The Effects of Auditory Training on Speech-in-noise Perception in Older Adults: A Systematic Review

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ABSTRACT

Speech perception in noisy environments is a common challenge for older adults, stemming from age-related auditory decline and cognitive limitations. This thesis explores the effects of auditory training on enhancing speech perception in older adults when faced with such challenging environments. Auditory training, a structured set of listening activities designed to improve auditory processing and comprehension, has shown promise in mitigating age-related auditory deficits. This study examines the theoretical foundation, methods, results, and implications of auditory training in enhancing speech perception in noisy environments, focusing on its practical application and measurable benefits. It investigates how auditory training impacts older adults' speech perception in noisy environments. It reviews the current state of research, identifies gaps in understanding, and outlines a systematic study to evaluate the benefits of AT. Results indicate that targeted auditory training programs improve speech perception, including in noisy environments, cognitive processing, and quality of life for older adults. This work addresses these questions and contributes to theoretical knowledge and practical applications in audiology and gerontology.

Keywords: *auditory training, speech perception in noise, elderly, hearing loss*

INTRODUCTION

According to the World Health Organization (WHO, 2021), more than 1.5 billion people globally suffer from some level of hearing loss, with approximately 430 million of them having disabling hearing loss. This means that about 5% of the global population requires rehabilitation to address their hearing impairment. With an aging population, the prevalence of hearing loss is expected to rise, with projections indicating that by 2050, over 700 million people—1 in every 10—will have disabling hearing loss. Adults over sixty account for 30% of people with hearing loss globally (WHO, 2021).

If left untreated, hearing loss can result in communication challenges, social isolation, depression, and a reduced quality of life (Morris et al., 2013; Davies et al., 2017). Comprehending speech in noisy environments is crucial for effective communication and social engagement (Milvae et al., 2016). However, this ability tends to decline with age, driven by a combination of peripheral auditory degradation (e.g., presbycusis) and central auditory processing deficits. This decline may be further exacerbated by reductions in cognitive functions, such as memory and processing speed, which are critical for everyday communication and commonly observed in individuals with peripheral or central hearing loss (Lin et al., 2011; Fulton et al., 2015). These listening challenges often lead to social withdrawal and reduced quality of life in older adults (Arsiwala-Scheppach et al., 2022)

One key component of aural rehabilitation is the use of hearing aids, but despite the constant improvement in technology, amplification by hearing aids alone does not prevent individuals with hearing impairment from struggling in difficult listening situations (Kaplan-Neeman et al., 2012). One complementary tool for aural rehabilitation is auditory training. Auditory training (AT) for individuals with hearing loss aims to improve their ability to process and understand sounds, particularly speech, through various methods and strategies. These techniques are based on neuroplasticity, the brain's ability to reorganize itself by forming new neural connections. Auditory training typically involves exercises designed to enhance sound discrimination, auditory memory, and speech-in-noise perception. A systematic review and meta-analysis by Henshaw and Ferguson (2013) found that AT improves cognitive skills in hard-of-hearing individuals.

Additionally, a study by Lawrence et al. (2018) supports the notion that auditory and cognitive training may enhance cognitive functions. Hence, training auditory and cognitive skills in combination with amplification seems to be one option to enhance listening and communication skills in elderly individuals with hearing impairment, providing a ray of hope for those struggling with their hearing (Anderson & Jenkins, 2015; Lawrence et al., 2018). Numerous auditory training (AT) programs are available, with some being provided in audiology clinics under the supervision of audiologists, while others are commercially accessible via the internet or through software installation on personal computers, notably the Listening and Communication Enhancement Program (LACE; Neurotone) and BrainHQ (Posit-Science).

Previous research has also indicated that the outcomes of auditory training (AT) studies are variable, and the generalization of training benefits is not consistently measurable (Henshaw & Ferguson, 2013; Stropahl et al., 2020). This thesis examines studies from the past decade, focusing on the impact of auditory training on speech perception in noisy environments among older adults. It reviews the current body of research, identifies existing gaps in knowledge, and assesses the benefits of auditory training.

Objectives

This systematic review examines older adults with hearing impairment, including those who do and do not use hearing aids and novice and experienced hearing aid users. It focuses on recent research conducted within the last decade. The findings assess the effectiveness of auditory training (AT) based on the results of eleven selected studies, including ten controlled studies and one cross-sectional study. Meta-analyses were not included in this review.

Need of the study

The main objectives of this thesis are to assess whether structured auditory training programs can improve the ability of older adults to perceive speech in the presence of background noise and to determine whether the benefits of auditory training are sustained over time and whether there is any decay in performance once the training period has ended. It also aims to compare the effectiveness of different auditory training modalities (e.g., computer-based training, in-person training, and self-guided training) on speech perception improvement in noisy environments. This objective explores which type of auditory training approach yields the best results for older adults in noisy environments, considering accessibility and feasibility. The review identifies gaps in understanding the long-term benefits of AT, the comparative effectiveness of different training modalities, and the extent to which AT improves cognitive functions alongside auditory perception.

By systematically analyzing existing studies, this work aims to clarify the impact of AT on speech-in-noise perception and inform best practices for aural rehabilitation in older adults.

METHODS

All processes and selection of studies for this review of the literature followed the preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (Prisma-P) statement (Moher et al., 2015).

Inclusion criteria

Studies considered for review in this thesis were published in French or English in a peer-reviewed journal between January 2015 and January 2025. Participants in all studies needed to be 50 years and older with or without hearing loss. Other screening items included:

- Intervention: Studies with music training or auditory training sessions such as computer-based programs, group sessions, or individualized training with at least one training session per week over a minimum of three weeks were all considered for review.
- Control: Control studies had to compare to a control group

undergoing either placebo or no training.
- Outcome: Studies comparing outcomes related to speech perception in noise between trained and untrained groups or pre-and post-training assessments within the same group were considered for review.
- Study design: Randomized and non-randomized controlled studies, as well as cross-sectional studies, were considered for review.

Exclusion criteria

Studies where participants were younger than 50 years old, cochlear implant users or patients with tinnitus were excluded. Meta-analysis studies were also excluded.

Information sources and data collection

A search of electronic databases such as PubMed, Medline and Cochrane.org was conducted. The last search was on January 25, 2025. In addition, ASHA's evidence maps online tool was also used to search for articles that were already screened for bias based on the American Speech-Language-Hearing Association's levels-of-evidence scheme (Mullen, 2007). Several keywords related to the effects of auditory training on speech in noise in older adults were used, such as auditory training, perceptual training, auditory discrimination, and speech in noise, were applied. The search revealed 1,480 results. After removing duplicates and the studies dated before 2015, 123 results remained. The abstract of each study was then reviewed, and eleven adhered to the selection criteria described above and were included in this review.

Assessment of study quality

The Evidence Database (PEDro) scale was used to evaluate the internal validity and potential sources of bias in each study. The PEDro scale rates randomized clinical control trials (RCTs) based on an 11-criteria rating system (Blobaum, 2006). Ten of the eleven selected studies were assessed using the PEDro scale. One study was a cross-sectional study, and its quality was evaluated using the NHLBI's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (NHLBI, 2013).

Data Extraction

For all included studies, we extracted data about the study design, the number of participants in each study group, their age, the intervention and frequency, and the outcomes of each study. Refer to Table 1 in Appendix A for an overview of all data extracted.

RESULTS

Using the PEDro Scale (Table 2, Appendix B), one was rated "excellent," with total values of 9 to 11 (Saunders et al., 2016), and seven were rated as "good," with scores between 6 and 8 (Whitton et al., 2017; Zendel et al., 2019; Humes et al., 2019; Lowe et al., 2023; Yu et al., 2017; Van Wilderode et al., 2023; Abrams et al., 2015). The remaining two studies (Kucuk et al., 2022; Matos Silva et al., 2020) were assessed as "fair," with scores between 4 and 5. The overall methodological quality was acceptable (total mean score=7). Mussoi (2021) was also rated as "Good" using the NHLBI's Quality Assessment

Tool for Observational Cohort and Cross-Sectional Studies. Refer to Table 2 and Table 3 in Appendix B for results of the assessment.

Characteristics of the studies

The characteristics of the selected studies are shown in Table 1, Appendix I. The data extracted from the eleven studies consists of the author, the year of publication, the characteristics of the participants and the different study groups, the description of the intervention and the frequency of training, as well as the description of the outcomes of the intervention.

Participants

The selected studies included participants aged fifty years and older. Among the eight studies focusing on hard-of-hearing individuals who were hearing aid users, some participants were newly fitted with hearing aids at the beginning of the study (Abrams et al., 2015; Yu et al., 2017), while others were experienced hearing aid users (Humes et al., 2019; Lowe et al., 2023; Van Wilderode et al., 2023; Whitton et al., 2017; Kucuk et al., 2022). One study specifically compared new and experienced hearing aid users (Saunders et al., 2016). Additionally, two studies focused on participants with hearing loss who were not using hearing aids (Mussoi, 2021; Zendel et al., 2019), while another study included a mix of hard-of-hearing participants both with and without hearing aids (Matos Silva et al., 2020). Overall, the sample sizes across the eleven studies ranged from 15 to 279 participants, with a median group size of 53 participants (SD = 75.30).

Intervention

The intervention analyzed in the study was auditory training (AT) or music training, specifically AT, for enhancing speech in noise perception. The intervention varied in duration, frequency and complexity across the eleven included studies. Training duration was classified into two categories: short (<500 minutes) or long (≥500 minutes). Three studies had a training duration of less than 500 minutes (Kucuk et al., 2022; Matos Silva et al., 2020; Abrams et al., 2015) while seven studies had a complete training duration of more than 500 minutes (Whitton et al., 2017; Lowe et al., 2023; Zendel et al., 2019; Humes et al., 2019; Yu et al., 2017; Van Wilderode et al., 2023; Saunders et al., 2016). One study did not involve auditory training intervention since it was a cross-sectional study, and the evaluation focused on the impact of music training from childhood on the participants (Mussoi, 2021).

The studies were also categorized into two environmental conditions: “at home” and “in clinic”. Seven studies conducted auditory training under “at home” conditions (Whitton et al., 2017; Zendel et al., 2019; Humes et al., 2019; Lowe et al., 2023; Van Wilderode et al., 2023; Abrams et al., 2015; Saunders et al., 2016) while two studies conducted auditory training under “in clinic” conditions (Kucuk et al., 2022; Matos Silva et al. (2020). Yu et al. (2017) combined both environmental conditions and compared traditional auditory training in-clinic with at-home auditory training. Mussoi (2021) offered in-clinic evaluation without training.

Auditory material differed significantly among studies. Two studies evaluated musical training to enhance speech perception in noise. Mussoi (2021) evaluated musicians and compared them to non-musicians, while Zendel et al. (2019) applied a music training protocol in which the participants learned how to play the piano. Three studies used a single training task, which included phoneme discrimination and word recognition (Yu et al., 2017; Van Wilderode et al., 2023; Kucuk et al., 2022) and six studies used speech perception training in noise using words and/or sentences (Humes et al., 2019; Whitton et al., 2017; Lowe et al., 2023; Matos Silva et al., 2020; Abrams et al., 2015; Saunders et al., 2016). One of the studies that trained speech perception in noise used a training program called ReadMyQuips that focused training on audiovisual speech comprehension (Abrams et al., 2015), while another focused on closed-loop audio motor skills (Whitton et al., 2017). The training of another study that focused on speech perception in noise was based on the participant's involvement in active conversations with their communication partner over a specific time (Lowe et al., 2023). Saunders et al. (2016) used a more complex commercial auditory program, Listening and Communication Enhancement (LACE), which included several training tasks. The program focuses on cognitive skills and speech perception training in the form of speech-in-noise perception, competing speaker paradigms and compressed speech.

Controls

Nine studies on eleven compared the results of the training groups to non-training or placebo-training groups (Humes et al., 2019; Whitton et al., 2017; Lowe et al., 2023; Matos Silva et al., 2020; Abrams et al., 2015; Saunders et al., 2016; Van Wilderode et al., 2023; Kucuk et al., 2022). Among these studies, two had more than one training groups compared to a control/placebo group (Zendel et al., 2019; Saunders et al., 2016). In all nine publications, the control groups either completed an unrelated placebo-training intervention or did not get any training intervention. Even though Yu et al. (2017) used the term “non-training group” for their control group, they were comparing the results of the auditory training group at home to a “non-training group” that was using traditional in-clinic auditory training. All ten clinical studies completed pre- and post-training comparisons between training and control groups. Mussoi (2021) did not have control groups, but the cross-sectional study compared older adults who were musicians and were regularly training to older adults who were non-musicians.

Outcome Measures

All studies evaluated speech perception in noise pre and post-training, including words and sentences. Other elements measured in six of the studies were cognitive performance, that is, auditory attention or auditory working memory (Saunders et al., 2016; Zendel et al., 2019; Lowe et al., 2023; Mussoi, 2021; Whitton et al., 2017). In three studies (Humes et al., 2019; Lowe et al., 2023; Van Wilderode et al., 2023), the self-perceived benefit of AT was also measured. One study evaluated pre and post-intervention with the participants aided and unaided by their hearing aids (Abrams et al., 2015).

Study Design

All but two of the selected studies reported randomizing the assignment of their participants into intervention and control groups. One study, conducted by Matos Silva et al. (2020), did not randomize the assignment of groups, and another study by Mussoi (2021) was a cross-sectional study. Each clinical trial's training protocol required regular training sessions. The total number of sessions and their duration varied significantly across the selected studies. Participants trained for durations ranging from 15 to 120 minutes per session, 1 to 5 days per week, over approximately 3 to 12 weeks. In the study by Abrams et al. (2015), it was acknowledged that participants in the training group trained for less time than initially prescribed by the study protocol.

Effects of AT on speech-in-noise perception

Several studies demonstrated improvements in speech-in-noise (SiN) recognition following AT interventions. Whitton et al. (2017) found that participants in the closed-loop training group improved their QuickSiN and BKBSin test scores, enabling them to hear 25% more in noise; however, the benefits were not sustained without continued practice. Similarly, Zendel et al. (2019) observed that music-training participants showed enhanced speech-in-noise perception.

Kucuk et al. (2022) employed mismatch negativity (MMN) and matrix tests, noting a significant reduction in MMN wave latency and improved matrix test scores post-training. Humes et al. (2019) indicated that auditory training benefits persisted for at least 8.5 months. Lowe et al. (2023) found a modest improvement in word-in-noise perception, though the experimental condition may not have been sufficiently controlled. Similarly, Yu et al. (2017) observed that performance on consonant and sentence tests improved significantly in the AT group and was retained for two weeks post-training. Van Wilderode et al. (2023) reported a relevant improvement (-2 and + 2 dB SNR SPIN test result) in speech-in-noise understanding after 12 weeks of training. Matos Silva et al. (2020) concluded that auditory training improved the discriminability of sounds in noisy environments. In this study, participants were tested right after training as well as 3 months after auditory training. The SNR indicated no statistically significant differences, suggesting that all the skills gained and enhanced during the training sessions were retained three months later.

Saunders et al. (2016) reported no benefits in speech-in-noise understanding in the LACE AT groups compared with the placebo or the control intervention groups. Abrams et al. (2016) also did not report any significant improvements in speech in noise understanding. HINT and Win outcomes at Visit 3 did not differ significantly between the AT and control groups after the intervention period, regardless of the hearing aid condition in which they were tested. Mussoi (2021) could not conclude that lifelong music training impacted speech-in-noise understanding and recognition, as there were no differences in test results between the musician and non-musician groups.

Effects of AT on cognitive, auditory attention and memory

None of the selected studies that evaluated the effects of cognitive functions demonstrated a significant improvement with auditory or music training. Saunders et al. (2016) found no improvements in cognitive effects following the auditory training (AT) intervention. In contrast, Zendel et al. (2019) reported that participants in the Music group demonstrated an increase in positive-going electrical brain activity during active listening, particularly at the fronto-left electrodes, from 200 to 1000 ms. This suggests that the benefits of AT are influenced by attention. To assess the cognitive effects of AT, Lowe et al. (2023) conducted the Dual-task of listening and memory (Howard et al., 2010) to evaluate the participants' listening effort. The results indicated that while performance improved for the AT Group, there was no significant difference between the intervention groups. Mussoi (2021) evaluated the cognitive effects of AT using a self-report test to measure the listening effort required for completing listening tasks. The self-reported listening effort scores did not differ between the Musician and Non-musician groups. Whitton et al. (2017) examined spectro-temporal processing ability and working memory capacity. However, neither frequency modulation (FM) detection nor working memory scores showed significant changes in either training group.

Self-perceived benefits of AT

The self-perceived benefits of auditory training (AT) were evaluated using questionnaires across three of eleven studies. Humes et al. (2019) assessed participant satisfaction with new hearing aids using questions from the Hearing Aid Satisfaction Survey (HASS). All three groups reported increased satisfaction with hearing aid features between the first and last intervention sessions. Van Wilderode et al. (2023) adapted the Nijmegen CI Questionnaire (Hinderink et al., 2000) to evaluate health-related quality of life for hearing aid users. However, neither the training nor the passive control group showed improvements in self-reported health-related quality of life post-treatment. Lowes et al. (2023) used the Hearing Handicap Inventory for the Elderly (HHIE; Ventry & Weinstein, 1982) and the Glasgow Hearing Aid Benefit Profile (GHABP; Gatehouse, 1999). The results for the HHIE indicated minor improvements from pre- to post-training, with reductions in hearing-related participation restrictions for the experimental group on both subscales (situational and emotional). In contrast, the active control group only showed improvement on the emotional subscale. No significant main effects were reported for the GHABP.

Follow-ups

Five of the selected studies (Saunders et al., 2016; Matos Silva et al., 2020; Yu et al., 2017; Humes et al., 2019; Whitton et al., 2017) assessed the long-term effects of AT on speech in noise perception. Long-term follow-ups were performed 1 to 4 months (Whitton et al., 2017; Matos Silva et al., 2020; Yu et al., 2017) and 4 to 9 months (Humes et al., 2019; Saunders et al., 2016) after the end of training. The effects of training persisted over time in three out of five studies (Humes et al., 2019; Yu et al., 2017; Matos Silva et al., 2020). Saunders et al. (2016) and Whitton et al. (2017) did not report any lasting effects of the training intervention.

Five of the selected studies did not complete follow-ups post auditory training intervention and, therefore, did not assess the long-term effects of AT (Abrams et al., 2015; Kucuk et al., 2022; Lowe et al., 2023;

Van Wilderode et al., 2023; Zendel et al., 2019). Mussoi (2021) completed tests to compare the long-term effects of music training on speech-in-noise understanding of older adults who practiced an instrument since childhood vs. older adults without a musical background.

DISCUSSION

Understanding speech in noisy environments is the most reported challenge for the elderly population (Quaranta et al., 2014). The purpose of this review was to synthesize current research on the impact of auditory training (AT) on speech-in-noise comprehension, specifically for older adults. Additionally, it aimed to determine whether the benefits of auditory training are maintained over time. This review included studies involving individuals aged 50 years and older with hearing impairment, both with and without hearing aids. The findings indicate that auditory training could be an effective intervention strategy for older adults experiencing hearing difficulties.

A few studies before 2015 indicated that AT might have more significant impacts on complex higher-level executive skills, such as memory updating and task switching, than on lower-level perceptual skills, such as understanding of words-in-noise (Anderson et al., 2013; Ferguson et al., 2014; Kuchinsky et al., 2014). Even though this review focused on AT's effects on speech in noise perception, a few of the selected studies investigated the impact on cognitive functions and memory updating. None have demonstrated a significant improvement in complex higher-level executive skills. Saunders et al. (2016) found no improvements in cognitive effects following the auditory training (AT) intervention. Whitton et al. (2017) examined spectro-temporal processing ability and working memory capacity. However, no working memory scores showed significant changes in either training group. Mussoi (2021) reported no changes in cognitive effects when comparing musicians to non-musicians groups. The only selected study that showcased a link between the impact of AT and higher-level executive skills was Zendel et al. (2019). It was reported that participants in the music group demonstrated an increase in positive-going electrical brain activity during active listening, particularly at the fronto-left electrodes, from 200 to 1000 ms. This suggests that the benefits of AT on speech in noise perception are influenced by auditory attention. The study attributed these improvements to increased activity in brain regions associated with speech-motor integration, highlighting the role of cross-modal plasticity in auditory rehabilitation. Given the cognitive demands of musical training, these findings align with broader research suggesting that interventions targeting both auditory and cognitive skills yield better outcomes for speech-in-noise (SIN) perception (Anderson et al., 2013).

The subsequent discussion will examine various factors that influence the effectiveness of auditory training. The results of this systematic review suggest that auditory training can enhance speech perception in noisy environments for older adults. Several studies demonstrated improvements in speech-in-noise recognition following auditory training interventions (Whitton et al., 2017; Zendel et al., 2019; Kucuk et al., 2022; Humes et al., 2019; Lowe et al., 2023; Van Wilderode et al., 2023; Matos Silva et al., 2020). These findings support the theoretical concept of auditory plasticity, where structured auditory exercises can improve neural processing and perceptual skills (Henshaw & Ferguson, 2013). However, the extent and sustainability of these benefits varied among studies, highlighting the complex nature of outcomes related to auditory training. Differences in training protocols may contribute to the variability in findings.

Effective AT programs

The relationship between the duration of auditory training programs and their effectiveness in improving speech-in-noise understanding is complex. Similar to perceptual training, auditory training produces plastic changes in the brain to enhance functionality; it seems very plausible that longer and intensive training is necessary. The results of this review demonstrates that while more extended programs may provide more practice and reinforcement; the effectiveness depends on factors such as training intensity, individual differences, and specific training methods. This review revealed that short-term and long-term auditory training interventions positively affected speech perception in noise in the older population. The duration of auditory training used in the studies ranged from 240 to 1,800 minutes. One of the short-term auditory training interventions (Matos Silva et al., 2020) reported positive and lasting effects of auditory training on speech-in-noise perception three months post-training. The training group of this study trained twice a week for 30 minutes for five consecutive weeks. The participants trained for a total of 300 minutes. The SIN test inspired the auditory training intervention. An audiologist in a clinical setting presented sound stimuli randomly.

Humes et al. (2019), had the most intensive auditory training intervention of our selected studies (1,350 to 1,800 minutes of training in 5 weeks). They reported an improvement in speech-in-noise perception for the AT Group, but only in the training materials provided and that these improvements were sustained over time and at least for a period of 8.5 months post-training intervention. No generalization was seen to non-trained materials though.

Abrams et al. (2015) explored the impact of the number of hours spent training on outcome measures. Although the overall difference in speech-in-noise performance between the training group and the control group was not statistically significant at the end of the intervention, there was a positive correlation in the training group between the number of hours spent training and improvements in understanding speech in noisy environments.

These studies suggest that while more extended auditory training programs can improve speech-in-noise understanding; even shorter, intensive sessions can offer immediate and lasting benefits. The effectiveness of the training also depends on factors such as the program's structure, the auditory training methods used and the participants' specific needs. For example, Van Wilderode et al. (2023) offered at-home auditory training that personalized the selection of tasks and difficulty levels for each participant. The AT Group showcased improvements in speech-in-noise perception at the end of the training, particularly in conditions where speech was directly streamed to their hearing aids. The study suggests that while training can be beneficial, the paradigm should sufficiently challenge each participant to optimize daily listening experiences and keep the participant motivated.

Long-lasting effects of AT

Determining the long-lasting effects of auditory training is crucial for understanding its benefits. All the selected clinical studies have measured the retention of improved speech-in-noise understanding by comparing participants' performance at baseline to their performance after completing the training. Zendel et al. (2019) demonstrated that musical training also enhances speech-in-noise perception in older adults. Their randomized controlled trial revealed that participants who engaged in six months of piano training showed significant improvements in recognizing words in noisy environments, a benefit not observed in the control groups. Five studies followed up weeks to months after completing auditory training (Saunders et al., 2016; Matos Silva et al., 2020; Yu et al., 2017; Humes et al., 2019; Whitton et al., 2017). Among these, two studies reported lasting effects one to four months after auditory training (Matos Silva et al., 2020; Yu et al., 2017), while one reported lasting effects 8.5 months after the auditory training (Humes et al., 2019).

These results suggest that auditory training offers long-lasting benefits beyond training occurring learning effects. Longer follow-ups are needed to evaluate whether the effects persist over time.

Limitations and future directions

The selected studies had their set of reported limitations. Silva Matos et al. (2020) reported that the study sample was too small and that the results should be taken as a pilot study and referenced for future, more significant studies. Zendel et al. (2019) reported that the Video Group experienced a high rate of withdrawals and that, because of this, they did not serve as an adequate control group. The study's results confirmed that music training positively impacted speech-in-noise perception. However, the claim is tentative, as it may have been related to learning a new skill that improved the participants' speech-in-noise perception. Lowe et al. (2022) reported that their participants had to train at a challenging level but that the interpretation of "challenging" could vary from person to person and day to day. This could have impacted the results, and better control should be completed in future studies to represent real-world training experiences best.

Evidence indicates that more extended training periods and more challenging training sessions yield more substantial improvements in speech perception. However, participants' compliance and motivation are crucial for the success of auditory training, especially in maintaining consistent practice several days per week. This underscores the need to determine the optimal training duration to maximize benefits while minimizing participant fatigue and disengagement.

CONCLUSION

Auditory training (AT) is recognized as a valuable tool in aural rehabilitation, with evidence demonstrating improvements in both auditory and cognitive skills. The findings from this review have significant implications for aural rehabilitation. Given the variability in outcomes from auditory training, clinicians should customize training programs to address individual needs. Important factors to consider include the severity of hearing loss, cognitive abilities, and patient motivation.

Additionally, combining auditory training with other rehabilitative approaches—such as hearing aid usage and communication training—may provide more comprehensive benefits (Humes et al., 2019). Accessible delivery methods, like home-based computer programs, can enhance patient adherence and help overcome logistical challenges related to participation in auditory training (Whitton et al., 2017; Van Wilderode et al., 2023). However, there is limited data on the long-term persistence of auditory training effects, leaving uncertainty about whether continuous training or periodic reinforcement is necessary to maintain these benefits over time. Further research is needed to fully understand the long-term efficacy of auditory training and establish standardized training protocols.

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Appendix A: Data extraction

Table 1.

Table of Data Extraction for the Characteristics of the Selected Studies

Study	Participants		Training		Outcomes
	Groups	Number, age	Intervention	Frequency	
1.Whitton et al. (2017) **RCT*	All: mild to severe SHL and bilateral full-time hearing aid users (1) Closed-loop training group (2) Randomized placebo group	Age range: 50 to 89 yrs old adults (1) CL Group: 13 Mean Age: 70 yrs ±11 (2) Placebo Group: 11 Mean Age: 70 yrs ±11 (24)	At-home game on a tablet: auditory memory game or the closed-loop audiomotor game Both tasks were embedded in a puzzle game. Subjects earned puzzle piece	3.5 hours/week for 8 weeks (sessions of minimum 30min at a time) (1,680 min)	CL Group improvement: QuickSiN and BKBSin for SRN tests: • Could hear 25% more in SiN • Benefits did not persist in the absence of practice
2. Zendel et al. (2019) **RCT*	All: Normal to mild hearing loss. French speaker. No music and no video game experience was a requirement (1) Music training group (2) Video Game training group	Age range: 55-64 years old (1) Music Group: 13 Mean Age: 67.5 (2) Video Game Group: 8 Mean Age: 66.9 (2) Control Group: 13	(1) Music group had to learn piano using Synthesia software (2) Video Game Group: At home using a Nintendo Wii console system equipped with a Wii Classic Controller. Game: Nintendo game "Super Mario 64."	(1) Participants moved at their own pace through 65 introductory lessons over a 6 month-period	Music training group: Improved the ability to understand speech in noise for older adults.

	(3) Control group	Mean Age: 69.3 (34)			
3. Kucuk et al. (2022) **RCT*	All: Hearing Impairment and hearing aid users (1) AT Group (2) Control Group	Age Range: 60 to 80 years old (1) AT Group: 17 Mean Age: 72.17 (2) Control Group: 16 Mean Age: 71.75 (34)	(1) Sound discrimination exercises and cognitive exercises for the AT group The AT was implemented once a week in 30-min sessions in the clinic	(1) 30min/week for 8 weeks of AT (240min)	The mismatch negativity (MMN) test and matrix test: • between the beginning of training and end of training: significant difference regarding the decrease of mean latency in the MMN wave ($p = 0.038$), and regarding the improving score of matrix test ($p = 0.004$)
4. Mussoi (2021) **Cross sectional study*	All: Participants had a normal pure-tone average, with most having high-frequency hearing loss. (1) Musician group Practice 3h/week at least and have been playing music since childhood (2) Non-musician	Age Range: 65-78 yrs old (1) Musician Group: 15 Mean Age: 69.5 years (2) Non-Musician Group: 16 Mean Age: 70.1 (31)	No training was involved. All participants completed tests to compare musicians and non-musicians capacity to recognize speech in noise	Test was completed once (lifetime of training)	Quick Speech in Noise, Hearing in Noise Test, and Revised Speech Perception in Noise results: • neither music training nor working memory was associated with differences on the speech recognition in noise measures used in this study • Duration of music training was not

	group				associated with speech-in-noise recognition.
5. Matos Silva et al. (2020) **NRCT*	All: Have mild to moderate hearing loss and low literacy. Only one of all the participants benefited from two hearing aids (1) AT Group 1 (2) AT Group 2	Age: Average of 78.6 ± 10.9 years (1) AT Group 1: 7 Mean Age: 73.6 +- 12.3 (2) AT Group 2: 8 Mean Age: 83.0+- 7.8 (15)	(1) Group 1: auditory training based on a speech-in-noise test (2) Group 2: underwent a filtered-speech test In-clinic AT	10 training sessions over 5 weeks (2 sessions of 30 min/week) (300 min)	Speech in noise test: Statistically significant changes in success rates were the identified mostly in G1 after 3 months post-training, with an increase from T0 to T1 and the maintenance of the mean success rates from T1 to T2 in both ears.
6. Humes et al. (2019) **RCT*	All: Have hearing loss with HA ranging from 6 weeks to 3 years. All participants wore hearing aids bilaterally. (1) Group AT: (2) Control Group: (3) Passive Group:	Age Range: 54 to 80 yrs old (1) Group AT: 13 Mean Age: 71.9 (2) Control Group: 15 Mean Age: 72 (3) Passive Group: 15 Mean Age: 69.4 (43)	(1) Group AT: received the at-home auditory training (2) CG: listened to audiobooks using a similar platform at home (3) Passive Group: only wore their hearing aids and returned for outcomes	(1) AT Group: 3 sessions/week for 5 weeks. 1 session = 90 to 120 minutes (1,350 to 1,800 min)	AT Improvements: • benefits observed for trained materials in the intervention group were sustained for a period of at least 8.5 months. • No improvement was seen for supplemental outcome measures.
7. Lowe et al. (2023) **RCT*	All: Hearing aid users and communication partners	Age range: 65 to 85 yrs old (1) AT Group: 18 Mean Age: 73.06	(1) AT Group: group held conversations with their nominated communication partner in the presence of a single-	30 min/day, 5 days/week over 4 weeks	AB word-in-noise perception: small statistically significant improvement for AT Group compared to active-controls, but this

	(1) AT Group (2) Active Control Group	(2) Active Control Group: 21 Mean Age: 72.67 (39)	talker distractor set to a challenging level (2) Control Group: Held comparable conversations in quiet	(600 min)	between-group Improvement was not reflected in any of the other speech-in-noise, cognitive or self-reported outcome measures.
8. Yu et al. (2017) **RCT*	Older adults with moderate-to-severe sensorineural hearing loss. New hearing aid users (1) AT Group (2) Non-training Group	Aged between 68 and 84 years old. (1) AT Group: 10 (2) Non-training Group: 10 (20)	(1) AT Group: using a mobile program, which had four levels and consisted of 10 Korean nonsense syllables, with each level completed in 1 week. (2) Non training Group: Received traditional auditory training in clinic once a week for 4 weeks	4 weeks training for both AT and non training group	• Performance on the consonant and sentence tests in the TG was significantly increased compared with that of the NTG. • Improved scores of speech perception were retained at 2 weeks after the training was completed.
9. Van Wilderode et al. (2023) **RCT*	All: Seasoned hearing aid users (1) AT Group: (2) Passive Group	Age Range: 60 to 80 yrs old (1) AT Group: 20 Mean Age: 69 (2) Passive Group: 20 Mean Age: 69.8 (40)	(1) The training group trained with a tablet at home five times a week for 15 to 20 min (2) The passive control group did not receive any training but returned after 12 weeks for comparison with the baseline session	AT Group: for 12 weeks (900 minutes)	SiN: participants improved slightly on average, speech-in-noise improvements were larger for the training group in the streaming condition, but not the sound field.

10. Abrams et al. (2015) **RCT*	All: first-time hearing aid users (1) AT Group (2) Control Group	Age Range: (1) AT Group: 15 Mean Age: 65.6 (2) Control Group: 14 Mean Age: 61.8 (29)	(1) AT Group: Hearing aid + remotely delivered, Internet-based auditory training program: Training material RMQ (Read My Quips) is an adaptive audio training Training condition In noise (2) Control Group: Hearing Aid alone, no training	3 weeks of AT: duration 30 min each day, five days a week, for 3 weeks total 450 min	The Hearing in Noise Test and the WIN test: Speech-in-noise understanding improved for both groups at the completion of the study; however, there was not a statistically significant difference in post intervention improvement between the AT and control groups.
11. Saunders et al. (2016) **RCT*	Veterans with hearing loss. Groups of HA users: 136 new Hearing aid users and 143 seasoned hearing aid users. 1. LACE-C training 2. LACE-DVD training 3. Control Group 4. Placebo	Age Range: 68.6 years old (279) LACE-C training: 64 New HA: 32, Experienced: 33 LACE-DVD training: 68 New: 33, Experienced: 35 Control Group: 73 New: 39, Experienced: 34 Placebo: 73	LACE-C training 30 min per day for 20 days LACE-DVD training 30 min for 10 days, total 300 min Training condition In noise, in quiet	AT Group: 20 days (600 min)	LACE training: • does not result in improved outcomes.

		New: 32, Experienced: 41			

APPENDIX B: STUDY QUALITY ASSESSMENT TOOLS

Table 2.

List of Quality Assessment using the PEDro Scale

	1	2	3	4	5	6	7	8	9	10	11	TOTAL	QUALITY
1.Whitton et al. (2017)	1	1	0	0	1	1	1	0	1	1	1	8/11	Good
2. Zendel et al. (2019)	1	1	0	1	1	0	0	0	0	1	1	6/11	Good
3. Kucuk et al. (2022)	1	0	0	1	0	0	0	1	0	1	1	5/11	Fair
4. Matos Silva et al. (2020)	1	0	0	0	0	0	0	1	0	1	1	4/11	Fair
5. Humes et al. (2019)	1	1	0	1	0	0	0	1	1	1	1	8/11	Good
6. Lowe et al. (2023)	1	1	1	1	0	0	0	0	1	1	1	7/11	Good
7. Yu et al. (2017)	1	1	0	1	0	0	0	1	1	1	1	7/11	Good
8. Van Wilderode et al. (2023)	1	1	1	1	0	0	0	1	1	1	1	8/11	Good
9. Abrams et al. (2015)	1	1	0	1	0	0	0	1	1	1	1	7/11	Good
10. Saunders et al. (2016)	1	1	1	1	1	1	0	1	1	1	1	10/11	Excellent

Table 3.

List of Quality Assessment using the NHLBI Assessment Tool for Cross-sectional studies

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	TOTAL	QUALITY
1. Mussoi (2021)	1	1	1	1	CD	1	1	1	1	no	1	no	NA	CD	9/14	Good