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Original Article

Tinnitus pitch, masking, and the effectiveness of hearing aids for tinnitus therapy

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Abstract

Objective: To assess the benefits of hearing aids on tinnitus according to the tinnitus reaction questionnaire (TRQ; Wilson et al, 1991), to verify whether the degree of masking provided by the hearing aid influenced the TRQ score, to examine whether the matched tinnitus pitch predicted the effectiveness of hearing aids in masking tinnitus, and to determine whether prescription of high-frequency amplification might be desirable in tinnitus management when tinnitus pitch is high. *Design and study sample:* A retrospective evaluation of the clinical outcomes of 70 tinnitus patients fitted with hearing aids was undertaken. The primary outcome measure was the TRQ, with a secondary subjective measure of tinnitus masking. *Results:* Participants who achieved masking with their hearing aids had greater reduction in TRQ scores. Masking was more likely to be achieved when participants had good low-frequency hearing and tinnitus pitch fell into the frequency range of the hearing aids. *Conclusions:* The results support the use of hearing aids for tinnitus management, and suggest that masking may be a significant contributor to hearing aid success, implying that high-frequency amplification may be effective in high-pitch tinnitus.

Key Words: Hearing aids; tinnitus; masking; pitch match

Hearing aids have become common therapeutic tools in the audiological management of tinnitus (Kochkin & Tyler, 2008). The potential benefits of hearing aids for tinnitus management have been known since the late 1940s (Saltzman & Ersner, 1947). It is only fairly recently that the potential physiological origins of tinnitus (Eggermont & Roberts, 2004) and mechanisms of sound-based treatments have become clearer (Norena & Eggermont, 2005; Schaette & Kempter, 2006).

From a perceptual and psychological viewpoint hearing aids have been presumed to impact tinnitus perception by: (1) improving quality of life related to hearing difficulties, (2) reducing attention to tinnitus, and (3) enabling masking by ambient sound (Coles, 1985). There is also a strong case for a neurophysiological mechanism whereby sound could prevent maladaptive neuroplastic changes that may result from permanent damage to the peripheral auditory system (Norena & Eggermont, 2005; Schaette & Kempter, 2006). The presence of tinnitus is strongly related to the presence of hearing loss and its pitch often corresponds to the frequency range neighbouring (Moore et al, 2010), or within the hearing loss region (Sereda et al, 2011). Following damage to the auditory peripheral system, plastic changes occur in the central nervous system. Cortical tonotopic maps change in response to injury, hearing loss frequencies become over-represented and associated with synchronous spontaneous activity (Eggermont & Roberts, 2004). These central changes have been shown to be largely preventable when animals are raised with auditory stimulation in the areas of hearing loss (Norena & Eggermont, 2005), and in humans might be reversed with the use of hearing aids (Schaette & Kempter, 2006).

Hearing aids are commonly used alongside counselling (Kochkin & Tyler, 2008) and form an important part of treatments such as tinnitus retraining therapy (Jastreboff & Jastreboff, 2000). Although hearing aids have been used for many years, and are a very popular tinnitus treatment tool, there has been less evidence for their tinnitus effectiveness when compared to some more recent sound based therapies, for example, the neuromonics tinnitus treatment (Davis et al, 2007, 2008; Hanley & Davis, 2008; Hanley et al, 2008; Henry et al, 2008; Goddard et al, 2009; Jang et al, 2010; Seidman et al, 2010; Távora-Vieira & Davis, 2010; Távora-Vieira et al, 2011; Wazen et al, 2011). As hearing aids are used "off label" as tinnitus treatments there have not been many commercial, or regulatory, driving forces for undertaking large randomized controlled trials. Small scale controlled or uncontrolled studies suggest that hearing aids can have a positive effect on tinnitus handicap or severity. Aside from one study showing that hearing aids did not improve tinnitus on a visual analogue scale (VAS) (Melin et al, 1987), all other studies we identified describe some tinnitus

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Abbreviations

TRQ	Tinnitus reaction questionnaire
VAS	Visual analogue scale

improvement with hearing aids. Sheldrake and Hazell (1991) demonstrated small changes on a VAS by the majority of patients. More recent studies suggest stronger treatment effects: Del Bo et al (2006) demonstrated a 51% change in Tinnitus Handicap Inventory (THI) three months following open-fit hearing aids; Folmer et al (2006) showed a 33% decrease in the tinnitus severity index following long term use of hearing aids. Searchfield et al (2010) demonstrated a 37% reduction in tinnitus handicap questionnaire, and Parazzini et al (2011) demonstrated a 52% change in THI after 12 months of hearing aid use. A simple review across these results would suggest that the effectiveness of hearing aids might have improved since the 1980s. Over this time period there have been very significant advances in hearing aid technology. Trotter and Donaldson (2008) reported on 25 years of hearing aid use for treating tinnitus and found that patients reporting a greater than 50% improvement in tinnitus, increased from 39% (1980–1999) to 65% (2000–2004) when digital hearing aids were made available to their patients. Digital hearing aids offer increased fitting flexibility, feedback reduction, and noise reduction unavailable in their analogue predecessors, but some of these advanced features may not be beneficial for tinnitus management (Searchfield, 2006). Trotter and Donaldson (2008) believed that the ability to provide more selective amplification of high frequencies was the single most important factor explaining the improvement seen with digital hearing aids.

The ability of more modern hearing aids to mask high frequency tinnitus may be one reason for the improved effect of hearing aids on tinnitus. However there is not a clear relationship between tinnitus pitch and sounds effective in masking it. Unlike masking of tones, frequencies close to tinnitus pitch are not always the most effective maskers (Feldman 1971). Feldman (1971) investigated and then characterized tinnitus into five masking types. Type 1 (convergent) tinnitus masking occurred when the lowest sensation of masking was near tinnitus pitch and in the region of high frequency hearing losses: it occurred in 34% of cases. Type 2 (divergent) tinnitus was seen in 3% of cases as threshold and masking curves diverge from low to high frequencies, high frequencies provided less masking. Type 3 (congruence) masking occurred in 32% of cases when any low sensation level sound was equally effective, independent of tinnitus pitch. Type 4 (distance) masking occurred in 20% of participants, but only at higher sensation levels irrespective of frequency. The Type 5 (resistant) masking occurred for 11% of cases where masking was not possible even at high intensities. These tinnitus-masking patterns are inconsistent with masking occurring only at the cochlea, so tinnitus masking is likely to include a central component. On the other hand, and even though it has been suggested that sound therapy such as masking need not contain sounds encompassing the tinnitus pitch (Penner & Zhang, 1996), recent computational models of tinnitus (Schaette & Kempter, 2006) and physiological evidence (Norena & Eggermont, 2005) suggest that stimulation of frequency regions of hearing loss (and tinnitus) should be important for treatment.

At least two small-scale studies have investigated the value of hearing aids with extended high-frequency response on tinnitus (Moffat et al, 2009; Schaette et al, 2010). Moffat et al compared the effect of conventional amplification to extended high-frequency amplification on tinnitus loudness up to 30 days following the hearing aid fitting. The authors concluded that high-frequency amplification had no effect, but this might have been due to the short period of hearing aid use (Moffat et al, 2009). Schaette et al (2010) undertook a similar study in which participants received hearing aids and sound generators for six months. Those with tinnitus pitch less than 6 kHz improved on a tinnitus loudness VAS and a tinnitus questionnaire, while those with tinnitus pitch above 6 kHz did not.

Although it is generally accepted that hearing aids mask tinnitus perception in many patients, there are currently no clinical tools available to reliably assess the likelihood of masking occurring. Audiologists usually recommend hearing aids for the management of tinnitus on a “trial and error” basis. Such a heuristic approach is not satisfactory for clinicians or patients and a more evidence-based method is desirable. A prognostic clinical tool is therefore needed to help the clinician to predict the effects of amplification on tinnitus perception for an individual before hearing aids are recommended as tinnitus treatment. The pilot results of Schaette (Schaette et al, 2010) suggest that tinnitus pitch may provide such a tool when compared to the frequency response of potential hearing aids.

This study aimed to:

1. Ascertain the benefits of hearing aids on tinnitus according to the Tinnitus Reaction Questionnaire (TRQ) (Wilson, et al, 1991).
2. Determine whether complete, partial or no masking influenced TRQ scores.
3. Consider whether tinnitus pitch match could be used to predict the effect of hearing aids in masking tinnitus perception.
4. Determine whether high frequency amplification might be desirable in tinnitus management.

It was hypothesized that hearing aids would be most effective when their frequency range encompassed an individual’s tinnitus pitch.

Methods

This was a retrospective study conducted by reviewing the clinical records of 70 patients (48 male and 22 female: mean age 55 years, SD 11 range 21–74) who attended Healthy Hearing & Balance Care in Sydney and Medical Audiology Services in Perth, Australia, for the management of tinnitus and hearing loss between January 2007 and November 2010. They were not selected on the basis of any factor other than the presence of hearing loss (ranging from mild to severe) and a primary or secondary complaint of bothersome chronic tinnitus. All participants were privately funded.

Audiometry and tinnitus assessment

Pure-tone audiometry (0.25–12.5 kHz) was undertaken using a Madsen Itera and GSI-61 audiometers with Seinheiser HD 200 headphones following the modified Hughson-Westlake threshold seeking method. Tympanometry and acoustic reflexes were used to exclude middle-ear pathologies. All participants had otologic investigation to exclude any treatable cause for their hearing losses prior to fitting hearing aids. Tinnitus pitch was measured in 102 ears prior to the fitting of hearing aids in the 70 patients. Tinnitus pitch match was conducted in a sound proof booth under headphones with the same equipment used for pure-tone audiometry. Participants were presented with two 10dB SL pure tones at a time on the ear opposite to the loudest tinnitus. They were asked to compare the two tones (e.g. 0.5 and 4 kHz) and identify which tone pitch was more similar to their tinnitus. The frequency of presented tones was then narrowed down until they identified the closest match to their tinnitus. The procedure was repeated three times for consistency of results.

Tinnitus distress was measured using the tinnitus reaction questionnaire. This tool was chosen due to its validated psychometric properties to measure tinnitus distress in the Australian tinnitus population. The TRQ comprises of 26 items that summates a maximum score of 104 and represents the level of tinnitus disturbance in daily life (Wilson et al, 1991). The TRQ was administered prior to and at least three months post hearing aid fitting. At that time patients were also asked to report the effect of their hearing aids on tinnitus perception answering a multiple choice question:

How do you hear your tinnitus with your hearing aid switched on in your ear?

1. I don't hear the tinnitus at all
2. I hear the tinnitus softer
3. I hear the tinnitus the same
4. I hear the tinnitus louder

Results were subsequently classified (1 = Total masking, 2 = Partial masking, 3 = No masking). No participants reported experiencing louder tinnitus.

Hearing aid fitting

Hearing aids were selected based on patients' needs and preferences amongst the range of Oticon, Phonak, and Widex instruments. Entry level to advanced hearing aid features were chosen based on individual needs, hence a range of technology was used. Hearing aids were fitted to the hearing loss with no specific considerations to the presence of tinnitus. They were programmed via Noah and Noah Link equipment using the algorithm prescribed by the manufacturers' software for the given audiogram. Fittings were verified with probe microphone measurements using MedRx Avant Real Ear Measurement equipment.

The frequency response amplified by the hearing aids, as described by the manufacturers' specifications, was compared with the tinnitus pitch and the patients were retrospectively separated in two groups: patients with tinnitus falling within the hearing aid frequency response and patients with tinnitus falling outside the hearing aid frequency response. Patients were counselled to use the hearing aids starting from one hour on the first day building up to full-time usage. Follow-up was conducted two and four weeks post-fitting for fine-tuning if required. Tinnitus review was conducted three months post-fitting.

Analysis

ANOVA was undertaken using SPSS (PASW Statistics 18). Chi-squared analysis was undertaken for categorical data. Criteria for significance was set at < 0.05 for all tests. Cohen's *d* was calculated using an online calculator (http://www.cognitiveflexibility.org/effectsize/) with corrections for within participant measurements.

Results

Hearing aid fitting outcome

Participants had change in TRQ from 49.02 (SD 20.90) prior to hearing aids to 34.08 (SD 17.48) with a Cohen's *d* effect size of 1.25 following three months of use. Twenty-six participants

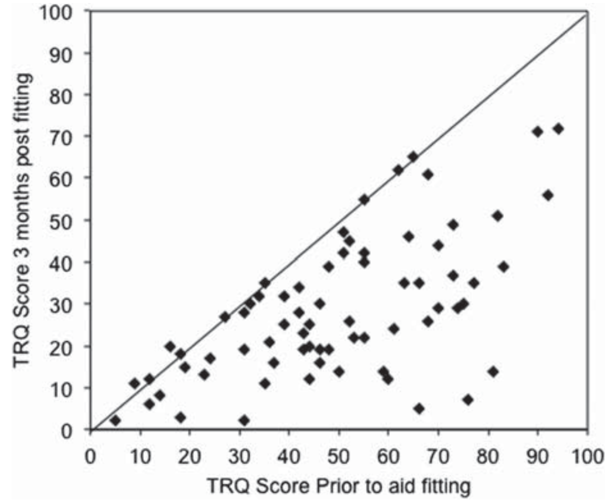

Figure 1. TRQ score following hearing aid fitting as a function of TRQ score prior to fitting for each participant in the study (N = 70). Symbols below the line indicate improved TRQ scores.

reported that while wearing the hearing aids, their tinnitus was totally masked, twenty-eight reported partial masking, sixteen reported no masking, and none reported an increase in loudness of tinnitus. The TRQ score for those with some masking effect was similar at baseline (total masking mean TRQ pre 51.9, SD 20.7; partial masking 53.1, SD 22.3), but the no masking group had a lower TRQ prior to having the hearing aids (mean TRQ 38.6, SD 19.5). There was overall improvement in tinnitus (TRQ mean prior to fitting 49.3, SD 21.6; mean post-fitting 28.4, SD 16.8; Figure 1), but this was not consistent across the masking groups. There was a reduction in tinnitus after fitting with hearing aids for those who experienced masking, but not for those who did not, as indicated by an interaction between masking group and time of completing the TRQ ($F(2,67) = 34.786$, $p < 0.001$; Figure 2). Three months following the fitting of the aids the no masking group's TRQ was similar to baseline (mean 36.1, SD 17.4) but the partial masking group's TRQ score (34.5, SD 16.4) had reduced, with an even greater reduction in TRQ score for the total masking group (mean 17.2, SD 10.0). A "clinically significant" change of 40% or greater in the TRQ (Davis et al, 2007) was achieved by 51% of all participants. In the total masking group

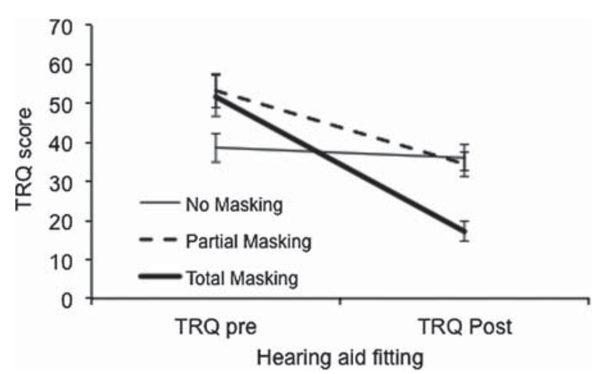

Figure 2. Mean TRQ scores (error bars represent ± 1 standard error of the mean [SE]) for each group prior to and three months post the fitting of hearing aids.

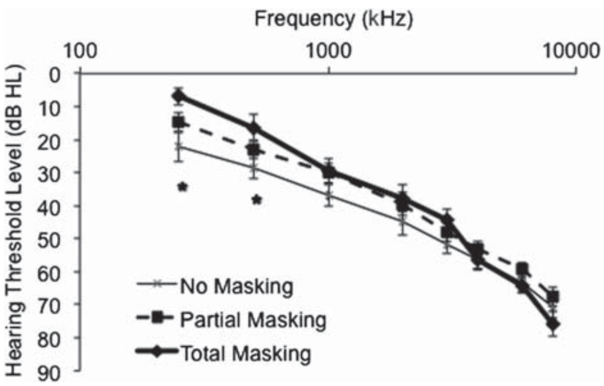

Figure 3. Mean audiogram (combined ears, error bars represent ± 1 SE) for each group. Values marked with an asterisk indicate statistically significant differences ($p < 0.05$).

100% achieved a 40% or greater improvement, in the partial masking group 36%, and 0% in the no masking group.

Audiogram

The majority of participants (65) had high-frequency symmetrical sensorineural hearing loss, three had flat hearing losses and two presented with "cookie bite" shaped audiograms. The audiograms were grouped according to masking effect, a significant difference was found between the groups' mean audiograms in the low frequencies (Figure 3). Participants who achieved total masking had on average more residual hearing at 0.25 and 0.5 kHz compared to those who achieved partial masking. In addition, the group that achieved no masking benefits had the worst hearing thresholds at 0.25 and 0.5 kHz.

Tinnitus pitch

Pitch matched frequencies for participants in this study were distributed around a mean pitch of 6.9 kHz, SD 3.4 (Figure 4). There were differences between masking groups in terms of tinnitus pitch ($F(2,67) = 4.471$, $p = 0.015$) (Figure 5). The group that did not achieve masking with hearing aids had a higher mean tinnitus pitch (8.0, SD 0.8) than the partial (7.6, SD 0.7) and total masking groups (5.4, SD 0.6).

Hearing aid frequency amplification

The hearing aids in this study had low frequency limits from 0.1 to 0.5 kHz and varied in high frequency response from 6.6 to 8.9 kHz (Figure 6). The groups differed in the frequency range of the hearing aids that they were using ($F(2,67) = 4.971$, $p = 0.010$). The mean upper frequency limit for the hearing aids used by the no masking group was 7.2 kHz (SD 0.519), for the partial masking group: 8 kHz (SD 0.368), and for total masking: 7.645 kHz (SD 0.847). A higher proportion of those who experienced better masking had tinnitus within the frequency range of the hearing aids used (chi-squared (2df) = 15.087, $p = 0.001$) (Figure 7). When participants were divided between those whose tinnitus pitch fell within and outside the frequency response range of their aids, a small difference in effect size were obtained; pitch within aid range: $n = 36$, mean TRQ before 49.64 (SD 22.55), after 23.08 (SD 14.48), correlation between means 0.51, Cohen's d = 1.49; pitch outside aid range: $n = 34$, mean TRQ before 49.02 (SD 20.9), after 34.08 (SD 17.48), correlation between means 0.82, Cohen's d = 1.3.

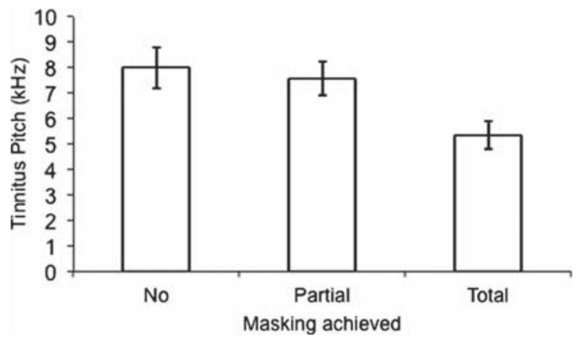

Figure 5. Mean tinnitus pitch (error bars represent ± 1 SE) for each group in the study.

Discussion

The results of this study suggest that the fitting of hearing aids can reduce the audibility of, and improve reaction to, tinnitus. Overall the fitting of hearing aids was associated with a Cohen's d of 1.25, values of 0.8 and greater which are considered large effects. Patients were divided into three groups following hearing aid fitting based on self-reported effects on tinnitus audibility (tinnitus unchanged/not masked, partial masking, and total masking/tinnitus not audible with aids in). Forty per cent achieved a reduction but not complete masking of tinnitus, 37% total masking, and 23% no masking at all. The TRQ for these groups showed progressive improvement across masking to total masking. Patients whose tinnitus pitch fell within the frequency range of their hearing aids had a larger treatment effect size than those for whom the tinnitus

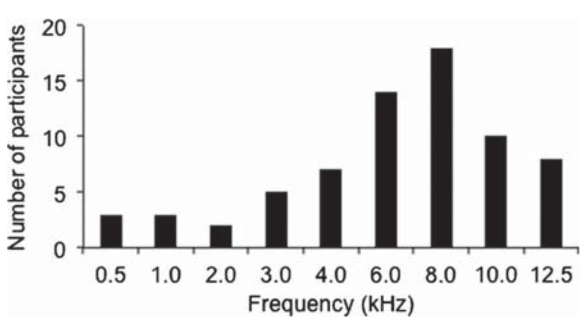

Figure 4. The number of participants grouped according to tinnitus pitch.

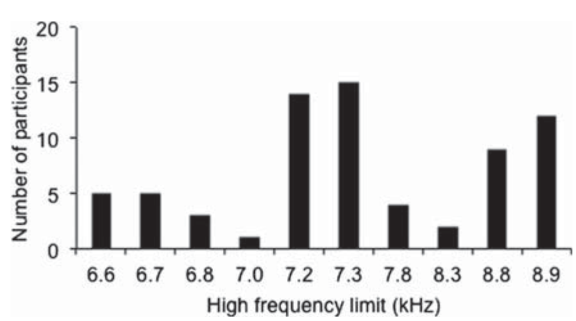

Figure 6. The number of participants grouped according to high frequency limit of hearing aid response.

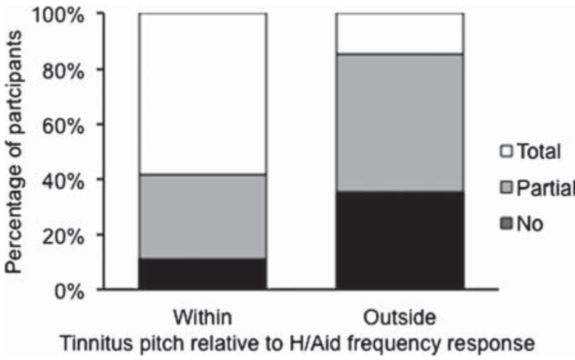

Figure 7. The percentage of participants with tinnitus pitch falling within and outside the frequency response of their hearing aids, for each group.

was outside of the frequency range. This is an important finding for discussion as the merits of sound therapy (McKenna & Irwin, 2008) and different levels of therapeutic sound on tinnitus has been debated (Tyler, 2006).

Despite the popularity of hearing aids in treating tinnitus (Kochkin & Tyler, 2008) there has been limited good quality research to support this practice. This study does not "prove" that amplification (as a form of sound therapy) is effective because assignment of participants to groups was based on the perceived benefit of the hearing aids. It must therefore be acknowledged that the improved perception of tinnitus may have resulted from some other characteristic of these participants that also made them more likely to report masking. On the other hand, provision of hearing aids did contribute to a reported reduction in tinnitus after three months for many participants, and was not associated with an increase in tinnitus. Our findings suggest that the difference in TRQ scores was not due to counselling, which all participants received, but the effect of masking. Total masking using hearing aids achieved a greater effect than partial masking and no masking based on TRQ results. The groups differed in that the no masking group had a lower TRQ prior to aid fitting, and these showed no improvement in tinnitus score, whereas clear improvements were observed for those who did experience a masking effect.

There has been a longstanding debate as to the most effective level of sound for tinnitus therapy. When broad-band noise is used for sound therapy a level at which tinnitus mixes (Jastreboff & Jastreboff, 2001) or is the lowest effective level (Tyler, 2006) are usually recommended over total masking. Total masking has been suggested as being counterproductive to habituation (Jastreboff & Jastreboff, 2001) and can be uncomfortably loud (Tyler, 2006). The finding that hearing aid users who achieved total masking had greater benefit might, at first glance, contradict this. However, masking through amplification of environmental sound may represent different mechanisms of action in the auditory pathway than masking using non-meaningful broad-band noise. Information in amplified sound may require attention and cognitive functioning and this might allow tinnitus masking to be achieved at a different level (Kidd et al, 2002). Personality has been linked to tinnitus and it is possible that awareness of tinnitus (masking to no-masking) was not solely reliant on sound-level but was determined to a large degree by the individuals' signal detection criterion (Welch & Dawes, 2008). It may be that those persons susceptible to masking are also more likely to adapt to tinnitus; as such masking might simply indicate likelihood of natural accommodation of tinnitus. The benefits may have been due to psychosocial effects such as improved communication and social interaction, however, although this was not formally measured, we suspect that hearing aid satisfaction was similar across the groups and psychosocial effects on tinnitus would be equivalent. Those participants who did not achieve any masking did not show the same reduction in their TRQ scores compared to those who obtained partial and total masking. These results challenge the view that sound therapy has limited benefit in tinnitus management and that hearing aid effects on tinnitus are rather due to psychosocial effects. If this were the case TRQ scores might be expected to be similar irrespective of the degree of masking.

It is also possible that the reduction in TRQ was not due to a masking effect but a central plastic reorganization as a consequence of the degree of neural excitation by sound (Norena & Eggermont, 2005). There is a need for systematic evaluation of the many potential contributing factors to hearing aid benefit. Objective evaluation through functional imaging or auditory evoked potentials may assist in elucidating the physiological cause for behavioural observations.

Not all patients obtained tinnitus masking from the hearing aids. Our results suggest that successful tinnitus management with amplification is most likely to occur in the presence of good low-frequency hearing, with poorer TRQ score, and when tinnitus pitch falls within the frequency range of the hearing aids chosen. It is possible that a change in prescribed hearing aid output might provide better results. Some prescription procedures typically weight response towards speech frequencies and reduce low frequency gain to prevent upward spread of masking. The DSL prescription procedure (Scollie et al, 2005) which generally provides greater low and high frequency amplification to NAL-NL1 (Byrne et al, 2001) may be preferred by tinnitus sufferers (Wise, 2003). Hearing aid noise reduction strategies, which reduce low frequency amplification, may also reduce masking effectiveness in individuals with low-frequency hearing loss to a greater extent than persons with normal low frequency hearing (not receiving/requiring low frequency amplification). A greater proportion of hearing aid users might achieve tinnitus masking if greater emphasis is placed on amplification of quiet ambient sounds (Searchfield, 2006) but this also must be balanced against potential reduction in hearing satisfaction. This study did not differentiate effect on the basis of level of hearing instrument technology; this may be a significant contributor to success that should be investigated in future studies.

One potential benefit from more recent technology is extended high-frequency responses. In this study the hearing aid frequency response limits were from manufacturer specifications reporting performance in couplers; this may not represent effective amplification in the real ear and one study suggests that extended high-frequency amplification does not provide additional benefits in changing tinnitus percept in the short-term (Moffat et al, 2009). Predicting hearing aid success on the basis of tinnitus pitch also requires the accurate measurement of tinnitus pitch. Due to variability inherent in tinnitus pitch matching from errors such as octave confusion (Tyler & Conrad-Armes, 1983) repeated measures of pitch, checking for octave confusion with higher frequencies than standard audiometers (preferably at or above 16 kHz) are necessary. Such care is necessary so to avoid artificially low matches forced by inability to compare estimated pitch against higher frequency sounds.

Based on our results we recommend the fitting of hearing aids for treatment of tinnitus in patients with hearing loss, and our prognosis is that better results are achieved when there is:

1. Good low-frequency hearing.
2. Strong reaction to tinnitus.
3. Tinnitus pitch within the fitting range of the selected hearing aid.

Conclusion

These results indicate that tinnitus pitch match may be a useful tool to predict the effects of hearing aid fitting in masking tinnitus. Based on this study, audiologists should be confident to recommend hearing aids for the treatment of tinnitus perception, especially when tinnitus pitch falls within the hearing aid frequency response. Clinicians are encouraged to include tinnitus pitch matches in their test battery to help with the prognosis of tinnitus treatment by means of hearing aid fitting. It should however be noted that treating tinnitus perception may not necessarily resolve tinnitus distress, and counselling is an important component of therapy. The mechanisms of hearing aid effects are worth investigating, as our results would suggest a greater benefit from total than partial masking. It was hypothesized that hearing aids would be most effective when their frequency range encompassed an individual's tinnitus pitch, the hypothesis was supported, but additional factors such as low frequency audibility may also contribute to hearing aid success.

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