

Review Article

Hearing Aids Mitigate Tinnitus, But Does It Matter if the Patient Receives Amplification in Accordance With Their Hearing Impairment or Not? A Meta-Analysis

Sebastian Waechter^a and Anders Jönsson^a

^aDepartment of Logopedics, Phoniatrics and Audiology, Lund University, Sweden

ARTICLE INFO

Article History:

Received January 5, 2022

Revision received March 11, 2022

Accepted April 19, 2022

Editor-in-Chief: Ryan W. McCreery

Editor: Fatima T. Husain

https://doi.org/10.1044/2022_AJA-22-00004

ABSTRACT

Purpose: The purpose of the present meta-analysis is to explore the potential effects of objective verification of hearing aid amplification on tinnitus-related outcomes.

Method: Twenty-seven studies reporting tinnitus outcomes pre and post hearing aid fitting were identified through a systematic literature search. From these studies, data from 1,400 participants were included in the present meta-analysis. Studies were divided into subgroups based on whether they had reported performing objective verification of the participants' hearing aid amplification or not. Outcome measures were tinnitus distress and tinnitus loudness.

Results: Meta-analyses of all included studies indicated verified amplification to result in significantly enhanced reduction of tinnitus loudness ($p < .00001$), while the enhanced reduction of tinnitus distress only approached statistical significance ($p = .07$). However, when excluding an outlier from the subgroup of studies using unverified amplification, individuals receiving verified amplification showed significantly greater reduction of tinnitus distress ($p = .02$). In addition, analyses of longitudinal effects revealed that the reductions of tinnitus distress decreased over time among individuals receiving unverified amplification but increased over time among individuals receiving verified amplification.

Conclusions: The present meta-analysis indicates verified hearing aid amplification to be superior to unverified amplification in terms of reduction of tinnitus loudness and distress. The longitudinal increase of mitigation of tinnitus distress with verified amplification only may reflect improved neural reorganization and/or better adherence to hearing aid use, with verified compared to unverified amplification. Due to the low cost of hearing aid verification compared to the high societal cost of tinnitus, objective verification of hearing aid amplification for tinnitus patients is recommended.

Tinnitus is a common symptom (McCormack et al., 2016) associated with increased risk of anxiety and depression (McCormack et al., 2015), long-term sick leave (Friberg et al., 2013), and major societal costs (Trochidis et al., 2021). Difficulties in establishing an objective

measure of tinnitus have resulted in subjective questionnaires to be the standard approach to estimate baseline tinnitus severity and efficacy of tinnitus treatments at clinic and in research. There are several questionnaires of this type, the most commonly used being the Tinnitus Handicap Inventory (THI; Newman et al., 1996) and the Tinnitus Functional Index (TFI; Meikle et al., 2012), which have both been validated (Chandra et al., 2018; McCombe et al., 2001). Typically, these questionnaires consist of a set of questions or claims covering different

Correspondence to Sebastian Waechter: sebastian.waechter@med.lu.se.
Disclosure: The authors have declared that no competing financial or nonfinancial interests existed at the time of publication.

aspects of tinnitus distress. The patient fills out the questionnaire by ticking the predefined answer alternative that best corresponds to their subjective experience, and the clinician/researcher can thereafter score the answers and get an estimate of the individual's tinnitus distress on a validated scale. Another aspect considered important by many tinnitus sufferers (Husain et al., 2018), yet not as commonly reported as an outcome in tinnitus intervention studies, is tinnitus loudness. Tinnitus loudness is estimated either through a loudness matching process with acoustic stimulus (typically a pure sine tone) or via magnitude estimation (i.e., subjective ratings of tinnitus loudness). A commonly used method for magnitude estimation of tinnitus loudness has been to adopt a visual analogue scale (VAS; Hayes & Patterson, 1921), which is a psychometric response scale where the patient is asked to indicate perceived magnitude (in this case tinnitus loudness) on a horizontal line with defined start and end points. VAS has shown good validity for estimations of tinnitus loudness (Adamchic et al., 2012).

One thing the European (Cima et al., 2019), U.S. (Tunkel et al., 2014), and Japanese (Ogawa et al., 2020) clinical guidelines for management of tinnitus all have in common is the recommendation of hearing aids for tinnitus patients. There are at least two reasons why this has become a globally agreed-upon strategy: (a) Majority of tinnitus sufferers experience significant improvement of tinnitus percept and tinnitus distress after being fitted with hearing aids (e.g., Trotter & Donaldson, 2008; Shekhawat et al., 2013b), while worsening of tinnitus after hearing aid fitting seems to be rare (Kochkin & Tyler, 2008), and (b) the typical tinnitus patient is in need of hearing aids regardless of their phantom sound experience, as clear majority of patients with tinnitus also have some degree of hearing impairment according to their audiogram (Sanchez et al., 2005). While tinnitus sufferers with normal audiograms exist, it should be noted that those individuals often have a hearing impairment above (Vielsmeier et al., 2015) or between (Xiong et al., 2019) the frequencies commonly tested at clinic. Theoretically, the amplification of external sounds achieved with hearing aids may mitigate tinnitus through amplification of ambient noise, which reduces the contrast between the internal sound experience and the external silence caused by the accompanying hearing impairment or through the stimulation of cerebral plasticity achieved with the increased auditory input (Del Bo & Ambrosetti, 2007). In the latter case, it is thought that tinnitus may be a symptom caused by maladaptive plasticity following hearing impairment, leading to increased spontaneous firing rates and synchrony of auditory neurons (Shore et al., 2016), and that reintroducing sufficient auditory stimulation via hearing aids may stimulate cerebral plasticity and reduce such neural hyperactivity (Wang et al., 2020).

However, a hearing aid is not a device that automatically provides gain adequate to the user's hearing impairment. The amplification that the hearing aid software claims the hearing aid to deliver is typically based on measurements with a standardized coupler, which is a cavity that connects the hearing aid to a microphone so that the amplitude from the hearing aid can be measured. The coupler's volume resembles, but is not identical to, the volume of an adult's ear canal. In fact, the volume and resonance of the outer ear canal are determined by its anatomical characteristics, which are unique for each individual (Ballachanda, 1997). Furthermore, additional individual factors, such as middle ear impedance as a function of the frequency and middle ear resonance characteristics, will also contribute to the difference in amplification in a real human ear compared to a coupler. This implies that the sound reaching the tympanic membrane is not identical to the sound presented by the hearing aid, and the specific alterations of the acoustic signal is different in every patient and ear. The gold standard for addressing this problem is to verify that the amplification delivered to the tympanic membrane is equal to the prescribed gain through so-called real-ear measurements (REMs). In REM verification, acoustic properties of the individual's ear canal are controlled for via simultaneous recording of sound pressure levels of presented sound stimuli at the outer ear (Microphone A) and at the tympanic membrane (Microphone B; probe microphone inserted deep into the patient's ear canal; American National Standards Institute, 1997). Comparing these two recordings when the patient is and is not wearing their hearing aids gives information regarding the individual ear canal's resonances and whether the hearing aid is providing the prescribed amount of gain for each frequency at the tympanic membrane. There are also other clinically present yet less accurate ways to try to verify the prescribed hearing aid gain. Examples include measure of functional gain (where free field hearing thresholds with and without hearing aids are compared; Kodera et al., 2016) and in situ verification/sensogram (where pure tones are presented via the hearing aids to control that in situ hearing thresholds are equal to audiogram hearing thresholds; Digiovanni & Pratt, 2010).

According to a survey by Mueller and Picou (2010), only about a third of professional hearing aid fitters (audiologists and hearing instrument specialists) in the United States use probe ear microphones on the day of fitting to verify the provided amplification. This is problematic, since deviations from prescribed gain with unverified fittings are not uncommon. A study by Aazh and Moore (2007) reported less than 40% of participants to hit ± 10 dB of prescribed gain at 0.25–4 kHz without adjustment in accordance to REM, but over 80% of participants to achieve the target gain after hearing aid adjustment in accordance with REM. In line with this, a recent meta-

analysis reported significantly better speech intelligibility in noise and quiet, self-rated listening abilities, and user preference with REM-verified amplification compared to amplification based on the manufacturer’s initial fit without REM verification (Almufarrij et al., 2021). The effect of verifying the hearing aid gain for tinnitus outcomes has, however, never been tested. Several studies have investigated the efficacy of hearing aids for tinnitus, some with verified amplification and others without any reports of attempts to verify the hearing aid’s amplification objectively. However, verified and unverified hearing aid gain for tinnitus has never been compared in the same study.

In an attempt to address this issue, this study reports a meta-analysis of previous studies investigating the effect of hearing aids on tinnitus pre- and postfitting. Specifically, we aimed to answer the following questions: When verifying the hearing aid amplification, is there an enhanced benefit in terms of (a) mitigation of tinnitus distress and (b) mitigation of tinnitus loudness?

Method

Literature Search

A structured literature search was conducted on September 17, 2021, in order to identify studies to include. For this purpose, the databases Scopus and PubMed were used. As digital hearing aids were launched on the market in year 1996 (Levitt, 2007), the time frame for the search was set to year 1996–2021, as analogue hearing aids have become virtually nonexistent and thereby of less relevance than today’s clinical setting and challenges. In the Scopus search, the time frame was embedded into the search string, while it was manually set postsearch with the publication time frame slider in the PubMed search. To find relevant articles, we searched for documents including the words “hearing aid/s” or “amplification” in combination with “tinnitus,” but not “cochlear implant.” Please see Table 1 for specific search strings and hits for each data base and in total.

Prior to the search, the following six criteria for inclusion were set: (a) non-case report, (b) peer-reviewed articles, (c) in English, (d) including original data, and measure of tinnitus distress and/or tinnitus loudness (e) pre and (f) post hearing aid intervention in humans. These criteria effectively excluded review articles, guidelines, case reports, animal studies, studies focusing on medications (either as a treatment of tinnitus or focusing on ototoxicity), studies focusing on genetic aspects of tinnitus, or surgery.

Titles and abstracts of all 993 documents were evaluated based on these criteria. Documents seeming to meet the stipulated inclusion criteria ($n = 59$) then underwent full-text evaluation. Documents that still met the stipulated inclusion criteria after full-text evaluation were then evaluated in terms of data reporting to determine if they could be included in the meta-analysis. In the case of insufficient data reporting, a request of the missing data was sent to the corresponding author. Articles were included when the corresponding authors provided sufficient information and excluded when the corresponding author did not reply or was unable to provide sufficient information. Please see Figure 1 for details regarding the selection process, resulting in 27 included studies of the present meta-analysis (see Table 2 for characteristics of each included study).

Data Analysis

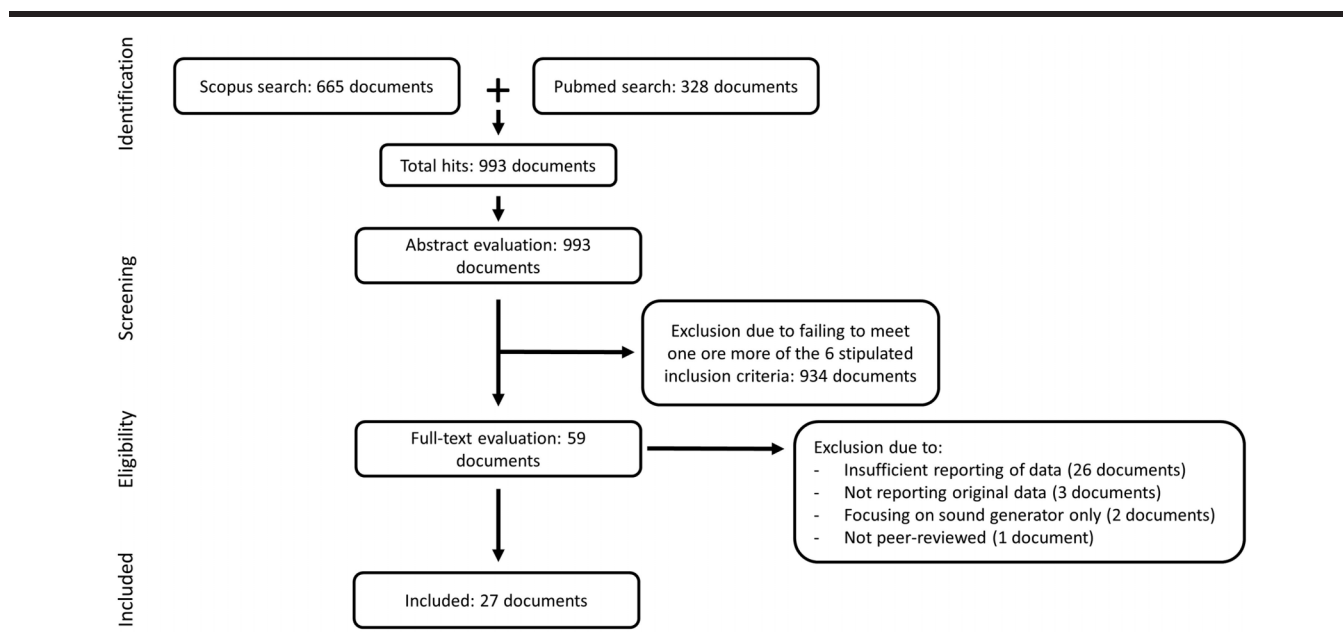
Data were analyzed with Cochrane’s software Review Manager 5.4.1. All meta-analyses were linear mixed model with a random intercept for study, so-called random-effects analyses (DerSimonian & Laird, 1986), conducted using subgroups. Subgroups were formed on the basis of whether the studies had reported objective verification of hearing aid amplification or not. Between-subgroups effect sizes were compared as described by Borenstein and Higgins (2013). First, we conducted two meta-analyses of all included studies, one with tinnitus distress as outcome measure and the other one with tinnitus loudness as outcome measure. As the included studies reported follow-up latencies ranging from 1 to 48 months,

Table 1. Summary of literature search.

Database	Search string	Total hits
Scopus	TITLE-ABS-KEY (“hearing aid*” OR “amplification”) AND “tinnitus” AND NOT “cochlear implant”) AND PUBYEAR >1995	665
PubMed	((hearing aid*[Title/Abstract]) OR (amplification[Title/Abstract])) AND (tinnitus[Title/Abstract]) NOT (cochlear implant[Title/Abstract])	328
Total		993

Note. Total hits = hits after setting the time frame to 1996–2021.

Figure 1. Flow chart of the study selection process.



there was an opportunity to explore whether the effect of verified versus unverified hearing aid amplification on tinnitus differed with time. Therefore, we conducted three additional meta-analyses in order to explore whether time with hearing aids was of relevance for intervention outcome. One with outcome data of ≤ 3 months from baseline to follow-up data collection to control for short-term effects, one with > 3 –6 months from baseline to follow-up data collection to control for medium-term effects, and one with ≥ 12 months from baseline to follow-up data collection to control for long-term effects. Due to the low number of studies reporting tinnitus loudness, the additional meta-analyses taking time since hearing aid fitting into account could only include measures of tinnitus distress.

As the included studies in the present meta-analysis used different scales to assess tinnitus outcomes, results needed to be standardized to a uniform scale before combining them. This was done by using standardized mean difference (SMD) as an effect measure (Higgins et al., 2021). In order to minimize imprecision in the aggregated results, the inverse variance method (Higgins et al., 2021) was adopted, which weighs the result of each study by its inverse variance so that studies with greater precision weigh more in the calculation of aggregated results.

In the first two meta-analyses, the end point results were used to calculate effect size for each included study. In the three subsequent meta-analyses, time with hearing aids was taken into account. Nine studies (Araujo & Iório, 2016; Barozzi et al., 2016; Bauer et al., 2017; Haab et al., 2019; Parazzini et al., 2011; Rocha & Mondelli, 2017; Shekhawat et al., 2013a; Shinden et al., 2021;

Sweetow & Sabes, 2010) collected data from each participant at several points in time post hearing aid fitting. In eight cases (Barozzi et al., 2016; Bauer et al., 2017; Haab et al., 2019; Parazzini et al., 2011; Rocha & Mondelli, 2017; Shekhawat et al., 2013a; Shinden et al., 2021; Sweetow & Sabes, 2010), this implied that data from the same study but different points in time were included in more than one of the three subsequent meta-analyses. In two cases (Araujo & Iório, 2016; Sweetow & Sabes, 2010), two data collections had occurred within the short-term time frame (short term: ≤ 3 months). For these studies, the most commonly reported duration (3 months post hearing aid fitting) among other studies reporting short-term data was selected for inclusion in the meta-analysis in order to enhance comparability. One study (Hodgson et al., 2017) reported a cross-over trial of two different fitting strategies for 6–8 weeks each. Both strategies successfully reduced tinnitus distress, but there was no significant difference in outcomes between the strategies. Therefore, the baseline measures of tinnitus distress before hearing aid fitting was compared with measures of tinnitus distress after the second tried fitting strategy. As only few participants had a follow-up duration of 3 months and majority had > 3 months follow-up duration, this study was categorized as having medium-term duration (> 3 –6 months). One study (Bauer et al., 2017) reported more than one data collection within the long-term span; for this study, the end point results were used. One study collected data at 6–48 months post hearing aid fitting (Folmer & Carroll, 2006); as the average latency between baseline and follow-up data collection was 18 months, this study

was categorized as a long-term study (≥ 12 months between baseline and follow-up).

According to Higgins et al. (2021), statistical testing of heterogeneity across studies is recommended as it is “essential to consider the extent to which the results of studies are consistent with each other.” The I^2 test (Higgins & Thompson, 2002) was used to assess statistical heterogeneity, while strength of heterogeneity was determined by the p value of χ^2 (as recommended by Higgins et al., 2021). Cutoff for a potential problem with heterogeneity was a $p < .1$ for χ^2 , and I^2 values were interpreted as “may represent moderate heterogeneity” when being within 30%–60%, as “may represent substantial heterogeneity” when being within 50%–90%, and as “considerable heterogeneity” when being within 75%–100%.

Subgroups

Studies were categorized as either testing “verified amplification” or “unverified amplification” based on information provided in the respective articles. Verified amplification was defined as an objective measure to verify the prescribed hearing aid fitting. Twelve of the 27 included studies reported some sort of objective verification of the hearing aid gain. Nine used REM only, one used REM for two thirds of the participants and in situ verification for the remaining third, one used in situ verification only, and one used functional gain. The remaining 15 studies reported no objective verification of the prescribed hearing aid gain. Please see Table 2a for each study’s verification approach.

Outcome Measures

Among the included studies, a majority (18 out of 27) used the THI (Newman et al., 1996) to assess tinnitus distress. THI is one of the most adopted measures for this matter in the clinical setting and has shown good validity and test–retest reliability (McCombe et al., 2001). Another questionnaire frequently used to assess tinnitus distress among the included studies was the TFI (Meikle et al., 2012), which was used in six out of 27 studies. The TFI is also widely used in the clinical setting and has been shown to be valid and reliable and responsive to treatment-related change of tinnitus distress (Chandra et al., 2018). Other tinnitus questionnaires (TQs) used among the included studies were the tinnitus severity index (TSI; Meikle et al., 1995), tinnitus reaction questionnaire (Wilson et al., 1991), tinnitus handicap questionnaire (Kuk et al., 1990), and versions of the TQ (Hallam et al., 1988). Five of the included studies used two measures of tinnitus distress. In two cases (Marcum et al., 2021; Shekhawat et al., 2013a), one questionnaire was THI/TFI, and the other questionnaire was another of the above-mentioned. In these cases, the

THI/TFI data were selected for inclusion in the present meta-analysis to increase comparability across studies. In three cases (Bauer et al., 2017; Noguchi et al., 2021; Shabana et al., 2018), both THI and TFI were used. For those studies, the THI data were selected for inclusion in the present meta-analysis, as THI was the most commonly used questionnaire among included studies. Please see Table 2a for details of reported outcome measures of tinnitus distress for each included study.

Among the included studies, only six of 27 studies reported tinnitus loudness as an outcome measure with sufficient data to be included in the meta-analysis. All of those used subjective ratings as an outcome measure for tinnitus loudness. Variants included VAS of tinnitus perceived loudness, the embedded subjective loudness rating from TSI (ranging from 1 to 10), numerical rating scales (Price et al., 1994) ranging from 0 to 10, and tinnitus experiences questionnaire (Bauer et al., 2017) rendering a subjective rating of tinnitus loudness from 0 to 100. Please see Table 2a for details of reported outcome measures of tinnitus loudness for each included study.

Data Extractions and Calculations

Mean scores and standard deviations were extracted from the included articles from texts, tables, or figures (see details for each study in Table 2a). Data were extracted from figures using the WebPlotDigitizer Version 4.4, an open-source digital tool designed to convert points in graphs and images into numbers (retrieved from <https://automeris.io/WebPlotDigitizer>). The decision to use this tool was made based on the recommendation of Higgins et al. (2021). In studies where standard deviation was not reported, the calculations recommended by Higgins were used to calculate standard deviations from available data. In cases where data relevant to the present meta-analysis could not be extracted or calculated as described above, the corresponding authors of the article were contacted with a request to provide the missing information. Studies were included if the corresponding author replied and provided relevant information and excluded if the corresponding author either did not reply or was unable to provide relevant information.

Selection of Participants

In eight of the included studies (Acar et al., 2014; Han et al., 2020; McNeill et al., 2012; Noguchi et al., 2021; Reinhart et al., 2021; Shinden et al., 2021; Sweetow & Sabes, 2010; Yokota et al., 2020), no control groups were used. In these studies, pre- and posttreatment scores of all study participants were included in the present meta-analysis. In six of the included studies (Araujo & Iório, 2016; Folmer & Carroll, 2006; Parazzini et al.,

Table 2a. Characteristics of all included studies.

Study	Year	Verification of hearing aid amplification (type)	Adjuvant treatment	Tinnitus distress measure	Tinnitus loudness measure	Participants included in the present meta-analysis	Age (years) mean; span	Outcome data from
Acar et al.	2014	No reported objective verification	No reported adjuvant treatment	THI	-	24	67; 65–74	Table 2
Araujo & Lório	2016	No reported objective verification	No reported adjuvant treatment	THI	-	12	67; 61–70	Table 5
Barozzi et al.	2016	Yes (in situ verification)	Counselling and sound stimulation (“nature sounds” in 19 participants, “broadband noise” in 17 participants)	THI	-	36	55; 18–65	Text
Bauer et al.	2017	No reported objective verification	Counselling for all 38 participants, TRT for 19 ^a participants	THI and TFI	TEQ	15	Not reported; 18–75	Table 5 & 7
Folmer & Carroll	2006	No reported objective verification	Counselling	TSI	TSI	50	56; not reported	Table 4
Haab et al.	2019	No reported objective verification	No reported adjuvant treatment	TQ	-	15	56; not reported	Figure 6
Han et al.	2020	No reported objective verification	No reported adjuvant treatment	THI	NRS	33	65; 26–88	Table 1
Henry, Frederick, et al.	2015	Yes (REM)	Counselling for all participants, broadband noise for 15 participants	TFI	-	30	67; not reported	Table 3
Henry et al.	2017	Yes (REM in 37 participants, functional gain in 18 participants)	Counselling using components of Progressive Tinnitus Management	TFI	-	54	63; 33–81	Table 2
Hodgson et al.	2017	Yes (REM)	Counselling	TFI	Loudness rating was performed using the University of Auckland software (not included in the meta-analyses due to insufficient reporting of data)	16	64; not reported	Correspondence with authors
Marcum et al.	2021	No reported objective verification	No reported adjuvant treatment	THI and TQ	-	39	54; 34–76	Figure 2
McNeill et al.	2012	Yes (REM)	No reported adjuvant treatment	TRQ	-	70	55; 21–74	Text

(table continues)

Table 2a. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Adjuvant treatment	Tinnitus distress measure	Tinnitus loudness measure	Participants included in the present meta-analysis	Age (years) mean; span	Outcome data from
Mondelli et al.	2021	Yes (REM)	TAT, and sound generator ("9 participants with white noise, 9 participants with pink noise, 9 participants with speech noise, 9 participants with high tone")	THI	-	36	68; not reported	Table 3
Noguchi et al.	2021	No reported objective verification	Individuals with adjuvant treatments were excluded	THI and TFI	-	21	62; 34–84	Table 1
Parazzini et al.	2011	No reported objective verification	TRT	THI	NRS	49	Inclusion criteria were 18–75 years, mean age and age span were not reported for individuals receiving hearing aids	Figures 1 & 3
Porika et al.	2021	No reported objective verification	No reported adjuvant treatment of tinnitus; however, patients with other medicines prescribed for coexisting conditions like diabetes and hypertension kept taking their medications	THI	-	72	Not reported; 18–81	Table 1
Reinhart et al.	2021	Yes (REM)	Sound stimulation (white noise, audiogram-shaped noise, or custom noise based on measurements of minimum masking level)	THI	-	26	63; not reported	Text
Rocha & Mondelli	2017	Yes (REM)	Counselling and sound stimulation	THI	-	15	56; not reported	Table 1
Schaette et al.	2010	No reported objective verification	Counselling	TQ	VAS	11	53; not reported	Figure 3C
Searchfield et al.	2010	Yes (REM)	Counselling	THQ	-	29	64; 16–84	Figure 4
Shabana et al.	2018	No reported objective verification	Relaxation strategy program for all 40 participants, sound stimulation for 20 ^a participants (Widex Zen)	THI and TFI	-	20	51; not reported	Figures 11 & 12

(table continues)

Table 2a. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Adjuvant treatment	Tinnitus distress measure	Tinnitus loudness measure	Participants included in the present meta-analysis	Age (years) mean; span	Outcome data from
Shekhawat et al.	2013a	No reported objective verification	No adjuvant treatment; however, participants underwent a 5-day (actual or sham) transcranial direct current stimulation prior to hearing aid fitting. Transcranial direct current stimulation had no significant effect on tinnitus distress.	TFI and THQ	-	40	59; 45–76	Correspondence with authors
Shinden et al.	2021	Yes (functional gain)	Counselling	THI	VAS	490 (of which 178 had dropped out of the study at 12 months post hearing aid fitting)	69; 22–91	Figures 5, 6, & 7
Sweetow & Sabes	2010	Yes (REM)	Counselling	THI	-	14	Not reported; 34–72	Figure 7
Yakunina et al.	2019	Yes (REM)	No adjuvant treatments	THI	VAS (not included in the meta-analyses due to insufficient reporting of data)	94	56; not reported	Figure 2
Yokota et al.	2020	No reported objective verification	No adjuvant treatments	THI	-	66	78; 52–97	Text
Zarenoue et al.	2016	No reported objective verification	Counselling for all 46 participants, motivational interview for 23 ^a patients	THI	-	23	63; 40–82	Table 1

Note. THI = Tinnitus Handicap Inventory; TRT = tinnitus retraining therapy; TFI = Tinnitus Functional Index; TEQ = tinnitus experiences questionnaire; TSI = tinnitus severity index; TQ = tinnitus questionnaire; NRS = numerical rating scale; REM = real ear measurement; RITE = receiver in the ear; TRQ = tinnitus reaction questionnaire; BTE = behind the ear; THQ = tinnitus handicap questionnaire; VAS = visual analogue scale.

^aExcluded from the present meta-analysis.

Table 2b. Characteristics of all included studies.

Study	Year	Verification of hearing aid amplification (type)	Hearing aid type	Unilateral/bilateral hearing aids	Prescription formula or fitting strategy	Previous hearing aid experience	Exclusion criteria	Follow-up
Acar et al.	2014	No reported objective verification	Not reported	Unilateral only	Not reported	Not reported	Ménière's disease or otosclerosis, objective tinnitus, or any mental, neurological, or psychological pathology	Baseline; 3 months
Araujo & Iório	2016	No reported objective verification	"Microchannel hearing aids of the same brand"	Bilateral only	Not reported	First time users	Neurological, articulatory and/or verbal fluency disorders, or previous experience with the use of hearing aids	Baseline; 1 month; 3 months
Barozzi et al.	2016	Yes (in situ verification)	ReSound hearing aids	Bilateral in 19 participants, not reported in 17 participants	Manufacturer's fitting formula	Not reported	Objective tinnitus or conductive hearing loss, Ménière's disease or tumors of the cerebellopontine angle	Baseline; 3 months; 6 months
Bauer et al.	2017	No reported objective verification	ReSound RITE hearing aids	Bilateral only	Not reported	No hearing aid experience in the preceding 6 months	Tinnitus amenable to medical or surgical treatment, subjective complaints of hyperacusis, loudness discomfort levels (LDLs) less than 100 dB SPL, prior tinnitus treatment, Beck Depression Inventory total score > 30; endorsing suicide or self-harm on BDI Item No.9, currently using hearing aids or use within the preceding 6 months	Baseline; 6 months; 12 months; 18 months
Folmer & Carroll	2006	No reported objective verification	Not reported	Not reported	"fitted with hearing aids to maximize their hearing and communication ability while minimizing problem such as occlusion, feedback and sound distortion"	Not reported	Not reported	Baseline; 6–48 months (average = 18)
Haab et al.	2019	No reported objective verification	"Commercially available hearing aids" ^b	Not reported	Notched filter according to the individual's tinnitus pitch in 19 ^a participants, standard hearing aid fitting for 15 participants	"Some patients had hearing aids for the first time"	Histories of neurological diseases such as Alzheimer's disease, Ménière's syndrome, acoustic neuromas, or psychopathologies such as attention-deficit disorder	Baseline; 3 months; 6 months

(table continues)

Table 2b. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Hearing aid type	Unilateral/bilateral hearing aids	Prescription formula or fitting strategy	Previous hearing aid experience	Exclusion criteria	Follow-up
Han et al.	2020	No reported objective verification	"Selection of HAs was based on patients' preferences and needs among all products available at our institute (Oticon, Resound, Siemens, Starkey, and Widex)"	Not reported	"Fitting of HAs was performed by routine procedures according to each manufacturer's guidelines"	Not reported	Ménière's disease, pulsatile tinnitus, histories of drug or alcohol abuse, psychiatric/neurological disorders, chronic headache; using current psychotropic or central nervous system-active medications; history of seizures; any history of head injury resulting in loss of consciousness	Baseline; 6 months
Henry, Frederick, et al.	2015	Yes (REM)	RITE hearing aids	Bilateral only	NAL-NL 2	"No hearing aid experience within the previous 12 months"	Active external ear disease or conductive component to hearing loss (i.e., abnormal tympanometry and/or air-bone gaps exceeding 10 dB at two consecutive frequencies); diagnosis of retrocochlear pathology, Ménière's disease, endolymphatic hydrops, or perilymphatic fistula; or presence of medical contraindications to a hearing aid fitting, including sudden onset hearing loss, fluctuating hearing sensitivity, ear pain, and vertigo	Baseline; 3 months
Henry et al.	2017	Yes (REM in 37 participants, functional gain in 18 participants)	Phonak hearing aids	Bilateral only	Manufacturer's fitting formula	Not reported	Not reported	Baseline; 4–5 months
Hodgson et al.	2017	Yes (REM)	RITE hearing aids	Bilateral only	All participants were fitted with a frequency compression strategy and wide dynamic compression strategy for 6–8 weeks, respectively	Not reported	Not reported	Baseline; 3–4 months
Marcum et al.	2021	No reported objective verification	Mini BTE hearing aids ^b	Bilateral only	Notched filter according to the individual's tinnitus pitch in 21 participants	First time users	Not reported	Baseline; 3 months
McNeill et al.	2012	Yes (REM)	"Selected based on patients' needs and preferences amongst the range of Oticon, Phonak, and Widex instruments"	Not reported	Manufacturer's fitting formula	Not reported	Not reported	Baseline; 3 months

(table continues)

Table 2b. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Hearing aid type	Unilateral/bilateral hearing aids	Prescription formula or fitting strategy	Previous hearing aid experience	Exclusion criteria	Follow-up
Mondelli et al.	2021	Yes (REM)	Not reported	Bilateral only	NAL-NL 2	First time users	Ménière's disease or "previous realization of some type of intervention for the tinnitus (hearing aids, sound generator, counseling, medication or any other intervention)"	Baseline; 3 months
Noguchi et al.	2021	No reported objective verification	Not reported	13 participants with bilateral hearing aids (10 with bilateral tinnitus, 3 with unilateral tinnitus) and 8 participants with unilateral hearing aids (all with unilateral tinnitus)	Not reported	Not reported	Missing data for 7 or more questions of the TFI, receiving treatments other than treatment with hearing aids, or other diseases requiring alternative treatments	Baseline; 12 months
Parazzini et al.	2011	No reported objective verification	Open ear hearing aids	Bilateral only	Not reported	First time users	Ménière's disease and middle ear disease	Baseline; 3 months; 6 months; 12 months
Porika et al.	2021	No reported objective verification	Not reported	Not reported	Not reported, however, 36 participants received hearing aids "with basic programming," 36 participants received hearing aids "with tinnitus specific programming," and 36 ^a participants received hearing aids "with inbuilt tinnitus masking facility"	First time users	External and middle ear disorders, chronic neurological disorders, or already on some treatment for tinnitus	Baseline; 2 months
Reinhart et al.	2021	Yes (REM)	Starkey hearing aids, 5 participants with BTE hearing aids with custom made earmolds, 16 with RITE hearing aids	Bilateral hearing aids for all participants except one who had unilateral hearing impairment	NAL-NL 2	Experienced hearing aid users, mean time with hearing aids was 4 years	Hyperacusis	Baseline; 2 months
Rocha & Mondelli	2017	Yes (REM)	Siemens hearing aids	Bilateral only	NAL-NL 1	Not reported	Not reported	Baseline; 3 months; 6 months
Schaette et al.	2010	No reported objective verification	Not reported	Bilateral hearing aids for participants with bilateral tinnitus, unilateral hearing aid for participants with unilateral tinnitus	Modified strategy based on the NAL-NL 1 rule	Not reported	Conductive or retrocochlear hearing loss, Ménière's disease, showing evidence of flow-limiting stenosis in carotid duplex, signs of degenerative diseases of the cervical spine, and temporomandibular joint disorder of bruxism	Baseline; 6 months

(table continues)

Table 2b. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Hearing aid type	Unilateral/bilateral hearing aids	Prescription formula or fitting strategy	Previous hearing aid experience	Exclusion criteria	Follow-up
Searchfield et al.	2010	Yes (REM)	"Open fitting slim tube hearing aids were often selected"	Bilateral hearing aids for all participants except one who had unilateral tinnitus and near normal hearing in the contralateral ear	"Hearing aids were optimized for amplification of low input sounds"	Not reported	Fitted with combination instruments, received additional therapies (e.g., neuromonics, cognitive behavioral therapy), low tinnitus handicap (THQ score less than 15) at their first evaluation, suffering from additional potentially confounding injuries (e.g., stroke, noise trauma) during the study period, or not using hearing aids as recommended	Baseline; 12 months
Shabana et al.	2018	No reported objective verification	Widex BTE hearing aids	Unilateral only	Not reported	40% of participants in both groups had previous hearing aid experience	Severe hyperacusis, pulsatile tinnitus, "complicated medical issues"	Baseline; 4 months
Shekhawat et al.	2013a	No reported objective verification	ReSound open fit hearing aids	Bilateral only	A modified DSL(I/O) v5.0	First time users	Contraindications for undergoing transcranial direct current stimulation (personal or family history of seizures, metal and electronic implants, pregnancy, heart conditions, brain surgery, and others)	Baseline; 3 months; 6 months
Shinden et al.	2021	Yes (functional gain)	Not reported	Not reported	"Final gain goal was set by applying the half-gain rule, with sound initiated at 70% of the final gain goal. Compression ratio was set from 1:1.3 to 1:1.7 at all frequencies"	First time users	Normal hearing, unilateral tinnitus, onset of hearing loss within 6 months of study commencement, or diseases requiring other treatments such as surgery at the start of this study	Baseline; 3 months; 12 months

(table continues)

Table 2b. (Continued).

Study	Year	Verification of hearing aid amplification (type)	Hearing aid type	Unilateral/bilateral hearing aids	Prescription formula or fitting strategy	Previous hearing aid experience	Exclusion criteria	Follow-up
Sweetow & Sabes	2010	Yes (REM)	Widex BTE hearing aids	Binaural hearing aids for all participants except three, two who had unilateral hearing loss and the third had a profound hearing loss in the contralateral ear	Manufacturer's fitting formula	Four participants were current or previous users of nonlinear hearing aids, the rest had no previous hearing aid experience	Medication or other treatments during the investigation that may alter progress in either a positive or negative direction, displaying cognitive deficits that might prevent the completion of the objective and subjective measures as well as the counseling, insufficient language skills to read and understand instructions and complete test measures	Baseline; 1 month; 3 months; 6 months
Yakunina et al.	2019	Yes (REM)	Widex RITE hearing aids	Bilateral hearing aids for participants with bilateral tinnitus, unilateral hearing aid for participants with unilateral tinnitus	Wide dynamic range compression for 38 participants, frequency translation for 37 participants, and linear frequency transposition for 39 participants	First time users	Previous hearing aid usage, hyperacusis, history of neuropsychological disorders, or history of taking antidepressants or other psychotropic medications	Baseline; 3 months
Yokota et al.	2020	No reported objective verification	Not reported	Bilateral hearing aids for 23 participants, unilateral hearing aids for the other 43	Not reported	Not reported	Not reported	Baseline; 12 months
Zarencoe et al.	2016	No reported objective verification	"Open-fit slim tube hearing aids were recommended to all patients. However, two patients in the control group preferred in-the-ear models"	Bilateral hearing aids for 33 participants, unilateral hearing aids for the other 13	"All hearing aids were optimized for the amplification of low-input sounds"	First time users	Middle ear disorders, hearing loss since birth/childhood, multihandicap (i.e., significant physical disability and/or a behavioral disorder), nonfluent in Swedish (in need of an interpreter)	Baseline; 3 months

Note. THI = Tinnitus Handicap Inventory; TRT = tinnitus retraining therapy; TFI = Tinnitus Functional Index; TEQ = tinnitus experiences questionnaire; TSI = tinnitus severity index; TQ = tinnitus questionnaire; NRS = numerical rating scale; REM = real ear measurement; RITE = receiver in the ear; NAL-NL 1 = first generation of the National Acoustics Laboratories' prescription procedures for fitting wide dynamic range compression instruments; NAL-NL 2 = second generation of the National Acoustics Laboratories' prescription procedures for fitting wide dynamic range compression instruments; TAT = tinnitus activities treatment. TRQ = tinnitus reaction questionnaire; BTE = behind the ear; THQ = tinnitus handicap questionnaire; VAS = visual analogue scale; DSL (I/O) v5.0 = fifth generation of the Desired Sensation Level method.

^aExcluded from the present meta-analysis. ^bIn these two studies, the authors did not specify the brand of the hearing aids that were used. However, Signia hearing aids is the only currently commercially available type with a module for notched filtering, which both studies used. In addition, Haab et al. (2019) used a picture of a Signia hearing aid in one of their figures, and both studies had one author associated with "Sivantos GmbH." Marcrum et al. (2021) reported their study to be partially funded by "Sivantos GmbH." In conclusion, these studies probably used Signia hearing aids, even though they did not state doing so.

2011; Rocha & Mondelli, 2017; Schaette et al., 2010; Searchfield et al., 2010), results of hearing aid fitting were compared to results of a non-hearing aid control group, receiving treatments such as counseling only or sound generator without amplification. In these studies, pre- and posttreatment scores of all study participants receiving hearing aids were included in the present meta-analysis. In 13 studies (Barozzi et al., 2016; Bauer et al., 2017; Haab et al., 2019; Henry, Frederick, et al., 2015; Henry et al., 2017; Hodgson et al., 2017; Marcum et al., 2021; Mondelli et al., 2021; Porika et al., 2021; Shabana et al., 2018; Shekhawat et al., 2013a; Yakunina et al., 2019; Zarenoe et al., 2016), different hearing aid fitting strategies (such as notched filter versus standard fitting) or adjuvant treatments (such as noise stimulation or motivational interviewing) were compared. Eight of these studies showed no significant differences in tinnitus mitigation across groups (Barozzi et al., 2016; Henry, Frederick, et al., 2015; Henry et al., 2017; Hodgson et al., 2017; Marcum et al., 2021; Mondelli et al., 2021; Shekhawat et al., 2013a; Yakunina et al., 2019), which is why it was deemed reasonable to combine study arms for those studies in the present meta-analysis. This was done via Review Manager's built-in tool for combining study arms. For the remaining five of these studies, significant benefits were found with a certain fitting strategy (Haab et al., 2019) or adjuvant treatment (Bauer et al., 2017; Porika et al., 2021; Shabana et al., 2018; Zarenoe et al., 2016). In order to avoid risk of overestimation of hearing aid-related treatment effect, participants receiving adjuvant treatments (in studies showing increased tinnitus mitigation with adjuvant treatment compared to hearing aid fitting only) were excluded from the present meta-analysis. In the work of Bauer et al. (2017), this meant exclusion of the participants receiving hearing aid fitting and tinnitus retraining therapy; in the work of Porika et al. (2021), this meant exclusion of the participants receiving hearing aids with built-in tinnitus masker (while outcome data from the remaining two groups were combined via Review Manager's built-in tool for combining study arms); in the work of Shabana et al. (2018), this meant exclusion of participants receiving hearing aids with Zen therapy activated; and in the work of Zarenoe et al. (2016), this meant exclusion of participants receiving hearing aids in combination with motivational interview. In the study reported by Haab et al. (2019), participants receiving hearing aids fitted with an individual tinnitus pitch-adapted notched filter showed significantly greater tinnitus mitigation compared to participants receiving standard procedure hearing aid fitting. As the notched filter strategy is currently only available with one hearing aid manufacturer and thus not available for the majority of tinnitus patients, participants receiving hearing aids fitted with a notched filter in the work of Haab et al. (2019) were excluded from the present meta-analysis.

Quality Assessments

Bias assessment was conducted for each study. Since this review article reports meta-analyses of nonrandomized intervention studies, quality analyses consisted of assessments of potential confounding, selection, information, and reporting biases, as recommended by Sterne et al. (2021). Hence, risk-of-bias judgments were low (i.e., "the study is comparable to a well-performed randomized trial with regard to this domain"), moderate (i.e., "the study is sound for a nonrandomized study with regard to this domain but cannot be considered comparable to a well-performed randomized trial"), serious (i.e., "the study has some important problems in this domain"), or critical (i.e., "the study is too problematic in this domain to provide any useful evidence on the effects of intervention") risk of bias. The last risk-of-bias judgment, "no information," was used when insufficient information was provided to make an assessment of the bias risk. Overall risk-of-bias judgment was made for each included study in accordance with Sterne et al. (2021), meaning that studies with low risk of bias for all domains were categorized as having an overall low risk of bias, studies with low or moderate risk of bias for all domains were categorized as having an overall moderate risk of bias, studies with serious risk of bias in at least one domain were categorized as having an overall serious risk of bias, and studies with critical risk of bias for at least one domain were categorized as having an overall critical risk of bias.

In the assessment of risk of confounding bias, studies inclusion of control for known factors impacting degree of tinnitus distress (such as degree of hearing impairment [Mahafza et al., 2021; Waechter, 2021], personality type [Simões et al., 2019], and comorbidity of anxiety or depression [Brüggemann et al., 2016]) and hearing aid outcomes (e.g., average daily hour hearing aid use; Wong et al., 2003) were explored. Studies were evaluated based on whether they had included control for any such factors, reporting data on such factors among their participants with or without clearly describing how the risk of confounding bias was decreased (e.g., via stratification or statistical correction). In the assessment of risk of selection bias, inclusion and exclusion criteria and prevalence of missing data were explored in the search of inclusion or exclusion of participants in a way that may have altered the association between intervention and outcomes compared to what would have been expected in the target population. In the assessment of risk of information bias, outcome assessors' awareness of intervention type, subjectivity of outcome measures, and misclassifications of interventions or outcomes were screened for. In the assessment of risk of reporting bias, studies were screened for possible desire of newsworthy findings, industry funding, and selective reporting of results when outcomes were measured in multiple ways.

Results

A total of 27 studies were included; please see Table 2 for study characteristics. Serious risks of confounding bias and information bias was identified in all included studies. All studies were regarded as having a serious risk of information bias, as outcome assessors were aware of the intervention (aware that the individual participant had received hearing aids, not all assessors were aware of the specific fitting strategy) and the outcome measures were subjective in all studies. The inclusion of measures of known confounders varied, but no study conducted statistical correction for these, which is why all studies were categorized as having serious risk of confounding bias. A greater variance of bias risks was seen across the included studies for the selection bias and reporting bias domains, where all risk-of-bias judgments were present, except for critical risk of bias. See Table 3 for quality assessments of each included study. As none of the included studies had low to moderate risk of bias across all domains and none of the included studies had a critical risk of bias, the overall risk of bias was categorized as serious for all studies.

The aggregated results from the initial meta-analysis of all included studies reporting tinnitus loudness as an

outcome indicated a significant reduction of tinnitus loudness after hearing aid fitting, with an effect size (g) of 1.21 (95% confidence interval [0.49, 1.92], $Z = 3.31$, $p = .0009$). Tests of statistical heterogeneity across included studies showed $\chi^2 = 76.58$, $df = 5$, $p < .00001$, $I^2 = 93\%$. The reduction of tinnitus loudness was significantly greater with verified compared to unverified amplification ($\chi^2 = 21.5$, $df = 1$, $p < .00001$). Tests of statistical heterogeneity for the unverified amplification subgroup showed $\chi^2 = 16.10$, $df = 4$, $p = .003$, $I^2 = 75\%$. Tests of statistical heterogeneity were not applicable to the verified amplification subgroup of this meta-analysis as it consisted of only one study. Please see Figure 2 for forest plot of tinnitus loudness reduction among studies with and without verified amplification and Table 4 for outcome data for each study and subgroup.

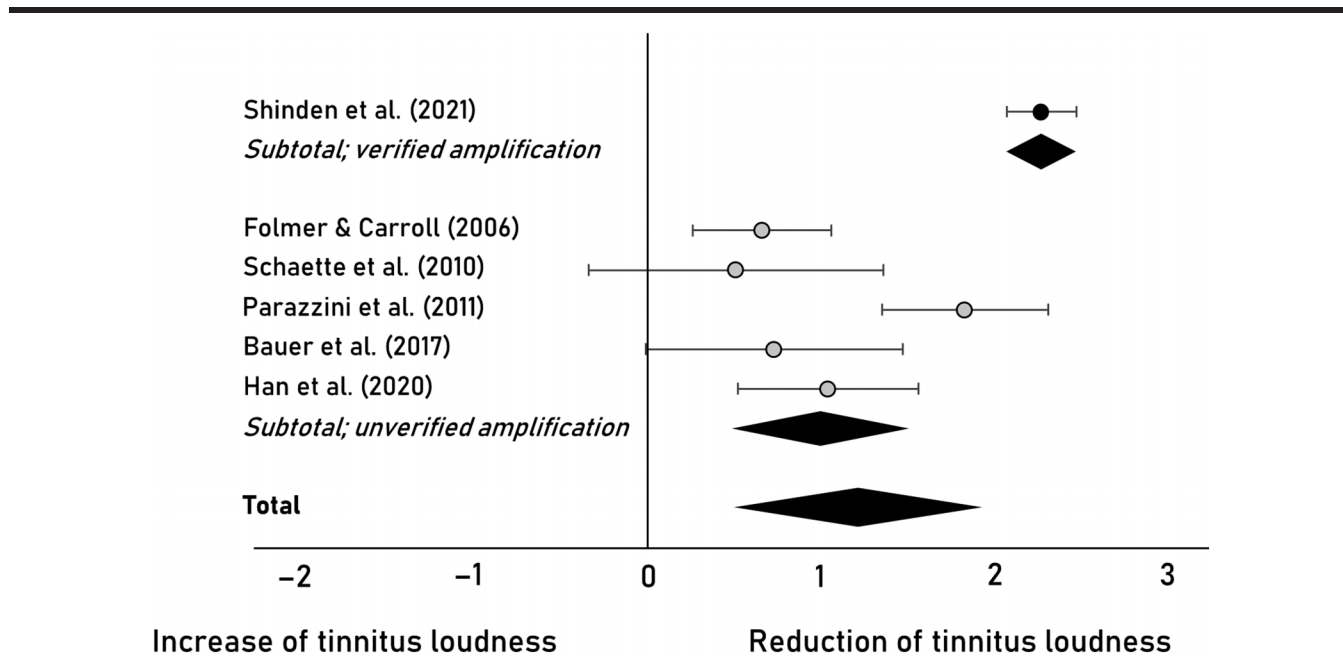
The aggregated results from the initial meta-analysis of all included studies reporting tinnitus distress as an outcome indicated a significant reduction of tinnitus distress after hearing aid fitting, with an effect size (g) of 1.29 (95% confidence interval [0.97, 1.60], $Z = 7.91$, $p < .00001$). Tests of statistical heterogeneity across included studies showed $\chi^2 = 287.83$, $df = 26$, $p < .00001$, $I^2 = 91\%$. The difference in terms of reduction of tinnitus distress between subgroups of verified versus unverified

Table 3. Summary of quality assessments of all included studies.

Study	Year	Confounding domains	Selection bias	Information bias	Reporting bias
Acar et al.	2014	Serious risk	Low risk	Serious risk	Low risk
Araujo & Lóio	2016	Serious risk	Serious risk	Serious risk	Serious risk
Barozzi et al.	2016	Serious risk	Low risk	Serious risk	Serious risk ^{Industry}
Bauer et al.	2017	Serious risk	Serious risk	Serious risk	Moderate risk
Folmer & Carroll	2006	Serious risk	No information	Serious risk	Low risk
Haab et al.	2019	Serious risk	Low risk	Serious risk	Serious risk ^{Industry}
Han et al.	2020	Serious risk	Moderate risk	Serious risk	Moderate risk
Henry, Frederick, et al.	2015	Serious risk	Low risk	Serious risk	Low risk
Henry et al.	2017	Serious risk	No information	Serious risk	Serious risk ^{Industry}
Hodgson et al.	2017	Serious risk	No information	Serious risk	Low risk
Marcum et al.	2021	Serious risk	No information	Serious risk	Serious risk ^{Industry}
McNeill et al.	2012	Serious risk	Low risk	Serious risk	Moderate risk
Mondelli et al.	2021	Serious risk	Low risk	Serious risk	Low risk
Noguchi et al.	2021	Serious risk	Moderate risk	Serious risk	Low risk
Parazzini et al.	2011	Serious risk	Moderate risk	Serious risk	Moderate risk
Porika et al.	2021	Serious risk	Moderate risk	Serious risk	Low risk
Reinhart et al.	2021	Serious risk	Low risk	Serious risk	Serious risk ^{Industry}
Rocha & Mondelli	2017	Serious risk	No information	Serious risk	Moderate risk
Schaette et al.	2010	Serious risk	Low risk	Serious risk	Low risk
Searchfield et al.	2010	Serious risk	Low risk	Serious risk	Low risk
Shabana et al.	2018	Serious risk	Low risk	Serious risk	Moderate risk
Shekhawat et al.	2013a	Serious risk	Moderate risk	Serious risk	Low risk
Shinden et al.	2021	Serious risk	Moderate risk	Serious risk	Low risk
Sweetow & Sabes	2010	Serious risk	Moderate risk	Serious risk	Serious risk ^{Industry}
Yakunina et al.	2019	Serious risk	Moderate risk	Serious risk	Low risk
Yokota et al.	2020	Serious risk	No information	Serious risk	Moderate risk
Zarenoue et al.	2016	Serious risk	Moderate risk	Serious risk	Moderate risk

Note. Industry = study was fully or partially funded by a hearing aid manufacturer, or one or more authors were employed by a hearing aid manufacturer.

Figure 2. Forest plot of reduction of tinnitus loudness after hearing aid fitting with verified versus unverified amplification.



amplification approached significance ($\chi^2 = 3.29$, $df = 1$, $p = .07$). Tests of statistical heterogeneity for the verified amplification subgroup showed $\chi^2 = 125.27$, $df = 11$, $p < .00001$, $I^2 = 91\%$. Tests of statistical heterogeneity for the unverified amplification subgroup showed $\chi^2 = 108.82$, $df = 14$, $p < .00001$, $I^2 = 87\%$. The analysis was reconducted after excluding an outlier in the unverified amplification subgroup (Araujo & Iório, 2016). Without inclusion of outlier data, the reduction of tinnitus distress was significantly greater with verified compared to unverified amplification

($\chi^2 = 5.48$, $df = 1$, $p = .02$). The exclusion of the outlier resulted in the following measures of statistical heterogeneity for the unverified amplification subgroup: $\chi^2 = 84.29$, $df = 13$, $p < .00001$, $I^2 = 85\%$. Please see Figure 3 for the forest plot of tinnitus distress reduction among studies with and without verified amplification (with and without outlier) and Table 5 for outcome data for each study and subgroup (with and without outlier).

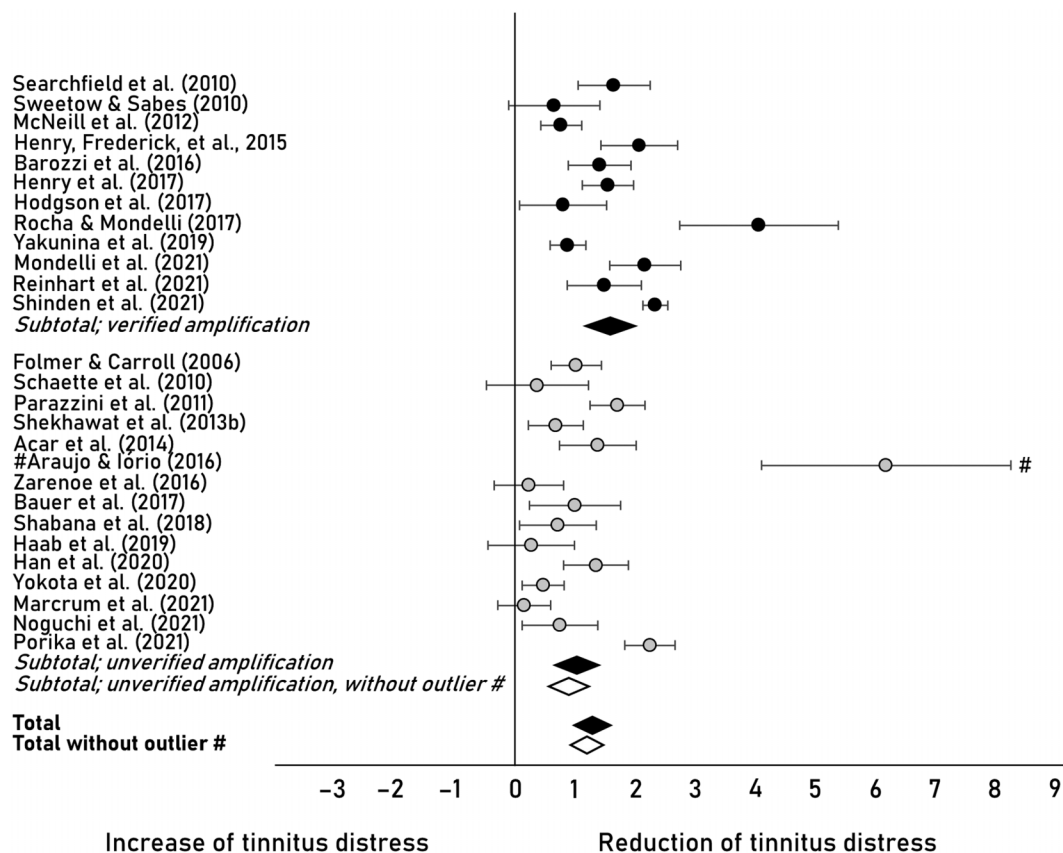
The aggregated results from the subsequent meta-analysis of short-term data indicated a significant reduction

Table 4. Tinnitus loudness outcomes for all included studies.

	Subgroup	Study	Year	Outcome measure	<i>n</i>	Pre hearing aid fitting <i>M (SD)</i>	Post hearing aid fitting <i>M (SD)</i>	Weight	Effect size (<i>g</i>)	95% Confidence interval
Subtotal	Verified amplification	Shinden et al.	2021	VAS	312	75 (25)	17 (26)	18.3%	2.27	[2.07, 2.47]
					312			18.3%	2.27	[2.07, 2.47]
	Unverified amplification	Folmer & Carroll	2006	TSI	50	7.5 (1.7)	6.3 (1.9)	17.2%	0.66	[0.26, 1.06]
		Schaette et al.	2010	VAS	11	71.2 (17.3)	60.1 (23.8)	14.7%	0.51	[−0.34, 1.37]
		Parazzini et al.	2011	NRS	49	7.13 (1.54)	3.74 (2.10)	17.1%	1.83	[1.35, 2.30]
		Bauer et al.	2017	TEQ	15	76.5 (16.3)	61.6 (22.8)	15.5%	0.73	[−0.01, 1.47]
		Han et al.	2020	NRS	33	7.0 (2.1)	4.8 (2.1)	16.9%	1.04	[0.52, 1.55]
Subtotal				158			81.7%	0.99	[0.52, 1.55]	
Total					470			100.0%	1.21	[0.49, 1.92]

Note. VAS = visual analogue scale; TSI = tinnitus severity index; TEQ = tinnitus experiences questionnaire; NRS = numerical rating scale.

Figure 3. Forest plot of reduction of tinnitus distress after hearing aid fitting with verified versus unverified amplification in all included studies.



of tinnitus distress ≤ 3 months post hearing aid fitting, with an effect size (g) of 1.38 (95% confidence interval [0.98, 1.78], $Z = 6.77$, $p < .00001$). Tests of statistical heterogeneity across included studies showed $\chi^2 = 211.74$, $df = 16$, $p < .00001$, $I^2 = 92\%$. The reduction of tinnitus distress did not differ significantly between subgroups of verified versus unverified amplification ($\chi^2 = 0.57$, $df = 1$, $p = .45$). Tests of statistical heterogeneity for the verified amplification subgroup showed $\chi^2 = 96.89$, $df = 8$, $p < .00001$, $I^2 = 92\%$. Tests of statistical heterogeneity for the unverified amplification subgroup showed $\chi^2 = 83.19$, $df = 7$, $p < .00001$, $I^2 = 92\%$. The analysis was reconducted after excluding an outlier in the unverified amplification subgroup (Araujo & Iório, 2016). Without inclusion of outlier data, the differences in reduction of tinnitus distress between verified and unverified amplification approached significance ($\chi^2 = 2.71$, $df = 15$, $p = .10$). The exclusion of the outlier resulted in the following measures of statistical heterogeneity for the unverified amplification subgroup: $\chi^2 = 59.00$, $df = 6$, $p < .00001$, $I^2 = 90\%$. Please see Figure 4 for forest plot of tinnitus distress reduction among studies with and without verified amplification (with and

without outlier) and Table 6 for outcome data for each study and subgroup (with and without outlier).

The aggregated results from the subsequent meta-analysis of medium-term data indicated a significant reduction of tinnitus distress > 3 –6 months post hearing aid fitting, with an effect size (g) of 1.10 (95% confidence interval [0.75, 1.45], $Z = 6.13$, $p < .00001$). Tests of statistical heterogeneity across included studies showed $\chi^2 = 42.53$, $df = 11$, $p < .0001$, $I^2 = 74\%$. The reduction of tinnitus distress did not differ significantly between subgroups of verified versus unverified amplification; however, the difference approached significance ($\chi^2 = 2.71$, $df = 1$, $p = .10$). Tests of statistical heterogeneity for the verified amplification subgroup showed $\chi^2 = 22.65$, $df = 4$, $p < .0001$, $I^2 = 82\%$. Tests of statistical heterogeneity for the unverified amplification subgroup showed $\chi^2 = 13.06$, $df = 6$, $p = .04$, $I^2 = 54\%$. Please see Figure 5 for forest plot of tinnitus distress reduction among studies with and without verified amplification and Table 7 for outcome data for each study and subgroup.

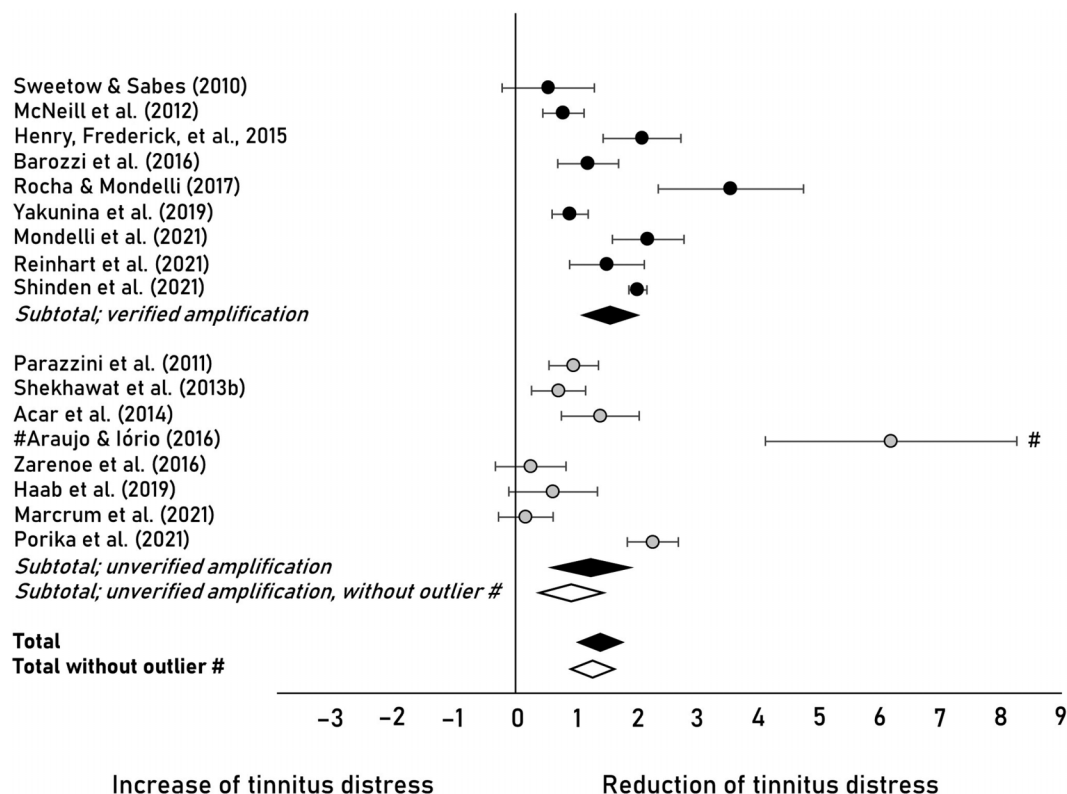
The aggregated results from the subsequent meta-analysis of long-term data indicated a significant reduction

Table 5. Tinnitus distress outcomes for all included studies.

Subgroup	Study	Year	Outcome measure	n	Pre hearing aid fitting M (SD)	Post hearing aid fitting M (SD)	Weight	Effect size (g)	95% Confidence interval
Verified amplification	Searchfield et al.	2010	THQ	29	59.2 (18.2)	21.8 (25.8)	3.8%	1.65	[1.05, 2.25]
	Sweetow & Sabes	2010	THI	14	58.7 (23.0)	41.9 (27.0)	3.5%	0.65	[−0.11, 1.41]
	McNeill et al.	2012	TRQ	70	49.0 (20.9)	34.1 (17.5)	4.1%	0.77	[0.43, 1.11]
	Henry, Frederick, et al.	2015	TFI	30	58.3 (15.8)	22.2 (18.6)	3.7%	2.07	[1.43, 2.70]
	Barozzi et al.	2016	THI	36	47.8 (15.5)	25.9 (15.2)	3.9%	1.41	[0.89, 1.93]
	Henry et al.	2017	TFI	54	56.4 (15.2)	28.2 (20.5)	4.0%	1.55	[1.12, 1.98]
	Hodgson et al.	2017	TFI	16	40.7 (17.1)	26.1 (18.6)	3.6%	0.80	[0.07, 1.52]
	Rocha & Mondelli	2017	THI	15	66.4 (13.8)	10.6 (12.9)	2.5%	4.07	[2.75, 5.39]
	Yakunina et al.	2019	THI	94	49.5 (21.6)	31.8 (18.5)	4.2%	0.88	[0.58, 1.18]
	Mondelli et al.	2021	THI	36	47.6 (16.9)	12.9 (14.7)	3.8%	2.17	[1.58, 2.75]
	Reinhart et al.	2021	THI	26	48.8 (16.7)	24.9 (14.8)	3.7%	1.49	[0.87, 2.11]
	Shinden et al.	2021	THI	312	55 (24)	9 (14)	4.3%	2.34	[2.13, 2.54]
Subtotal				732			45.1%	1.58	[1.13, 2.03]
Unverified amplification	Folmer & Carroll	2006	TSI	50	38.2 (8.3)	29.6 (8.4)	4.0%	1.02	[0.60, 1.44]
	Schaette et al.	2010	TQ	11	29.7 (13.1)	24 (16.6)	3.3%	0.37	[−0.48, 1.21]
	Parazzini et al.	2011	THI	49	59.1 (19.6)	28.7 (15.4)	4.0%	1.71	[1.25, 2.18]
	Shekhawat et al.	2013a	TFI	40	37.7 (17.3)	26.6 (15.2)	4.0%	0.68	[0.22, 1.13]
	Acar et al.	2014	THI	24	60.1 (11.9)	42.3 (13.5)	3.7%	1.38	[0.74, 2.01]
	#Araujo & Iório	2016	THI	12	45.0 (7.4)	9.2 (2.9)	1.5%	6.19	[4.11, 8.26]
	Zarenoue et al.	2016	THI	23	30.7 (21.6)	25.8 (20.4)	3.8%	0.23	[−0.35, 0.81]
	Bauer et al.	2017	THI	15	63.4 (14.0)	39.3 (15.4)	3.5%	1.00	[0.24, 1.77]
	Shabana et al.	2018	THI	20	39.3 (12.0)	30.9 (11.1)	3.7%	0.71	[0.07, 1.36]
	Haab et al.	2019	TQ	15	55.7 (13.7)	51.4 (16.9)	3.6%	0.27	[−0.45, 0.99]
	Han et al.	2020	THI	33	56.8 (24.0)	27.9 (18.0)	3.9%	1.35	[0.81, 1.88]
	Yokota et al.	2020	THI	66	28.0 (30.0)	15.2 (23.6)	4.1%	0.47	[0.12, 0.82]
	Marcum et al.	2021	THI	39	42.4 (21.0)	39.0 (24.0)	4.0%	0.15	[−0.30, 0.59]
	Noguchi et al.	2021	THI	21	37.3 (20.9)	22.4 (18.1)	3.7%	0.75	[0.12, 1.38]
	Porika et al.	2021	THI	72	79.5 (11.3)	42.5 (20.2)	4.0%	2.25	[1.83, 2.67]
Subtotal				490			54.9%	1.03	[0.63, 1.42]
Subtotal without outlier#				475				0.90	[0.54, 1.25]
Total				1,222			100.0%	1.29	[0.97, 1.60]
Total without outlier#				1,210				1.21	[0.90, 1.52]

Note. THQ = tinnitus handicap questionnaire; THI = Tinnitus Handicap Inventory; TRQ = tinnitus reaction questionnaire; TFI = Tinnitus Functional Index; TSI = tinnitus severity index; TQ = tinnitus questionnaire.

Figure 4. Forest plot of short-term (≤ 3 months post hearing aid fitting) reduction of tinnitus distress with verified versus unverified amplification.



of tinnitus distress ≥ 12 months post hearing aid fitting, with an effect size (g) of 1.29 (95% confidence interval [0.62, 1.96], $Z = 3.77$, $p = .0002$). Tests of statistical heterogeneity across included studies showed $\chi^2 = 107.88$, $df = 6$, $p < .00001$, $I^2 = 94\%$. The reduction of tinnitus distress was significantly greater with verified compared to unverified amplification ($\chi^2 = 6.65$, $df = 1$, $p = .01$). Tests of statistical heterogeneity for the verified amplification subgroup showed $\chi^2 = 4.50$, $df = 1$, $p < .03$, $I^2 = 78\%$. Tests of statistical heterogeneity for the unverified amplification subgroup showed $\chi^2 = 18.15$, $df = 4$, $p = .001$, $I^2 = 78\%$. Please see Figure 6 for the forest plot of tinnitus distress reduction among studies with and without verified amplification and Table 8 for outcome data for each study and subgroup.

Discussion

Main Findings

The meta-analysis of all included studies indicated verified amplification to result in significantly enhanced reduction of tinnitus loudness ($p < .00001$), while the enhanced reduction of tinnitus distress only approached

statistical significance ($p = .07$). However, it should be noted that there was an outlier in terms of reduction of achieved reduction of tinnitus distress (Araujo & Iório, 2016) in the unverified amplification subgroup. The reduction seen in the work of Araujo and Iório (2016) had an effect size of Hedges' g of 6.19 (confidence interval [4.11, 8.26]), which is approximately 3–41 times greater than the effect sizes seen in the other studies of the same subgroup. There is no clear explanation of this remarkable effect and no report of a special fitting strategy or potentially interfering adjuvant treatment. When excluding the work of Araujo and Iório from the initial meta-analysis, it indicated significantly greater reduction of tinnitus distress with verified compared to unverified amplification ($p = .02$). It should also be noted that interpretations of the meta-analysis of tinnitus loudness should be made with great caution as the verified amplification subgroup only consisted of one study.

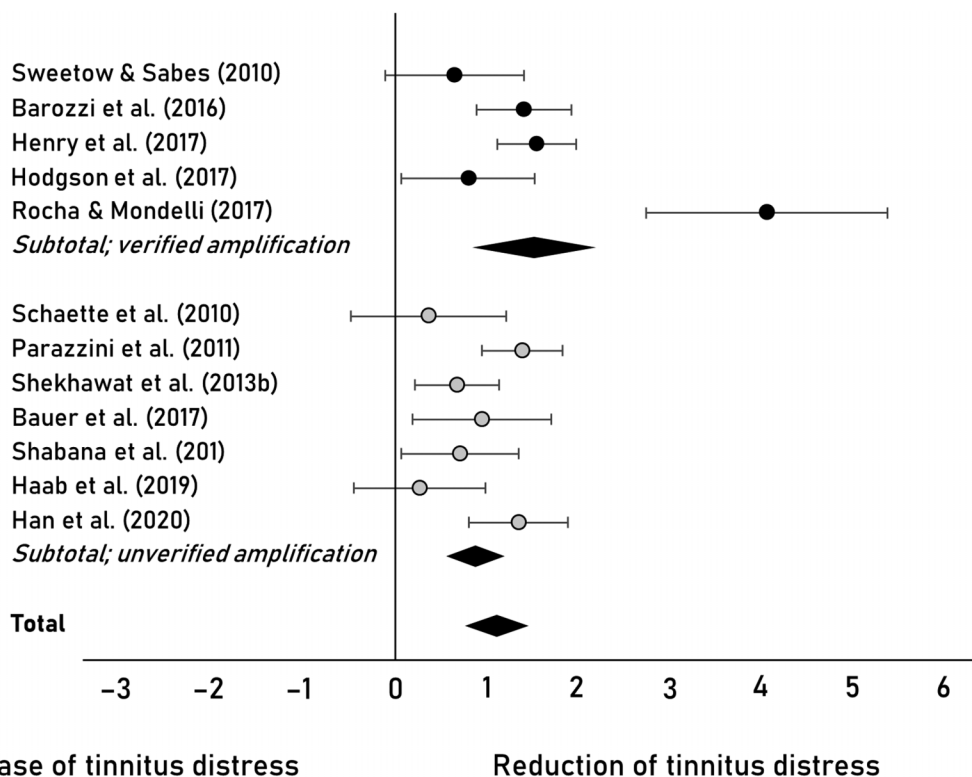
In the subsequent meta-analyses, where time since hearing aid fitting was taken into account, interesting trends in opposite directions were observed for the two subgroups. The short-term effects were somewhat similar for both subgroups, effect size Hedges' g being 1.54 with verified amplification and 1.22 with unverified amplification ≤ 3 months post hearing aid fitting. However, the effect

Table 6. Short-term (≤ 3 months post hearing aid fitting) tinnitus distress outcomes.

Subgroup	Study	Year	Outcome measure	<i>n</i>	Pre hearing aid fitting <i>M</i> (<i>SD</i>)	Post hearing aid fitting <i>M</i> (<i>SD</i>)	Weight	Effect size (<i>g</i>)	95% Confidence interval
Verified amplification	Sweetow & Sabes	2010	THI	14	58.7 (23.0)	44.6 (29.7)	5.6%	0.52	[−0.24, 1.27]
	McNeill et al.	2012	TRQ	70	49.02 (20.9)	34.08 (17.48)	6.6%	0.77	[0.43, 1.11]
	Henry, Frederick, et al.	2015	TFI	30	58.3 (15.79)	22.2 (18.56)	5.9%	2.07	[1.43, 2.70]
	Barozzi et al.	2016	THI	36	47.8 (15.5)	29.5 (15.1)	6.3%	1.18	[0.68, 1.69]
	Rocha & Mondelli	2017	THI	15	66.4 (13.79)	18.7 (12.5)	4.3%	3.54	[2.34, 4.73]
	Yakunina et al.	2019	THI	94	49.5 (21.6)	31.8 (18.5)	6.7%	0.88	[0.58, 1.18]
	Mondelli et al.	2021	THI	36	47.6 (16.9)	12.9 (14.7)	6.0%	2.17	[1.58, 2.75]
	Reinhart et al.	2021	THI	26	48.8 (16.7)	24.9 (14.8)	6.0%	1.49	[0.87, 2.11]
	Shinden et al.	2021	THI	490	53 (25)	11 (16)	6.9%	2.00	[1.85, 2.15]
	Subtotal			811			54.2%	1.54	[1.06, 2.03]
Unverified amplification	Parazzini et al.	2011	THI	49	59.1 (19.6)	41.1 (18.2)	6.5%	0.94	[0.53, 1.36]
	Shekhawat et al.	2013a	TFI	40	37.7 (17.3)	25.9 (16.6)	6.4%	0.69	[0.24, 1.14]
	Acar et al.	2014	THI	24	60.1 (11.9)	42.3 (13.5)	5.9%	1.38	[0.74, 2.01]
	#Araujo & Iório	2016	THI	12	45.0 (7.4)	9.2 (2.9)	2.4%	6.19	[4.11, 8.26]
	Zarenoue et al.	2016	THI	23	30.7 (21.6)	25.8 (20.4)	6.1%	0.23	[−0.35, 0.81]
	Haab et al.	2019	TQ	15	55.7 (13.7)	47.0 (14.5)	5.6%	0.60	[−0.13, 1.33]
	Marcum et al.	2021	THI	39	42.4 (21.0)	39.0 (24.0)	6.4%	0.15	[−0.30, 0.59]
	Porika et al.	2021	THI	72	79.5 (11.3)	42.5 (20.2)	6.5%	2.25	[1.83, 2.67]
	Subtotal			274			45.8%	1.22	[0.55, 1.90]
Subtotal without outlier#				262				0.90	[0.30, 1.49]
Total				1,085			100.0%	1.38	[0.98, 1.78]
Total without outlier#				1,073				1.26	[0.87, 1.65]

Note. THI = Tinnitus Handicap Inventory; TRQ = tinnitus reaction questionnaire; TFI = Tinnitus Functional Index; TQ = tinnitus questionnaire.

Figure 5. Forest plot of medium-term (> 3–6 months post hearing aid fitting) reduction of tinnitus distress with verified versus unverified amplification.



sizes seen with unverified amplification decreased over time, down to Hedges' g of 0.87 after > 3–6 months post hearing aid fitting, stabilizing at Hedges' g of 0.99 after ≥ 12 months post hearing aid fitting. With verified amplification, the effect size was almost identical at medium follow-up (> 3–6 months: Hedges' $g = 1.53$) compared to short-term follow-up (≤ 3 months: Hedges' $g = 1.54$). However, with long-term follow-up (≥ 12 months), the effect size increased to Hedges' g of 2.06, that is, roughly twice the effect size seen with unverified verification with the same follow-up duration (Hedges' $g = 0.99$). The differences in effect size between subgroups were far from significant at short-term follow-up ($p = .45$), approached significance at medium-term follow-up ($p = .10$), and reached statistical significance at long-term follow-up ($p = .01$). Please see Figure 7 for a visual presentation of subgroup trends in reduction of tinnitus distress over time.

These findings are consistent with Kochkin et al. (2011), who compared subjective tinnitus mitigation among 732 patients grouped based on the quality of the audiological care they had received. In the study reported by Kochkin et al. (2011), audiological care was evaluated using seven criteria for best practice, of which use of real-ear measurement in fitting the hearing aid was one. Tinnitus mitigation was evaluated using an ordinal scale regarding perceived tinnitus

mitigation with hearing aids, with response options (a) tinnitus worsening, (b) no effect on tinnitus, (c) mild mitigation, (d) moderate mitigation, and (e) significant mitigation. The study revealed that ratings indicating tinnitus mitigation (mild, moderate, or significant) were about twice as likely among patients receiving highest (62% reporting tinnitus mitigation) versus lowest (32% reporting tinnitus mitigation) quality of audiological care. While Kochkin et al. (2011) highlighted the importance of overall quality of audiological care (where objective verification with probe microphones is one of the aspects considered) for tinnitus mitigation, this study specifically highlights the importance of objective verification of the amplification.

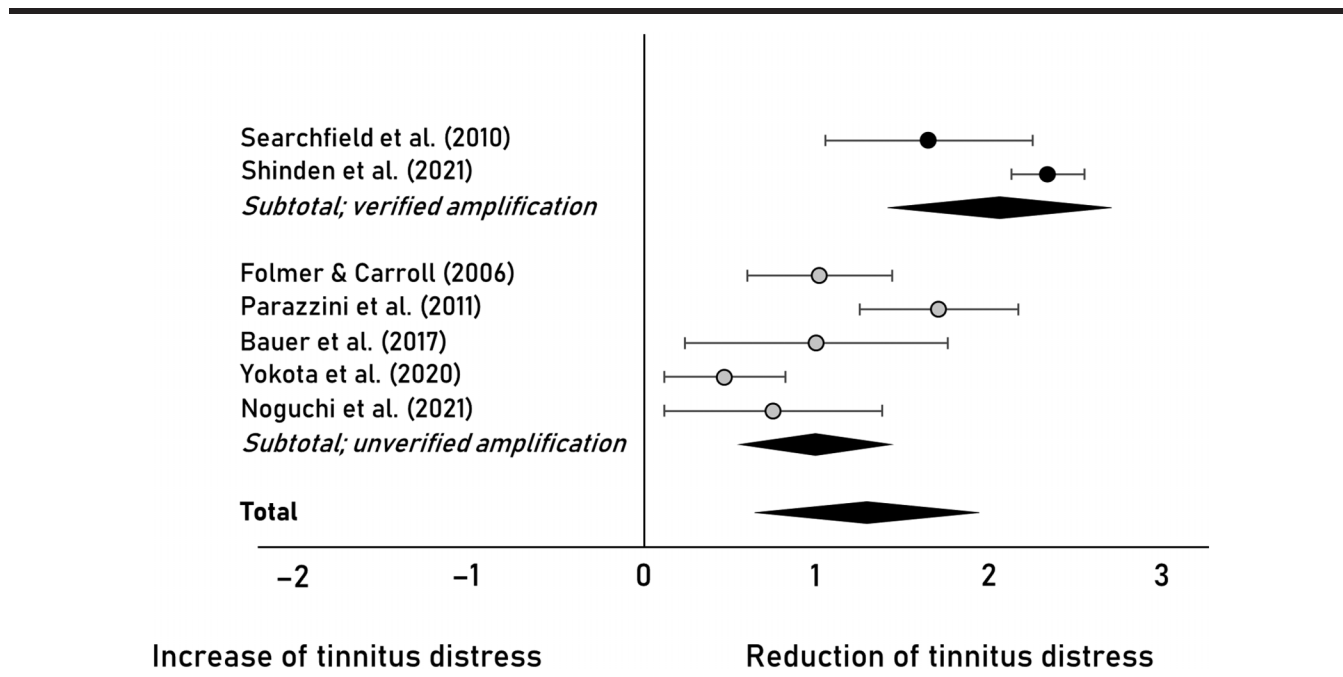
Overall, measures of heterogeneity indicated substantial to considerable heterogeneity for all conducted meta-analyses. This was expected as the included studies used different types of hearing aids, fitting strategies, adjuvant treatments, and outcome measures. In addition, they studied participants of different age ranges and different degrees of previous hearing aid experience and had different exclusion criteria. Furthermore, most included studies did not report thoroughly on possible confounders such as degree of hearing impairment (Mahafza et al., 2021; Waechter, 2021), personality type (Simões et al., 2019), and comorbidity of anxiety or depression

Table 7. Medium-term (> 3–6 months post hearing aid fitting) tinnitus distress outcomes.

Subgroup	Study	Year	Outcome measure	<i>n</i>	Pre hearing aid fitting <i>M</i> (<i>SD</i>)	Post hearing aid fitting <i>M</i> (<i>SD</i>)	Weight	Effect size (<i>g</i>)	95% Confidence interval
Verified amplification	Sweetow & Sabes	2010	THI	14	58.7 (23.0)	41.9 (27.0)	7.6%	0.65	[−0.11, 1.41]
	Barozzi et al.	2016	THI	36	47.8 (15.5)	25.9 (15.2)	9.5%	1.41	[0.89, 1.93]
	Henry et al.	2017	TFI	54	56.4 (15.2)	28.2 (20.5)	10.1%	1.55	[1.12, 1.98]
	Hodgson et al.	2017	TFI	16	40.7 (17.1)	26.1 (18.6)	7.9%	0.80	[0.07, 1.52]
	Rocha & Mondelli	2017	THI	15	66.4 (13.79)	10.6 (12.9)	4.5%	4.07	[2.75, 5.39]
Subtotal				135			39.5%	1.53	[0.82, 2.24]
Unverified amplification	Schaette et al.	2010	TQ	11	29.7 (13.1)	24 (16.6)	7.1%	0.37	[−0.48, 1.21]
	Parazzini et al.	2011	THI	49	59.1 (19.6)	33.5 (16.8)	10.0%	1.39	[0.95, 1.83]
	Shekhawat et al.	2013a	TFI	40	37.7 (17.3)	26.6 (15.2)	10.0%	0.68	[0.22, 1.13]
	Bauer et al.	2017	THI	15	48.8 (15.9)	33.8 (14.9)	7.6%	0.95	[0.19, 1.71]
	Shabana et al.	2018	THI	20	39.3 (12.0)	30.9 (11.1)	8.5%	0.71	[0.07, 1.36]
	Haab et al.	2019	TQ	15	55.7 (13.7)	51.4 (16.9)	7.9%	0.27	[−0.45, 0.99]
	Han et al.	2020	THI	33	56.8 (24.0)	27.9 (18.0)	9.3%	1.35	[0.81, 1.88]
Subtotal				183			60.5%	0.87	[0.54, 1.21]
Total				318			100.0%	1.10	[0.75, 1.45]

Note. THI = Tinnitus Handicap Inventory; TFI = Tinnitus Functional Index; TQ = tinnitus questionnaire.

Figure 6. Forest plot of long-term (≥ 12 months post hearing aid fitting) reduction of tinnitus distress with verified versus unverified amplification.



(Brüggemann et al., 2016) and average daily hour hearing aid use (Wong et al., 2003). According to Higgins et al. (2021), there are several ways to address heterogeneity in a meta-analysis. As recommended by Higgins et al., we have double-checked that all data are correct, used the SMD as effect measure to minimize differences seen due to different studies using different scales as outcome measures, performed a random effects analysis, and redone analyses after excluding outliers (Araujo & Iório, 2016). However, we did not follow the suggestions of exploring the heterogeneity using a meta-regression approach (since too few studies reported data on known confounders), choosing a fixed effects model instead of a random effect model (as this would not allow generalization of results beyond the included studies), or choosing to only perform a systematic review without meta-analysis (since the meta-analysis aspect of this review article is important for conveying the trends seen in previous literature).

It should be noted that there is a hypothetical possibility that some studies included in the unverified amplification subgroup may have used methods to objectively verify their participants' hearing aid amplification without reporting doing so. If this would be the case, the relationship between objectively verifying the amplification and tinnitus mitigation may be stronger or weaker than reported in this study. However, clinicians and researchers have historically often failed to adopt objective verification of hearing aid amplification, despite its importance for hearing aid outcomes being known and communicated for decades. Thus,

we suspect that most researchers actually performing objective verification of hearing aid amplification would be motivated to report this in their methods description to let readers know about their high-quality research design. While we cannot completely rule out the possibility that studies performed objective verification of the hearing aid amplification without reporting it (except for studies where it was clearly communicated that the amplification was verified by the participant's subjective experiences; e.g., Zarenog et al., 2016), it seems more likely that the studies not reporting use of objective verification have not verified the amplification objectively.

Economic Aspects

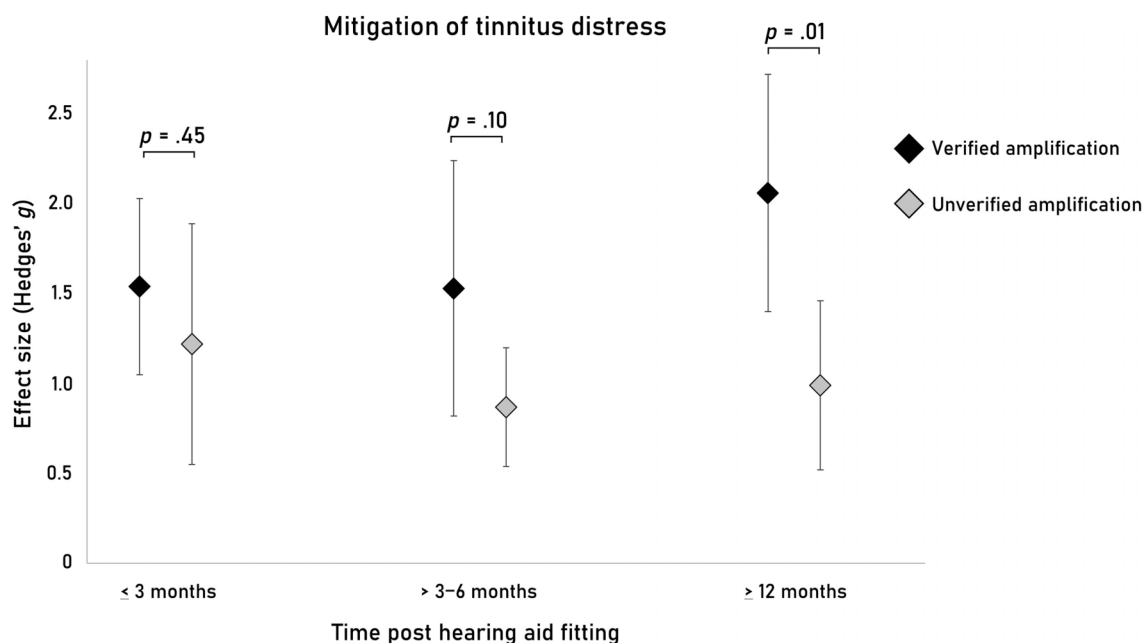
The enhanced efficacy of verified hearing aid gain for tinnitus mitigation should also be evaluated out of an economic perspective. Tinnitus is associated with societal cost approximately equivalent to 1% of gross domestic product, and only about a fourth of this cost is due to health care costs (Maes et al., 2013). The rest can be assumed to be related to decreased production (Maes et al., 2013) and increase of long-term sick leave (Friberg et al., 2013). In contrast, the cost of performing an REM verification is relatively low. An REM verification takes about 5–10 min to perform; hence, implementing this as a routine measure would not increase the cost of labor much. Prices of equipment to perform REM measurements start at approximately \$5000, and possible additional costs come

Table 8. Long-term (≥ 12 months post hearing aid fitting) tinnitus distress outcomes.

					<i>M (SD)</i>	<i>M (SD)</i>			95%	
Subgroup	Study	Year	Outcome measure	<i>n</i>	Pre hearing aid fitting	Post hearing aid fitting	Weight	Effect size (<i>g</i>)	Confidence interval	
Subtotal	Verified amplification	Searchfield et al.	2010	THQ	29	59.2 (18.2)	21.8 (25.8)	13.8%	1.65	[1.05, 2.25]
		Shinden et al.	2021	THI	312	55 (24)	9 (14)	15.4%	2.34	[2.13, 2.54]
					341			29.2%	2.06	[1.39, 2.72]
	Unverified amplification	Folmer & Carroll	2006	TSI	50	38.2 (8.3)	29.6 (8.4)	14.7%	1.02	[0.60, 1.44]
		Parazzini et al.	2011	THI	49	59.1 (19.6)	28.7 (15.4)	14.5%	1.71	[1.25, 2.18]
		Bauer et al.	2017	THI	15	48.8 (15.9)	30.3 (19.8)	12.9%	1.00	[0.24, 1.77]
		Yokota et al.	2020	THI	66	28.0 (30.0)	15.2 (23.6)	15.0%	0.47	[0.12, 0.82]
Noguchi et al.		2021	THI	21	37.3 (20.9)	22.4 (18.1)	13.7%	0.75	[0.12, 1.38]	
Subtotal				201			70.8%	0.99	[0.52, 1.46]	
Total				542			100.0%	1.29	[0.62, 1.96]	

Note. THQ = tinnitus handicap questionnaire; THI = Tinnitus Handicap Inventory; TSI = tinnitus severity index.

Figure 7. Longitudinal reduction of tinnitus distress with verified versus unverified hearing aid amplification.



with yearly calibration and occasional need of repair, which is why this may result in a substantial expense for a small clinic. However, out of a societal perspective, REM is very cheap compared to the alternative—not improving tinnitus care. Despite the contrast between societal cost of not performing objective verification of hearing aid gain and the relatively low cost of implementing the measurements, one of the most common arguments among audiologists and hearing instrument specialists for not performing REM verification is the price (Mueller & Picou, 2010). In the light of this, governmental financial support aimed to enable implementation of REM verification routinely may be a successful strategy.

Explanatory Models

It is plausible that hearing aids' reductive effect on the contrast between tinnitus percept and ambient noise and their effect on neuroplasticity may be greater with verified amplification compared to unverified. Therefore, the findings of the present meta-analyses (verified amplification showing greater reduction of tinnitus distress and tinnitus loudness) may reflect both proposed ways of tinnitus mitigation due to hearing aids. However, in light of the identified longitudinal effects seen with verified amplification (i.e., the positive impact on tinnitus outcomes increase with longer duration between baseline and follow-up measures), hearing aids' effect on neural reorganization processes seems to be the primary contributor. On *group level*, verified amplification could theoretically reduce the

contrast between tinnitus and ambient noise to a greater extent than unverified amplification. However, this is not necessarily true at the *individual level*, as unverified amplification by chance could result in greater gain than prescribed in critical frequency regions. This may sound counter intuitive but could be the case if the individual's tinnitus pitch and ear canal resonance characteristics match so that the ear canal's resonance characteristics happen to amplify sounds at the same frequency as the patient is experiencing their tinnitus. The possibility of such enhanced efficacy of unverified amplification is, however, not plausible in terms of neuroplasticity. Furthermore, it is unclear why the mitigating effect explained by reducing the contrast between tinnitus percept and ambient noise would increase over time in the verified amplification subgroup, unless the participant kept returning for recurring fine tuning of their hearing aids. Unfortunately, most studies only provided sparse, if any, reporting regarding follow-up fitting sessions, which limits estimation of the likelihood of this possibility. However, hearing aid use has clear impacts on both neural functioning and anatomy, suggesting that auditory stimulation with hearing aids may lead to neural reorganization (e.g., Glick & Sharma, 2020; Munro, 2008; Pereira-Jorge et al., 2018). Those changes do not manifest instantaneously but develop over time (Leite et al., 2018), which may explain why tinnitus mitigation increases longitudinally with verified amplification according to the present meta-analysis. While most studies investigating neural reorganization in response to hearing aid use do not focus on tinnitus, a recent study by Simonetti et al. (2022) compared

cerebral metabolism measured with positron emission tomography pre and post 6 months hearing aid use in individuals with and without tinnitus. Simultaneous with the expected significant reduction in tinnitus distress, the researchers found decreased minimum masking levels (meaning that weaker sound levels were needed to achieve residual inhibition, i.e., masking the patient's tinnitus), along with tinnitus-specific metabolic changes in several brain regions in response to (REM-verified) hearing aid use. This indicates specific neuroplastic changes to be associated with tinnitus mitigation due to hearing aid use. In addition, in the study reported by Yakunina et al. (2019), a unique study design was used where participants first were fitted with hearing aids providing objectively verified amplification and then they were asked to wear their hearing aids for 3 months, but after that, participants were asked to stop wearing their hearing aids. A new data collection was performed after 6 months (i.e., after 3 months without hearing aids). This data collection showed that tinnitus distress only regressed slightly and was still significantly milder compared to pre hearing aid fitting. This finding probably reflects tinnitus mitigation due to neuroplasticity, since such effects would be present even when the hearing aids are not worn as the neural reorganization would not regress immediately. Tinnitus mitigation via reduction of the contrast between tinnitus and ambient noise, on the other hand, would disappear when hearing aids are not worn, as it is a direct real-time effect of the amplification. Hence, if the driving effect of tinnitus mitigation in the study reported by Yakunina et al. (2019) would have been reduction of the contrast between tinnitus and ambient noise, the effect would have vanished after 3 months without hearing aid use. Taken together, the longitudinal increase of tinnitus mitigation with verified hearing aid gain seems to mainly be associated with processes of neural reorganization. This hypothesis could be confirmed or discarded by future studies using a randomized controlled approach when examining neuroplasticity and tinnitus distress in individuals receiving verified versus unverified hearing aid gain.

It is worth noting that neural reorganization due to verified hearing aid gain is accompanied with improvements of speech perception, global cognitive function, executive function, processing speed, and visual working memory (Glick & Sharma, 2020). In the light of this, it is possible that a portion of the observed reduction in subjective tinnitus distress may be attributed to improved auditory and cognitive functions rather than improved tinnitus. In line with this hypothesis, tinnitus patients tend to associate their auditory problems with their tinnitus, rather than their hearing impairment (Henry, Griest, et al., 2015), and degree of hearing impairment is associated with degree of tinnitus distress (Mahafza et al., 2021; Waechter, 2021). In addition, concentration difficulties among tinnitus patients (which was first reported by

Tyler & Baker, 1983) are one of the most common complaints from the present patient group (Hall et al., 2018). However, studies carefully controlling for hearing status indicate that tinnitus is not associated with cognitive performance (Glick & Sharma, 2020; Hamza & Zeng, 2021; Jensen et al., 2021; Waechter & Brännström, 2015; Waechter et al., 2019, 2021, 2022). Hence, it may be possible to reduce subjective tinnitus distress by improving auditory and cognitive function, which verified hearing aid gain has been shown to do (Glick & Sharma, 2020). Better auditory function with verified compared to unverified hearing aid gain was indicated in a recent meta-analysis (Almufarrij et al., 2021); however, the implications of verified versus unverified hearing aid gain for cognitive function has not yet been sufficiently addressed.

While neuroplasticity may explain the longitudinal increase of tinnitus mitigation with verified hearing aid gain, it does not serve as an explanation for opposite effect seen with unverified gain. One phenomenon that is likely to have initial (but less likely long-term) impact is the placebo effect. Duckert and Rees (1984) showed that the placebo effect is of importance when evaluating tinnitus treatments, as 40% of their participants reported changes in tinnitus percept after receiving a placebo saline injection. Dawes et al. (2013) showed that the placebo effect also need to be taken into account in studies on hearing aid interventions, as participants informed they were fitted with new hearing technology showed significantly greater speech intelligibility and subjective rating of sound quality post hearing aid fitting compared to participants informed that they were fitted with conventional hearing technology, despite receiving identical hearing aids fitted with the same strategy. While the placebo effect is thought to be temporary, its longitudinal characteristics have not yet been studied in the context of hearing aid interventions. However, an example from a different field of research is a study by Hansen et al. (1996) where the longitudinal characteristics of the placebo effect in the context of benign prostate hyperplasia were studied. Hansen et al. reported maximal placebo effect after approximately 4–6 months, with a declining effect after that point in time. If similar longitudinal characteristics of the placebo effect have been present among the studies included in the present meta-analysis, the trend of longitudinal decrease of tinnitus mitigation with unverified hearing aid gain may be explained by an initial placebo effect.

Another possibility is that there may be differences in adherence to hearing aid use across the subgroups. The tendency among patients to stop using their hearing aids is a widespread problem, and the primary reason for this behavior is experience of poor benefit (McCormack & Fortnum, 2013). This tendency can, however, be assumed to be less prevalent among patients receiving verified hearing aid gain, as verified hearing aids give better speech intelligibility and self-rated listening abilities compared to

unverified hearing aid gain (Almufarrij et al., 2021). None of the included studies in the present meta-analysis described explicit questions at follow-up regarding how often the hearing aid had been used, and only few reported data on the hearing aids built in logging of average use. These limitations among the included studies hinder our ability to control whether there in fact were differences in adherence to hearing aid use across the subgroups. However, patients' statements of daily hearing aid use despite their hearing aids built in logging of average use indicating otherwise is common in the clinical setting, which is why it is easy to imagine that this behavior may also be present in a research setting.

Conclusions

Studies reporting having verified the hearing aid gain with objective measures show greater reduction of tinnitus distress and tinnitus loudness than studies not reporting having verified the hearing aid gain with objective measures. Specifically, the short-term effects of hearing aids on tinnitus distress (outcome measures at ≤ 3 months post hearing aid fitting) are similar regardless of gain verification. However, the verified hearing aids' tinnitus mitigating effect increases over time, while the unverified hearing aids' tinnitus mitigating effect decreases over time. When analyzing outcome measures ≥ 12 months post hearing aid fitting, the effect size seen in studies with verified hearing aid gain is about twice compared to studies with unverified hearing aid gain. Due to the low cost of hearing aid verification compared to the high societal cost of tinnitus, objective verification of hearing aid gain for tinnitus patients is recommended.

Acknowledgments

This study did not receive any financial support from any public, commercial, or nonprofit funding agencies.

References

- Aazh, H., & Moore, B. C. (2007). The value of routine real ear measurement of the gain of digital hearing aids. *Journal of the American Academy of Audiology*, 18(8), 653–664. <https://doi.org/10.3766/JAAA.18.8.3>
- Acar, A., Sahin, H., Kum, R. O., Öztürk, Z., Cayönü, M., Eker, F., & Göcer, C. (2014). Effects of hearing aids on tinnitus in geriatric patients with age-related hearing loss. *Turkish Journal of Geriatrics*, 17(2), 152–156.
- Adamchic, I., Langguth, B., Hauptmann, C., & Tass, P. A. (2012). Psychometric evaluation of visual analog scale for the assessment of chronic tinnitus. *American Journal of Audiology*, 21(2), 215–225. [https://doi.org/10.1044/1059-0889\(2012\)12-0010](https://doi.org/10.1044/1059-0889(2012)12-0010)
- Almufarrij, I., Dillon, H., & Munro, K. J. (2021). Does probe-tube verification of real-ear hearing aid amplification characteristics improve outcomes in adults? A systematic review and meta-analysis. *Trends in Hearing*, 25, 2331216521999563. <https://doi.org/10.1177/2331216521999563>
- American National Standards Institute. (1997). *Methods of measurement of real-ear performance characteristics of hearing aids. ANSI S3.46–1997*.
- Araujo, T. D. M., & Iório, M. C. (2016). Effects of sound amplification in self-perception of tinnitus and hearing loss in the elderly. *Brazilian Journal of Otorhinolaryngology*, 82(3), 289–296. <https://doi.org/10.1016/j.bjorl.2015.05.010>
- Ballachanda, B. B. (1997). Theoretical and applied external ear acoustics. *Journal of the American Academy of Audiology*, 8(6), 411–420.
- Barozzi, S., Del Bo, L., Crocetti, A., Dyrlund, O., Passoni, S., Zolin, A., Panicucci, E., Mancuso, A., Kaur, M., & Searchfield, G. D. (2016). A comparison of nature and technical sounds for tinnitus therapy. *Acta Acustica united with Acustica*, 102(3), 540–546. <https://doi.org/10.3813/AAA.918971>
- Bauer, C. A., Berry, J. L., & Brozoski, T. J. (2017). The effect of tinnitus retraining therapy on chronic tinnitus: A controlled trial. *Laryngoscope Investigative Otolaryngology*, 2(4), 166–177. <https://doi.org/10.1002/lio2.76>
- Borenstein, M., & Higgins, J. P. (2013). Meta-analysis and subgroups. *Prevention Science*, 14(2), 134–143. <https://doi.org/10.1007/s11121-013-0377-7>
- Brüggemann, P., Szczepek, A. J., Rose, M., McKenna, L., Olze, H., & Mazurek, B. (2016). Impact of multiple factors on the degree of tinnitus distress. *Frontiers in Human Neuroscience*, 10, 341. <https://doi.org/10.3389/fnhum.2016.00341>
- Chandra, N., Chang, K., Lee, A., Shekhawat, G. S., & Searchfield, G. D. (2018). Psychometric validity, reliability, and responsiveness of the Tinnitus Functional Index. *Journal of the American Academy of Audiology*, 29(07), 609–625. <https://doi.org/10.3766/jaaa.16171>
- Cima, R., Mazurek, B., Haider, H., Kikidis, D., Lapira, A., Noreña, A., & Hoare, D. J. (2019). A multidisciplinary European guideline for tinnitus: Diagnostics, assessment, and treatment, Einschätzung und Behandlung. *HNO*, 67(Suppl. 1), 10–42. <https://doi.org/10.1007/s00106-019-0633-7>
- Dawes, P., Hopkins, R., & Munro, K. J. (2013). Placebo effects in hearing-aid trials are reliable. *International Journal of Audiology*, 52(7), 472–477. <https://doi.org/10.3109/14992027.2013.783718>
- Del Bo, L., & Ambrosetti, U. (2007). Hearing aids for the treatment of tinnitus. *Progress in Brain Research*, 166, 341–345. [https://doi.org/10.1016/S0079-6123\(07\)66032-4](https://doi.org/10.1016/S0079-6123(07)66032-4)
- DerSimonian, R., & Laird, N. (1986). Meta-analysis in clinical trials. *Controlled Clinical Trials*, 7(3), 177–188. [https://doi.org/10.1016/0197-2456\(86\)90046-2](https://doi.org/10.1016/0197-2456(86)90046-2)
- Digiovanni, J. J., & Pratt, R. M. (2010). Verification of in situ thresholds and integrated real-ear measurements. *Journal of the American Academy of Audiology*, 21(10), 663–670. <https://doi.org/10.3766/jaaa.21.10.6>
- Duckert, L. G., & Rees, T. S. (1984). Placebo effect in tinnitus management. *Otolaryngology—Head & Neck Surgery*, 92(6), 697–699. <https://doi.org/10.1177/019459988409200618>
- Folmer, R. L., & Carroll, J. R. (2006). Long-term effectiveness of ear-level devices for tinnitus. *Otolaryngology—Head & Neck Surgery*, 134(1), 132–137. <https://doi.org/10.1016/j.ototns.2005.09.030>
- Friberg, E., Rosenhall, U., & Alexanderson, K. (2013). Sickness absence due to otoaudiological diagnoses; a descriptive nationwide study. *BMC Public Health*, 13(1), 635. <https://doi.org/10.1186/1471-2458-13-635>

- Glick, H. A., & Sharma, A. (2020). Cortical neuroplasticity and cognitive function in early-stage, mild-moderate hearing loss: Evidence of neurocognitive benefit from hearing aid use. *Frontiers in Neuroscience*, 14, 93. <https://doi.org/10.3389/fnins.2020.00093>
- Haab, L., Lehser, C., Corona-Strauss, F. I., Bernarding, C., Seidler, H., Hannemann, R., & Strauss, D. J. (2019). Implementation and long-term evaluation of a hearing aid supported tinnitus treatment using notched environmental sounds. *IEEE Journal of Translational Engineering in Health and Medicine*, 7, 1600109. <https://doi.org/10.1109/JTEHM.2019.2897570>
- Hall, D. A., Fackrell, K., Li, A. B., Thavayogan, R., Smith, S., Kennedy, V., Tinoco, C., Rodrigues, E. D., Campelo, P., Martins, T. D., Lourenço, V. M., Ribeiro, D., & Haider, H. F. (2018). A narrative synthesis of research evidence for tinnitus-related complaints as reported by patients and their significant others. *Health and Quality of Life Outcomes*, 16(1), 61. <https://doi.org/10.1186/s12955-018-0888-9>
- Hallam, R. S., Jakes, S. C., & Hinchcliffe, R. (1988). Cognitive variables in tinnitus annoyance. *The British Journal of Clinical Psychology*, 27(3), 213–222. <https://doi.org/10.1111/j.2044-8260.1988.tb00778.x>
- Hamza, Y., & Zeng, F. G. (2021). Tinnitus is associated with improved cognitive performance in non-Hispanic elderly with hearing loss. *Frontiers in Neuroscience*, 15, 735950. <https://doi.org/10.3389/fnins.2021.735950>
- Han, J. J., Ridder, D., Vanneste, S., Chen, Y. C., Koo, J. W., & Song, J. J. (2020). Pre-treatment ongoing cortical oscillatory activity predicts improvement of tinnitus after partial peripheral reafferentation with hearing aids. *Frontiers in Neuroscience*, 14, 410. <https://doi.org/10.3389/fnins.2020.00410>
- Hansen, B. J., Meyhoff, H. H., Nordling, J., Mensink, H. J., Mogensen, P., & Larsen, E. H. (1996). Placebo effects in the pharmacological treatment of uncomplicated benign prostatic hyperplasia. The ALFECH Study Group. *Scandinavian Journal of Urology and Nephrology*, 30(5), 373–377. <https://doi.org/10.3109/00365599609181313>
- Hayes, M. H. S., & Patterson, D. G. (1921). Experimental development of the graphic rating method. *Psychological Bulletin*, 18, 98–99.
- Henry, J. A., Frederick, M., Sell, S., Griest, S., & Abrams, H. (2015). Validation of a novel combination hearing aid and tinnitus therapy device. *Ear and Hearing*, 36(1), 42–52. <https://doi.org/10.1097/AUD.0000000000000093>
- Henry, J. A., Griest, S., Zaugg, T. L., Thielman, E., Kaelin, C., Galvez, G., & Carlson, K. F. (2015). Tinnitus and hearing survey: A screening tool to differentiate bothersome tinnitus from hearing difficulties. *American Journal of Audiology*, 24(1), 66–77. https://doi.org/10.1044/2014_AJA-14-0042
- Henry, J. A., McMillan, G., Dann, S., Bennett, K., Griest, S., Theodoroff, S., Silverman, S. P., Whichard, S., & Saunders, G. (2017). Tinnitus management: Randomized controlled trial comparing extended-wear hearing aids, conventional hearing aids, and combination instruments. *Journal of the American Academy of Audiology*, 28(06), 546–561. <https://doi.org/10.3766/jaaa.16067>
- Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2021). *Cochrane Handbook for Systematic Reviews of Interventions version 6.2 (updated February 2021)*. Cochrane, 2021. <https://www.training.cochrane.org/handbook>
- Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, 21(11), 1539–1558. <https://doi.org/10.1002/sim.1186>
- Hodgson, S. A., Herdering, R., Singh Shekhawat, G., & Searchfield, G. D. (2017). A crossover trial comparing wide dynamic range compression and frequency compression in hearing aids for tinnitus therapy. *Assistive Technology*, 12(1), 97–103. <https://doi.org/10.3109/17483107.2015.1079266>
- Husain, F. T., Gander, P. E., Jansen, J. N., & Shen, S. (2018). Expectations for tinnitus treatment and outcomes: A survey study of audiologists and patients. *Journal of the American Academy of Audiology*, 29(04), 313–336. <https://doi.org/10.3766/jaaa.16154>
- Jensen, M., Hüttenrauch, E., Müller-Mazzotta, J., Stuck, B. A., & Weise, C. (2021). On the impairment of executive control of attention in chronic tinnitus: Evidence from the attention network test. *Behavioural Brain Research*, 414, 113493. <https://doi.org/10.1016/j.bbr.2021.113493>
- Kochkin, S., & Tyler, R. S. (2008). Tinnitus treatment and the effectiveness of hearing aids: Hearing care professional perceptions. *Hearing Review*, 15(13), 14–18.
- Kochkin, S., Tyler, R. S., & Born, J. (2011). MarkeTrak VIII: Prevalence of tinnitus and efficacy of treatments. *Hearing Review*, 18(12), 10–26.
- Kodera, K., Hosoi, H., Okamoto, M., Manabe, T., Kanda, Y., Shiraishi, K., Sugiuchi, T., Suzuki, K., Tauchi, H., Nishimura, T., Matsuhira, T., & Ishikawa, K. (2016). Guidelines for the evaluation of hearing aid fitting (2010). *Auris, Nasus, Larynx*, 43(3), 217–228. <https://doi.org/10.1016/j.anl.2015.10.015>
- Kuk, F. K., Tyler, R. S., Russell, D., & Jordan, H. (1990). The psychometric properties of a tinnitus handicap questionnaire. *Ear and Hearing*, 11(6), 434–445. <https://doi.org/10.1097/00003446-199012000-00005>
- Leite, R. A., Magliaro, F., Raimundo, J. C., Bento, R. F., & Matas, C. G. (2018). Monitoring auditory cortical plasticity in hearing aid users with long latency auditory evoked potentials: A longitudinal study. *Clinics*, 73, e51. <https://doi.org/10.6061/clinics/2018/e51>
- Levitt, H. (2007). A historical perspective on digital hearing aids: How digital technology has changed modern hearing aids. *Trends in Amplification*, 11(1), 7–24. <https://doi.org/10.1177/1084713806298000>
- Maes, I. H., Cima, R. F., Vlaeyen, J. W., Anteunis, L. J., & Joore, M. A. (2013). Tinnitus: A cost study. *Ear and Hearing*, 34(4), 508–514. <https://doi.org/10.1097/AUD.0b013e31827d113a>
- Mahafza, N., Zhao, F., El Refaie, A., & Chen, F. (2021). A comparison of the severity of tinnitus in patients with and without hearing loss using the Tinnitus Functional Index (TFI). *International Journal of Audiology*, 60(3), 220–226. <https://doi.org/10.1080/14992027.2020.1804081>
- Marcum, S. C., Picou, E. M., Steffens, T., Hannemann, R., Vielsmeier, V., Schecklmann, M., Langguth, B., & Schlee, W. (2021). Conventional versus notch filter amplification for the treatment of tinnitus in adults with mild-to-moderate hearing loss. *Progress in Brain Research*, 260, 235–252. <https://doi.org/10.1016/bs.pbr.2020.06.020>
- McCombe, A., Baguley, D., Coles, R., McKenna, L., McKinney, C., Windle-Taylor, P., & British Association of Otolaryngologists, Head and Neck Surgeons. (2001). Guidelines for the grading of tinnitus severity: The results of a working group commissioned by the British Association of Otolaryngologists, Head and Neck Surgeons, 1999. *Clinical Otolaryngology and Allied Sciences*, 26(5), 388–393. <https://doi.org/10.1046/j.1365-2273.2001.00490.x>
- McCormack, A., Edmondson-Jones, M., Fortnum, H., Dawes, P. D., Middleton, H., Munro, K. J., & Moore, D. R. (2015). Investigating the association between tinnitus severity and symptoms of depression and anxiety, while controlling for

- neuroticism, in a large middle-aged UK population. *International Journal of Audiology*, 54(9), 599–604. <https://doi.org/10.3109/14992027.2015.1014577>
- McCormack, A., Edmondson-Jones, M., Somerset, S., & Hall, D. (2016). A systematic review of the reporting of tinnitus prevalence and severity. *Hearing Research*, 337, 70–79. <https://doi.org/10.1016/j.heares.2016.05.009>
- McCormack, A., & Fortnum, H. (2013). Why do people fitted with hearing aids not wear them? *International Journal of Audiology*, 52(5), 360–368. <https://doi.org/10.3109/14992027.2013.769066>
- McNeill, C., Távora-Vieira, D., Alnafjan, F., Searchfield, G. D., & Welch, D. (2012). Tinnitus pitch, masking, and the effectiveness of hearing aids for tinnitus therapy. *International Journal of Audiology*, 51(12), 914–919. <https://doi.org/10.3109/14992027.2012.721934>
- Meikle, M. B., Griest, S. E., Stewart, B. J., & Press, L. J. (1995). Measuring the negative impact of tinnitus: A brief severity index. *Abstracts Association Research Otolaryngology*, 167.
- Meikle, M. B., Henry, J. A., Griest, S. E., Stewart, B. J., Abrams, H. B., McArdle, R., Myers, P. J., Newman, C. W., Sandridge, S., Turk, D. C., Folmer, R. L., Frederick, E. J., House, J. W., Jacobson, G. P., Kinney, S. E., Martin, W. H., Nagler, S. M., Reich, G. E., Searchfield, G., Sweetow, R., ... Vernon, J. A. (2012). The Tinnitus Functional Index: Development of a new clinical measure for chronic, intrusive tinnitus. *Ear and Hearing*, 33(2), 153–176. <https://doi.org/10.1097/AUD.0b013e31822f67c0>
- Mondelli, M., Cabreira, A. F., Matos, I. L., Ferreira, M. C., & Rocha, A. V. (2021). Sound generator: Analysis of the effectiveness of noise in the habituation of tinnitus. *International Archives of Otorhinolaryngology*, 25(02), e205–e212. <https://doi.org/10.1055/s-0040-1713377>
- Mueller, H. G., & Picou, E. M. (2010). Survey examines popularity of real-ear probe-microphone measures. *The Hearing Journal*, 63(5), 27–28,30,32. <https://doi.org/10.1097/01.HJ.0000373447.52956.25>
- Munro, K. J. (2008). Reorganization of the adult auditory system: Perceptual and physiological evidence from monaural fitting of hearing aids. *Trends in Amplification*, 12(3), 254–271. <https://doi.org/10.1177/1084713808323483>
- Newman, C. W., Jacobson, G. P., & Spitzer, J. B. (1996). Development of the Tinnitus Handicap Inventory. *Archives of Otolaryngology—Head & Neck Surgery*, 122(2), 143–148. <https://doi.org/10.1001/archotol.1996.01890140029007>
- Noguchi, M., Suzuki, N., Oishi, N., & Ogawa, K. (2021). Effectiveness of hearing aid treatment in patients with chronic tinnitus: Subscale evaluations using the Tinnitus Functional Index and factor analysis. *The Journal of International Advanced Otolaryngology*, 17(1), 42–45. <https://doi.org/10.5152/jiao.2020.9161>
- Ogawa, K., Sato, H., Takahashi, M., Wada, T., Naito, Y., Kawase, T., Murakami, S., Hara, A., & Kanzaki, S. (2020). Clinical practice guidelines for diagnosis and treatment of chronic tinnitus in Japan. *Auris, Nasus, Larynx*, 47(1), 1–6. <https://doi.org/10.1016/j.anl.2019.09.007>
- Parazzini, M., Del Bo, L., Jastreboff, M., Tognola, G., & Ravazzani, P. (2011). Open ear hearing aids in tinnitus therapy: An efficacy comparison with sound generators. *International Journal of Audiology*, 50(8), 548–553. <https://doi.org/10.3109/14992027.2011.572263>
- Pereira-Jorge, M. R., Andrade, K. C., Palhano-Fontes, F. X., Diniz, P., Sturzebecher, M., Santos, A. C., & Araujo, D. B. (2018). Anatomical and functional MRI changes after one year of auditory rehabilitation with hearing aids. *Neural Plasticity*, 2018, Article 9303674. <https://doi.org/10.1155/2018/9303674>
- Porika, R. K., Doraisami, B., & Ravichandran, A. (2021). The efficacy of digital hearing aids in the management of tinnitus in individuals with sensorineural hearing loss. *The International Tinnitus Journal*, 25(1), 100–106. <https://doi.org/10.5935/0946-5448.20210018>
- Price, D. D., Bush, F. M., Long, S., & Harkins, S. W. (1994). A comparison of pain measurement characteristics of mechanical visual analogue and simple numerical rating scales. *Pain*, 56(2), 217–226. [https://doi.org/10.1016/0304-3959\(94\)90097-3](https://doi.org/10.1016/0304-3959(94)90097-3)
- Reinhart, P., Griffin, K., & Michey, C. (2021). Changes in heart rate variability following acoustic therapy in individuals with tinnitus. *Journal of Speech, Language, and Hearing Research*, 64(4), 1413–1419. https://doi.org/10.1044/2021_JSLHR-20-00596
- Rocha, A. V., & Mondelli, M. (2017). Sound generator associated with the counseling in the treatment of tinnitus: Evaluation of the effectiveness. *Brazilian Journal of Otorhinolaryngology*, 83(3), 249–255. <https://doi.org/10.1016/j.bjorl.2016.03.021>
- Sanchez, T. G., Medeiros, I. R., Levy, C. P., Ramalho, J., & Bento, R. F. (2005). Tinnitus in normally hearing patients: Clinical aspects and repercussions. *Brazilian Journal of Otorhinolaryngology*, 71(4), 427–431. [https://doi.org/10.1016/s1808-8694\(15\)31194-0](https://doi.org/10.1016/s1808-8694(15)31194-0)
- Schaette, R., König, O., Hornig, D., Gross, M., & Kempter, R. (2010). Acoustic stimulation treatments against tinnitus could be most effective when tinnitus pitch is within the stimulated frequency range. *Hearing Research*, 269(1–2), 95–101. <https://doi.org/10.1016/j.heares.2010.06.022>
- Searchfield, G. D., Kaur, M., & Martin, W. H. (2010). Hearing aids as an adjunct to counseling: Tinnitus patients who choose amplification do better than those that don't. *International Journal of Audiology*, 49(8), 574–579. <https://doi.org/10.3109/14992021003777267>
- Shabana, M. I., Dabbous, A. O., Abdelmajeed, M. A., & Abdelkarim, A. M. M. (2018). Counselling and amplification with and without fractal music (Zen tones) for management of patients suffering from hearing loss and tinnitus. *Hearing, Balance and Communication*, 16(1), 41–55. <https://doi.org/10.1080/21695717.2017.1421812>
- Shekhawat, G. S., Searchfield, G. D., & Stinear, C. M. (2013a). Randomized trial of transcranial direct current stimulation and hearing aids for tinnitus management. *Neurorehabilitation and Neural Repair*, 28(5), 410–419. <https://doi.org/10.1177/1545968313508655>
- Shekhawat, G. S., Searchfield, G. D., & Stinear, C. M. (2013b). Role of hearing aids in tinnitus intervention: A scoping review. *Journal of the American Academy of Audiology*, 24(8), 747–762. <https://doi.org/10.3766/jaaa.24.8.11>
- Shinden, S., Suzuki, N., Oishi, N., Suzuki, D., Minami, S., & Ogawa, K. (2021). Effective sound therapy using a hearing aid and educational counseling in patients with chronic tinnitus. *Auris, Nasus, Larynx*, 48(5), 815–822. <https://doi.org/10.1016/j.anl.2021.01.001>
- Shore, S. E., Roberts, L. E., & Langguth, B. (2016). Maladaptive plasticity in tinnitus—Triggers, mechanisms and treatment. *Neurology*, 12(3), 150–160. <https://doi.org/10.1038/nrneurol.2016.12>
- Simões, J., Schlee, W., Scheckmann, M., Langguth, B., Farahmand, D., & Neff, P. (2019). Big five personality traits are associated with tinnitus improvement over time. *Scientific Reports*, 9(1), 18234. <https://doi.org/10.1038/s41598-019-53845-4>
- Simonetti, P., Ono, C. R., Godoi Carneiro, C., Ali Khan, R., Shahsavarani, S., Husain, F. T., & Oiticica, J. (2022). Evaluating the efficacy of hearing aids for tinnitus therapy—A positron emission tomography study. *Brain Research*, 1775, 147728. <https://doi.org/10.1016/j.brainres.2021.147728>

- Sterne, J. A. C., Hernán, M. A., McAleenan, A., Reeves, B. C., & Higgins, J. P. T. (2021). Assessing risk of bias in a non-randomized study. In J. P. T. Higgins, J. Thomas, J. Chandler, M. Cumpston, T. Li, M. J. Page, & V. A. Welch (Eds.), *Cochrane Handbook for Systematic Reviews of Interventions Version 6.2 (updated February 2021b)*. Cochrane. <https://www.training.cochrane.org/handbook>
- Sweetow, R. W., & Sabes, J. H. (2010). Effects of acoustical stimuli delivered through hearing aids on tinnitus. *Journal of the American Academy of Audiology*, 21(7), 461–473. <https://doi.org/10.3766/jaaa.21.7.5>
- Trochidis, I., Lugo, A., Borroni, E., Cederroth, C., Cima, R., Kikidis, D., Langguth, B., Schlee, W., & Gallus, S. (2021). Systematic review on healthcare and societal costs of tinnitus. *International Journal of Environmental Research and Public Health*, 18(13), 6881. <https://doi.org/10.3390/ijerph18136881>
- Trotter, M. I., & Donaldson, I. (2008). Hearing aids and tinnitus therapy: A 25-year experience. *The Journal of Laryngology and Otology*, 122(10), 1052–1056. <https://doi.org/10.1017/S002221510800203X>
- Tunkel, D. E., Bauer, C. A., Sun, G. H., Rosenfeld, R. M., Chandrasekhar, S. S., Cunningham, E. R., Jr., Archer, S. M., Blakley, B. W., Carter, J. M., Granieri, E. C., Henry, J. A., Hollingsworth, D., Khan, F. A., Mitchell, S., Monfared, A., Newman, C. W., Omole, F. S., Phillips, C. D., Robinson, S. K., Taw, M. B., Tyler, R. S., Waguespack, R., & Whamond, E. J. (2014). Clinical practice guideline: Tinnitus. *Otolaryngology—Head & Neck Surgery*, 151(Suppl. 2), S1–S40. <https://doi.org/10.1177/0194599814545325>
- Tyler, R. S., & Baker, L. J. (1983). Difficulties experienced by tinnitus sufferers. *Journal of Speech and Hearing Disorders*, 48(2), 150–154. <https://doi.org/10.1044/jshd.4802.150>
- Vielsmeier, V., Lehner, A., Strutz, J., Steffens, T., Kreuzer, P. M., Schecklmann, M., Landgrebe, M., Langguth, B., & Kleinjung, T. (2015). The relevance of the high frequency audiometry in tinnitus patients with normal hearing in conventional pure-tone audiometry. *BioMed Research International*, 2015, Article 302515. <https://doi.org/10.1155/2015/302515>
- Waechter, S. (2021). Association between hearing status and tinnitus distress. *Acta Oto-Laryngologica*, 141(4), 381–385. <https://doi.org/10.1080/00016489.2021.1876919>
- Waechter, S., & Brännström, K. J. (2015). The impact of tinnitus on cognitive performance in normal-hearing individuals. *International Journal of Audiology*, 54(11), 845–851. <https://doi.org/10.3109/14992027.2015.1055836>
- Waechter, S., Hallendorf, L., Malmstein, E., Olsson, A., & Brännström, K. J. (2019). The impact of tinnitus on *n*-back performance in normal hearing individuals. *Journal of the American Academy of Audiology*, 30(3), 169–177. <https://doi.org/10.3766/jaaa.17048>
- Waechter, S., Wilson, W. J., & Brännström, J. K. (2021). The impact of tinnitus on working memory capacity. *International Journal of Audiology*, 60(4), 274–281. <https://doi.org/10.1080/14992027.2020.1822550>
- Waechter, S., Wilson, W. J., Magnusson, M., & Brännström, K. J. (2022). Extended high frequency hearing, but not tinnitus, is associated with every-day cognitive performance. *Frontiers in Psychology*, 13, 913944. <https://doi.org/10.3389/fpsyg.2022.913944>
- Wang, K., Tang, D., Ma, J., & Sun, S. (2020). Auditory neural plasticity in tinnitus mechanisms and management. *Neural Plasticity*, 2020, 7438461. <https://doi.org/10.1155/2020/7438461>
- Wilson, P. H., Henry, J., Bowen, M., & Haralambous, G. (1991). Tinnitus reaction questionnaire: Psychometric properties of a measure of distress associated with tinnitus. *Hearing Research*, 34(1), 197–201. <https://doi.org/10.1044/jshr.3401.197>
- Wong, L. L., Hickson, L., & McPherson, B. (2003). Hearing aid satisfaction: What does research from the past 20 years say? *Trends in Amplification*, 7(4), 117–161. <https://doi.org/10.1177/108471380300700402>
- Xiong, B., Liu, Z., Liu, Q., Peng, Y., Wu, H., Lin, Y., Zhao, X., & Sun, W. (2019). Missed hearing loss in tinnitus patients with normal audiograms. *Hearing Research*, 384, 107826. <https://doi.org/10.1016/j.heares.2019.107826>
- Yakunina, N., Lee, W. H., Ryu, Y. J., & Nam, E. C. (2019). Tinnitus suppression effect of hearing aids in patients with high-frequency hearing loss: A randomized double-blind controlled trial. *Otology & Neurotology*, 40(7), 865–871. <https://doi.org/10.1097/MAO.0000000000002315>
- Yokota, Y., Yamashita, A., Koyama, S., Kitano, K., Otsuka, S., & Kitahara, T. (2020). Retrospective evaluation of secondary effects of hearing aids for tinnitus therapy in patients with hearing loss. *Auris, Nasus, Larynx*, 47(5), 763–768. <https://doi.org/10.1016/j.anl.2020.03.005>
- Zarenoe, R., Söderlund, L. L., Andersson, G., & Ledin, T. (2016). Motivational interviewing as an adjunct to hearing rehabilitation for patients with tinnitus: A randomized controlled pilot trial. *Journal of the American Academy of Audiology*, 27(08), 669–676. <https://doi.org/10.3766/jaaa.15126>