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

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Author Contributions Statement

Clarissa Wentzel conducted the study, performed the literature search, data analysis, extracted data from the included studies, and drafted the manuscript. De Wet Swanepoel provided supervision, contributed to key decisions, and critically revised the manuscript. Faheema Mahomed-Asmail co-supervised, assisted with the literature search, reviewed retrieved articles, and provided feedback on article inclusion and manuscript revision. Eldré Beukes contributed to the attempted meta-analysis and provided insights during data exploration. Piers Dawes critically revised the manuscript and contributed to structuring the discussion and clinical implications. Kevin Munro reviewed the manuscript and contributed to the interpretation of the results. Ibrahim Almufarrij revised the methodology section and provided feedback on the meta-analysis. Vinaya Manchaiah conceptualized the study, supervised the project, and provided substantial revisions. All authors approved the final manuscript for submission.

ABSTRACT

Purpose: Auditory acclimatization refers to systematic changes in auditory performance over time, linked to the acoustic modifications introduced by hearing aids, with improvements extending beyond task-specific or training effects. This pre-registered systematic review expands on previous reviews by examining a broader range of outcomes, including auditory (e.g., speech recognition, electrophysiological responses) and selected non-auditory measures (e.g., self-reported measures). It aimed to determine the presence and magnitude of acclimatization and identify influencing factors, focusing on controlled trials comparing post-fitting changes in aided outcomes against a control group. Notably, this was the first review to comprehensively report on self-reported outcomes, marking a potentially significant contribution to the field.

Method: A systematic literature search was conducted in CINAHL, PubMed, and Web of Science in March 2024. Eligibility criteria, based on the PICOST framework, required studies to focus on new adult hearing aid users with sensorineural hearing loss using air conduction hearing aids, reporting speech recognition, self-reported, or electrophysiological outcomes, and employing a comparator in prospective designs with at least two data points measured within the same condition to observe changes over time. Exclusions applied to studies involving children, advanced feature devices, surgical implants, non-peer-reviewed work, or those with no comparator (uncontrolled studies). The review was registered on PROSPERO and followed PRISMA guidelines. A meta-analysis was attempted but excluded due to missing data.

Results: The systematic review included 25 controlled studies on auditory acclimatization. Of these, 18 examined behavioural speech recognition, with 10 reporting acclimatization, 1

mixed result, and 7 no acclimatization. Among 8 studies with self-reported outcomes, 3 supported acclimatization, 3 showed mixed results, and 2 found no evidence. For electrophysiological outcomes, 4 of 7 studies reported acclimatization, and 3 did not. Consistent hearing aid use and hearing loss severity appeared to influence acclimatization, while cognitive abilities and age showed no significant impact. Of the 25 studies reviewed, 16% were rated as good quality, 80% as fair, and 4% as poor, with common quality issues including lack of randomization, blinding, and insufficient reporting on sample size.

Conclusion: This review highlighted the complexity of auditory acclimatization to hearing aids, which could be influenced by various factors. Evidence suggested that acclimatization occurred in some users and for certain outcomes, while not for others, with overall modest improvements and variable results. The most consistent gains were observed in speech recognition in noise and self-reported measures, including the APHAB, HHIE, and GHABP questionnaires, although changes were generally modest. Future studies should include essential statistical data, such as correlation coefficients for within-subject designs, to enable robust meta-analyses, prioritize well-controlled studies, and ensure early baseline and key interval measurements to better isolate and quantify acclimatization effects.

KEYWORDS

Hearing aids, Amplification, Acclimatization, Adaptation, Perceptual learning, Benefit changes over time, Improvements over time

INTRODUCTION

Auditory acclimatization is conceptualised as the improvement in auditory performance that occurs after the provision of amplified acoustic information, during 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) track changes over time, and (iii) compare with a control group. 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 (Karawani et al., 2022; Munro & Lutman, 2003), while others have not (Choi et al., 2011; Dawes et al., 2013; Saunders & Cienkowski, 1997).

With respect to speech recognition outcomes, accuracy of aided speech recognition is typically assessed in terms of percentage correct (Horwitz & Turner, 1997), 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 listening conditions of the fitted ear at the outset and after a 12-week period. The investigation found that the

ear with the hearing aid experienced an improvement in speech recognition over the 12 weeks in the aided listening condition, whereas there was a decline in speech recognition in the fitted ear in the unaided listening condition. 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. Similarly other studies have also noted improvements in aided listening for new hearing aid users (Munro & Lutman, 2003). Wright and Gagné (2021) observed a 2 dB improvement in SNR for new users over four weeks, whereas experienced users showed no change. However, several studies (Amorim & Almeida, 2007; Dawes et al., 2014a; Saunders & Cienkowski, 1997) did not find improvements in speech recognition.

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; 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., 2002; Yund et al., 2006).

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) measures. Results have been mixed. Dawes et al. (2013) reported no changes in Auditory Brainstem response (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.

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).

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. 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). There remains ongoing uncertainty about the presence and significance of auditory acclimatization, emphasizing the need for this updated and comprehensive review. Unlike the previous review by Lavie et al. (2022), which focused exclusively on speech perception outcomes, this review examined a broader range of outcome domains. These included (a) behavioural measures, such as the accuracy of aided speech recognition, (b) self-reported changes, including hearing aid benefit and satisfaction, and (c) electrophysiological measures. Notably, this was the first review to report comprehensively on self-reported measures, offering a novel and significant contribution to the field.

The aim of this review was to systematically evaluate auditory acclimatization in new hearing aid users in an up-to-date synthesis of research. This review builds on the foundational work of Arlinger et al. (1996) and Gatehouse (1992) by broadening the scope of auditory acclimatization to include both auditory and selected non-auditory factors, such as self-reported satisfaction and quality of life, as measuring potential changes over time. We incorporate Patient-Reported Outcome Measures (PROMs), alongside speech recognition and electrophysiological measures, to capture a more comprehensive view of acclimatization than previous reviews. Our analysis excludes broader, indirect benefits of hearing aids, such as changes in depression, physical activity, listening effort or social engagement, which fall outside the definition of auditory acclimatization.

Many previous studies on acclimatization lacked control groups (Humes et al., 2002; Philibert et al., 2005; Yund et al., 2006), making it difficult to distinguish acclimatization effects from those arising from repeated testing. Without a control group, attributing observed improvements solely to acclimatization is challenging, as factors such as familiarity with the testing environment or practice effects could provide a more parsimonious explanation for any improvements. To address this, our review explicitly focused on findings from controlled studies, which offer stronger evidence by enabling clearer differentiation between acclimatization effects and other potential influences.

Controlled studies were defined as those including a comparison group (e.g., experienced hearing aid users or non-hearing aid users) to isolate acclimatization effects from confounding factors. This criterion ensured our findings were drawn from robust evidence, allowing us to

examine the magnitude, time course, clinical relevance, and influencing factors of acclimatization.

The specific research questions were:

1. Is there evidence of systematic improvement in speech recognition, self-reported, and electrophysiological measures consistent with acclimatization following hearing aid use?
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?

METHOD

The review protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO) website [protocol ID: (CRD42021258723)]. The review was performed and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 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 1).

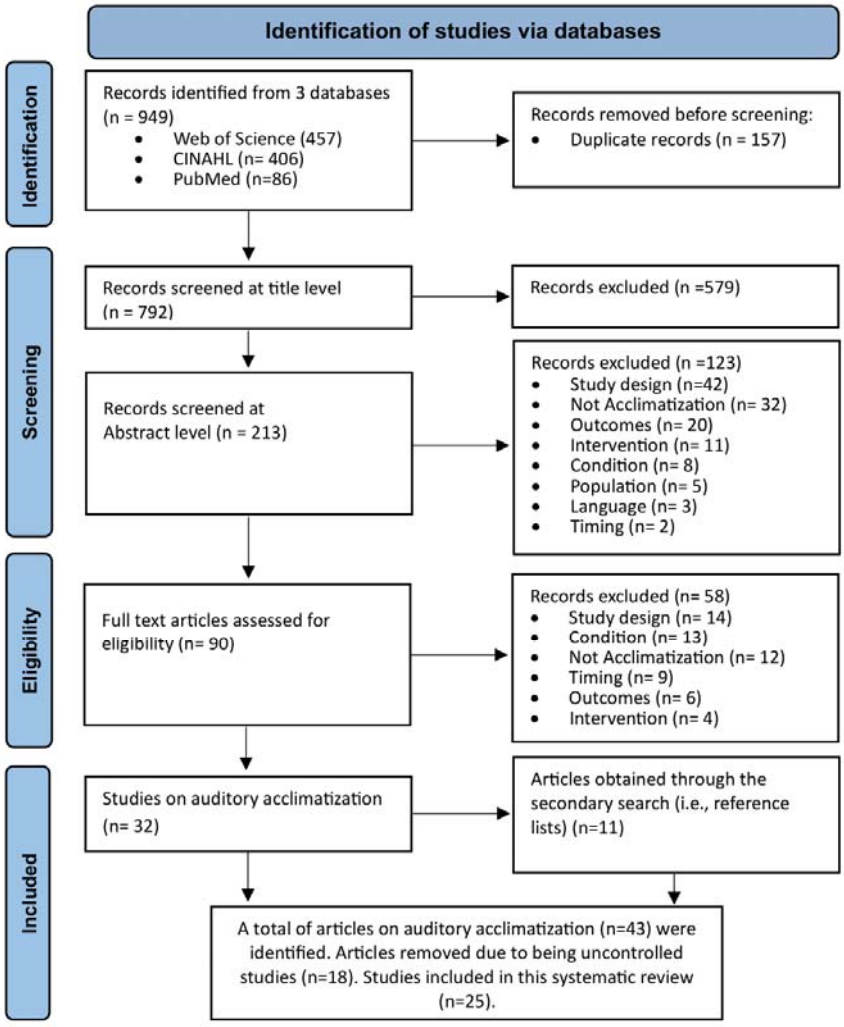
Table 1: Eligibility Criteria

	Inclusion	Exclusion
Population	New hearing aid users aged 18 and above. Studies exclusively involving human subjects.	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, aided ear versus unaided ear as the control in unilateral fittings).	Uncontrolled studies (Where there was no comparator)
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, depression, social engagement, and listening effort 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. Studies were included from 1992 onward.	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 (https://www.rayyan.ai/). 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 (Figure 1).

Figure 1. PRISMA flow diagram



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 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, scores were categorized as follows: 11–14 as 'good,' 6–10 as 'fair,' and 0–5 as 'poor.' For Before-After (Pre-Post) studies without a control group, scores of 9–12 were considered 'good,' 5–8 as 'fair,' and 0–4 as 'poor.' This scoring categorization follows the system used by 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. 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 (OCEBM) 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 conducted following the methods outlined by Campbell et al. (2020) and Popay et al. (2006).

*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. A quantitative analysis was not performed. The challenge of calculating standard deviations for each group over time—due to the interdependence of data points across time points—hindered further 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.

RESULTS

Search and Study Selection

A database search conducted in February 2023 and repeated in March 2024 yielded 949 records. After removing duplicates, 792 records were screened by title, resulting in the exclusion of 579 based on titles and 123 based on abstracts. The full texts of 90 articles were reviewed, and 32 met the inclusion criteria. An additional 11 relevant studies were identified through reference list review, bringing the total to 43 articles on acclimatization. Of these, 18 were uncontrolled studies and were excluded to focus on the 25 controlled studies, as shown in Figure 1. This review incorporates a larger number of studies, including 10 additional studies not included in previous reviews, reflecting expanded inclusion criteria and recent advancements in acclimatization research.

Study Characteristics

Table 2 provides an overview of the key characteristics of the 25 included studies. Among these studies, 18 studies focused on speech recognition, 8 examined self-reported outcomes, and 7 assessed electrophysiological measures. Notably, 7 studies investigated multiple outcomes, spanning two or more of these domains. These 25 studies were examined for outcome analysis in Tables 3-5, and 11 of them were included in the attempted meta-analysis. The 14 studies that were not considered for meta-analysis were excluded due to insufficient reporting on means and standard deviations. Almost half of the studies were conducted in North America (44%) while slightly more than a third were conducted in Europe (36%). All studies used a longitudinal design, assessing scores at multiple time points post-hearing aid

Table 2: Key characteristics of included studies (n= 25)

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)	UK	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	✓		✓		
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	✓	✓	✓		
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)	Yes (experienced HA users)	New vs experienced, Degree of HL, Configuration, Circuit type & wear time.	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	✓		✓		
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	✓		✓	✓	
Saunders & 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		✓	✓		
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.	✓		✓		
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		✓		✓	
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)	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	✓	✓		✓	
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	✓		✓		
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 (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	✓	✓	✓		✓
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		✓			✓

Note: AEP= Auditory electrophysiological potentials, 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, SNHL: Sensorineural hearing loss, SR= Self-reported, UK= United Kingdom, uni= unilateral, US= United States, vs= verses and WRS= Word recognition score.

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

intervention. The study designs included true experimental (n=4) and quasi-experimental (n=17) studies. Additionally, there were pre-experimental studies, which consisted of within-subject designs (n=4), where participants with unilateral fittings acted as their own control. 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 4 weeks to 1 year, with the most common duration being 12 weeks, followed by 6 months and 3 months. Sample sizes ranged from 4 to over 200 participants. Among the studies, 20% involved unilateral hearing aid users, 36% involved bilateral hearing aid users, and 44% included both types.

Tables 3 to 5 detail each study's 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 present study outcomes across the three main domains.

Summary of Studies on Speech recognition Outcomes

This systematic review analysed 18 studies on speech recognition, with 11 focusing on recognition in noisy environments, 2 in quiet, and 5 in both conditions (Supplementary Table 1). In total, 10 (56%) out of the 18 (39%) studies observed an acclimatization effect, while 7 studies did not. Additionally, 1 study (5%), Habicht et al. (2018), reported improvement in processing times but not in speech recognition threshold (SRT) (Table 3).

Table 3: Summary of controlled studies on Speech recognition outcomes (n=18)

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	• The initial three weeks post-fitting, benefits between the fitted and non-fitted ears were similar. • After approximately four to six weeks, a distinct pattern emerged. Over 12 weeks, the fitted ear showed significant speech recognition improvement in aided FAAF conditions, with a decline in unaided conditions. • In contrast, the non-fitted ear showed no significant 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.
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: Study group- A Student-Newman-Keuls post hoc test (α = .05) revealed no difference between the 0- and 12-week unaided scores. However, the 12-week aided scores were higher than the 0-week aided scores. While statistically significant, its absolute magnitude was only about 4 to 5% on average. Mean benefit in noise rose from approximately 4% at fitting to about 8% after 12 weeks of regular use. Control group: No observed improvement in scores over time. • SPAC: Study group- There were no significant differences across sessions for unaided listening. However, there was a significant change across sessions for aided listening ($F[3, 60] = 5.57$, $p < .01$). Student-Newman-Keuls post hoc test (α = .05) revealed that scores at 9 weeks post-fitting were better than those obtained at 0, 3, and 6 weeks. The time course of improved performance was between 6- and 9-weeks post-fitting. Control group- Both aided and unaided listening conditions showed no significant differences in overall scores across the four tests.
Horwitz et al. (1997)	18 weeks	Baseline, 3w, 6w, 10w, 14w, 18w post fitting	Not reported	-	NST	N	Yes	• Fixed initial gain NST: For new HA users, benefit increased from 7 rau at fitting to 14 rau over five follow-up visits. In contrast, long-standing users maintained a stable benefit, averaging 10 rau initially and 9 rau after 18 weeks. Statistical analysis showed a significant time effect on benefit for new users ($F[5, 120] = 4.187$; $p < .01$), but no significant change for long-standing users over the 18 weeks ($F[5, 120] = 0.592$; $p > .05$). • Daily adjusted gain NST: Average benefit for new HA users started at almost 8 rau and increased to 12 rau by Week 18. Long-standing users also experienced a slight increase, from 10 to 13 rau. The effect of time on mean benefit was significant for new users ($F[5, 120] = 2.978$; $p < .025$), but not for long-standing users ($F[5, 120] = 1.465$; $p > .05$).
Saunders & 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 showed no significant differences across visits for unaided listening on all measures (SRT-Q, PSRT-N, SSRT-N), with no interaction between volume setting and performance across sessions. However, a main effect of volume was found on SRT-Q ($p = .02$), as well as a session effect on SRT-Q ($p = .018$), but not PSRT-N or SSRT-N. • Aided advantages were similar for new and experienced users across all tests, with no significant interactions between user status and session. HA configuration only affected performance on PSRT-N ($p = .03$) and had a main effect on SRT-Q ($p = .02$).
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%. • The unaided scores initially were 55% with speech at 55 dB SPL but increased to approximately 71% with speech at 69 dB SPL. • The results confirmed acclimatization, indicating improved auditory performance over time. However, this effect was evident only at higher presentation levels, not the lowest. Therefore, the conclusion is that acclimatization in FAAF depends on speech presentation level, with greater improvements seen at higher levels.
Amorim & Almeida (2007)	18 weeks	Baseline, 4w, 16/18 w post fit	Not reported	-	Speech discrimination	Q	No	• The study noted that the word discrimination scores in aided and non-aided ears across the study's phases, showed no significant differences between groups ($p < .05$). • Unilateral users saw a decline in speech recognition in their non-aided ear and an improvement in their aided ear, which was linked to the audibility of the HAs. These results lacked statistical significance.

								• Conclusions: short-term benefits were obtained with the use of hearing aids; however the phenomenon of acclimatization was not observed through the SRPI
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 ($p < .05$), 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.
Dawes et al. (2014a)	12 weeks	Baseline & 12w post fitting	7.5 hrs/day	Objective (dataloggin g 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 (dataloggin g 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 $p > .05$).
Lavie et al. (2015)	14 weeks	Baseline, 4w, 8w, 14w post fitting	Not reported	-	Dichotic Tests, SIN, Monosyllab ic Word Identificati on 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. Bilateral amplification appeared more effective than monaural use, as it notably reduced ear asymmetry in dichotic listening tests. • 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. • The study concluded that even a short period of hearing aid use can improve auditory processing in older adults, particularly in speech-in-noise and dichotic listening tasks, suggesting that the central auditory system retains a capacity for beneficial plasticity.
Dawes & Munro (2017)	1 month	Baseline, 1-, 7-, 14- and 30-day post fitting.	Subgroup (>6 hrs/day)	Objective (dataloggin g feature)	SIN	N	Subset: Yes	• At day 30, new users did not significantly improve their SIN scores 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 significant SIN improvement of around 3 dB signal-to-noise ratio when compared to experienced users. Notably, this SIN enhancement in new users was associated with consistent HA use and more severe HL. Experienced users did not exhibit significant SIN improvement over time. • No discernible link was found between SIN improvements and cognitive ability or auditory distraction.
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: dataloggin g ExpHA: self-reported	Processing times & SRT	SRT: N	Processin g 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 (dataloggin g 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 ($p > .08$). The improvement in both groups likely reflects a practice effect rather than a true change due to HA use.
Megha & Maruthy (2020)	2 months	Initial, 1mo, 2mo post fitting. Control: recorded twice, 2 months apart.	8.1 hrs/day	Objective (dataloggin g 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.
Wright & Gagné (2021)	10 months	Baseline, 2w, 4w, 6w, 8w, 14w, 22w, 38w post fit.	12hrs/day	Objective (dataloggin g 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.

Note: ALLR= Auditory Late Latency Responses, ANOVA= Analysis of Variance, CST= Connected Speech Test, FAAF= Four Alternative Auditory Feature Test, HA= hearing aids, HINT= Hearing in Noise Test, hrs/day= hours per day, mo= month, NST= Nonsense Syllable Test, PSRT-N= Performance SRT-N, Q= quiet, SIN= Speech in Noise, SPAC= Speech Pattern Contrast, SPIN= Speech Perception in Noise, SNR= Signal to noise ratio, SRPI= Speech recognition performance index, SRT= Speech recognition threshold, SSRT-N= Subjective SRT-N, w= weeks, WIN= Words in noise and WRS= Word Recognition Score.

Aided Speech Recognition in Quiet

The evidence for changes in aided speech recognition in quiet varied across studies. Silman et al. (1993) reported significant improvement in the fitted ear of new, monaurally aided users, while the non-fitted ear slightly declined, suggesting an acclimatization effect for monaural hearing aid users. No changes were observed in the control group of non-hearing aid users, indicating that the improvement in the aided ear was specific to hearing aid use. In contrast, Bentler et al. (1993a) found no significant time effect on the Nonsense Syllable Test (NST) in quiet conditions for both part-time and full-time hearing aid users over a year, with minimal score changes under 5%, suggesting stable performance without substantial acclimatization. Similarly, Saunders and Cienkowski (1997) found no differences in speech recognition scores in quiet (SRT-Q) over three months between new and experienced users, and Amorim and Almeida (2007) also reported no significant differences in word discrimination scores in quiet for new unilateral and bilateral hearing aid users over the study period.

Aided Speech Recognition in Noise

The studies showed more consistent improvement in aided speech recognition in noise, often attributed to acclimatization. Gatehouse (1992) found a clear pattern of improvement in speech recognition for new unilateral hearing aid users in noise conditions, with aided scores in the fitted ear improving significantly over 12 weeks, while the non-fitted ear remained stable. Silman et al. (1993) reported similar findings, where monaural users demonstrated improved Speech Perception in Noise (SPIN) test scores in the aided ear, with a decline observed in the non-fitted ear. Additionally, Cox et al. (1996) found a gradual increase in noise benefit from approximately 4% to 8% over 12 weeks for new hearing aid users, with no change

in the control group. The Speech Pattern Contrast (SPAC) test also indicated enhanced performance between 6 and 9 weeks, suggesting an acclimatization effect.

Horwitz et al. (1997) noted an increase in benefit from 7 to 14 Rationalized Arcsine Units (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. Munro and Lutman (2003) reported further confirmation of acclimatization in noise, with aided scores in the fitted ear improving by 1.0%, 2.6%, and 3.6% at 55-, 62-, and 69-dB SPL, respectively, over 12 weeks, while the non-fitted ear showed consistent negative changes around -2.0%. Choi et al. (2011) found that new bilateral users showed improvement in the Words in noise (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 subset of new users with moderate hearing loss using hearing aids for at least 6 hours daily, who showed a significant improvement of approximately 3 dB in SNR over 30 days, particularly for speech-in-noise (SIN) tasks. However, experienced users did not show a similar improvement, highlighting the role of consistent use in achieving acclimatization effects in noise environments. Megha and Maruthy (2020) also observed improvements in speech-in-noise performance over two months in bilateral hearing aid users. Wright and Gagné (2021) reported a 2 dB SNR improvement over 4 weeks in new bilateral users, with no change in experienced users.

On the other hand, some studies did not find evidence of acclimatization. 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

Similar to Saunders and Cienkowski (1997), who reported no significant differences in unaided listening across visits, other studies also observed stability in unaided speech recognition over time. For instance, Song et al. (2011) found that unaided Word Recognition Scores (WRS) generally remained the same or decreased, while Lavie et al. (2015) reported no changes in unaided monosyllabic word identification in quiet across a 14-week period. Similarly, Amorim and Almeida (2007) found no significant differences in unaided speech recognition scores between aided and non-aided ears, though a slight decline was observed in the non-aided ear for unilateral users.

Unaided Speech Recognition in Noise

In unaided speech recognition in noise, most studies reported either no changes or slight declines over time. Gatehouse (1992) observed a decline in the fitted ear's performance over 12 weeks, while the non-fitted ear showed no significant changes. Cox et al. (1996) found no difference in unaided Connected Speech test (CST) scores between baseline and 12 weeks for both the study and control groups. Similarly, Saunders and Cienkowski (1997) observed no changes in unaided listening across visits. Munro and Lutman (2003) also found a slight, non-

significant decrease in mean unaided speech recognition scores in noise over time. In contrast, 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. However, Karawani et al. (2018b) noted improved QuickSIN scores in both experimental and control groups, but these improvements were likely attributable to a practice effect rather than true acclimatization.

In summary, evidence for acclimatization was inconsistent for aided speech recognition in quiet, with some studies (e.g., Silman et al., 1993) showing improvements in the fitted ear, while others (e.g., Bentler et al., 1993a; Saunders & Cienkowski, 1997) reported stable performance. In aided speech recognition in noise, most studies (e.g., Gatehouse, 1992; Munro & Lutman, 2003) showed consistent improvements, though some (e.g., Dawes et al., 2014a; Karawani et al., 2018b) attributed gains to practice effects. Unaided speech recognition in quiet was generally stable (e.g., Saunders & Cienkowski, 1997), with occasional declines in non-fitted ears, while unaided speech recognition in noise showed stability or slight declines (e.g., Munro & Lutman, 2003), with rare improvements probably due to practice effects (e.g., Karawani et al., 2018b)

Summary of Studies on Self-reported Outcomes

A diverse range of self-reported measures has been used to evaluate outcomes in auditory studies, focusing on factors such as hearing aid benefits and use. These include the Hearing Performance Inventory (HPI), Expectation Checklist, and tools like the Satisfaction Questionnaire, which assess user perceptions and satisfaction. The Profile of Hearing Aid Benefit (PHAB), GHABP, International Outcome Inventory for Hearing Aids (IOI-HA), and Hearing Aid Performance Questionnaire (HAPQ) are commonly employed to quantify

perceived hearing aid effectiveness. Additional tools like the Hearing Handicap Inventory for the Elderly (HHIE), APHAB, and SSQ address broader domains such as handicap, annoyance, and spatial hearing. Of the 8 studies reporting on self-reported outcomes, 3 showed clear evidence of acclimatization, 3 demonstrated evidence on certain measures but not others, and 2 indicated no evidence of acclimatization.

Horwitz et al. (1997) found that new hearing aid users experienced significant improvement in the aided condition on the PHAB scale across multiple visits, while experienced users showed no change; notably, no changes were observed in the unaided condition for either group. Vestergaard (2006) observed that first-time hearing aid users who wore their devices over four hours daily reported improvements on the GHABP and IOI-HA scales, but no change was noted on the Satisfaction with Amplification in Daily Life (SADL) and HAPQ scales. Metselaar et al. (2009) noted improvements in new users on the Handicap and Disability Inventory (HHDI) and APHAB scales, especially in areas like "withdrawal," ease of communication, background noise, and reverberation. Dawes et al. (2014a) found significant improvements on the SSQ scale for new unilateral and bilateral users, with no change observed for experienced users. Additionally, no correlation was found between SSQ-D scores and performance changes on the Four Alternative Auditory Feature Test (FAAF) for any listening condition among new users. Chang et al. (2016) reported significant improvements on the HHIE scale from pre-fitting to 1- and 3-months post-fitting, while IOI-HA scores showed no significant differences. Karawani et al. (2018b) observed statistically significant improvements in the APHAB subscales of ease of communication, reverberation, and background noise but noted an increase in awareness of aversive sounds; no improvements were observed on the SSQ scale.

Bentler et al. (1993b) tracked both part-time and full-time hearing aid users over one year. While HPI scores remained stable overall, items related to communication in quiet environments showed reduced difficulty over time. The Expectation Checklist revealed no changes in overall scores, but self-perceived communication performance exceeded expectations over time. Qualitative judgments and satisfaction measures showed no significant changes. Importantly, while trends in improved outcomes were noted across groups, the only statistically significant difference was the higher daily use time reported by experienced users. Dawes and Munro (2017) found no evidence of acclimatization, as no significant changes were reported in annoyance or distraction ratings for either new or experienced users during a background noise task.

In summary, acclimatization was most frequently detected in subjective measures assessing general hearing aid benefit, such as PHAB, GHABP and APHAB. In contrast, measures like the HPI, Expectation Checklist, Qualitative Judgments & Satisfaction Questionnaire, SADL, HAPQ, and IOI-HA showed no evidence of acclimatization. These findings suggest that while overall improvements in hearing aid benefit can be observed, specific measures—such as aversiveness, distraction, expectations, satisfaction, and situational responses—may not consistently reflect acclimatization (Table 4).

Summary of Studies on Electrophysiological Outcomes

A total of 7 studies examined electrophysiological outcomes, specifically ABR, Cortical Auditory Evoked Potentials (CAEPs), and late ERPs, to assess the effects of hearing aid use on neural adaptation and auditory processing over varying time frames. Among the studies, 4 (57%) provided evidence supporting acclimatization, whereas 3 (43%) did not find such

Table 4: Summary of studies on self-reported outcomes (n=8)

Study	*Duration of study*	*Time points measured*	*HA Use*	*How HA use was measured*	*Assessment measures*	*HA Acclimatization*	*Outcomes*
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. • The statistical analyses confirm that while there were trends in improved outcomes for both groups, there were no statistically significant differences between new and experienced hearing aid users in most measures, except for the significantly higher daily use time reported by experienced users.
Horwitz et al., (1997)	18 weeks	Initial fitting, 3w, 6w, 10w, 14w, 18w post fitting	Not reported	-	PHAB	Yes	• The simple main effects tests indicated a significant decrease in aided frequency of problems over five visits for new users ($F [4, 96] = 2.610$; $p < .05$), while no significant change was observed for long-standing users ($F [4, 96] = 0.804$; $p > .05$). Indicating that there was a significant interaction between hearing aid experience and time ($F [4, 96] = 3.049$; $p < .025$). • The average unaided results for both groups showed stable frequencies of problems over time. A 2-way repeated measures ANOVA found no significant effects of time ($F [4, 96] = 0.948$; $p > .05$) or hearing aid experience ($F[1, 24] = 0.062$; $p > .05$), nor was there a significant interaction between hearing aid experience and time ($F[4, 96] = 0.679$; $p > .05$). • In summary, while subjective benefit improvement (unaided minus aided conditions) was not significant, there was a significant improvement over time in the aided condition for new hearing aid users.
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 who wore their devices for over four hours daily reported improved outcomes over time compared to users with prior HA experience or those using their HAs for less than four hours daily. Notably, this improvement was observed in the GHABP ($F1,23= 5.95$, $p= .023$) an and IOI-HA scales ($F1,23=5.13$, $p = .033$), which address general aspects of HA benefit and satisfaction. In contrast, there was no such change over time in the SADL ($F1,23=3.86$, $p = .062$) and HAPQ ($F1,23= 0.54$, $p = .472$) scales, which focus on HA performance in specific situations.
Metselaar et al (2009)	12 months	Baseline, 2wk, 6wks, 12wks, 6mo, 12 months post fitting.	Not reported	-	HHDI, APHAB	Yes	• HHDI: New HA users experienced significant improvements in various aspects immediately after fitting, with sustained results over a year. Notably, new users showed better results in 'withdrawal,' while fitting procedures generally didn't differ significantly. In summary the new hearing-aid users reported lower withdrawal and greater benefit from their hearing aids compared to experienced users. • APHAB: After the initial fitting, users reported significant benefits in most subscales, except for aversiveness. These benefits remained consistent at the 26-week follow-up, and no significant differences were found between fitting procedures or levels of speech recognition. First-time users of hearing aids reported significantly greater benefit at 6 and 26 weeks compared to experienced users in subscales 'EC', 'BN', and 'RV'. However, in subscale 'AV', the benefit was negative: first-time users reported encountering more problems compared to experienced users.
Dawes et al., (2014a)	12 weeks	Baseline & 12w post fitting	7.5 hrs/day	Objective (datalogging feature)	SSQ	Yes	• The mean SSQ-D scores for new unilateral users (26.2, SD = 14.5) and new bilateral users (20.5, SD = 14.6) showed positive performance improvements over time, contrasting with experienced users (-0.2, SD = 11.7) who showed no significant change ($F(2,46) = 17.2$; $p < .01$). • The new unilateral and bilateral groups did not significantly differ from each other ($p = .65$), while the experienced user group scored significantly lower than both ($p < .01$). • Additionally, no significant correlations were found between SSQ-D scores and aided performance changes on the FAAF for any listening condition among new users (r's ranged from 0.00 to 0.10, all ns).
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: Statistically significant improvements in the EC, RV, and BN subscales with HA use. However, AV to sounds increased with HAs. Notably, despite heightened awareness of aversive sounds, the improvements in the EC, RV, and BN subscales indicate enhanced communication with HA use over the 6-month period. • SSQ: The paired samples t-test showed a significant improvement in the experimental group's speech subscale scores from pre- to post-assessment ($t(16) = 2.183$, $p = .044$), although this significance was lost after multiple comparison correction. No significant differences were found in the control group's pre- and post-scores ($t(12) = 0.699$, $p = .498$).

Note: APHAB= Abbreviated Profile of Hearing Aid Benefit, AV= Aversiveness, BN= Background Noise, EC= Ease of Communication, FAAF= Four Alternative Auditory Feature Test, GHABP= Glasgow Hearing Aid Benefit Profile, HA= Hearing Aid, , HAPQ= Hearing Aid Performance Questionnaire, HHDI= Handicap and Disability Inventory, HHIE= Hearing Handicap Inventory for the Elderly, hrs/day= Hours per day, IOI-HA= International Outcome Inventory for Hearing Aids, mo= Month, PHAB= Profile of Hearing Aid Benefit, RV= Reverberation, SADL= Satisfaction with Amplification in Daily Life, SSQ= Speech, Spatial and Qualities of Hearing Scale.

effects. 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.

The findings on acclimatization to hearing aids through electrophysiological outcomes were mixed, with some studies showing improvements in neural measures, while others found no significant changes over time. In Karawani et al. (2018a), the experimental group demonstrated increased N1 and P2 amplitudes, particularly in quiet conditions, suggesting that hearing aids had a positive impact on auditory processing. This improvement was driven by a significant interaction between time, amplification, and group, with the experimental group showing enhanced N1 and P2 amplitudes in aided conditions compared to the control group, which showed no significant changes. Similarly, in Karawani et al. (2018b), the experimental group exhibited stable peak latencies, while the control group showed delayed latencies, suggesting that hearing aids helped to mitigate neural timing delays, particularly for the F0 magnitude. Megha and Maruthy (2020) also found evidence of acclimatization, with the experimental group showing reduced latency and increased amplitude for P1 and N1 components, indicating neural adaptation, while P2 latency remained stable. In contrast, the control group showed minimal changes in latency and amplitude. In Karawani et al. (2022), neural changes were observed as early as 2 weeks post-fitting, with significant increases in N1 amplitude, followed by similar increases in P2 amplitudes by 6 weeks. This early change in N1 amplitude is indicative of neuroplasticity.

However, three studies found no significant evidence of acclimatization. Dawes et al. (2013), for example, found no changes in the latency or amplitude of ABR wave V after 3 months of

hearing aid use, despite participants using the devices for at least 6 hours a day. Similarly, Dawes et al. (2014b) observed no significant changes in N1 and P2 latencies or amplitudes after 12 weeks, suggesting that acclimatization did not occur. Habicht et al. (2018) also found no changes in ERP measures (N1, P2, N2, P3) over 24 weeks, indicating that the prolonged use of hearing aids did not result in significant neural adaptations in either new or experienced users (Table 5).

Factors Influencing Acclimatization

The factors potentially influencing acclimatization to hearing aids explored across the various controlled studies include hearing aid usage patterns, degree of hearing loss, cognition, age, and presentation levels (Table 6). Some studies found a link between consistent hearing aid use (>4 hours/day) and improved self-reported outcomes ($r = .37$, $p < .02$) but showed limited impact on speech recognition or electrophysiological measures. New users with severe hearing loss demonstrated significant speech-in-noise improvement (4.1 dB in 30 days, $p < 0.01$), while milder losses showed negligible changes. No significant correlations were found between acclimatization and cognitive factors or age. Acclimatization effects were inconsistent regarding presentation levels, with one study reporting improvements at higher presentation levels and not at lower levels, while another found no such effects at a higher intensity level.

Table 5: Summary of studies on electrophysiological outcomes (n=7)

Study	*Duration of study*	*Time points measured*	*HA Use*	*How HA use was measured*	*Assessment measures*	*Assessing*	*HA Acclimatization*	*Outcomes*
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 the new unilateral (NU) group, level significantly affected N1 and P2 amplitude, but no time-related effects were observed. For the new bilateral (NB) group, both N1 and P2 latencies were significantly influenced by level, and ear also significantly affected amplitudes, with no time-related changes. • The experienced user group showed significant effects of level on N1 latency and N1/P2 amplitudes, but no time-related effects. No significant correlations were found between changes in N1/P2 measures and factors such as age, hearing loss, or hearing aid use in new users. • Correlations between baseline and week 12 amplitudes and latencies were significant across all groups. Overall, no significant changes over time were detected in N1 or P2, suggesting that acclimatization effects related to hearing aid use were not observed.
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	• Significant differences in peak latencies were found between groups for quiet listening conditions (65 dB: $t(13) = 3.357$, $p = .005$; 80 dB: $t(13) = 3.684$, $p = .003$), with delayed latencies in the control group and no change in the experimental group ($t(17) < 0.868$, $p > .397$). Amplification led to earlier latencies (65 dB: $p = .002$; 80 dB: $p < .001$; Noise: $p = .002$). F0 amplitude decreased in the experimental group, particularly at 65 dB (interaction: $F(1,30) = 5.890$, $p = .021$). A main effect of amplification ($F(1,12) = 5.758$, $p = .023$) and region ($F(1,12) = 14.585$, $p = .001$) was observed, with no significant interactions. In summary, while the experimental group showed no latency changes, the control group exhibited delayed latencies. Physiological changes, such as reduced F0 magnitude, were seen in the experimental group, suggesting hearing aids may mitigate neural timing delays and affect subcortical processing
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, $\chi2\ (2, 30) = 38.64$, $p < .001$, $W = .64$, and N1, $\chi2\ (2, 30) = 24.88$, $p < .001$, $W = .41$, but not in P2, $\chi2\ (2, 30) = 0.47$, $p = .79$, $W = .008$. The amplitude also increased in P1 and N1 in ALLRs over three sessions, while P2 latency remained stable. • In contrast, the control group exhibited minimal alterations in both latency and amplitude of ALLRs across the two sessions, with no significant differences between the first and third session. • Overall, the clinical group showed acclimatization to the hearing aids with decreased latency and increased amplitude of P1 and N1, while the control group displayed minimal changes.
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 in CAEPs were noticeable as early as 2 weeks after initial fitting. Specifically, there were significant increases in N1 amplitude ($p = .031$), indicating early neural adaptation. However, it took 6 weeks of hearing aid use to see similar amplitude increases in the P2 component ($p = .033$), reflecting stimulus detection and identification. Furthermore, a significant increase in P2 amplitudes in noise was observed in the final session—24 weeks following the initial hearing aid visit ($p = .012$), but N1 in noise amplitudes did not show any significant changes ($p > .3$). Taken together, these results demonstrate evidence of neuroplasticity in N1 amplitudes earlier (2 weeks following hearing aid fitting) than P2 amplitude changes (6 weeks after hearing aid fitting). • In contrast, the control group exhibited no significant changes in the amplitudes and latencies of 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, ExpHA= Experienced HA users, FFR= Frequency Following Response, HAs= Hearing Aids, hrs/day= hours per day, mo= month, M1= Month 1, M2= Month 2, M3= Month 3 and NovHA= novice HA users

Table 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 et al. (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 ($F(3,22) = 7.21$, $p < .01$). Wright & Gagne (2021) found that more severe hearing loss was associated with greater improvement in speech perception in noise.
	Self-reported Measures	Bentler et al. (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 et al. (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. 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.
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, as detailed in Supplementary Table 2, showed an average score of approximately 62% on the NIH Quality Assessment Scale. Of the 25 studies reviewed, 4 (16%) were rated as good quality, 20 (80%) as fair quality, and 1 (4%) as poor quality. Common factors contributing to lower quality included the lack of randomization, absence of blinding in group assessments, and insufficient reporting on sample size considerations to ensure adequate statistical power for detecting significant differences in primary outcomes. Notably,

only 8 of the 25 studies conducted sample size estimations or power analyses. Regarding the OCEBM levels of evidence, where level 1 represents the highest quality of evidence and level 5 represents the lowest, out of the 25 studies analysed, 1 (4%) was classified as level 4, 20 (80%) as level 3, and 4 (16%) as level 2, representing true experimental studies (Supplementary Table 2).

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 to moderate in magnitude. This conclusion is consistent with the observations of Turner and Bentler (1998), who, in their letter on hearing aid acclimatization, indicated 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 including studies that made use of a controlled design. Some frequently cited studies, such as Gatehouse (1993 & 1995), were excluded from this review as they involved participants with previous hearing aid experience (12 to 15 months and 1 to 4 years, respectively). Since this review focuses on acclimatization in new hearing aid users, studies involving experienced users for the study group were not included.

Among the studies focusing on speech recognition outcomes, there was a tendency toward acclimatization, with 10 studies reporting evidence of acclimatization and 7 reporting no such effect. Speech recognition in noise showed the strongest support for acclimatization, as controlled studies frequently reported improvements in the aided ear over time (e.g., Gatehouse, 1992; Munro & Lutman, 2003). However, aided speech recognition in quiet and unaided conditions generally demonstrated limited or inconsistent improvements, with some gains attributed to practice effects rather than true acclimatization (e.g., Dawes et al., 2014a). Self-reported measures provide partial evidence of acclimatization, with findings varying across studies and assessment tools. Specifically, 3 studies observed clear acclimatization effects, while 3 others reported mixed results, showing acclimatization in certain measures but not others. In contrast, 2 studies found no evidence of acclimatization. In terms of electrophysiological outcomes, out of the 7 studies, 4 provided evidence for acclimatization, while 3 did not.

It is important to note that the number of studies available, particularly in the self-reported and electrophysiological category, may not be sufficient to allow for robust comparisons. 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.

In conclusion, systematic improvements consistent with acclimatization are most evident in speech recognition in noise and selected self-reported measures, but they are inconsistent in quiet conditions, unaided settings, and electrophysiological outcomes. This variability underscores the complex interplay between individual, environmental, and measurement factors in auditory acclimatization research.

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

Speech Recognition

Studies that reported the magnitude of change in speech recognition performance following hearing aid use include Munro and Lutman (2003), who observed aided improvements in the fitted ear across all presentation levels, with gains of 1.0%, 2.6%, and 3.6% at 55, 62, and 69 dB SPL, respectively. The control ear consistently showed declines of around -2.0%. Cox et al. (1996) documented a mean benefit in noise, rising from 4% at fitting to 8% after 12 weeks, with significant improvements occurring between 6 and 9 weeks. Horwitz et al. (1997) found that new hearing aid users experienced an increase in NST benefit from 7 rau at fitting to 14 rau after 18 weeks, while long-standing users showed no significant change. Dawes and Munro (2017) reported a 3 dB improvement in SIN scores after 30 days for new hearing aid users with moderate hearing loss and consistent use, compared to experienced users. Megha and Maruthy (2020) observed significant improvements in SIN scores after two months, while Wright and Gagné (2021) found a 2 dB gain in SNR for new users. Habicht et al. (2018) reported a 30% improvement in processing times for novice users. Overall, while statistically significant changes are observed, the clinical impact depends on the context, measures, and user conditions. Most improvements are modest.

Self-Reported Outcomes

Studies on self-reported measures further illustrate the magnitude of changes associated with hearing aid use. Horwitz et al. (1997) found a significant decrease in aided problems for new

users ($F[4, 96] = 2.610$, $p < 0.05$), while experienced users showed no change ($F[4, 96] = 0.804$, $p > 0.05$). Vestergaard (2006) reported significant improvements on the GHABP ($F[1, 23] = 5.95$, $p = 0.023$) and IOI-HA scales ($F[1, 23] = 5.13$, $p = 0.033$) for first-time hearing aid users who wore their devices for more than four hours daily. Metselaar et al. (2009) found significant improvements on the APHAB subscales 'Ease of Communication,' 'Background Noise,' and 'Reverberation' at 6 and 26 weeks for new users, although 'Aversiveness to Sounds' showed a negative effect. Dawes et al. (2014a) found significant improvements in SSQ-D scores for new unilateral (mean = 26.2, SD = 14.5) and bilateral users (mean = 20.5, SD = 14.6) over 12 weeks ($F[2, 46] = 17.2$, $p < 0.01$), while experienced users showed no significant change (mean = -0.2, SD = 11.7). Chang et al. (2016) observed significant reductions in HHIE scores from pre-fitting (54.07 ± 27.35) to 1 month (43.25 ± 27.87) and 3 months (37.79 ± 27.07), indicating reduced hearing-related difficulties ($p < 0.01$). Karawani et al. (2018b) noted significant improvements on the APHAB subscales 'Ease of Communication,' 'Background Noise,' and 'Reverberation' ($p < 0.05$), although aversiveness scores increased for some users. These findings highlight that new hearing aid users often experience statistically significant improvements, with communication-related benefits being the most clinically relevant. Most observed changes are small to moderate in magnitude, with some showing larger effects depending on the measure and user group.

Electrophysiological Outcomes

Several studies have shown measurable changes in auditory markers as a result of hearing aid use, reflecting physiological adaptation. Megha & Maruthy (2020) found significant reductions in P1 and N1 latencies ($\chi^2 = 38.64$, $p < .001$ for P1, $\chi^2 = 24.88$, $p < .001$ for N1) and increased

amplitudes in both components, while the control group showed minimal changes. Karawani et al. (2018a) observed increased N1 and P2 amplitudes in quiet conditions for the experimental group, though no changes were observed in noisy conditions. Karawani et al. (2018b) reported earlier latencies for the experimental group in quiet conditions (65 dB: $p = 0.002$, 80 dB: $p < 0.001$), while the control group exhibited delayed latencies. A reduction in F0 amplitude ($F(1,30) = 5.890$, $p = 0.021$) suggested that hearing aids might help mitigate neural timing delays. Karawani et al. (2022) found evidence of early neural adaptation, with significant N1 amplitude increases as early as 2 weeks post-fitting ($p = 0.031$), and significant P2 amplitude increases at 6 weeks ($p = 0.033$) and at 24 weeks in noisy conditions ($p = 0.012$), indicating neuroplasticity. In summary, these studies suggest that hearing aid use leads to significant changes in auditory processing, including reduced latencies and increased amplitudes in the P1, N1, and P2 components, indicating potential neuroplasticity. While these changes are of moderate magnitude, they highlight the possible long-term benefits of hearing aid use on auditory function.

Overall, acclimatization effects tend to result in small to moderate improvements in auditory performance. While the evidence for auditory acclimatization in new adult hearing aid users is inconsistent, some studies have reported these small to moderate effects. It is important to recognize, however, that some research shows improvements in performance over time. These gains, particularly in speech recognition in noise, self-reported communication, and early cortical electrophysiological responses, suggest that even modest improvements may have clinical significance by enhancing both daily functioning and neural adaptation.

However, given that the improvements from acclimatization are generally modest and not consistently observed, audiologists should prioritize addressing other factors that have a more substantial impact on patient outcomes. Focusing on barriers to hearing aid uptake and consistent use—such as patient education, proper device fitting, and expectation management—may lead to more meaningful and lasting improvements than the relatively modest benefits of acclimatization alone.

If changes occur, what is the time course?

Study durations varied from 4 weeks to 1 year. Hearing aid acclimatization improvements for speech recognition generally occurred within the first few months. Studies show that new users often experience gradual gains in speech recognition, particularly in challenging environments like noise, with the most significant improvements observed between 4 and 6 weeks (Gatehouse, 1992; Cox et al., 1996; Wright & Gagné, 2021). Benefits continued over several months, with gradual improvements up to a year (Horwitz et al., 1997), though most enhancements were noted within the initial three months, emphasizing this period for maximizing hearing aid benefits. However, long-standing users generally show stable performance (Megha & Maruthy, 2020).

For self-reported measures the time course of hearing aid outcomes varies, with most improvements occurring within the first few months. For new users, benefits such as reduced communication difficulties and increased satisfaction are often observed within the first 1-3 months, as seen in studies by Chang et al. (2016) and Horwitz et al. (1997). Longer-term improvements, particularly in communication and hearing benefit, can continue up to a year for users who wear their devices consistently, as shown in Vestergaard (2006) and Metselaar

et al. (2009). Experienced users tend to show stable or minimal changes over time, with significant benefits less frequently observed beyond initial adjustments.

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 (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.

The clinical implications for audiology patients and clinicians regarding the time course emphasize the importance of the first 3 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.

While Munro and Lutman (2003) observed acclimatization effects at higher speech levels, Dawes et al. (2014a) found no improvements at higher stimulus intensities, highlighting variability in findings regarding stimulus level impacts.

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.

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 7 could help future studies.

Table 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 8 out of the 25 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.

CONCLUSIONS

This review highlighted the complexity of auditory acclimatization to hearing aids, a process that can be influenced by various factors. Evidence suggested that acclimatization occurred in some users and for certain outcomes, with the most consistent improvements observed in speech recognition in noise and self-reported measures, including the APHAB, HHIE, and GHABP questionnaires. However, overall changes in outcomes remained inconsistent, and when acclimatization was present, its effects were generally modest. Notably, the first 4–12 weeks after hearing aid use appeared to be the most likely period for acclimatization to occur. The variability and modest effects observed across numerous studies indicated that, while acclimatization may have contributed to the adjustment process, it was unlikely to be the primary factor influencing overall hearing aid success.

Future research on auditory acclimatization should emphasize the inclusion of essential statistical metrics, such as correlation coefficients in within-subject designs, to facilitate robust meta-analyses. Studies should prioritize rigorous control group methodologies to accurately quantify the magnitude of changes directly attributable to acclimatization. Additionally, audiologists must address barriers to hearing aid adoption by promoting consistent device use and implementing innovative, patient-centred strategies tailored to individual needs. By focusing on these areas, research and clinical practice can better support

patients in achieving optimal auditory outcomes and improving satisfaction with their hearing aids.

ACKNOWLEDGEMENTS

KJM and PD are supported by the NIHR Manchester Biomedical Research Centre.

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