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Tinnitus and Hearing Loss

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1. Introduction

Tinnitus is a symptom present in approximately 15% of the world, and this proportion increases to 33% in individuals over 60 years (Jastreboff and Hanzel, 1993). It carries a negative impact on quality of life for 20% of them.

May be associated with more than 300 diseases (Ganança et al, 1994), with a hearing loss of the most common (Hiller and Goebel, 2006). Only 80-10% of patients with tinnitus have normal hearing (Barnea et al, 1990), while 85 to 96% have some degree of hearing loss (Fowler, 1994; Sanchez e Ferrari, 2002).

The influence of hearing loss in the degree of suffering of tinnitus remains no consensus (Baskell and Coles, 1999). Findings relate tinnitus severity to hearing loss at high frequencies (Weisz et al, 2004). Mazurek et al (2010) found a significant correlation between the degree of hearing loss and tinnitus loudness. They found that patients with decompensated chronic tinnitus had more hearing loss than those with compensated tinnitus. The study concluded had evidence that indirectly support the hypothesis that the degree of hearing loss affects the severity of tinnitus (Mazurek et al, 2010).

Clinically significant hearing loss in patients with tinnitus was associated with anxiety and depression as a reaction to hearing loss that could interfere with the impact of tinnitus (McKinney et al, 1999). However it is not possible to say whether the hearing loss is only one cause of tinnitus or whether it also influences the severity and handicap (Davis, 1996).

Searches related to gender discomfort is inconclusive. While Davis (1983) observed higher scores for discomfort due to tinnitus in women compared with men (Davis and Cole, 1983 and Coelho et al, 2004), and Hiller and Goebel (2006) a higher intensity and severity of tinnitus annoyance in older men. Méric et al (1998) and Pinto et al (2010) assessed the impact of tinnitus on quality of life and found no correlation between age, sex or duration of tinnitus and the annoyance it causes.

The subjectivity of tinnitus, its symptoms, the different characteristics of each patient and the many causes of tinnitus are issues that require investigation. It is known that hearing loss is one of the largest generators of tinnitus and its pathology and diagnostics must be studied and known to offer the patient the 'most successful treatment option in symptom remission.

It is well established that after lesions of the peripheral auditory receptor, the cochlea, increased spontaneous activity (hyperactivity) develops in central auditory nuclei. This plasticity has been demonstrated in a wide range of animal models, using either mechanically, acoustically, or drug-induced cochlear lesions (Brozoski et al., 2007; Bauer et

al., 2008; Dong et al., 2009; Mulders and Robertson, 2009). Hyperactivity has been suggested to be involved in the generation of tinnitus, an auditory phantom perception (Brozoski et al., 2002; Bauer et al., 2008). This hypothesis is supported by the fact that the hyperactivity seems restricted to tonotopic regions broadly corresponding to the area of hearing loss as shown in cochlear nucleus, the central nucleus of the inferior colliculus, and the auditory cortex (Dong et al., 2009; Mulders et al., 2009) and the observation in human studies that there is a strong correlation between the tinnitus pitch and the hearing loss frequencies (Norena et al., 2002; Eggermont and Roberts, 2004).

The study of Mulders et al (2010) indicate a strong effect of stimulation of the medial olivocochlear (OC) system on hyperactivity caused by acoustic trauma. This demonstration that an intrinsic control system can modify maladaptive plastic phenomena in the auditory pathway, could have important clinical implications. If spontaneous hyperactivity is indeed involved in the generation of tinnitus (Brozoski et al., 2002; Bauer et al., 2008), then our results could indicate a beneficial effect of OC system activation on tinnitus. Mulders et al (2010) find that the suppressive effects on spontaneous activity lasted after the stimulation had ceased, is consistent with a role for the OC system in residual inhibition, a temporary reduction of tinnitus experienced in tinnitus patients that persists for a few seconds after masking sounds are turned off (Vernon and Meikle, 2003; Roberts et al., 2008). Likewise, activation of the OC system could be a contributory mechanism to the often beneficial effects of masking sounds on the perception of tinnitus (Jastreboff, 2007; Lugli et al., 2009, Holdefer et al, 2010), since the OC system itself can be activated by sound (Thompson and Thompson, 1991; Lugli et al., 2009).

2. Tinnitus loudness in hearing loss patients

The loudness of tinnitus can be estimated by asking the individual to adjust an external sound so as to match the loudness of the tinnitus. One method is for the listener to first select a sound that is similar to their tinnitus. For example, if the tinnitus is tonal, the listener might adjust the frequency of a pure tone until it matches the pitch of their tinnitus. Then, the external tone is adjusted in level so as to match the loudness of the tinnitus.

Often, the matching sound is presented to the ear opposite to that for which the tinnitus is reported to be louder, so as to avoid the matching sound masking the tinnitus or reducing its loudness. A common finding of such studies is that the tinnitus is matched by a sound with a low sensation level (SL; the level of a sound relative to an individual's absolute threshold), as first described by Fowler in 1941. Fowler reported that most matches were at 5 or 10 dB SL, leading him to describe "the illusion of loudness of tinnitus." Graham and Newby in 1962 found that the majority of people with troublesome tinnitus matched to a level of 5 dB SL or less. Reed in 1960 reported that 41% of tinnitus patients matched to a level of 5 dB SL or less, 69% to a level of 10 dB SL or less, and 87% to a level of 20 dB SL or less. Vernon in 1976 reported no matches higher than 20 dB SL. For a review of other studies showing similar results, see Tyler and Conrad-Armes in 1983. Recently, automated methods for computerized assessment of tinnitus loudness have been described: unsurprisingly, these produced similar results.

These findings led to the idea that tinnitus is usually perceived as soft, rather than as loud, despite causing marked distress for some people. Vernon considered 3 possible explanations for this apparent paradox: first, the method for estimating the loudness of tinnitus may not be valid; second, distress may not be related to loudness; and third, the loudness of the

tinnitus may actually be quite high even when the matching sound has a low SL because of the existence of loudness recruitment at the frequency of the matching sound. Loudness recruitment is a phenomenon usually associated with cochlear hearing loss.

For a frequency where a person has a hearing loss, the loudness of a tone or other sound increases more rapidly than normal once the sound level is increased above the absolute threshold, and at high levels, the loudness is similar to what would be experienced by a person with normal hearing. Thus, if the listener has a hearing loss at the frequency of the tone used to obtain a tinnitus match, the loudness of the matching tone may be moderately high, although its SL is low.

The explanation in terms of loudness recruitment was explored further by Goodwin and Johnson in 1980. They tested 9 adults with tonal tinnitus, all of whom had a "normal" audiometric threshold (20 dB HL or better, where hearing level [HL] is the level of a sound relative to the absolute threshold of humans with "normal" hearing at that frequency) for at least 1 frequency. They compared loudness matches to the tinnitus using 2 methods: 1) the frequency of the matching tone was chosen to match the pitch of the tinnitus. This was called the matching frequency. For all listeners, the hearing loss was 25 dB or more at this frequency. The matching tone was presented to the ear opposite to the ear in which the tinnitus was loudest. This was called the traditional method. 2) The frequency of the matching tone was chosen as the closest audiometric frequency to the matching frequency for which the absolute threshold was 20 dB HL or better. This was called the normal frequency. It was assumed that loudness recruitment would be small or absent at the normal frequency. In this case, the matching tone was presented to the same ear as the ear in which the tinnitus was loudest because it was assumed that the matching tone would have a negligible effect in masking the tinnitus or reducing its loudness. This was called the proposed method.

For every listener, the matching SLs were higher for the proposed method than for the traditional method. For the traditional method, the matches ranged from 1 to 20 dB SL, with a mean of 6.6 dB SL. For the proposed method, the matches ranged from 8 to 50 dB SL, with a mean of 33.4 dB SL. Goodwin and Johnson concluded that loudness recruitment did have a clear influence on the tinnitus matches and that the proposed method gave more realistic estimates of the loudness of the tinnitus. Their results suggested that tinnitus is usually soft to medium in loudness.

A similar study was conducted by Tyler and Conrad-Armes, who additionally used formulae based on abnormal loudness functions and uncomfortable loudness levels to calculate the loudness of their matches in sones. However, the values obtained depended strongly on the formula used; the mean calculated loudness of the tinnitus ranged from 6 (a low-to-moderate loudness) to 76 sones (rather loud).

It is well known that, for many tinnitus patients, the loudness of tinnitus can be reduced by external sounds. If the external sound is sufficiently intense, the tinnitus may be rendered inaudible, that is, it may be masked. Indeed, reduction of loudness or masking of tinnitus forms part of many methods for alleviating the effects of tinnitus. However, there have been few quantitative studies of the influence of background sounds on the loudness of tinnitus. Furthermore, it seems that this effect is variable between individuals.

3. Tinnitus and noise loud exposure

Hearing loss and tinnitus are the two most prevalent service-connected disabilities for U.S. veterans, including those who served in Operation Iraqi Freedom or Operation Enduring

Freedom (Folmer et al, 2011). Currently, in the Department of Veterans Affairs (VA), more than 570,000 veterans are service-connected for hearing loss and more than 639,000 are service-connected for tinnitus, which means they qualify for monthly compensation and/or VA clinical services related to these auditory disorders.

Because many veterans were exposed to loud sounds during military service, the author anticipated that they would exhibit higher (that is, poorer) pure tone thresholds than age-matched groups of nonveterans and predicted that males with histories of loud noise exposure would exhibit higher pure tone thresholds than age-matched males who reported less noise exposure. Finally, they hypothesized that the chronic tinnitus prevalence would be significantly greater among male veterans than the prevalence among male nonveterans and that tinnitus prevalence among males with histories of loud noise exposure would be greater than that among age-matched males with less noise exposure.

Tinnitus is the perception of ringing, buzzing, hissing, or other noises in the ears or head in the absence of external sources for these sounds. These perceptions can be transient, intermittent, occasional, or constant. "Chronic" tinnitus is present all or most of the time during a person's waking hours. Like sensorineural hearing loss, chronic tinnitus more likely occurs in middle-aged and older people, especially those who have been repeatedly exposed to loud sounds without using hearing protection devices.

Analysis of data from Folmer et al in 2011, showed that the overall chronic tinnitus prevalence is greater for veterans (11.7%) than the prevalence for nonveterans (5.4%), with statistically significant differences in the 50 to 59 and 60 to 69 age groups. Also, the prevalence of tinnitus among males who reported a noise exposure history is significantly higher than the prevalence among males who reported less noise exposure. However, with few exceptions, the pure tone hearing thresholds for veterans did not differ significantly from nonveteran audiograms; males who reported more noise exposure did not have substantially worse hearing than males the same age with less noise exposure.

These surprising audiometric results probably occurred because the larger effect of age in our decade-by-decade comparisons obscured the small differences in pure tone thresholds, if they exist between groups (veterans vs nonveterans or noise-exposed vs non-noise-exposed males).

In the near future, hearing loss and tinnitus will likely remain the most prevalent service-connected disabilities among all U.S. veterans. In addition, increasing numbers of veterans will probably seek and receive VA compensation and medical and rehabilitative services for these conditions. As they plan for future costs of healthcare and compensation, the Veterans Health Administration (VHA) and the VBA should be able to use results of this study and its estimates of audiometric thresholds and tinnitus prevalence among male veterans in the United States.

4. Tinnitus after resection of Vestibular Schwannoma (VS)

Slater et al in 1987 reported that 28% of respondents (n = 255) to a questionnaire survey about tinnitus agreed that external sound could result in tinnitus being more "noticeable." In particular, we have noted clinically that the subgroup of individuals who have undergone surgical resection of VS report that their tinnitus is much more troublesome in noisy environments.

For these patients, a noise presented to the "dead" ear would not be heard, so it is unlikely that the noise would have any influence on the tinnitus. However, a noise presented to the

functioning ear might influence the loudness of tinnitus, although it would be unable to mask it at the cochlear level. To our knowledge, this possibility has not been systematically investigated.

Cope et al in 2011 showed that, for listeners who are unilaterally deaf after surgery for VS, the loudness of the tinnitus heard in the deaf ear usually increases with increasing level of a noise applied to the "good" ear. The threshold-equalizing-noise (TEN) started to lead to an increase in the loudness of the tinnitus when presented at a level approximately 15 dB below the matching level in quiet, after which higher levels of the TEN produced progressive increases in loudness. The authors showed relatively consistent effect across participants (with one exception) suggesting a common underlying cause.

There were at least 2 plausible and not mutually exclusive explanations for the effect of background noise on tinnitus loudness for VS participants. The first is that it reflects a plausible perceptual interpretation of the sensory evidence. All perception may be regarded as hypothesis driven, with the brain attempting to arrive at the best possible interpretation of the sensory evidence.

For a target sound (an acoustic sound as opposed to the perception of tinnitus) to be audible in the presence of a broadband background sound, the level of the target must be comparable to the level of the background at the output of at least one auditory filter.

Returning to tinnitus, if tinnitus remains audible in the presence of increasing levels of background sound, as it did for our listeners with VS, then the most plausible perceptual interpretation is that the source of the tinnitus is increasing in intensity with increasing background level, and this may give rise to the perception of increasing loudness of the tinnitus. Note that the perceptual processes involved do not involve conscious reasoning, rather they reflect "unconscious inference"

The action of the efferent pathways in the auditory system, especially the medial olivocochlear (MOC) system. One role of the MOC system is to regulate the gain provided by the active mechanism in the cochlea, by controlling the operation of the outer hair cells. With increasing input sound level, signals from the MOC system cause a reduction of the gain of the active mechanism, effectively acting as a form of automatic gain control, provided that the auditory system is functioning normally.

The regulatory signals from the MOC system are taken into account in interpreting the information flowing from the auditory nerve to higher centers, thus allowing the brain to arrive at an accurate and consistent interpretation of the magnitudes of sounds.

For the listeners with VS, MOC signals would still have been sent from the brainstem, but they would not have reached the cochlea because the efferent system was severed at the VIIIth nerve level as part of the surgery (and even if the cochlea did respond, this would be no resulting signal at higher levels in the auditory system because the auditory nerve itself was severed). The signals from the higher centers would have carried "instructions" to decrease the gain of the active mechanism as the level of the noise in the "good" ear was increased. However, the abnormal activity in the auditory pathway that gave rise to the tinnitus was presumably not affected by the signals from the MOC system. The unchanging tinnitus signal, in combination with MOC "instructions" to decrease the gain, may have resulted in the increasing loudness of the tinnitus with increasing background level.

This finding that the loudness of tinnitus increases with increasing background noise level in the contralateral ear of participants with VS has important clinical implications. Patients who are about to receive treatment for VS, or have recently received treatment for VS, should be counseled about this at an appropriate point in their treatment pathway, and this

counseling should raise the possibility that the increase in the loudness of tinnitus may affect their ability to concentrate on speech in noise.

Also, some clinicians faced with a VS patient with severe tinnitus may consider the use of wideband therapy in the contralateral ear: suggest that this intervention may well be unhelpful and doomed to failure, and indeed, some protocols (specifically tinnitus retraining therapy) already indicate that this is contraindicated. It should be noted that individuals who had undergone surgical resection and were rendered unilaterally deaf after treatment; it is not known whether those treated with hearing preservation surgery or radiologic techniques have the same experience.

5. Tinnitus in otosclerosis patients

Many papers have been written about tinnitus outcome after stapes surgery. However, none has attempted to quantify the intensity of the symptom pre- and postoperatively in order to evaluate the influence of surgery on the degree of annoyance caused by tinnitus. Severe disabling tinnitus (SDT) is defined by Shulman as a symptom severe enough to disrupt the patient's routine and to prevent him from performing his daily tasks.

In 1953, Heller and Bergman (9) showed that over 90% of normal-hearing people reported tinnitus when placed in a soundproof cabin. However, the symptom did not cause any discomfort to those patients in daily life. Being so, it becomes necessary to separate common garden variety tinnitus from serious, disrupting ones.

Shulman (10) coined the term severe disabling tinnitus (SDT) for a symptom that is severe enough to disrupt the patient's routine and to keep him from performing his daily tasks. Usually, this kind of patient seeks medical attention because of his tinnitus, while in less severe cases the symptom is mentioned during medical consultation for other problems.

Tinnitus is certainly very common among otosclerosis patients; some of them report very intense annoyance from the symptom and ask what will happen to the symptom after stapes surgery.

We tried to quantify the intensity of tinnitus in otosclerosis patients pre- and postoperatively by means of a visual analogue scale (VAS) going from 1 (very low intensity) to 10 (unbearable intensity). We considered SDT as having an intensity of 7-10 on the VAS. By comparing the tinnitus score before and after stapes surgery for otosclerosis, we tried to determine the influence of the surgical procedure on SDT. The results of this study are reported below.

We applied a VAS, in which 1 meant a very low intensity and 10 an unbearable intensity for the symptom of tinnitus, to 48 consecutive otosclerosis patients before and after stapes surgery. We considered SDT as yielding a score of 7 or above on the VAS.

In all patients pure-tone audiometry and a word discrimination test were performed pre- and postoperatively.

Forty-four patients underwent stapedotomy and 4 stapedectomy. Hearing results were evaluated by comparing the pre- and postoperative four-tone average air-bone gaps. The influence of surgery on SDT was measured by comparing pre- and postoperative scores for the symptom on the VAS. The operative notes were carefully reviewed for any problem occurring during surgery.

The VAS was applied 4-10 months after surgery. We considered significant a score improvement of ≥ 2 points on the VAS. Twenty-five patients were contacted 14-48 months after surgery and were asked about the tinnitus status at this late follow-up time.

The protocol was approved by the ethics committee on research involving human subjects of our institution.

6. Results

There were 29 female and 19 male patients. Forty-four of the 48 patients reported tinnitus preoperatively (91.6%). Mean age was 44.5 years (range 16-62). SDT was present in 19 patients preoperatively (39.6%) and female patients tended to report more SDT than male counterparts (55.5% of female and 15.8% of male patients).

Patients with SDT	19
Total remission	10 (52.6%)
Significant improvement	6 (31.7%)
Slight improvement	1 (5.2%)
No change	2 (10.4%)

Table 1. SDT: postoperative outcome

Preoperative air-bone gap in patients with SDT	n	Total remission
>30 dB	14	8 (57.14%)
<30 dB	5	2 (40.0%)

Table 2. Preoperative air-bone gap and postoperative SDT remission

Air-bone gap	n	Total remission	Significant improvement	Slight improvement	No improvement
0-20 dB	17 (89.46%)	9 (52.9%)	7 (41.2%)	0	1 (5.84%)
>20 dB	2 (10.52%)	0	0	1 (50%)	1 (50%)

Table 3. Postoperative air-bone gap and SDT

Overall 40 (90.9%) tinnitus patients reported postoperative improvement and 4 (9.09%) noted no change in tinnitus. None said the symptom was worse.

Table 1 shows postoperative tinnitus outcome of the 19 SDT patients. Ten of the 19 tinnitus patients reported total remission of tinnitus after surgery and 6 had a significant improvement (at least 2 points on the VAS). One reported a slight improvement and 2 noted no change in the symptom.

The intensity of preoperative tinnitus was not related to the preoperative air-bone gap (mean air-bone gap of 34.3 dB for SDT and 31.4 dB for less intense tinnitus). However, larger preoperative air-bone gaps seemed to predict better postoperative improvement in SDT (table 2) when a good hearing result was achieved. Smaller postoperative air-bone gaps correlated with more remission and improvement of SDT postoperatively (table3).

There was a trend for lower preoperative bone conduction levels to correlate with preoperative SDT (44.1% of patients with a four-tone average bone conduction level below 40 dB had preoperative SDT while 28.5% of patients with a preoperative four-tone average bone conduction level above 40 dB had SDT).

Twenty-five patients (7 SDT) contacted 14-48 months after surgery said their tinnitus status had not changed since surgery.

There were no untoward events during surgery and no postoperative complications other than 6 patients with an air-bone gap above 20 dB were seen.

7. Comments

In 1999, Oliveira ET AL (11) applied a tinnitus questionnaire that included a VAS to all new patients seen at the Otology Clinic of the Brasília University Hospital for a 6-month period of time. Five hundred tinnitus patients were identified. These patients had presbycusis, chronic otitis media, otosclerosis, acoustic trauma, Menière's disease, ototoxicity and vestibular schwannoma in this order of frequency. However, 81% of the tinnitus patients had a very mild symptom and only mentioned tinnitus because they were asked about it. Eighteen percent had a mild symptom they could tolerate well or were easily relieved with routine medical treatment. Only 1% had tinnitus that was very intense (above 7 on the VAS), disrupting the patient's routine, and they were refractory to medical treatment (central vasodilators, vestibular suppressants, calcium channel blockers, anticholinergics, anticonvulsants). To sum up, tinnitus is a very common symptom among patients of an otology clinic but only 1% of these patients have SDT.

Otosclerosis was the 3rd most frequent diagnosis listed above and we have found an incidence of tinnitus (91.6%) in our 48 otosclerosis patients similar to the one in the general population (9). However, 39.6% of our otosclerosis patients had SDT as compared to 1% in the patients of our otology clinic. Therefore, otosclerosis seems to be strongly associated with SDT.

Otosclerosis patients who have SDT are the ones who always ask the doctor what will happen to their tinnitus after stapes surgery and often mention tinnitus relief as their priority. Because all papers published up to now (1-8) had not targeted SDT, we undertook the present study.

Our results allow the following statements:

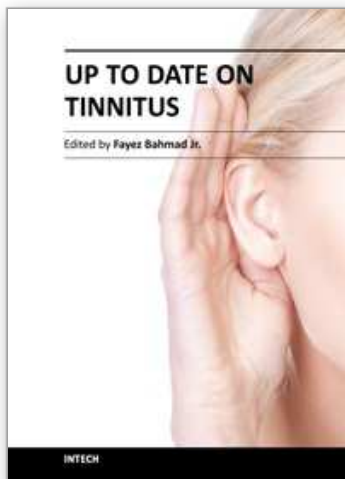
1. Otosclerosis is a major cause for SDT. How the otosclerosis process leads to severe tinnitus remains to be clarified.
2. Stapes surgery (namely stapedotomy, because 44 of our 48 patients had this operation performed) can totally relieve SDT in roughly 50% of cases and significantly improve another 31%. About 10.4% of SDT patients will not have any relief after stapes surgery. These patients probably have already developed a paradoxical memory in the medial temporal lobe system as proposed by Shulman ET AL (10) and will not respond to any treatment of the peripheral organ.
3. Because larger air-bone gaps preoperatively predict better tinnitus improvement when the stapes surgery results in smaller postoperative air-bone gaps (tables 2 and 3), we suggest that the masking effect produced by better postoperative hearing is probably responsible for the tinnitus improvement.
4. Since 25 tinnitus patients (7 SDT) contacted up to 48 months after surgery said their tinnitus status had not changed compared to the early follow-up situation, it is safe to say that the influence of stapes surgery on SDT in otosclerosis patients is long-lasting.
5. Worsening of SDT after stapes surgery is unlikely provided an atraumatic procedure was performed.

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Up to Date on Tinnitus encompasses both theoretical background on the different forms of tinnitus and a detailed knowledge on state-of-the-art treatment for tinnitus, written for clinicians by clinicians and researchers. Realizing the complexity of tinnitus has highlighted the importance of interdisciplinary research. Therefore, all the authors contributing to the this book were chosen from many specialties of medicine including surgery, psychology, and neuroscience, and came from diverse areas of expertise, such as Neurology, Otolaryngology, Psychiatry, Clinical and Experimental Psychology and Dentistry.

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