6-2020

Changes in Tinnitus Perception Following Cochlear Implantation and Hearing Aid Use

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A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology, The City University of New York

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This manuscript has been read and accepted for the Graduate Faculty in Audiology in satisfaction of the capstone research requirement for the degree of Doctor of Audiology, Au.D.

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ABSTRACT

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Corinne Kohan

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The purpose of this literature review is to identify changes in tinnitus post cochlear implantation and post amplification. Primarily subjective, qualitative measures including the Tinnitus Handicap Inventory, the Tinnitus Handicap Questionnaire, the Tinnitus Reaction Questionnaire, and the Tinnitus Questionnaire were used to obtain the data included. The questionnaires used were demonstrated to be valid in research. The results of this study indicate that both types of interventions consistently provide tinnitus relief or diminished tinnitus handicap among sufferers, although the mechanisms by which the suppression or reduction occurs may be a result of numerous factors. Cochlear implantation is more likely to result in post-operative tinnitus or in patients who did not report tinnitus previously or worsen pre-existing tinnitus, although it often resolves with time. Use of traditional amplification never resulted in tinnitus if tinnitus was not present previously; however, there were cases where amplification did not suppress tinnitus sufficiently such that perceived tinnitus handicap was eliminated altogether. Conclusion: both interventions have been demonstrated to often reduce tinnitus perception in sufferers.

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INTRODUCTION

As defined by Baguley et al. (2013b), a symptom, tinnitus refers to the conscious perception of an auditory sensation in the absence of a corresponding external stimulus. It is usually subjective where the individual alone is able to perceive it or, occasionally, objective where the tinnitus may be detected by another person. The latter type of tinnitus that is observable will not be considered in this research as it is often associated with vascular processes. Subjective tinnitus perceptions vary and are described as intermittent or constant “ringing”, “hissing”, “buzzing”, or “whooshing” sound (Gallus et al., 2015; Kleinstauber et al., 2015; Stohler et al., 2019). Tinnitus in its subjective form is a common symptom and is typically a byproduct of sensorineural hearing loss, that occurs alongside hearing loss in a high percentage of cases (Amoodi et al., 2011; Kloostra et al., 2014; Hoare et al., 2014; Cabral et al., 2016; Bhatt et al., 2018). Hoare et al. (2014) suggested that this abnormal auditory perception may arise from erroneous neural activity along the damaged auditory pathway. The numerous possible etiologies are complicated by the fact that not all those with hearing loss have tinnitus and not all those with tinnitus have a significant degree of hearing loss. It is also one of the most common audiologic complaints as well as one of the most common chronic conditions that drives patients to seek out care (Van de Heyning et al., 2011 & Bhatt et al., 2018).

The etiology of tinnitus is still not well understood and may vary across sufferers, but is a common condition that is debilitating to many people with hearing loss (Langguth et al., 2006; Shekhawat et al., 2013; Kloostra et al., 2014; Greenberg et al., 2016; Stohler et al., 2019). The association between tinnitus and various other otologic

disorders was highest with sensorineural hearing loss (Baguley et al., 2013b). The degree of disability that arises from tinnitus varies; some people are able to exist with it successfully whereas others find tinnitus frequently interferes with their daily life (Kloostra et al., 2014). As many as 10% of those with tinnitus report that it has had a significant impact on their everyday lives (Baguley et al., 2013b). Bothersome tinnitus is often associated with several comorbidities including insomnia, concentration difficulties, problems communicating, anxiety, and depression (Lasisi & Gureje, 2011; Baguley et al., 2013b; Hoare et al., 2014; Kloostra et al., 2014; Kleinstauber et al., 2015; Macias et al., 2015; Araujo and Iorio, 2016; Cabral et al., 2016; McCormack et a., 2016; Bhatt et al., 2018; Koning, 2019; Stohler et al., 2019).

Prevalence is on the rise among those with age-related hearing loss, who are living longer due to advancements in healthcare (Stohler et al., 2019). It follows that the number of people living with tinnitus will increase as the number of people with hearing loss increases (Stohler et al., 2019). The incidence appears to change when individuals reach 70 years of age. Once people reach that age, incidence decreases. Stohler et al. (2019) attributed this to tinnitus being less burdensome in the presence of other significant health conditions (i.e. cardiovascular disease) rather than the tinnitus resolving. Prevalence in younger adults, however, is also on the rise, possibly as a result noise-induced damage to their synapses or due to higher health awareness and expectations.

Prevalence of Tinnitus

Guidelines exist for conducting epidemiologic research for hearing loss, but no such standards exist for researching tinnitus (McCormack et al., 2016). This often results in inconsistent reporting across populations or underreporting of this symptom, so it is difficult to establish its true prevalence. Bhatt et al. (2017) suggest that the worldwide prevalence of tinnitus is between 8% to 25.3%. Despite the disadvantages in evaluating prevalence of tinnitus in a population, Fujii et al. (2011) sought to determine the prevalence of tinnitus in a population of approximately 14,000 adults in Japan. Responses were gathered through a questionnaire sent to the individual's homes. Of this sample, 11.9% reported recurrent tinnitus and only 0.4% reported debilitating tinnitus. The prevalence was slightly higher in women and increased with age in both men and women.

Gallus et al. (2015) conducted epidemiologic research with a focus on tinnitus among adults in Italy. Their data was obtained via face-to-face interview with a sample of nearly 3,000 individuals. In their sample, self-reported prevalence of all tinnitus (constant and intermittent) was 6.2%. The prevalence of severe tinnitus was 1.2%. No sex effects were found in this population either for general tinnitus, however, there was a higher prevalence of severe tinnitus in women. There were age effects as Stohler et al. (2019) determined as well: prevalence of tinnitus plateaued around 70 years of age.

Bhatt et al. (2018) evaluated the prevalence of tinnitus among the United States adult population using National Health Interview Survey (NHIS) phone interviews. In their population of approximately 75,000 people (which they stated represented a larger sample of approximately 220 million), 9.6% had experienced tinnitus in the past year.

56.1% of that group reported that their tinnitus had been present for longer than five years and 27% reported that their tinnitus had been present for longer than fifteen years. Bhatt et al. (2018) found that the prevalence of tinnitus was higher in men, contradicting Fujii et al. (2011) and Gallus et al.'s (2015) findings. Additionally, they found that tinnitus severity plateaus around 70 years of age and declines thereafter as seen before (Figure 1). Finally, they noted that tinnitus was often comorbid with hearing loss.

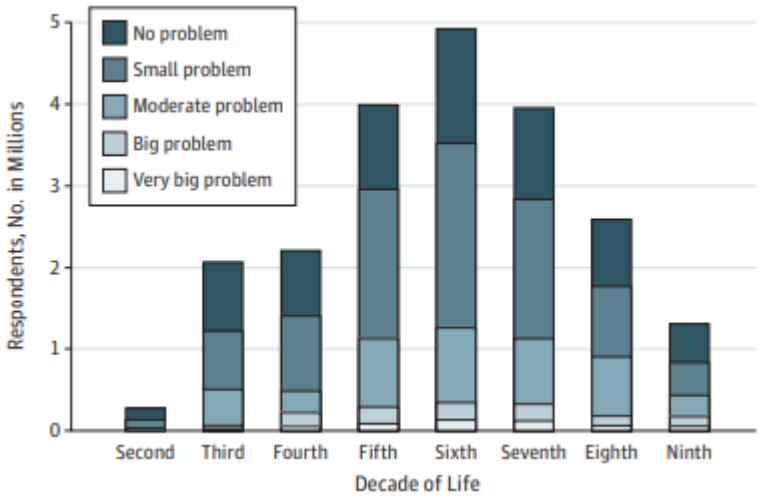

Figure 1: Subjects representing a weighted national sample of adults in the United States who reported tinnitus organized by age and severity (Adapted from Bhatt et al., 2018).

As demonstrated in these studies, prevalence varies slightly across the world. This could be attributed to differences in how the data were obtained, different health perspectives, what factors were included, or different definitions of tinnitus. However, what is consistent is that tinnitus prevalence increases with age and then tends to plateau or decrease after a person reaches approximately 70 years of age. There also appeared to be no significant, consistent gender effects across these studies. Finally, one of the most significant risk factors for tinnitus was hearing loss.

Impacts of Tinnitus

While many individuals with tinnitus are able to adjust to it and are not bothered by the sound, there are others who report a decline in their quality of life (McCormack et al., 2016). Those with bothersome tinnitus have reported sleep disturbances, which can lead to distress, worsened anxiety, or worsened depression (Bhatt et al., 2018). As was discussed in the previous section, the older adult population has the highest prevalence of tinnitus. Lasisi & Gureje (2011) conducted a study geared towards the impact of tinnitus on the quality of life of this population of 1,300 adults, ages 65 and older. The researchers also wanted to evaluate sleep difficulties in their sample as tinnitus is often comorbid with insomnia, which can further decrease an individual's quality of life. Lasisi & Gureje (2011) cited a study that stated insomnia was among the three most common complaints from tinnitus sufferers. They gathered data via face-to-face interviews. and their findings demonstrated a relationship between tinnitus and sleep difficulties, specifically maintaining sleep. Furthermore, the participants reported a perceived decrease in quality of life as a result of tinnitus-induced sleep difficulty.

According to Koning (2019), one characteristic that separates those who can cope with their tinnitus versus those who struggle is the perceived loudness. Koning (2019) conducted a retrospective study using medical data and a survey on 202 adults with tinnitus. Roughly half of the participants in the sample reported concentration difficulty and feeling depressed, which was correlated to the perceived loudness of their tinnitus. In other words, the louder the perceived tinnitus, the more concentration difficulty and depression was present.

Anxiety and depression are often comorbid with tinnitus, which may increase the risk of suicide among tinnitus sufferers (Bhatt et al., 2017). Bhatt et al. (2017) suggested that the severity of tinnitus is positively correlated with anxiety/depression severity. The researchers also stated tinnitus is associated with sleep disorders leading to issues with concentration and irritability, as was discussed by Lasisi & Gureje (2011). Using the aforementioned NHIS phone interviews, data from adults that suffered from tinnitus was examined by Bhatt et al. (2017). They compared the reported severity of the subjects' tinnitus with frequency of anxiety experienced, frequency of depression experienced, number of hours slept per night, work days missed, and average amount of days when alcohol was consumed. Their findings confirmed a correlation between tinnitus and mood disorders as well as a correlation between tinnitus and sleep disturbances with fewer hours of sleep per night. Aspects not as commonly evaluated included the number of work-days missed and alcohol consumption. For the amount of work missed, there was a strong positive correlation; tinnitus sufferers in this sample missed approximately 1.8 times more work compared to those who did not have tinnitus. For alcohol consumption, there was no significant relationship found among their sample.

Tinnitus Treatment Options

Currently, there is no proven cure for tinnitus, which is likely due to the number of possible etiologies (Langguth et al., 2006; Noble, 2008; Macias et al., 2015; Stohler et al, 2019). However, there are management options and therapies that have been demonstrated to make qualitative differences in the lives of tinnitus sufferers. Similarly,

there are homeopathic, anxiety-reducing, or other options that have not consistently been shown in research to be beneficial, but have benefitted some tinnitus-sufferers anecdotally (Langguth et al., 2016; Baguley et al., 2013a). Options with empirical evidence include tinnitus-retraining therapy, cognitive behavioral therapy, and use of an amplification device. Common options without empirical evidence, referred to as complementary and alternative medicine or CAM, include but are not limited to acupuncture, ginkgo biloba, and meditation. Baguley et al. (2013a) state that these options have gained traction among tinnitus sufferers due to the fact that there is no cure to be found in Western medicine. These treatments that have been beneficial anecdotally should not necessarily be dismissed even if the perceived benefit is only a placebo effect; the individual feels that there is improvement. Searchfield et al. (2010) and Bovo et al. (2011) suggest that there are significant placebo effects associated with tinnitus and tinnitus treatments. However, these "alternative" treatments must also be clinically demonstrated to be harmless when used. In other words, healthcare professionals could still recommend these alternative treatments provided they counsel the patients regarding the empirical evidence available and establish that it is safe for the patient to pursue these alternative options.

Treatments that do have empirical evidence supporting their advantages include Tinnitus Retraining Therapy, Cognitive Behavioral Therapy, and hearing aid use (Noble, 2008). Tinnitus Retraining Therapy (TRT) is based on a combination of directive counseling used in conjunction with sound therapy (i.e. on ear sound generators or hearing aids with or without maskers). The goal of TRT is primarily habituation such that the tinnitus does not consistently elicit negative emotions or reactions (Cabral et al.,

2016). The use of counseling has been effective among tinnitus sufferers due to the links between tinnitus and psychosomatic and psychological distress (Bovo et al., 2011). However, Noble (2008) stated that the research suggests TRT to be inferior in addressing tinnitus when compared to Cognitive Behavioral Therapy (CBT). CBT has more consistently resulted in a reduction in tinnitus handicap than any other therapy evaluated to date through restructuring distressing and dysfunctional thought processes related to tinnitus (Bhatt et al., 2018). For both of these therapies, the goal is not to eliminate the tinnitus but rather to diminish an individual's perception of their tinnitus. Amplification, on the other hand, specifically traditional hearing aids, has also been shown to be an effective tinnitus treatment even without tinnitus-directed counseling (Noble, 2008). There are also cases where the hearing loss is so significant that hearing aids are not able to provide benefit neither for hearing complaints nor for tinnitus relief. In these cases, cochlear implantation may be another option to address both conditions.

Cochlear implants (CIs) are primarily recommended for persons with severe to profound, bilateral, sensorineural hearing loss with poor speech recognition, who do not demonstrate benefit with traditional amplification (Andersson et al., 2009; Amoodi et al., 2011). However, off-label (non-FDA approved) use of CIs is also possible for lesser degrees of hearing loss and unilateral hearing loss, especially in the presence of debilitating tinnitus. This is likely changing as the FDA has recently approved unilateral implantation for single-sided deafness for one of the largest cochlear implant manufacturers. CIs are designed to provide speech awareness in those that were essentially deaf prior to treatment and today's recipients may also have improved quality of life and psychological wellbeing as a result (Greenberg et al., 2016). This intervention

may also be used to address those with tinnitus as a primary complaint in potential cochlear implant candidates, which may contribute to the aforementioned positive effects reported. The evidence is only recently emerging regarding the impact of CI on tinnitus perception (Amoodi et al., 2011; Kloostra et al., 2014).

According to Amoodi et al. (2011) & Macias et al. (2015), CI candidates frequently have complaints of tinnitus; as many as 66% to 86% experience this symptom. In addition to providing improved speech awareness and improved quality of life, some implant recipients also find reduced tinnitus perception after being implanted (Amoodi et al., 2011; Greenberg et al., 2016). Similar outcomes have been established with the use of hearing aids (Searchfield et al., 2010). Cabral et al. (2016) used the Tinnitus Handicap Questionnaire (THQ) to track changes in tinnitus with amplification. The participants had hearing loss in at least one ear and also had complaints of tinnitus. The questionnaire was administered before being fit with hearing aids and then another questionnaire was administered 3 months post fitting. There was an overall decrease in how bothersome the tinnitus was with the use of amplification in terms of depression and anxiety. However, there was still residual handicap reported in the participants in terms of insomnia and concentration difficulties.

Van de Heyning et al. (2011), suggested that hearing aids are not useful for addressing tinnitus in those with comorbid sensorineural hearing loss that is severe in degree. Alternatively, electrical stimulation by way of cochlear implants may be a better solution. They performed a review of studies that evaluated tinnitus after CI surgery and found consistent attenuation or suppression of tinnitus symptoms. They also investigated changes in subjects with unilateral deafness with debilitating tinnitus on the same side as

the damaged cochlea. Their small sample of 21 individuals revealed an improvement in tinnitus symptoms in every subject, with their implant activated. Furthermore, the tinnitus did not "adapt" over time, meaning that tinnitus did not worsen with consistent stimulation according to their findings.

The mechanism by which tinnitus perception is reduced post implantation is not well understood, but they may include effects from the surgery itself, masking from the auditory input, reorganization of the central auditory nervous system, and intracochlear stimulation even in the absence of sound (Andersson et al., 2009; Amoodi et al., 2011; Bovo et al., 2011; Macias et al., 2015; Greenberg et al., 2016; Kim et al., 2016). Shekhawat et al. (2013) suggested that traditional hearing aids could also benefit tinnitus sufferers in that they may allow for better distinction between sound with a source versus "pseudo sound". They also hypothesized the hearing aids could foster neural activity in the brain and overcome the effects of disinhibition from insufficient auditory stimulation (Searchfield et al., 2010; Shekhawat et al., 2013). Another possibility offered is that hearing aids may act on the mechanism of tinnitus itself if stress related; diminished stress when communicating may lead to diminished tinnitus perception overall. Hearing aids have been one of the most common treatments used to address tinnitus in patients that have comorbid hearing loss (Cabral et al., 2016). However, as with cochlear implantation, there is no guarantee of diminished tinnitus perception with hearing aids.

Subjects in Moffat et al.'s (2009) study with sensorineural hearing loss and tinnitus were fit with amplification. Pitch and loudness matching were performed before and after amplification fitting, which entailed finding the closest pure tone frequency to a subject's tinnitus, then using the staircase procedure to estimate the intensity of the

tinnitus. The pitch and loudness matching were performed the day of being fit with hearing aids, 7 days after fitting, 15 days after fitting, and 1 month after fitting. There was no statistically significant difference noted in tinnitus loudness after one month of consistent use of amplification. The researchers postulated that the reason for their results could be that 1 month of hearing aid use was insufficient for auditory stimulation and longer use may have resulted in an improvement in tinnitus perception. They also suggested that the increment used to determine a significant change within a subject, .10 dB difference or greater, was perhaps too large and therefore the research masked possible benefit because it was smaller than anticipated. There is also the issue that they used a method of measuring changes in tinnitus that required no subjective data from their participants.

Simultaneous or Sequential Bilateral Cochlear Implantation and Tinnitus

For those individuals who are candidates for bilateral CIs, there is an ongoing global debate regarding whether implantation should be done concurrently or consecutively (Ramakers et al., 2017). This simply refers to whether an individual, who is a CI candidate in both ears, should be implanted bilaterally at once (simultaneously) or should the surgeries be spaced out (sequentially). From the limited data available, no trends have appeared that indicate either strategy is superior for improved tinnitus outcomes. Despite the limited data currently available, a brief discussion will be included here using Ramakers et al. (2017) and Kraaijenga et al.'s (2019) research regarding impacts on tinnitus.

Ramakers et al.'s (2017) sample consisted of 38 adults, ages 36 to 64, who were all post-lingually deafened. Half of the subjects underwent simultaneous implantation and half of them underwent sequential implantation. 42% of the overall sample reported pre-operative tinnitus. All of the subjects with tinnitus completed the Tinnitus Handicap Inventory and the Tinnitus Questionnaire. Those with tinnitus previously, had lower scores on both of the questionnaires post implantation. Their results indicated that simultaneous implantation yielded more benefit for those with pre-existing tinnitus, but also resulted in a higher rate of new tinnitus among recipients. It is worth noting that in the 5 subjects who developed new tinnitus, it dissipated in 3 of them after 3 years. These findings corroborated statements made in Van de Heyning et al.'s (2011) research as well.

Kraaijenga et al. (2019) compared patient performance and reported quality of life outcomes after simultaneous versus sequential implantation. The subjects were all adults, ages 18 to 70, who were all post-lingually deafened. Their hypothesis was that simultaneous recipients would outperform sequential recipients, due to the known benefits of binaural hearing (i.e. localization). Their findings revealed that simultaneous implantees only had better outcomes before the sequential implantees received their second implants. Once all subjects were bilaterally implanted, no significant long-term differences were found in performance or quality of life measures, including reported tinnitus burden.

While these findings are useful for further consideration, they were not included in the systematic review as such limited information is available on the subject. Additionally, the researchers who discussed bilateral implantation in this systematic

review did not make mention of whether or not their participants had been simultaneously or sequentially implanted. Therefore, no statement can be made at this time describing the relationship between tinnitus and these implantation strategies.

Electroacoustic Stimulation and Tinnitus

A limited amount of research has been conducted on the subject of electroacoustic stimulation (EAS), also known as hybrid, cochlear implants, and impacts on tinnitus. These types of devices are for CI candidates who still have residual low-frequency hearing (Mertens et al., 2018). The recipient receives electric stimulation for high frequency information and acoustic stimulation for low frequency information. Due to the very limited information on hybrid CIs and tinnitus, it will only be mentioned briefly in this section using Mertens et al.'s (2018) research.

Mertens et al. (2018) conducted a case study and compared that subject to 11 other subjects who served as a control group. The main patient is an adult, age 51, who was unilaterally implanted with a hybrid device and suffered from tinnitus. This participant was compared to a group (all adults ages 32 to 68) of unilateral non-hybrid CI recipients who also suffered from tinnitus. Their findings demonstrated that all of the subjects reported a decrease in tinnitus handicap after intervention. No significant differences were found between the case study patient and the control group patients.

Due to the limited data available, hybrid CIs will not be discussed in this systematic review. As previously mentioned, the researchers included in this study did not always include the cochlear implant model used or the degree of residual hearing

among the recipients (if any). Consequently, no correlation can be established between electroacoustic stimulation and tinnitus perception.

Quantifying Impacts of Tinnitus

Langguth et al. (2006) suggested that self-report inventories that measure the severity of an individual's tinnitus should take the following factors into account: cultural differences, language differences, different healthcare systems, existing databases, and existing routines. Ideally, measures that include all the aforementioned aspects would be the only ones utilized clinically and for research. This is not always the case. While commonly used tinnitus measures may be more limited in scope, they are more advantageous in conducting a systematic review as patient populations can be compared across studies more reliably (Figure 2).

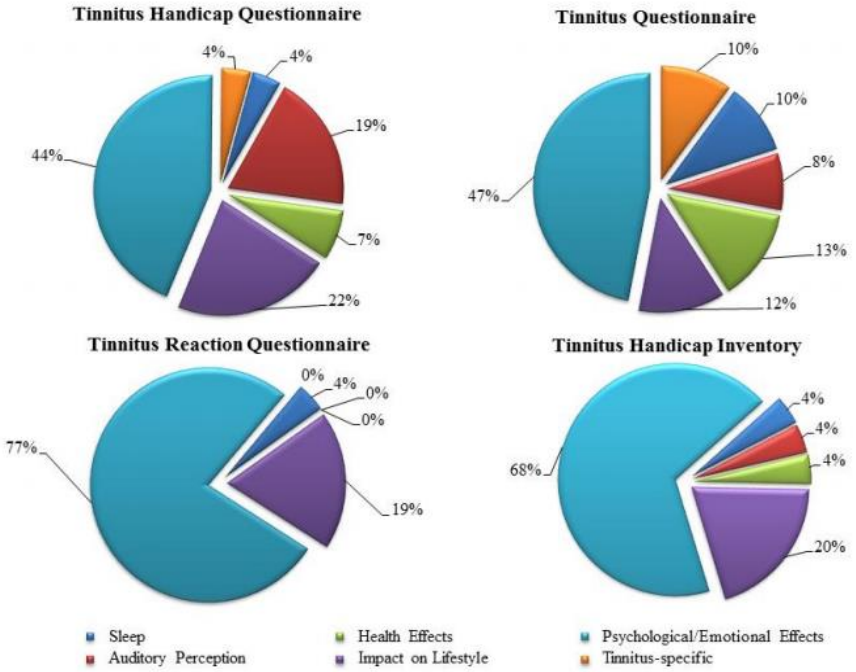

Figure 2: Questionnaires assessed on six domains with a different number of items focused on each domain: The Tinnitus Handicap Questionnaire (THQ), Tinnitus Questionnaire (TQ), Tinnitus Reaction Questionnaire (TRQ), and Tinnitus Handicap Inventory (THI) (Adapted from Fackrell et al.'s 2014 study).

Greenberg et al. (2016) evaluated changes in the qualities of tinnitus using a non-standardized questionnaire including suppression, localization, characteristics (i.e. high-tone, hissing, etc.), and duration. In their study, 57% of CI recipients reported total or partial tinnitus suppression after implantation. These researchers suggested that this suppression arose as a result of the reduction in the complexity of tinnitus characteristics. The average number of tinnitus characteristics reported prior to treatment was 2.4 and decreased to 1.4 after implantation. This study had a unique approach to qualifying changes in tinnitus. Creating a tinnitus inventory that abides by research-based guidelines, as suggested by Langguth et al. (2006), can be invaluable as a researcher is able to customize what aspects are addressed. However, there is the issue that in creating and using a "homemade" questionnaire, the results cannot be generalized to other populations that have been evaluated differently and no statement can be made regarding its validity.

A cross-sectional questionnaire-based study conducted by Gomersall et al. (2019) revealed that a significant percentage of their subjects still had bothersome tinnitus post cochlear implantation. The researchers here also designed their own tinnitus measure. The data from participants who reported success with the cochlear implants and less noticeable tinnitus suggests that the tinnitus is simply being masking out rather than having lessened, as was suggested in the previous studies. These researchers did not have a structure in place to obtain the data included in their study. The results of these studies

indicate that if bothersome tinnitus was present prior to implantation, the CIs will help diminish it but will not eradicate it. However, there is a possibility that the results may have been different had they used a tinnitus inventory to measure changes that occurred with implantation. It is important to ensure consistency when evaluating tinnitus before and after intervention; using appropriate measures will allow for a more accurate review of results. Measures that are most frequently used in research include the Tinnitus Handicap Inventory, the Tinnitus Handicap Questionnaire, the Tinnitus Reaction Questionnaire, and the Tinnitus Questionnaire (Table 1).

Table 1: Review of Questionnaire Features that will be Included in Systematic Review

	Tinnitus Handicap Inventory (THI)	*Tinnitus Handicap Questionnaire (THQ)*	*Tinnitus Reaction Questionnaire (TRQ)*	*Tinnitus Questionnaire (TQ)*
Number of Items	25 items	27 items	26 items	52 items
Severity Scale	Yes: 1-16% no handicap, 18-36% mild handicap, 38-56% moderate handicap, 58-100% severe handicap	No: higher score indicates higher perceived handicap	No: higher score indicates higher perceived handicap	No: higher score indicates higher perceived handicap
Validated in Research	Yes	Yes	Somewhat	Somewhat
Used to Track Changes	Not originally designed for this function	Yes	Not originally designed for this function	Yes

(Langguth et al., 2006; Andersson et al., 2009; Searchfield et al., 2010; McNeill et al., 2012; Fackrell et al, 2014; Kleinstauber et al., 2015; Macias et al., 2015; Cabral et al., 2016).

Validity of Tinnitus Questionnaires

Over 20 million Americans in the United States suffer from tinnitus (Bovo et al., 2011). Despite the prevalence of this condition, there is no standardized method of measuring a patient's subjective handicap or for tracking progress or benefit from treatment (Langguth et al., 2016; Fackrell et al., 2014; Greenberg et al., 2016). There are research-based measures available, but these assessments may not evaluate the same information and are therefore not interchangeable. Additionally, many clinicians have created their own informal tinnitus evaluations, as previously mentioned. For the purposes of research, it becomes difficult to evaluate tinnitus across a population due to the lack of methodology with respect to its measurement and subjective severity (Langguth et al., 2006 & McCormack et al., 2016). Treatments addressing tinnitus are difficult to compare across facilities because of the variety in the assessments available and the protocols in place, if any. Reliable and valid questionnaires most commonly used for examining tinnitus, also used as tracking tools if an intervention is implemented, will be discussed in this section. However, Greenberg et al. (2016) discussed in their research that even validated measures used today do not always measure all the relevant aspects of tinnitus. Despite this point, the validated questionnaires available will still be used in this paper rather than using possibly better questionnaires that have rarely, if ever, been used clinically to ensure consistency in the results.

There are numerous resources available that measure tinnitus severity and perceived degree of handicap in individuals. Four tinnitus questionnaires which have undergone psychometric analyses and are widely used include the Tinnitus Handicap

Inventory (THI), the Tinnitus Handicap Questionnaire (THQ), the Tinnitus Reaction Questionnaire (TRQ), and the Tinnitus Questionnaire (TQ) (Table 1). The THI is the best known and the most widely used (Fackrell et al., 2014). It is reliable, has been validated, and has been translated so it is actively in use globally. The THQ, the TRQ, and the TQ are more commonly used in research than clinically and are also reliable and valid. They have all also been demonstrated to be good measures of the impacts of tinnitus and are especially useful in tracking changes in tinnitus perception post intervention.

Nahad et al. (2014) evaluated the validity and reliability of the Tinnitus Handicap Questionnaire as a tinnitus measure and as an outcome measure post intervention. The results confirmed the THQ has high validity and reliability in English as well as in a Persian translation. Nahad et al. (2014) also stated that this measure is an effective tool in the treatment or management process of tinnitus. Newman & Sandridge (2004) discussed the TRQ's properties in a research-based chapter on tinnitus questionnaires in James Snow's book *Tinnitus: Theory and Management*. The authors stated that the TRQ has high internal consistency, high construct validity, and high test-retest reliability. Newman & Sandridge (2004) concluded that the TRQ is useful in quantifying tinnitus treatment outcomes. Finally, the psychometric properties of the TQ were examined by Zeman et al. (2012); these researchers demonstrated the TQ has high internal consistency, high convergent validity, and good change sensitivity. Zeman et al. (2012) stated that the TQ is an appropriate outcome measure with tinnitus intervention. The research on the validity and reliability of these three measures indicates that they may be used in conjunction with or in the place of the THI to identify tinnitus severity as well as changes in tinnitus with treatment.

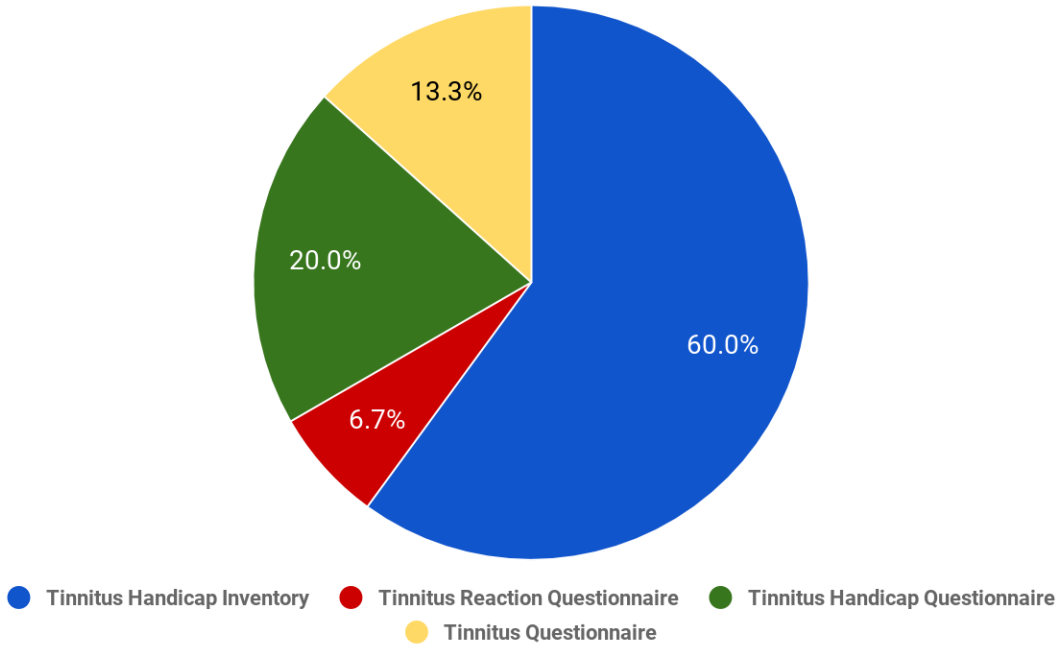

Figure 3: Pie Chart Evaluating Which Questionnaires were Most Frequently in Systematic Review.

Conclusions

Tinnitus negatively impacts many of those who suffer from it and one of the more acceptable and evidence-based recommendations to treat tinnitus is through the use of hearing aids. For those that have severe to profound hearing loss, cochlear implants may also be beneficial. The goal of this systematic review is to examine the evidence regarding the value of cochlear implantation in terms of reducing perceived tinnitus handicap in adults and how efficacy compares to hearing aid use. The following research questions will be addressed in the scope of this review:

1. Does cochlear implantation reduce tinnitus handicap?

2. How frequently does tinnitus arise, worsen, or remain post cochlear implantation?
3. How effective is cochlear implantation in contrast to hearing aid use in terms of moderating the severity of tinnitus?

The hypothesis is that both cochlear implantation and traditional amplification will be demonstrated in the literature to be effective and reliable methods of decreasing tinnitus perception in patients when using valid questionnaires to determine changes post intervention.

Methodology

The City University of New York Graduate Center Onesearch, Google Scholar, Web of Science, and PubMed databases were searched for the articles included in this literature review. Information for this systematic review was gathered by evaluating articles that have been published in reputable, peer-reviewed journals like Ear and Hearing, the Journal of the American Academy of Audiology, or The Laryngoscope. The articles will be sourced from journal databases and content on professional websites (i.e. American Speech-Language Hearing Association, JAMA Otolaryngology--Head and Neck Surgery, International Journal of Audiology, etc.). The goal is to use articles from within the last ten to fifteen years approximately, articles that come from peer-reviewed journals exclusively, articles that are primarily qualitative (but will also include some quantitative for certain sections), articles that use empirical data/evidence and articles that include subjective/qualitative data. Search terms included tinnitus handicap, cochlear

implants and tinnitus, tinnitus prevalence, reducing subjective tinnitus, solutions for bothersome tinnitus, single sided deafness and tinnitus, unilateral cochlear implantation and tinnitus, bilateral cochlear implantation and tinnitus, changes in tinnitus with hearing aids, validity of tinnitus questionnaires, tinnitus treatment options, etc.

Criteria for considering studies for this review

Types of studies:

Studies selected for this literature review include, retrospective/prospective studies, meta-analyses, and literature reviews that evaluated effects of cochlear implantation or hearing aids on tinnitus or articles that evaluated the validity of tinnitus questionnaires. Additionally, studies discussing psychological effects of tinnitus and tinnitus epidemiology were also included in this review.

Characteristics of participants:

Adults (≥ 16 years old) who have unilateral or bilateral sensorineural or mixed hearing loss, with or without tinnitus. For inclusion, sensorineural hearing loss of participants had to be determined using standard audiometry procedures and hearing loss had to be verified as severe or profound for CI recipients. The CI candidates included, unilateral or bilateral, were all post-lingually deafened.

Types of interventions:

Tinnitus interventions included in this research were hearing aids, analog or digital, as well as cochlear implants (all manufacturers included for both types of amplification). Counseling alone was not considered in this study. Hearing aids with tinnitus maskers were not included to make the comparison between cochlear implants

and hearing aids more valid; maskers introduce a potentially extraneous variable. Implantable devices designed for bone conduction sound or those that detect and deliver sound via air conduction to the contralateral ear (CROS devices) were also not considered in this paper as the goal is to evaluate tinnitus perception when the hearing loss affected cochlea is stimulated. Additionally, personal sound amplifiers (PSAPs) were not considered as the amplification provided by these devices may not be sufficient or appropriate for its users.

Type of outcome measures:

Outcome measures considered for tinnitus perception include subjective data primarily obtained from self-report and research validated questionnaires.

Primary outcomes:

The outcomes post intervention included the following questionnaires. Abbreviated versions were not included.

- Tinnitus Handicap Inventory
- Tinnitus Handicap Questionnaire
- Tinnitus Reaction Questionnaire
- Tinnitus Questionnaire

Search methods for identification of studies:

Various online databases were used to collect research studies that were relevant to this paper's topics of interest. There were no language restrictions. A timeline of 2005 through the present was set for cochlear implantation studies included in this literature review as there have been significant advancements made in CI surgery as well as with the devices currently available. This was also a decision made to address advancements

in hearing aid technology.

Results

Upon the initial search for articles, 51 articles were identified that included the search terms detailed earlier (Figure 4). 9 articles were excluded as they did not evaluate changes in tinnitus with intervention. From the remaining 42 articles, 16 of them were excluded as their sample population included participants ages 15 years or younger. An additional 12 articles were excluded as their outcome measures did not include the THI, THQ, TRQ, or TQ. In total, 14 articles met the criteria for inclusion for this systematic review. There were 10 articles that targeted changes with cochlear implantation and 4 articles that targeted changes with hearing aids.

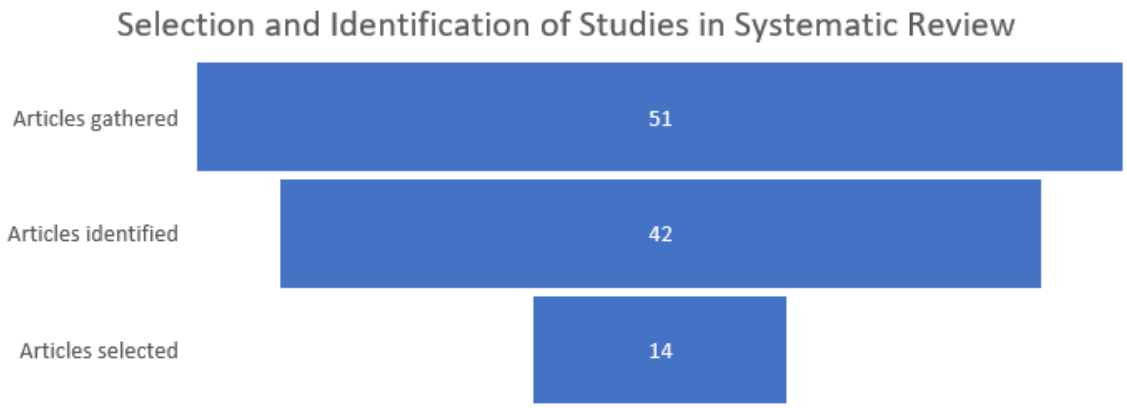

Figure 4: Inclusion of Studies in Systematic Review.

Research Question #1: Does cochlear implantation reduce tinnitus handicap?

In this systematic review, 10 studies were sourced that discussed changes post cochlear implantation using the aforementioned validated questionnaires. Approximately

850 participants were included across all the studies. The prevalence of new, worsened, or no change in tinnitus was roughly 20%. While there is a risk of new or worsened tinnitus with the procedure, many CI recipients still perceived benefit. It is worth noting, however, that the benefits were largely present as long as their processors were on. This may aid in carrying out daily activities and concentration, but does not address one of the major impacts of tinnitus: sleep disturbances. As long as potential candidates are made aware of the risks, CIs can continue to be recommended as an appropriate treatment for candidates with primary complaints of tinnitus.

Table 2: Summary of Studies Included that Evaluated Tinnitus after Implantation

	Sample Size	*Measure Used*	*Sample Characteristics*	*Outcomes*
Andersson et al. (2009)	111	THI	-Adults ages 19-85 -Bilateral severe to profound sensorineural hearing loss -All unilaterally implanted -Some with pre-existing tinnitus -Some without pre-existing tinnitus	-Approximately 58.5% had no/slight/mild tinnitus handicap post implantation -Tinnitus did not improve/began/worsened in remaining 41.5%
Pan et al. (2009)	244	THQ	*-Adults ages 18-90 -Bilateral severe to profound sensorineural hearing loss -Some unilaterally implanted -Some bilaterally implanted (had a CI before study) -Some with pre-existing tinnitus -Some without pre-existing tinnitus	-Overall decrease in THQ scores post implantation -No significant correlations found between amount of time with hearing loss with tinnitus reduction or suppression -Tinnitus began in 12% of sample (higher amount than found in previous research)
Amoodi et al. (2011)	142	THI	-Adults ages 40-68 -Bilateral severe to profound hearing loss or unilateral severe to profound hearing loss -Unilaterally implanted -All had pre-existing tinnitus	-Overall decrease in THI scores post implantation -THI reduction correlated with the HHI reduction -Higher tinnitus handicap before implantation correlated with higher satisfaction after -Tinnitus did not improve or worsened in 34% of sample
Bovo et al. (2011)	51	THI	-Adults ages 16-76 -Bilateral severe to profound sensorineural hearing loss	-Overall decrease in THI scores post implantation -Some subjects reported continued tinnitus

			-Unilaterally implanted -Some with pre-existing tinnitus -Some without pre-existing tinnitus	inhibition with the processor off -Some subjects experienced tinnitus reduction in the ear contralateral to implantation -Tinnitus did not improve or worsened in 22% of sample
Olze et al. (2011)	43	TQ	-Adults ages 19-77 -Unilateral severe to profound hearing loss -Unilaterally implanted -Some with pre-existing tinnitus -Some without pre-existing tinnitus	-Overall decrease in TQ scores post implantation -Improved quality of life and lower stress
Van de Heyning et al. (2011)	21	TQ	*-Adults -Unilateral severe to profound hearing loss with normal to moderate hearing loss contralaterally -Unilaterally implanted -All had pre-existing tinnitus	-All subjects reported tinnitus reduction as long as the implant was on -Tinnitus still present in most when processor was off -Tinnitus still present in 0-9% of their sample
Kloostra et al. (2014)	~153	THQ & THI	*-Adults ages 18 years and older -Bilateral severe to profound sensorineural hearing loss or unilateral severe to profound hearing loss -Some unilaterally implanted -Some bilaterally implanted -All had pre-existing tinnitus	-Overall decrease in THI and THQ scores post implantation -Decrease in THI scores was not statistically significant -Tinnitus did not improve or worsened or began in 25% of sample
Macias et al. (2015)	16	THI	-Adults ages 31-70 -Unilateral severe to profound hearing loss -Unilaterally implanted -All had pre-existing tinnitus and hyperacusis	-Half of the subjects had reduced THI scores -Tinnitus reduction was only present when processor was on -Full electrode insertion was correlated with better hearing and tinnitus outcomes -Tinnitus did not improve in in 50% of sample
Kim et al. (2016)	79	THI	-Adults ages 35-66 -Bilateral severe to profound hearing loss -Some with pre-existing tinnitus -Some without pre-existing tinnitus	-Overall significant decrease in THI scores post implantation in those with pre-existing tinnitus -No correlation with operation technique, depth of insertion, residual hearing -Tinnitus worsened or began in 14% of their sample
Holder et al. (2017)	12	THI	-Adults ages 36-66 -Unilateral severe to profound hearing loss -All unilaterally implanted -All had pre-existing tinnitus	-Overall significant decrease in THI scores post implantation and continued to decrease over time

(* Indicates an incomplete description of sample characteristics in the study.)

Diminished Tinnitus Perception Post Cochlear Implantation

It has been suggested that cochlear implants may have the added benefit of tinnitus suppression or reduction in addition to improved speech awareness in patients (Amoodi et al., 2011; Kloostra et al., 2014). There are numerous possible mechanisms by which this reduction may happen (Andersson et al., 2009; Amoodi et al., 2011; Bovo et al., 2011; Macias et al., 2015; Greenberg et al., 2016; Kim et al., 2016). The research obtained for this systematic review demonstrates overall benefit from cochlear implants with respect to tinnitus perception with a risk of negative tinnitus outcomes (see Table 2).

Pan et al. (2009) tracked changes in THQ scores in 244 cochlear implant candidates and then approximately 5 years after they were implanted at follow-up visits. They included 153 participants, ages 18 to 90, with pre-existing tinnitus and 91 participants without tinnitus. From the group without pre-existing tinnitus, 12% reported new tinnitus, and 88% reported they still did not have it. From the group with pre-existing tinnitus, 61% of subjects reported their tinnitus resolved and 39% reported it persisted. The latter group had a mean THQ score of 41.2 with a standard deviation of 22.35 before being implanted, which decreased to a mean score of 29.8 with a standard deviation of 19.45 after implantation. This indicates that the trend is for tinnitus to be suppressed or diminished with stimulation from the implant. The researchers also endeavored to find why some users do not report improved tinnitus symptoms with surgical intervention. The amount of time the person had hearing loss, age at implantation, implant manufacturer, sex, and hearing thresholds appeared to have no significant effect on THQ scores. In other words, they were unable to find a possible explanation for lack of tinnitus reduction in some patients after surgery.

Amoodi et al. (2011) also evaluated changes in tinnitus with cochlear implantation, using the THI instead, with a sample of 142 participants ages 40 to 68. All subjects reported tinnitus prior to implantation. The short-form 36 (SF 36) was also used; this inventory measures the subject's perceived quality of life with respect to health-related functions. Finally, the Hearing Handicap Inventory (HHI), used to measure perceived hearing handicap was included. All of the subjects included in this study reported tinnitus of varying degrees prior to CI implantation. The THI, the SF 36, and the HHI questionnaires were given to the patients to complete before surgery and then one year afterwards. Amoodi et al. (2011) anticipated lower THI scores post implantation as well as an improvement in quality of life as reflected on the SF 36 and a decreased score on the HHI. Their results revealed total suppression of tinnitus in 37% of their population after the procedure and 29% revealed reduced tinnitus perception. They include that participants that had the highest THI scores before receiving the implant reported a higher quality of life after the surgery, although overall, the correlation was not statistically significant. Those who reported a lesser handicap reported insignificant changes with regard to quality of life indicating no significant correlation on the SF 36. Additionally, a moderate significant positive correlation was found on the HHI scores and THI scores, indicating that perceived hearing handicap decreased as perceived tinnitus handicap decreased.

Bovo et al. (2011) evaluated THI scores obtained from 51 post-lingually, bilaterally deafened patients, ages 16 to 76, who had undergone unilateral cochlear implantation. Approximately 75% of subjects reported pre-operative tinnitus. The questionnaires were completed before implantation and then again 6 months afterwards.

In their sample of 51 adults, they found that 36.1% of the subjects reported total tinnitus suppression and 41.6% noticed a reduction in the intensity of the tinnitus. THI scores were reduced in 72.2% of the patients in this sample; mean THI score was 45.8 (indicating a moderate handicap) and decreased to 32.3 (indicating a mild handicap) 6 months after activation. Furthermore, 44.4% of the participants noted that the tinnitus reduction persisted even when the processor was inactive. The authors attributed these changes to habituation, acoustic masking, direct electrical nerve stimulation, and cortical reorganization. The researchers suggest that cortical reorganization and central masking are the more likely factors in subjects who experienced tinnitus suppression contralateral to the implanted ear, which was an interesting finding.

Another study conducted by Olze et al. (2011) evaluated TQ scores in a sample of 43 adults, ages 19 to 77, who were unilaterally implanted. 91% of the sample reported pre-operative tinnitus. They also evaluated the impact of CI on quality of life and its psychological comorbidity. The mean TQ score before surgery was 31 and decreased to a score of 23 after surgery; none of the patients reported new or worsened tinnitus post-operatively. Participants noted that their tinnitus handicap was reduced or was gone altogether. For the quality of life measure, there was a statistically significant increase in scores in this sample. There was also a benefit psychologically: the participants reported feeling less worried and less stressed after being implanted.

Kloostra et al. (2014), conducted a retrospective qualitative study of approximately 153 CI recipients 18 years of age and older (approximate sample size given as not all participants submitted complete questionnaires and no age range disclosed). Some participants were unilateral recipients and some were bilateral

recipients. All reported tinnitus prior to implantation. On average, the subjects were implanted approximately 4.5 years prior to receiving the follow-up questionnaires. The subjects were primarily unilaterally implanted and all received a packet of questionnaires pre-implantation and post-implantation including the THQ and the THI. 45 of the subjects did not experience tinnitus prior to surgical intervention, which remained stable. 23 of the subjects reported a tinnitus reduction and 11 reported total suppression. In those with tinnitus before the surgery, the mean THI score was 30 (indicating a mild handicap) and after the surgery, the mean THI score was below 20 (indicating a lesser but still mild handicap). Before the surgery, the mean THQ score was 40 and after the surgery, it decreased to approximately 30. This indicates an essentially mild decline in perceived handicap post-implantation and the changes were only statistically significant for the THQ scores.

Macias et al. (2015) researched the efficacy of cochlear implants as a treatment for debilitating tinnitus, unilateral severe to profound sensorineural hearing loss, and hyperacusis in a small sample of 16 subjects ages 31 to 70 years old. All the participants reported bothersome tinnitus and hyperacusis prior to implantation. They measured a change in tinnitus perception using the THI, which was administered prior to surgery, then 6 months after, then 12 months after. All the participants in this study scored 58% or higher on the THI pre-operatively, consistent with a severe perceived handicap. For 3 patients, post-operative THI scores revealed no perceived handicap, scores for another 3 patients revealed mild perceived handicap, and scores for another 2 patients revealed moderate perceived handicap. In the remaining subjects, no significant change was noted (handicap remained severe). In this relatively small sample, they reported good efficacy

of cochlear implants in diminishing participants' tinnitus 6 months after the operation. This significant change was noted as long as the cochlear implants were in use and occasionally, there was residual tinnitus inhibition with the implant turned off. However, none of the subjects were completely rid of their tinnitus as was demonstrated by its presence with the CIs off. Additionally, a finding from this study supported previous research that stated full-length electrode array activation is necessary for positive outcomes with the CI as well as tinnitus suppression. Overall, the results indicate that cochlear implantation may be beneficial in some for decreasing handicap from tinnitus, with proper patient compliance and post implantation rehabilitation.

In a multicenter study conducted by Kim et al. (2016), they found results that corroborated those of previous researchers included in this section. These researchers recruited 79 participants, ages 35 to 66, 59 of whom reported prior tinnitus, with severe to profound hearing loss bilaterally. Not all participants had tinnitus as they wanted to examine the prevalence of tinnitus that began after being implanted. Several questionnaires, including the THI, were administered 5 times: once pre-operatively and 4 times post-operatively at various intervals (immediately after, 1 month after, 3 months after, and 6 months after). For the purposes of this literature review, only the THI results will be discussed. Average THI scores before implantation were around 45 indicating a moderate handicap then decreased to 40 (still a moderate handicap) immediately after, then decreased further to 25 (indicating a mild handicap) and remained stable at 1, 3, and 6 months after. The results revealed a significant decrease in tinnitus handicap soon after surgery was completed. Additionally, in a small but significant portion of the sample, some patients' tinnitus was eliminated altogether. No significant relationship was found

between diminished tinnitus and electrode insertion depth, surgery technique, or residual hearing post implantation in this study.

Holder et al. (2017) conducted a small-scale study in a population of 12 adults, ages 36 to 66, who were unilaterally implanted for single-sided deafness (SSD). All of the patients reported comorbid pre-existing tinnitus. The researchers used the THI to track changes before and after being implanted. It was administered at 1 month, 3 months, 6 months, and 12 months after surgery. 45% of the sample reported total tinnitus suppression while their processor was on post implantation. The mean pre-operative THI score was 61 (consistent with a severe handicap) and the mean postoperative THI score at 3 months was 24 (consistent with a mild handicap), indicating a significant overall decline in perceived tinnitus handicap. The score decreased even further to 13 (consistent with a slight or no handicap) at the 12-month appointment, indicating that tinnitus may decrease over time with consistent CI use.

All of these studies support the hypothesis that cochlear implantation is often successful in diminishing tinnitus perception and handicap. The majority of participants reported tinnitus suppression or reduction after intervention. However, there were cases where a substantial proportion of the sample reported worsened, new, or no change in their tinnitus even with consistent CI usage, which will be discussed further in the following section.

Research Question #2: How frequently does tinnitus arise, worsen, or remain post cochlear implantation?

In the previous section, the literature revealed that many CI recipients experienced tinnitus reduction or suppression after surgery with the implant on. However, as Bovo et al. (2011) suggest, results from these studies should be interpreted carefully for CI candidates with primary complaints of tinnitus, due to the possibility of new, worsened, or persisting tinnitus after implantation. In this section, negative tinnitus effects in CI recipients will be discussed (Table 2).

Increased, New, or Persisting Tinnitus Perception Post Cochlear Implantation

Pan et al.'s (2009) study (mentioned in the previous section) demonstrated tinnitus suppression or elimination with cochlear implantation, however, a 12% of their participants reported the onset of tinnitus after surgery. They disclosed that this percentage was a higher prevalence than what was found in previous studies. Similar results were found by Bovo et al. (2011); in 16.6% of their sample, tinnitus was unchanged and in 5.5%, the tinnitus worsened. While Kim et al.'s (2016) study also ultimately found cochlear implantation to be beneficial for those suffering from tinnitus, they reported that many of their subjects would experience an initial flare up of tinnitus when their processor(s) were turned off, that would only partially resolve. Additionally, 5 patients out of 20 who did not suffer from tinnitus before being implanted, developed tinnitus afterwards. 4 of these patients eventually reported that their tinnitus resolved. In 8.4% of their study sample, subjects reported their tinnitus had actually worsened with a mean THI increase of 17.1 +/- 21.1, indicating an essentially mild self-perceived handicap.

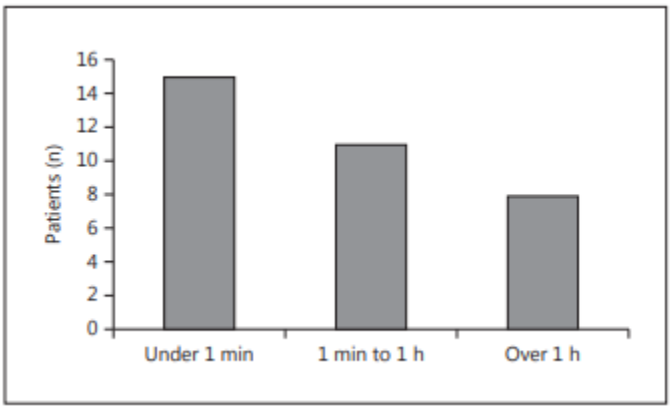

Figure 5: Tinnitus reduction time in patients after their processor was turned off (Adapted from Kim et al., 2016).

Andersson et al. (2009) investigated tinnitus handicap in 111 unilateral cochlear implant recipients, using the THI, only post implantation. The subjects' tinnitus was not assessed prior to implantation. The major finding from this study was that 17% of the recipients reported a severe perceived tinnitus handicap. If those with moderate scores are included, then 24.5% still experienced a significant impact from their tinnitus. This still indicates a significant proportion had minimal or no handicap after implantation, but these researchers did find a much larger portion of their study population still felt debilitated by their tinnitus. In the aforementioned study conducted by Kloostra et al. (2014), 5 of their subjects reported worsened tinnitus after cochlear implantation as well. Additionally, 11 participants within their sample developed tinnitus that was not present pre-operatively. Finally, 22 subjects reported their tinnitus was unchanged. These subjects also reported a lack of benefit in speech understanding, which may be due to the tinnitus interfering with their ability to communicate. While their study did demonstrate improvement in THI and THQ scores, the changes were relatively mild overall.

Van de Heyning et al. (2011) conducted a systematic review of the impact of unilateral cochlear implantation on tinnitus and included their own research in their study. The researchers demonstrated overall improvement in tinnitus after implantation, however, they did also reveal that the changes were active so long as the implant was active (see Figure 5). When turned off, the tinnitus was still largely present. As tinnitus can often interfere with one's sleep, this finding is still problematic as it shows potential for this symptom's debilitating effects to persist even with intervention. They also reported that the prevalence of new tinnitus in cochlear implant recipients ranged between 0 to 9%; it is worth noting that it often became less bothersome with time or disappeared entirely. Similar findings were discovered in Macias et al.'s (2015) research. Only 46% of those participants reported tinnitus reduction with their implant inactive and none reported total elimination of their tinnitus. The remaining participants had THI scores that still indicated a severe perceived handicap with their implants.

Like many of the studies included in this section, Amoodi et al.'s (2011) found that cochlear implantation did result in tinnitus reduction or suppression in a significant portion of their subjects. However, left over, there was still a large portion that either reported no change in their tinnitus (29%) or even worsened tinnitus (5%) after implantation. While they state that CIs are frequently beneficial for diminished tinnitus perception, informed consent for the procedure should consider the possibility of new, worsened, or persistent tinnitus.

Research Question #3: <u>How effective is cochlear implantation in contrast to hearing aid use in terms of moderating the severity of tinnitus?</u>

Four studies were sourced that discussed changes in tinnitus with the use of hearing aids. Hearing aids offer the advantage over cochlear implants that there is no risk of new or worsened tinnitus; the consequences may be limited to lack of benefit or tinnitus that simply does not change. There were about 243 hearing aid users included and the vast majority reported a decrease in tinnitus perception after intervention. Based on the results, there was no apparent contraindication for a trial with hearing aids for those with hearing loss with comorbid tinnitus (provided they have received medical clearance).

Table 3: Summary of Studies Included that Evaluated Tinnitus after Fit with Hearing Aids

	Sample Size	*Measure Used*	*Sample Characteristics*	*Outcomes*
Searchfield et al. (2010)	58	THQ	-Adults ages 16-84 -Bilateral mild to moderately-severe high frequency hearing loss (with exception of 1 subject with unilateral hearing loss) -All but 1 subject fit binaurally fit with amplification -All had pre-existing tinnitus	-Overall decrease in THQ scores after fitting -Decreased tinnitus handicap with hearing aids and counseling rather than counseling alone
McNeill et al. (2012)	70	TRQ	*-Adults ages 21-74 -Hearing loss of varying degrees -All were fit with amplification -All had pre-existing tinnitus	-Decrease in THQ scores with 3 months of hearing aid usage -Better outcomes for those whose tinnitus pitch was in the frequency range of the hearing aid amplification -23% of sample did not perceive any change in their tinnitus with amplification
Hoare et al. (2014)	91	THI	*-Adults ages 20-56 -All had some degree of "significant" bilateral hearing loss -All were fit with hearing aids binaurally -All had pre-existing tinnitus	-Significantly decreased THI scores with hearing aid use
Araujo & Iorio (2016)	24	THI	-Adults ages 61-70 -Bilateral moderate sensorineural hearing loss -All were fit with hearing aids binaurally -12 had pre-existing tinnitus and 12 did not	-Decreased THI scores -Older adults may still have neural plasticity allowing for positive cortical changes with intervention

(* Indicates an incomplete description of sample characteristics in the study.)

Changes in Tinnitus Perception with Traditional Amplification

Traditional amplification may diminish perception in several ways (Searchfield et al., 2010; Van de Heyning et al., 2011; McNeill et al., 2012; Shekhawat et al., 2013; Hoare et al., 2014). The first may be that the soft sounds that are amplified by hearing aids may be sufficient in masking out tinnitus noise, such that it is no longer bothersome (Searchfield et al., 2010). Hoare et al. (2014) suggested that cortical reorganization that occurs with auditory stimulation may also result in diminished tinnitus as with cochlear implants. Regardless of the mechanism, the research has shown that hearing aid amplification is an appropriate and low-risk option for those with hearing loss and comorbid tinnitus. In this section, changes in tinnitus with the use of hearing aids will be examined.

Searchfield et al. (2010) conducted a retrospective study with a sample of 58 participants, ages 16 to 84, mostly with bilateral hearing loss and tinnitus. Their hypothesis was that patients who decided to proceed with hearing aids in conjunction with tinnitus management therapy perform better than those who only opted for tinnitus management therapy alone. The subjects' responses on the THQ prior to intervention (counseling or amplification and counseling) were compared to those from one year post intervention. The subjects all scored 15 or higher on the THQ before a trial with hearing aids and/or counseling. The findings indicated that patients with hearing loss and coexisting tinnitus should at least consider a trial with amplification. THQ scores decreased for both test groups, but only decreased significantly for the group who were fit with hearing aids. Beyond ease of listening provided by the gain from the hearing

devices, patients' scores on the THQ decreased by 37% and revealed reduced psychosocial effects from their tinnitus; this included reduced depression, tension, anxiety, and sleeplessness.

These researchers undertook a secondary hypothesis to compare amplification to other treatments used in other studies, rather than counseling alone. They investigated prior research and found hearing aids to be more effective as a treatment when compared to research on Paroxetine (a selective serotonin reuptake inhibitor or SSRI) or placebos. Cochlear implantation was shown to be effective as well, in addition to CBT and TRT. Searchfield et al. (2010) stated that their results overlap with results found in previous studies performed using similar models, further demonstrating hearing aids to be an appropriate and effective option for tinnitus sufferers with hearing loss, especially with the use of tinnitus-directed counseling.

McNeill et al. (2012) designed a retrospective study with 70 adult participants, ages 21 to 74, suffering from hearing loss (various degrees and configurations) and tinnitus. The subjects were fit with hearing aids and were given the TRQ to complete before being fit and then 3 months or more after being fit. Their results indicated a decrease in the audibility of the tinnitus as well as the negative emotions associated with it. 37% of patients reported that their tinnitus was masked entirely and 40% reported that it was partially masked out. The mean THQ score prior to intervention was 49 and the mean THQ score post intervention decreased to 34. They also had the interesting finding that if their tinnitus's pitch fell within the frequency range of the hearing aids, there was a larger effect size. McNeill et al. (2012) also found that patients with low-frequency hearing within normal limits sloping to a high frequency hearing loss had the best

outcomes. This may be a consideration going forward in terms of programming strategies for patients with tinnitus in lieu of using a masker overlay. Additionally, the results somewhat corroborated those of Searchfield et al. (2010) in that McNeill et al. (2012) found that the benefit was primarily gleaned from the amplification regardless of any additional counseling. However, they contradict Moffat et al.'s (2009) finding that high frequency amplification was not beneficial for lowering tinnitus handicap long term. Additionally, 23% of their subjects reported no masking from amplification despite consistent usage. All these researchers were still able to demonstrate a statistically significant improvement overall for their participants with tinnitus and hearing loss.

Hoare et al. (2014) conducted a systematic review evaluating a population of 91 adults, ages 20 to 56, with bilateral hearing loss who were fit with amplification binaurally. They selected studies that used the THI to evaluate changes in tinnitus before and after intervention. All of the participants included had a severe score on the THI of 58 or higher. According to Hoare et al. (2014), use of amplification was associated with a statistically significant decrease in tinnitus perception in subjects. The average decrease in scores in this sample was approximately 30 points lower on the THI. The tinnitus did not necessarily stop altogether, but subjects became less aware of it or were less bothered by it post intervention. The subjects reported an overall decrease in loudness after consistent hearing aid use.

In a prospective study conducted by Araujo and Iorio (2016), 24 participants, ages 61 to 70, with bilateral sensorineural hearing loss were fit with amplification binaurally. Half did not have comorbid tinnitus (control group) and the other half did. The researchers cited studies where the outcome measures showed no improvement in the

subjects and wanted to perform their own investigation. Those with tinnitus were given the THI to complete prior and post being fit with amplification. They too found a statistically significant decline in scores with consistent hearing aid usage. Subjects either reported that they were less bothered by the tinnitus than before or that the perceived intensity of their tinnitus actually decreased. THI scores decreased from an average handicap of moderate to a mild or slight/no handicap with amplification. The researchers suggested that auditory stimulation can counter the maladaptive plasticity that arose from auditory deprivation even in older adults. Moreover, the participants were essentially older adults, indicating that the brain still has plastic properties among this age group. This research demonstrated that there was a positive effect on the subjects' tinnitus perception with prolonged use of amplification.

The research consistently revealed that tinnitus-sufferers experience a decrease in how bothersome their tinnitus is with the use of amplification. However, Shekhawat et al. (2013) suggest that it is difficult to separate the benefit a user perceives in terms of more ease of listening from lessened tinnitus handicap. The researchers suggested the following solution to address this: administer both a tinnitus questionnaire and a hearing questionnaire to better parse the information, so that positive effects from amplification can be identified more effectively on communication and tinnitus. This is a good consideration for further research and clinical use.

As has been shown above by numerous researchers, hearing aid use for those with hearing loss and tinnitus is an effective treatment. Unlike cochlear implantation, there is no risk of permanent damage from appropriate use of traditional amplification that would result in new, persistent tinnitus. Hearing aids provide a lower risk option to those who

are candidates and can still benefit in terms of speech comprehension. Additionally, there is the obvious point that an individual is not bound to their hearing aids. They may choose to trial them, but do not need to continue use if they do not perceive benefit either for diminishing tinnitus or for having improved access to speech. This is often not the case with cochlear implantation.

Discussion

The goal of this systematic review was to identify tinnitus changes with cochlear implantation and with hearing aids, using clinically relevant questionnaires. Overall, both methods of amplification included in this systematic review are effective in reducing tinnitus perception. This effect often disappeared when the devices, either type, were not in use, which is an important finding as tinnitus may impact an individual's ability to sleep (Bhatt et al., 2018). There was also a small possibility that CI candidates with pre-existing tinnitus would not perceive benefit after implantation or report more tinnitus burden. Additionally, candidates without tinnitus prior to implantation, occasionally noted new tinnitus after.

Research Question #1: Does cochlear implantation reduce tinnitus handicap?

It is clear from the findings that the majority of CI recipients experience either partial or total relief from their tinnitus after implantation. This decrease in perceived handicap was measured consistently across the included studies with varying effect sizes using the THI, THQ, and TQ. Quality of life rating and communication ability, which

may have an effect on tinnitus perception, also improved accordingly after intervention. Most recipients reported that the reduction in tinnitus persisted as long as their processors were active, but the tinnitus usually returned when the processor was turned off. This aspect should not be neglected as tinnitus often affects sleep, which could still be debilitating to some (Baguley et al., 2013b).

Research Question #2: How frequently does tinnitus arise, worsen, or remain post cochlear implantation?

While a majority of CI recipients reported a decline in perceived tinnitus handicap, there were also a significant number of patients that reported no change in their tinnitus after implantation. Furthermore, there is a risk of worsened tinnitus perception with the procedure, which is a major consideration for those with tinnitus as a primary complaint. Additionally, there is the risk of new tinnitus after implantation, although according to this sample of the research, the new tinnitus would often not persist long term. There was roughly a 20% prevalence of tinnitus difficulties after implantation, which is clearly a significant risk. However, with proper counseling, cochlear implants are still an appropriate recommendation for candidates with comorbid tinnitus provided there is informed consent.

Research Question #3: How effective is cochlear implantation in contrast to hearing aid use in terms of moderating the severity of tinnitus?

The vast majority of patients pursue hearing aids prior to undergoing cochlear implantation. There are fewer risks associated with traditional amplification: namely the

lack of general surgical risks and no risk of increased or new tinnitus. It is important to ensure that hearing aids do not provide benefit before considering a CI. The research is in favor of addressing hearing loss and comorbid tinnitus with hearing aids with or without tinnitus-directed counseling according to the decrease in THI, THQ, and TRQ scores. Through an unknown mechanism, many patients reported total or partial tinnitus relief in addition to the improved ability to communicate, which may have the added benefit of stress reduction. As with cochlear implants, there were still a number of subjects that reported no change in their tinnitus with consistent hearing aid use, although there were fewer reports in this body of literature than were found in the corresponding CI recipient studies included in this systematic review.

Clinical Implications

According to this systematic review of the literature, both cochlear implantation and hearing aids often provide tinnitus relief either through suppression or reduction. As long as the devices are on or active, subjects frequently reported diminished tinnitus perception and corresponding decreased handicap. This indicates that either intervention is appropriate and beneficial for those with hearing loss and comorbid tinnitus.

However, when the implant is inactive or when the hearing aid(s) are not being worn, tinnitus is usually still present for most. While good outcomes are suggested overall, it is important to consider the effects of tinnitus even if there is overall benefit. Tinnitus can still be debilitating or bothersome even if there was improvement. As this auditory perception can often affect sleep (Lasisi & Gureje, 2011; Baguley et al., 2013b;

Hoare et al., 2014; Kloostra et al., 2014; Kleinstauber et al., 2015; Macias et al., 2015; Araujo and Iorio, 2016; Cabral et al., 2016; McCormack et al., 2016; Bhatt et al., 2018; Koning, 2019; Stohler et al., 2019), it is worth mentioning because processors or hearing devices are rarely worn during this time. While new tinnitus did arise in some participants after cochlear implantation, it frequently resolved over time.

Future Research Needs

A consideration in conducting additional research on this topic is to evaluate outcomes in children. Children were not considered at present due to the lack of research available regarding children's' perception of tinnitus as well as tinnitus measures appropriate for the pediatric population. Additionally, separating unilateral implantation or bilateral implantation changes for CI recipients and unilateral versus bilateral hearing aid fitting could be another topic of interest. A more in-depth review of tinnitus suppression with hearing aids alone versus hearing aids with maskers would also be a good topic for further investigation. Finally, conducting further research on simultaneous or sequential implantation and hybrid cochlear implants could provide useful data for audiologists or otologists.

Limitations

One possible limitation of this study is that the electrode arrays selected for the cochlear implant patients (i.e. lateral wall versus perimodiolar) were not considered in

gathering data. This may be problematic as the method of insertion with the selected array may dictate the amount of damage done to the delicate inner ear structures (Dhanasingh & Jolly, 2017). It is possible that methods not intended for hearing preservation and therefore more aggressive, may have been more likely to cause damage resulting in new or worsened tinnitus. Additionally, depth of insertion was not considered in most of the included studies. This may have impacted results if the auditory stimulation theory of tinnitus is considered. If parts of the cochlea were not receiving stimulation due to a shallower insertion depth, then auditory masking or cortical reorganization from stimulation would not be able to take place. Many of the researchers did not mention whether the CI recipients were bimodal or received simultaneous/sequential implantation so no statement can be made in this systematic review regarding a correlation between those topics and changes in tinnitus,

Another possible limitation of this study was its heavy reliance on subjective and qualitative data. An individual's ability to reliably report data may be variable among the subjects included in a study. Randomized Control Trials (RCTs) are the gold standard for demonstrating the efficacy of treatments (Shekhawat et al., 2013); there is a lack of RCTs available on this subject as there is no objective method for measuring tinnitus or tinnitus handicap.

Furthermore, the manufacturers of the amplification used, the level of technology selected, and the fitting strategy were not evaluated for the purposes of this study. The researchers that evaluated changes in tinnitus with hearing aids also stated that binaural fittings are better for tinnitus reduction as both pathways are receiving stimulation; monaural versus binaural fittings were both included in this literature review. The

frequencies at which hearing loss was present were also not considered. McNeill et al. (2012) suggested that the pitch of the tinnitus is related to the frequencies that are affected by hearing loss, which is why most tinnitus sufferers report their tinnitus is high-pitched.

The duration of the tinnitus prior to intervention may also be a confounding variable even though researchers included in this study did not find a significant relationship between the amount of time the tinnitus was present and tinnitus outcomes. This may be due to the small sample sizes used in their studies. Certain individuals with sudden or new tinnitus may adapt to the tinnitus over time and it may decrease or disappear altogether in the absence of treatment. The amount of time a subject experienced tinnitus was not included in this research.

Children were not included in this literature review as tinnitus is a highly subjective condition and children are often unable to provide consistent, accurate self-report based data. Additionally, there are differences in the cochlear implant candidacy criteria, which could potentially introduce a confounding variable into this research. However, this topic applied to children could also provide valuable information on pediatric cochlear implantation outcomes.

There is also the consideration of personal variables like socio-economic status and healthcare quality in the country of residence that were not considered in this study as research was included worldwide. The availability of treatment in terms of cost or in terms of a physical office in close proximity could confound the results identified in this literature review, making the results inapplicable to all populations.

Conclusions

Changes in tinnitus across two types of intervention were evaluated using validated measures (THI, THQ, TRQ, and TQ). Cochlear implantation in patients with tinnitus often results in tinnitus suppression or reduction. Despite the overall positive findings, research is still ongoing so findings in this paper should be interpreted with caution. Patients considering CIs to address a primary complaint of tinnitus should be informed of the possibility of their tinnitus worsening or staying the same after implantation. However, if a patient may still receive benefit using hearing aids, as is protocol in most facilities, hearing aids should be trialed prior to pursuing surgery. Hearing aids will not permanently worsen tinnitus but, like CIs, could provide tinnitus reduction as well as improved speech detection and eventually comprehension.

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