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A consideration of the effect of ear canal resonance and hearing loss upon white noise generators for tinnitus retraining therapy

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Abstract
Tinnitus retraining therapy has been heralded as a major advance in the alleviation of tinnitus perception. A cornerstone of this technique is to use white noise produced by a white noise generator (WNG) over a period of several months in order to assist the patient to habituate to their tinnitus. There are three factors which influence the frequency spectrum of the perceived noise such that the perception of white noise from a WNG is unlikely. These factors are the actual spectrum of the emitted noise, the ear canal resonance of the patient and the hearing sensitivity of the patient.

Advocates of tinnitus retraining therapy state that white noise is the optimal stimulation to assist habituation of tinnitus. This paper demonstrates that this optimal situation is unlikely to be achieved and that this may account for the long periods needed for patients to achieve benefit from the technique. The development of devices that allow for the above factors to be countered is suggested.

Key words: Tinnitus; Acoustic stimulation; Therapy

Introduction

Masking therapy for tinnitus has been a key element in alleviating the distress of patients with this troublesome symptom (Vernon, 1987). Recent work has suggested, however, that it may be more effective to use a low-level stable white noise which makes detection of tinnitus by the auditory cortex more difficult, and so facilitates habituation to the tinnitus (Jastreboff and Hazell, 1993). The aim of the use of the white noise is said to be 'stable, random excitation of neurons . . . in as wide a frequency range as possible' (*ibid.,* p 14) and so the use of narrow band noise at similar frequency to the tinnitus, such as is provided by programmable tinnitus maskers, is inappropriate. Thus, the use of white noise generators (WNG) as therapy for tinnitus patients is advocated.

To achieve this recommendation in clinical practice the clinicians have sought to utilize WNGs which have as broad and as flat a spectrum as possible, i.e. that which is as close as possible to true 'white noise' (a 'broadband noise that has a pressure spectrum level that is independent of frequency', Kinsler *et al.*, 1982). The assumption thus being made that the introduction of white noise into the ear canal of a patient will result in the perception of white noise. Several well known factors cause the situation to be more complex than this however. The first is that the ear canal resonance of the patient will result in modulation of the noise such that the frequency spectrum at the tympanic membrane may be substantially different from that at the entrance to the external auditory meatus. The second is that once at the eardrum the minimum audible pressure (the sound pressure level corresponding to threshold) varies with frequency, and third, the patient requiring therapy for tinnitus may very often have an associated hearing impairment (Coles, 1987, 1995), so that the perceived spectrum of the noise will be influenced by the frequency pattern of hearing impairment. These factors will clearly mean that the ideal objective of a patient experiencing a perceived sound that has a flat spectrum will rarely be achieved. An additional factor is that the devices used as WNG will not produce a perfectly flat frequency spectrum of noise themselves, and so account of this must be taken into consideration when examining the sound perceived by a WNG wearer.

Whilst white noise is said to be optimal in tinnitus therapy (Jastreboff and Hazell, 1993; Jastreboff, 1995), the point has been made that an external stimulus that includes the frequency range of the tinnitus and is stable, and not anxiety-inducing, should also be effective although less so than white noise and needing a longer time to achieve benefit. It

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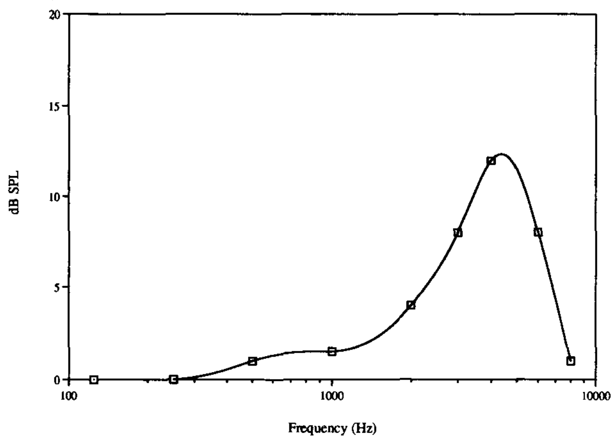

FIG. 1

Transformation characteristics from the ear canal entrance to the eardrum.

may be that the modification of perceived sound by the factors mentioned could result in a sub-optimal fitting which extends the length of therapy required.

These acoustic factors are relatively well known (Sheldrake *et al.*, 1995) but have received little systematic attention. This paper is a theoretical examination with the aim of providing a clear explanation of how these factors will influence perceived sound from a WNG, and illustrating how retraining therapy could be significantly influenced for some patients. The consequence of this for clinical practice and for further research is discussed.

The effect of ear canal resonance

That the resonance of the ear canal can modulate the frequency spectrum of sound has been demonstrated as a result of research into hearing aid prescription. This effect shall be considered for both an idealized white noise, and then for that actually produced by WNG in clinical use.

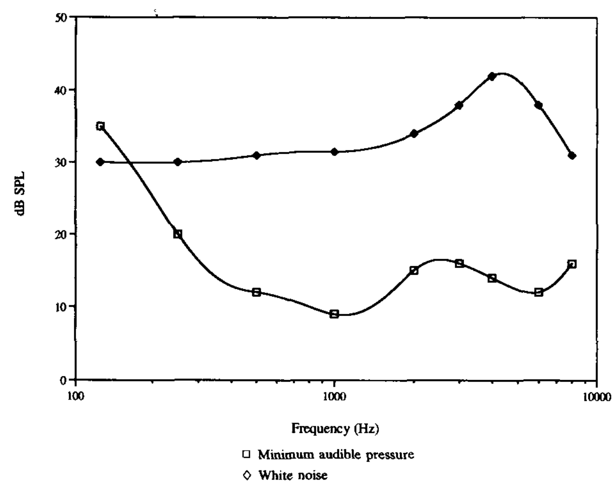

FIG. 2

Spectrum of a white noise at the ear drum and the minimum audible pressure (MAP).

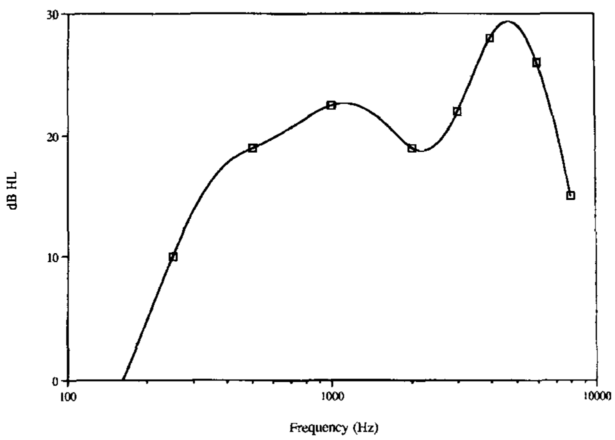

FIG. 3

Perceived loudness of a 30 dB SPL white noise.

Idealized white noise

The average transformation characteristics of the external ear canal have been well documented (Weiner, 1946; Kuhn and Guernsey, 1983), and are shown in Figure 1 for a plane progressive sound field. These transformation characteristics are the difference between the sound pressure level (SPL) present at the entrance to the ear canal and the SPL at the eardrum. Therefore, if an ideal white noise is present at the entrance to the ear canal it is modulated by the ear canal resonance to result in the spectrum shown in Figure 1 being present at the eardrum. This clearly deviates from an ideal white noise, introducing a peak in the 2–3 kHz region.

The actual perceived sound spectrum is also dependent on the SPL spectrum that corresponds to auditory threshold. At the eardrum this spectrum is called the minimum audible pressure (MAP) documented by Killion, 1978. The perceived loudness of a sound is determined by how far above the MAP at the eardrum is the SPL. This concept is illustrated in Figure 2: an ideal white noise of 30 dB SPL at the ear canal entrance is modulated by the ear canal resonance to give the SPL at the eardrum shown. The perceived volume is then the difference between this and the MAP. The actual perceived

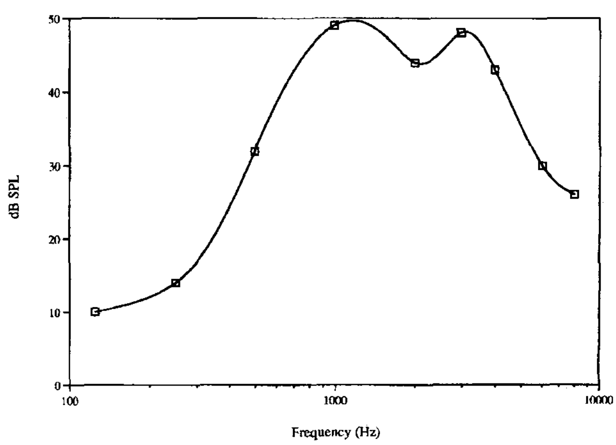

FIG. 4

Output of a white noise generator.

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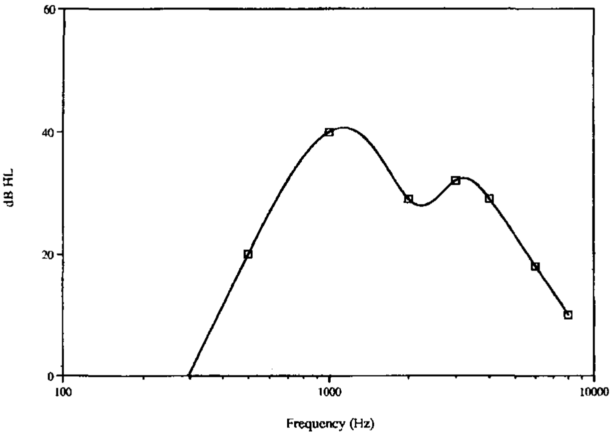

FIG. 5
Perceived loudness of a white noise generator.

spectrum of sound is shown in Figure 3. This perceived loudness spectrum clearly deviates from the ideal flat spectrum desired.

WNG noise

The above discussion assumes the introduction of an ideal white noise into the ear canal. However, white noise generators do not produce idealized white noise and so their output must be taken into account in considering the perceived spectrum of sound. The output of a commonly used white noise generator is shown in Figure 4. To observe the perceived loudness of this WNG we can apply the principles outlined above for a white noise. The resulting perceived loudness is shown in Figure 5 illustrating that a flat output has not been achieved.

The effect of hearing loss

A significant number of patients with tinnitus that is troublesome enough for them to seek therapy will have associated sensorineural hearing loss (Coles, 1995). The effect of a sensorineural hearing loss is to alter the minimum audible pressure at the ear drum. In order to demonstrate the effect of such impairment upon the perceived frequency spectrum of a noise, the calculations have been performed for three patients with tinnitus and diagnoses of presbyacusis, Menière's disease and of noise-induced hearing loss. These three hearing losses are illustrated in Figure 6. The minimum audible pressure (MAP) for these hearing losses can be calculated and is shown in Figure 7. The principles applied above to estimate perceived loudness for a person with normal hearing can be applied to these hearing losses. The resulting perceived loudnesses for a WNG are shown in Figure 8.

Discussion

It has been shown that fitting a WNG to a patient with tinnitus may result in the perception of a narrow band (or bands) of noise. This is sub-optimal and may account in part for the length of time needed to reduce tinnitus perception by this method (sometimes 12–18 months), (Hazell, 1995) and for the

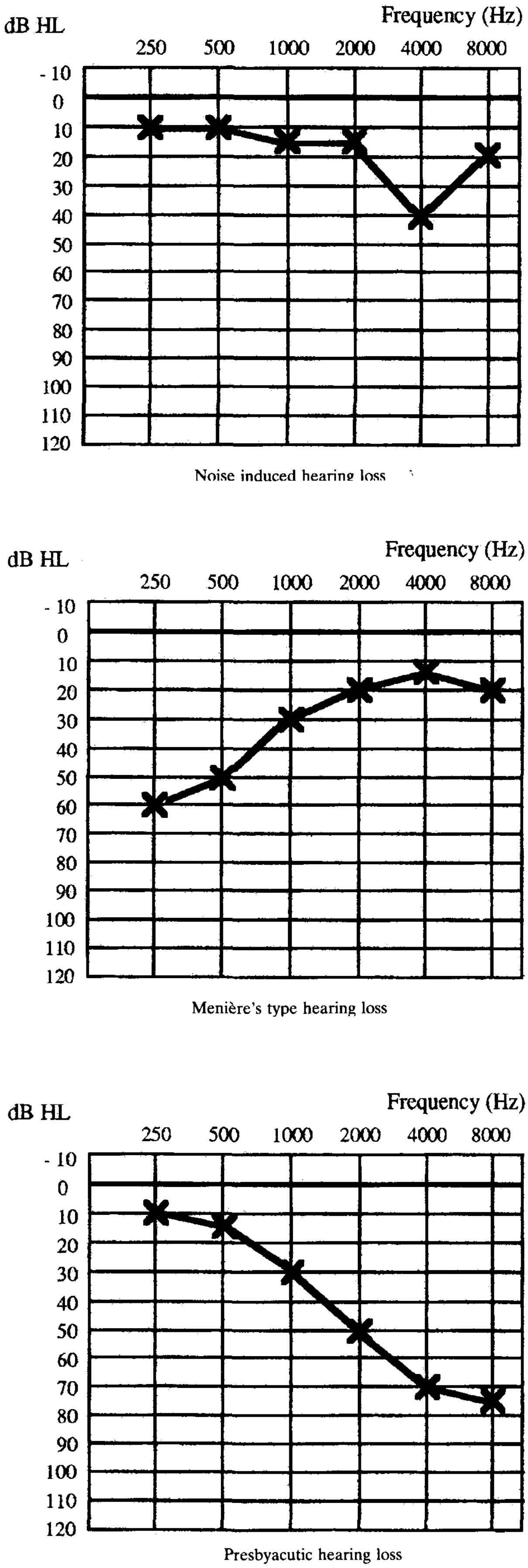

FIG. 6
Hearing losses associated with tinnitus.

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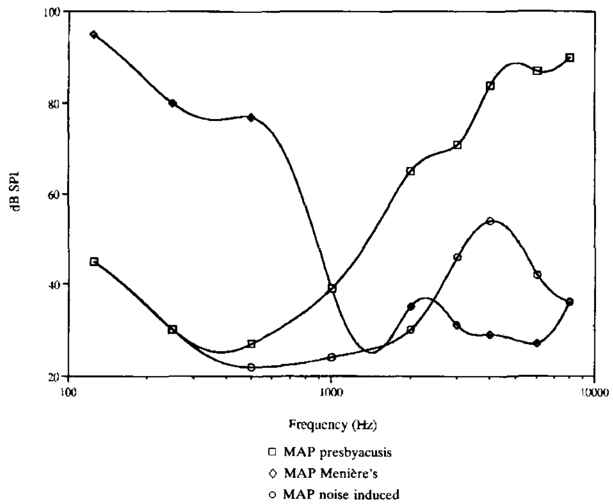

FIG. 7

Minimum audible pressure for different hearing losses.

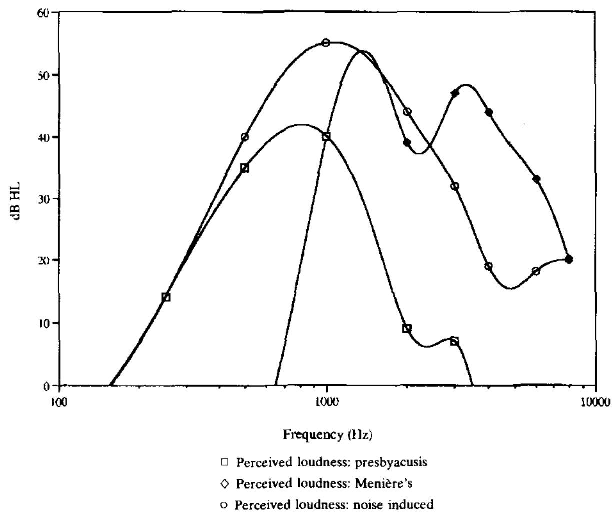

FIG. 8

Perceived loudness of a white noise generator for different hearing losses.

failure of this method in some cases. If such a situation is suspected, either due to the reports of the patient of the noise they are perceiving, or due to lack of progress, then probe tube microphone measures should be undertaken to determine the noise spectrum at the tympanic membrane, and the audiogram considered to determine the spectrum of the noise perceived. Manipulation of the tone control of the WNG and of the earmould should then be considered as an attempt to influence this spectrum toward a broad band stimulus. This is no more complex than hearing aid fitting using probe tube microphones.

The use of programmable tinnitus maskers has been said to be inappropriate (Jastreboff and Hazell, 1993) as they attempt to introduce a narrow band stimulus. An implication of the present study is that a programmable masker that conversely enabled the patient to perceive white noise despite the modulations of ear canal resonance and of audiometric configuration might be expected to be very effective in facilitating habituation of tinnitus. The development and clinical trial of such a device is recommended.

Acknowledgement

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