional needs, unmet needs and access to hearing aids. *International Journal of Audiology, 59*(3), 166-172. https://dx.doi.org/10.1080/14992027.2020.1721577

Oxford Centre for Evidence-Based Medicine Levels of Evidence. (2011). https://www.cebm.net/wp-content/uploads/2014/06/CEBM-Levels-of-Evidence-2.1.pdf

Palmer, C. V., Bentler, R., & Mueller, H. G. (2006). Amplification with digital noise reduction and the perception of annoying and aversive sounds. *Trends in Amplification, 10*(2), 95-104. https://dx.doi.org/10.1177/1084713806289554

Palmer, C. V., Nelson, C. T., & Lindley IV, G. A. (1998). The functionally and physiologically plastic adult auditory system. *The Journal of the Acoustical Society of America, 103*(4), 1705-1721. https://dx.doi.org/10.1121/1.421050

Peelle, J. E., & Wingfield, A. (2016). The neural consequences of age-related hearing loss. *Trends in Neurosciences, 39*(7), 486-497. https://dx.doi.org/10.1016/j.tins.2016.05.001

Philibert, B., Collet, L., Vesson, J. F., & Veuillet, E. (2005). The auditory acclimatization effect in sensorineural hearing-impaired listeners: Evidence for functional plasticity. *Hearing Research, 205*(1-2), 131-142. https://dx.doi.org/10.1016/j.heares.2005.03.013

Picton, T. W., Alain, C., Woods, D. L., John, M. S., Scherg, M., Valdes-Sosa, P., ... & Trujillo, N. J. (1999). Intracerebral sources of human auditory-evoked potentials. *Audiology and Neurotology, 4*(2), 64-79. https://dx.doi.org/10.1159/000013823

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., ... & Duffy, S. (2006). Guidance on the conduct of narrative synthesis in systematic reviews. A product from the ESRC Methods Programme *Version, 1*(1), b92.

Prates, L. P. C. S., & Iório, M. C. M. (2006). Acclimatization: Speech recognition in hearing aid users. *Pró-Fono Revista de Atualização Científica, 18*, 259-266.

Reber, M. B., & Kompis, M. (2005). Acclimatization in first-time hearing aid users using three different fitting protocols. *Auris Nasus Larynx, 32*(4), 345-351. https://dx.doi.org/10.1016/j.anl.2005.05.008

Rosenman, R., Tennekoon, V., & Hill, L. G. (2011). Measuring bias in self-reported data. *International Journal of Behavioural and Healthcare Research, 2*(4), 320-332.

Saunders, G. H., & Cienkowski, K. M. (1997). Acclimatization to hearing aids. *Ear and Hearing, 18*(2), 129-139.

Scherg, M., Vajsar, J., & Picton, T. W. (1989). A source analysis of the late human auditory evoked potentials. *Journal of Cognitive Neuroscience, 1*(4), 336-355.

Taylor, K. S. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14*(6), 390-394.

Turner, C. W., Humes, L. E., Bentler, R. A., & Cox, R. M. (1996). A review of past research on changes in hearing aid benefit over time. *Ear and Hearing, 17*(3), 14S-28S.

Turner, C. W., & Bentler, R. A. (1998). Does hearing aid benefit increase over time? *The Journal of the Acoustical Society of America, 104*(6), 3673-3674.

Vestergaard, M. D. (2006). Self-report outcome in new hearing-aid users: Longitudinal trends and relationships between subjective measures of benefit and satisfaction. *International Journal of Audiology, 45*(7), 382-392. https://dx.doi.org/10.1080/14992020600690977

World Health Organization. (2024, February 2). Deafness and hearing loss. *WHO*. https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

World-Health-Organization. (2021). World report on hearing. *World Health Organization*. https://www.who.int/publications/i/item/world-report-on-hearing

Wright, D., & Gagné, J. P. (2021). Acclimatization to hearing aids by older adults. *Ear and Hearing, 42*(1), 193-205. https://dx.doi.org/10.1097/AUD.0000000000000913

Yund, E. W., Roup, C. M., Simon, H. J., & Bowman, G. A. (2006). Acclimatization in wide dynamic range multichannel compression and linear amplification hearing aids. *Journal of Rehabilitation Research and Development, 43*(4), 517.

APPENDICES

Appendix A: Ethical approval letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Fakulteit Geesteswetenskappe
Lefapha la Bomotho

Humanities 100
Since 1919

6 April 2023

Dear Miss C Wentzel

Project Title:	Auditory acclimatization in adult hearing aid users: A systematic review and meta- analysis
Researcher:	Miss C Wentzel
Supervisor(s):	Prof DCDW Swanepoel Prof VK Hannapatna Manchaiah Dr I Oosthuizen Prof F Mahomed Asmail
Department:	Speech Language Pathology and Audiology
Reference number:	19001178 (HUM004/0223)
Degree:	Masters

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

The Research Ethics Committee notes that this is a literature-based study and no human subjects are involved.

The application has been approved on 30 March 2023 with the assumption that the document(s) are in the public domain. Data collection may therefore commence, along these guidelines.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. However, should the actual research depart significantly from the proposed research, a new research proposal and application for ethical clearance will have to be submitted for approval.

We wish you success with the project.

Sincerely,

Prof Karen Harris
Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: tracey.andrew@up.ac.za

Appendix B: Data extracted

	Items
1	Magnitude (or size) of change in speech recognition (i.e., speech in noise, speech in quiet) as a result of HA acclimatization.
2	Magnitude (or size) of change in self-reported outcome measures as a result of HA acclimatization.
3	Magnitude (or size) of change in electrophysiological measures as a result of HA aid acclimatization.
4	Measurement tools used within each of the three outcome domains (items 1-3).
5	The time course until HA acclimatization reaches an asymptote.
6	Factors (e.g., duration of hearing loss, HA use, the severity of hearing loss) influencing HA acclimatization.

Appendix C: National Institute of Health Quality Assessment Tools

Quality Assessment of Controlled Intervention Studies

Criteria	**Yes**	**No**	**Other (CD, NR, NA)***
1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?			
2. Was the method of randomization adequate (i.e., use of randomly generated assignment)?			
3. Was the treatment allocation concealed (so that assignments could not be predicted)?			
4. Were study participants and providers blinded to treatment group assignment?			
5. Were the people assessing the outcomes blinded to the participants' group assignments?			
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g., demographics, risk factors, co-morbid conditions)?			
7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?			
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?			
9. Was there high adherence to the intervention protocols for each treatment group?			
10. Were other interventions avoided or similar in the groups (e.g., similar background treatments)?			
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?			
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?			
13. Were outcomes reported or subgroups analyzed prespecified (i.e., identified before analyses were conducted)?			
14. Were all randomized participants analyzed in the group to which they were originally assigned, i.e., did they use an intention-to-treat analysis?			

Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the research question or objective in this paper clearly stated?			
2. Was the study population clearly specified and defined?			
3. Was the participation rate of eligible persons at least 50%?			
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?			
5. Was a sample size justification, power description, or variance and effect estimates provided?			
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?			
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?			
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?			
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
10. Was the exposure(s) assessed more than once over time?			
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?			
12. Were the outcome assessors blinded to the exposure status of participants?			
13. Was loss to follow-up after baseline 20% or less?			
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?			

Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group

Criteria	Yes	No	Other (CD, NR, NA)*
1. Was the study question or objective clearly stated?			
2. Were eligibility/selection criteria for the study population prespecified and clearly described?			
3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?			
4. Were all eligible participants that met the prespecified entry criteria enrolled?			
5. Was the sample size sufficiently large to provide confidence in the findings?			
6. Was the test/service/intervention clearly described and delivered consistently across the study population?			
7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?			
8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?			
9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?			
10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?			
11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?			
12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?			

Appendix D: Oxford Centre for Evidence Based Medicine (CEBM)

Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence

Question	Step 1 (Level 1*)	Step 2 (Level 2*)	Step 3 (Level 3*)	Step 4 (Level 4*)	Step 5 (Level 5)
How common is the problem?	Local and current random sample surveys (or censuses)	Systematic review of surveys that allow matching to local circumstances**	Local non-random sample**	Case-series**	n/a
Is this diagnostic or monitoring test accurate? (Diagnosis)	Systematic review of cross sectional studies with consistently applied reference standard and blinding	Individual cross sectional studies with consistently applied reference standard and blinding	Non-consecutive studies, or studies without consistently applied reference standards**	Case-control studies, or "poor or non-independent reference standard**	Mechanism-based reasoning
What will happen if we do not add a therapy? (Prognosis)	Systematic review of inception cohort studies	Inception cohort studies	Cohort study or control arm of randomized trial*	Case-series or case-control studies, or poor quality prognostic cohort study**	n/a
Does this intervention help? (Treatment Benefits)	Systematic review of randomized trials or *n*-of-1 trials	Randomized trial or observational study with dramatic effect	Non-randomized controlled cohort/follow-up study**	Case-series, case-control studies, or historically controlled studies**	Mechanism-based reasoning
What are the COMMON harms? (Treatment Harms)	Systematic review of randomized trials, systematic review of nested case-control studies, *n*-of-1 trial with the patient you are raising the question about, or observational study with dramatic effect	Individual randomized trial or (exceptionally) observational study with dramatic effect	Non-randomized controlled cohort/follow-up study (post-marketing surveillance) provided there are sufficient numbers to rule out a common harm. (For long-term harms the duration of follow-up must be sufficient.)**	Case-series, case-control, or historically controlled studies**	Mechanism-based reasoning
What are the RARE harms? (Treatment Harms)	Systematic review of randomized trials or *n*-of-1 trial	Randomized trial or (exceptionally) observational study with dramatic effect			
Is this (early detection) test worthwhile? (Screening)	Systematic review of randomized trials	Randomized trial	Non -randomized controlled cohort/follow-up study**	Case-series, case-control, or historically controlled studies**	Mechanism-based reasoning

*** Level may be graded down on the basis of study quality, imprecision, indirectness (study PICO does not match questions PICO), because of inconsistency between studies, or because the absolute effect size is very small; Level may be graded up if there is a large or very large effect size.**

**** As always, a systematic review is generally better than an individual study.**

How to cite the Levels of Evidence Table
OCEBM Levels of Evidence Working Group*. "The Oxford 2011 Levels of Evidence".
Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653

** OCEBM Table of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson*

Appendix E: Article Submission Status - Currently Under Review

Submission Confirmation for Auditory acclimatization in new adult hearing aid users: A registered systematic review of magnitude, key variables, and clinical relevance - [EMID:3a4235a46f8337d2] Inbox ×

JSLHR <em@editorialmanager.com> Wed, 4 Dec 2024, 14:12
to me

JSLHR-24-00856
Auditory acclimatization in new adult hearing aid users: A registered systematic review of magnitude, key variables, and clinical relevance
Journal of Speech, Language, and Hearing Research

Dear Miss Clarissa Wentzel,

This message serves as confirmation that your submission entitled "Auditory acclimatization in new adult hearing aid users: A registered systematic review of magnitude, key variables, and clinical relevance" has been received by the Journal of Speech, Language, and Hearing Research.

You will be able to check on the progress of your paper by logging on to Editorial Manager as an author. The URL is https://www.editorialmanager.com/jslhr/.

The manuscript number is JSLHR-24-00856.

Appendix F: Detailed Speech Recognition Percentages, Signal-to-Noise Ratios (SNRs), and Performance Criteria

Study	Assessment measures	Speech in Quiet /noise	Measurement (percentage / SNR) & Performance criteria
Gatehouse, (1992)	WRS & FAAF	WRS: Q FAAF: N	WRS used AB (S) word lists, difficulty equated British PB lists with ten items each. Masking noise simulated the speech spectrum in the non-test ear. SIN employed an adaptive FAAF test with 80 items, presenting them at a calibrated intensity of 65 dB SPL. In both adaptive and fixed SNR presentations, performance was assessed by randomizing the order of 80 items and measuring the percent correct identification of words.
Silman et al. (1993)	SRT, W-22, SIN & NST	SRT, NST, W-22: Q SIN: N	SRT testing covered taped spondaic W-1 words and suprathreshold speech-recognition with CID W-22 monosyllabic PB words. The SPIN test, with 96 sentences and 12-talker babble, employed an up-down adaptive procedure to find the SNR for 50 percent sentence recognition, presented at 40 dB SL. The NST consisted of seven subtests with a closed-set format.
Taylor, (1993)	SRT, WRS	WRS: Q+N	The word recognition tests were conducted both in quiet and in the presence of speech spectrum noise at a +10 dB SNR. The word lists were presented at 50 dB HL
Bentler et al, (1993a)	NST & SPIN	NST: Q/N SPIN: N	The SPIN test used a background of 12-talker babble at a +8 dB signal-to-noise ratio. It comprises 50 sentences, with half having high predictability and half low predictability. The NST utilized 62 items organized into subtests of seven to nine syllables, covering major consonant sounds with the vowels. Each subject heard two randomly selected NST lists per session, one in quiet and one in speech-weighted noise. Two types of noise were used: multi-talker babble and random noise. Presentation levels and signal-to-background noise ratios were constant for all sessions (+8 for SPIN, +5 for NST), with slight variations based on circuit activation or listener preference.
Cox et al., (1996)	CST & SPAC	N	The CST has 10 sentences per passage on common topics, spoken by a female talker, with six-talker babble as competing sound. Each passage has 25 scoring words, and this study used 12 passages (300 words) per score. The SPAC test requires selecting a target word from a set of four embedded in short sentences, featuring eight speech features, 48 items per form, and 12 test items per feature pair. To control for talker intelligibility, the same talker recorded material for both tests. Scoring for both CST and SPAC is based on percent correct responses.
Humes et al, (1996)	NST & HINT	NST: Q HINT: N	The NST, comprising 11 subtests and 102 items, was conducted in quiet at 70 dB SPL. The sound field presentation level was specified using a speech-shaped noise at a rms level equivalent to the stimuli's average, determined through substitution. Additionally, the HINT, a sentence-based measure, was presented in multitalker babble at a fixed +8 dB signal-to-babble ratio. Scores were based on separate lists for each ear and session, with speech and babble mixed before transduction.
Horwitz et al., (1997)	NST	N	Speech recognition ability was objectively assessed using a digitized subset of UCLA's NST stimuli. Subjects completed three randomized runs, each with different lists of 16 syllables varying in talker and consonant position, with the first run serving as a practice session and excluded from scoring. Scores were derived from four repetitions of the three lists (192 syllables in total). Speech was presented at 70 dB SPL with a background of speech-shaped noise at 50 dB SPL, determined through pilot studies to minimize ceiling effects while maintaining a sufficient signal-to-noise ratio. For subjects whose unaided practice scores exceeded 80%, the noise level was increased to 55-65 dB SPL to avoid ceiling effects.
Suanders & Cienkowski. (1997)	SRT-Q, PSRT-N, and SSRT-N.	SRT-Q PSRT-N SSRT-N	SRT-Q used CID W-1 spondees with a 2 dB step size. For SRT-N, HINT test sentences were employed, consisting of 250 short, intelligible sentences divided into 25 lists. Sentences were masked by spectrally shaped noise. SRT-Ns were measured through two procedures: Subjective SRT-N (SSRT-N), which eliminated silent intervals, and Performance SRT-N (PSRT-N), involving sentence repetition. S/N adjustments were made based on responses, with different SRT calculations for each procedure. Both SSRT-N and PSRT-N maintained the same speech level.
Arlinger & Billermark, (1999)	SRT	N	SRT in noise was assessed using an adaptive test procedure, yielding a SNR corresponding to 40% correct recognition of test words from Hagerman's lists (1984). The material, recorded on CD, comprises low-redundancy sentences with ten lists, each containing five words. Two speech levels, 60 dB and 75 dB, were utilized, measured as equivalent C-weighted sound pressure levels in the quasi-free sound field.
Humes et al., (2002b)	NST & CST	NST: N CST: Q+N	The four test conditions included: (1) NST at 65 dB SPL with +8 dB SNR using recorded multitalker babble; (2) CST at 50 dB SPL in quiet; (3) CST at 65 dB SPL with +8 dB SNR using recorded multitalker babble; and (4) CST at 80 dB SPL with 0 dB SNR. The NST utilized the full 102-item version, while the CST scores were based on two consecutive passages, each containing 25 key words for scoring.
Munro & Lutman, (2003)	FAAF for quiet, normal, and raised speech levels	N	The FAAF test consists of 20 sets of four words, creating an 80-item vocabulary. Speech and noise levels were defined at the reference point, approximating quiet, normal, and raised speech at 55-, 62-, and 69-dB SPL, respectively. Subjects were tested at a fixed SNR across conditions, determined individually for each subject using an adaptive FAAF strategy targeting 71% correct at a 62 dB SPL presentation level. Performance was measured at this fixed SNR for all speech presentation levels, assessing the percentage of correctly identified words
Humes & Wilson, (2003)	NST & CST	NST: N CST: Q+N	NST at 65 dB SPL with +8 dB SNR in babble, CST at 50 dB SPL in quiet, and CST at 65 dB SPL with +8 dB SNR in babble. The speech signal for all speech-recognition measurements emanated from a loudspeaker, positioned 1 meter in front of the participant at 0° azimuth and elevation. Noise competition was delivered from an identical loudspeaker located 1 meter behind the participant at 180° azimuth and 0° elevation.
Reber & Kompis, (2005)	SRT (German ''Freiburger'' word-test & the German ''Basler'' sentence test)	SRT: Q+N	Patients underwent German 'Freiburger' monosyllabic word tests at 50-, 65-, and 80-dB SPL, along with the German 'Basler' sentence test in noise. To avoid ceiling effects, speech tests in quiet were conducted at three intensity levels. Speech audiometry in both quiet and noise conditions occurred during these sessions.

Prates & Iório., (2006)	PISR & SRT	PISR: Q SRT: N	PISR included presenting 25 monosyllabic words at 65-75 dB[A] intensity, with the patient repeating them. Mistakes were noted, and a percentage of correct repetitions was calculated. For SRT in noise, a list of sentences with competitive noise was used to establish a SNR. The adaptive sequential strategy adjusted stimulus intensities based on responses, using 4 dB and later 2 dB intervals. Starting with the first sentence at 65 dB and competitive noise at 65 dB, the SNR was calculated as the difference between the SRT and competitive noise intensity (65 dB).
Yund et al, (2006)	NST	N	NST: Each run involved one of each of the 54 syllables, employing LA and WDRMCC processing, resulting in a total of 108 trials. A 2-hour laboratory session comprised 12 experimental runs (1,296 trials) with varying SNRs presented in descending order (15, 5, and –5 dB). Subjects were instructed to respond to each trial, making their best guess if uncertain.
Amorim & Almeida., (2007)	Speech discrimination	Q	Speech discrimination percentage scores were evaluated using a word list featuring 50 monosyllables recorded on a compact disk. The list was presented at a comfortable level of 25-40 dBNS above the SRT. This phonetically balanced word list consists of 25 monosyllable words presented in four different combinations. Each ear was individually assessed, totaling 50 words for the overall evaluation.
Petry et al., (2010)	SRTS, SRTN, SRPRS & SRPRN	SRTS: Q SRTN: N	SRTS, SRTN, SRPRS, and SRPRN employed a 25-sentence list in seven sets with speech spectrum noise. Unique lists were chosen to prevent repetition. The SRT was determined using a sequential, adaptive, or ascending-descending strategy, adjusting intensity until subjects correctly identified about 50% of stimuli. Initial 4 dB intervals were followed by 2 dB intervals. Mean threshold values and percentage rates were calculated based on the first response change in intensity and correct responses, respectively.
Choi et al., (2011)	WIN	N	The subjects were presented with 25 monosyllables in the Korean language, spoken live under multi-talker babble noise. The noise intensity was consistently set at 70 dB HL, with a SNR of -3 dB. The correct reaction rate was denoted as the speech discrimination score (SDS) in noise (%).
Song et al., (2011)	WRS	Q	WRS was assessed using 50 phonemically balanced words, presented through insert earphones at 30 to 40 dB above the patient's speech recognition threshold. Randomized presentation mitigated learning effects. Statistical significance, determined by Raffin and Thornton criteria, identified clinically significant differences between pre-aided and post-aided word recognition scores within the 70% to 100% range, while scores outside this interval were considered different.
Pinheiro et al., (2012)	PISR & DDT	Q	For the PISR, words were presented at an intensity of 30 dBNS, calculated from the average hearing thresholds at 500 Hz, 1 kHz, and 2 kHz. For the DDT, only the binaural integration component was administered, targeting the subject's ability to group acoustic stimuli for verbal sound figure-ground discrimination. The stimulus intensity was set at 40 dBNS, based on the mean thresholds at the same frequencies, ensuring both audibility and comfort for the subjects.
Dawes et al., (2014a)	FAAF	N	The FAAF test comprises 20 sets of four binary words, resulting in an 80-item test that focuses on auditory/phonetic distinctions. Responses are scored as correct or incorrect, with an overall percentage and error breakdown. Target phrases were presented at 65 dB SPL and 75 dB SPL against steady noise with the same spectrum. At baseline, the SNR for 50% correct was determined for each participant and listening condition. Adaptive testing began with an initial noise level of 55 dB SPL (SNR +10 dB), with a 4 dB step size, reduced to 2 dB steps for the last ten reversals. The final eight reversals provided the SNR for the 50% criterion performance for each condition. This criterion SNR was then used for testing with the full 80-item FAAF version at baseline and week 12. Note that SNR was set independently for each condition.
Dawes et al., (2014b)	FAAF	N	The FAAF test comprises 20 sets of four binary words, totaling 80 items, scored for overall percentage correctness. Targets were presented at 65- and 75-dB SPL against a steady noise with the same spectrum, both from the same loudspeaker at zero degrees azimuth. In each session, participants first completed a familiarization run of 40 words at easy levels. At the baseline session, the adaptive FAAF determined the SNR for 50% correctness for each participant and listening condition. Subsequently, participants were tested at this SNR using the 80-item FAAF version at both baseline and week 12.
Lavie et al., (2015)	Dichotic Tests, SIN, Monosyllabic Word Identification in Quiet	Dichotic & SIN: N Mono syllabic: Q	Participants were tested on SIN and dichotic listening tasks using Hebrew word lists. For the SIN test, 28 lists of 20 bisyllabic words were presented with multitalker babble noise from three loudspeakers positioned around the listener. The SNRs were adjusted by varying the noise levels while keeping word levels constant, and SNRs were pre-identified for each participant to achieve 30%–80% word recognition. Follow-up tests at 1 and 2 months, as well as at a later stage, measured identification scores using the pre-identified SNRs to reflect both threshold estimation and everyday listening environments. For the dichotic listening test, participants were presented with six lists of 25 pairs of monosyllabic words, with one word of each pair presented to each ear simultaneously. The test aimed to determine ear dominance, with scores based on the percentage of correctly repeated words. The scores from the pretest established the dominant ear, which was used for further analysis.
Chang et al., (2016)	WRS	Q	WRS were determined using 50 single-syllable words presented at 30 dB above the speech reception threshold for each ear.
Dawes & Munro., (2017)	SIN	N	Sentence were presented at 65 dB SPL from a center speaker at 0° azimuth and ear level, had initial background noise at an SNR of +4 dB. Six random noise recordings, free of intelligible speech, were used from ±45° azimuth loudspeakers, adjusting based on correct content word identification.The 50% correct recognition threshold was adaptively estimated, beginning with a 4 dB step size for the initial 4 reversals and decreasing to 2 dB steps for the final 10 reversals. The average of the last eight reversals determined the criterion performance SNR.
Habicht et al., (2018)	Processing times & SRT	SRT: N	The Oldenburg corpus consists of two sentence structures: subject–verb–object (low linguistic complexity) and object–verb–subject (high linguistic complexity), determined by subtle grammatical cues in German. Participants repeated words from these sentences, first in a training session of 40 sentences, then estimating the SNR for 80%-correct speech reception (SRT80) with 40 additional sentences. Stationary speech-shaped noise at 65 dB SPL was used for all measurements, with speech stimuli amplified based on individual REIGs.
Karawani et al. (2018b)	QuickSIN	N	QuickSIN is a nonadaptive clinical test where sets of six sentences were presented binaurally at 70 dB HL in four-talker babble. The sentences started at +25 dB SNR and decrease by 5 dB for subsequent sentences, reaching 0 dB SNR. SNR scores were averaged across four lists to get a composite score, with lower SNR loss values indicating improved speech understanding in noise.

Megha & Maruthy, (2019b)	Sentence Recognition scores (quiet & in noise)	N	It measures the dB difference between speech and noise levels at which 50% of words were correctly repeated. Participants repeated words in MATLAB-generated speech spectrum-shaped noise. Starting at 20 dB SL with +8 dB SNR, noise levels adjusted based on performance: increasing for correct repetitions and decreasing for errors, with a minimum of eight reversals.
Megha & Maruthy, (2020)	SIN	N	The study used 20 consonant-vowel syllables for the SIN test. These syllables were presented amid speech-spectrum shaped noise at 0 dB SNR to explore how participants adapted to task difficulty. Participants identified syllables from a randomly ordered set, with each syllable repeated five times.
Glick & Sharma., (2020)	QuickSIN, Arizona Auditory-Visual (AzAv) test	N	Quick SIN: Used SNR loss to show the SNR needed for the subject to get 50% of words correct. Lower scores mean better auditory speech perception in noise, while higher scores indicate poorer performance. AzAv: The performance was evaluated based on visual (lip-reading) benefit
Wright & Gagné, (2021)	HINT	N	SNR, indicating the level for 50% sentence accuracy. The SNR for each sentence list was adjusted based on participant performance within specified score ranges (0-24%, 25-44%, 45-55%, 56-75%, 76-100%), resulting in proportional increases or decreases for subsequent lists.
Ito et al. (2023)	Speech Discrimination: Japanese Monosyllabic List	Q	Speech discrimination was measured with the Japanese 67-S monosyllabic word list (20 words) before hearing aid fitting. The test was conducted at 40-50 dB above the hearing threshold, with adjustments of ±10-15 dB to determine the speech recognition curve. The highest score on this curve was used as the maximum speech discrimination score.To evaluate clinical improvement, this score was compared to those obtained under aided conditions using pure tone audiometry and functional gain measures. A 10% or greater increase in the score with the 57-S word list, indicated clinical improvement.

Note: CST= Connected Speech Test, DDT= Dichotic Digits Test, dB HL= decibels hearing level, dB SPL= decibels sound pressure level, dB SL= decibels sensation level, HINT= Hearing in Noise Test, N= Noise, NST= Nonsense Syllable Test, PB= Phonetically balanced, PISR= Percentage Index of Speech Recognition, PSRT-N= Performance SRT-N, Q= Quiet, SRT= Speech recognition threshold, SPAC= Speech Performance in Noise, SPIN= Speech Perception in Noise, SSRT-N= Subjective SRT-N, WIN= Words in noise , WRS= Word Recognition Score.

Appendix G: Quality Assessment and Level of Evidence ratings

Study	12/14-question NIH quality assessment score	NIH Quality rating (good, fair, poor)	Level of evidence (CEBM)
Gatehouse (1992)	7/12	Fair	3
Mulrow et al. (1992)	9/12	Good	4
Silman et al. (1993)	10/14	Fair	3
Taylor (1993)	9/12	Good	4
Bentler et al. (1993a)	7/14	Fair	3
Bentler et al. (1993b)	7/14	Fair	3
Cox et al. (1996)	6/14	Fair	3
Humes et al. (1996)	7/14	Fair	3
Horwitz et al. (1997)	7/14	Fair	3
Saunders & Cienkowski (1997)	7/14	Fair	3
Arlinger & Billermark (1999)	10/14	Fair	3
Humes et al. (2002a)	8/12	Fair	4
Humes et al. (2002b)	7/12	Fair	4
Munro & Lutman (2003)	10/12	Good	3
Humes & Wilson (2003)	7/12	Fair	4
Munro & Lutman (2004)	8/14	Fair	3
Philibert et al. (2005)	8/12	Fair	4
Reber & Kompis (2005)	8/12	Fair	4
Vestergaard (2006)	7/14	Fair	3
Prates & Iório. (2006)	8/12	Fair	4
Yund et al. (2006)	7/14	Fair	3
Amorim & Almeida (2007)	7/12	Fair	3
Metselaar et al. (2009)	9/14	Fair	2
Petry et al. (2010)	8/14	Fair	3
Choi et al. (2011)	8/14	Fair	3
Song et al. (2011)	8/12	Fair	4
Pinheiro et al. (2012)	9/12	Good	4
Laperuta & Fiorini (2012)	10/12	Good	3
Dawes et al. (2013)	8/14	Fair	3
Dawes et al. (2014a)	9/14	Fair	3
Dawes et al. (2014b)	9/14	Fair	3
Lavie et al. (2015)	10/14	Fair	3
Chang et al. (2016)	5/14	Poor	3
Dawes & Munro (2017)	9/14	Fair	3
Habicht et al. (2018)	10/14	Fair	3
Karawani et al. (2018a)	11/14	Good	2
Karawani et al. (2018b)	11/14	Good	2
Maruthy (2019)	9/12	Good	4
Megha & Maruthy (2019)	7/12	Fair	4
Megha & Maruthy (2020)	7/14	Fair	3
Glick & Sharma (2020)	8/14	Fair	3
Wright & Gagné (2021)	13/14	Good	2
Karawani et al. (2022)	8/14	Fair	3
Ito et al. (2023)	9/12	Good	4