Measuring the Pitch and Loudness of Tinnitus

BY BRIAN CJ MOORE

Matching the characteristics of tinnitus

Many researchers and clinicians have explored the subjective nature of tinnitus by asking people with tinnitus to adjust a sound so that it matches their tinnitus in some way. This can be useful both for diagnostic purposes and to gain some insight into what is being experienced by the person with tinnitus. Perhaps the simplest, but rather rare case is when the tinnitus is described as sounding like a single pure tone. In that case, the person with tinnitus can be asked to adjust a pure tone in frequency until it matches the pitch of their tinnitus and in level until it matches the loudness of their tinnitus. Such an approach is more problematic in the more common situation where the tinnitus does not sound like a pure tone. Nevertheless, people with tinnitus often report that it has one or more pitches, and in such cases they can be asked to make a match to the most prominent pitch and to adjust a tone to match its loudness. They often find this difficult to do.

Matching the pitch of tinnitus

People without musical training sometimes confuse loudness and pitch. Hence, it can be useful to adjust the level of the matching tone to achieve a loudness match to the tinnitus, before a pitch match is made. However, loudness matches are difficult when the matching sound differs in pitch from the sound to which it is being matched. There is thus a circular problem: valid pitch matches to tinnitus require a prior loudness match to the tinnitus, and valid loudness matches require a prior pitch match. Another problem arises when the matching sound itself does not have a clear pitch. This can happen, for example, when the frequency of the matching sound leads to maximum basilar-membrane vibration in a dead region, which is a region of the cochlea with few or no functioning inner hair cells and / or neurons [1,2].

When pitch matches to tinnitus are made across several sessions, the matches often vary markedly from one session to the next [3-5]. This may reflect genuine variability in the underlying percept, or it may reflect the fact that the tinnitus does not usually sound like a pure tone; rather it sounds much more complex, perhaps having multiple pitches or sometimes not having a clear pitch at all. Participants may match one of the component pitches in one session, and a different component pitch in another session.

Relation of pitch matches to the audiogram

When tinnitus is matched in pitch with a single pure tone, the hearing loss at the frequency corresponding to the tinnitus pitch tends to be greater than at adjacent (usually lower) frequencies. Some researchers have reported that the pitch of tinnitus corresponds to the 'edge frequency' of the audiogram, the frequency at which the hearing loss starts to increase markedly [6]. However, most researchers have found that the pitch corresponds to the frequency range where the hearing loss is greatest; for a review, see Moore [7]. Henry and Meikle concluded that "pitch matches for tinnitus can occur practically anywhere in frequency regions where there is hearing loss" [8].

> **"Tinnitus can be moderately loud even when the sensation level of the matching stimulus is low."**

Characterisation of the tinnitus 'spectrum'

Noreña et al. attempted to characterise the percept of the tinnitus by measuring what they called the 'tinnitus spectrum', using ten people who described their tinnitus as tonal [9]. Following measurement of absolute thresholds over a wide frequency range, a pure tone was presented whose frequency was pseudo-randomly selected from the range used for measuring absolute thresholds. Each person was asked to adjust the level of the tone until it matched the loudness of their tinnitus and then to indicate whether the tone matched the pitch of one of the components of their tinnitus. If so, they were asked to rate its contribution to their tinnitus, on a scale from 0 to 10. This was repeated for a series of pseudo-randomly selected tone frequencies.

Some example results are shown in Figure 1. Frequencies judged to form part of the tinnitus spectrum covered a wide range, and the frequencies contributing most generally fell within the range where a hearing loss was present. The contribution to tinnitus tended to increase for frequencies where the hearing loss was greatest. Although the tinnitus was described as tonal, there was often a wide frequency region where the rated contribution was high. For example, for the subject whose results are shown in the top-right panel, ratings were close to eight for all frequencies from 2000 to 9000 Hz. For the subject whose results are shown in the bottom-right panel, ratings were in the range eight to nine for all frequencies from 6000 to 12000 Hz. It seems that, even for people reporting tonal tinnitus, the percept is usually more complex than that evoked by a pure tone.

Matching the loudness of tinnitus

The loudness of tinnitus has most often been estimated by asking the individual to adjust an external sound so as to match the loudness of the tinnitus. Usually, the individual first selects a sound that is similar to their tinnitus and 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.

The magnitude of the matching sound has often been expressed in dB sensation level (SL), which is the level relative to the absolute threshold of the individual for detection of the matching sound. Tinnitus is usually matched in loudness by a sound with a low SL, typically in the range 6-20 dB SL; for a review, see Moore [7]. However, when loudness matches to tinnitus are made over a series of days, the matches can range up to 30-45 dB SL [3]. The finding that tinnitus is usually matched in loudness with tones at low SLs initially led to the idea that tinnitus is perceived as soft, despite causing marked distress for some people [10]. However, this interpretation ignores the effects of loudness recruitment. 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 SL is more than 4-6 dB, and at high levels the loudness is similar to what would be experienced by a person with normal hearing [11]. If there is 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, even though its SL is low [7,12]. The unit of subjective loudness is the sone [13]. Calculations using the model of loudness perception published by Moore and Glasberg show that an SL of, say, 20 dB, leads to a loudness of 0.11 sones for a person with normal hearing, but a loudness of 2.13 sones for a person with a 60 dB hearing loss

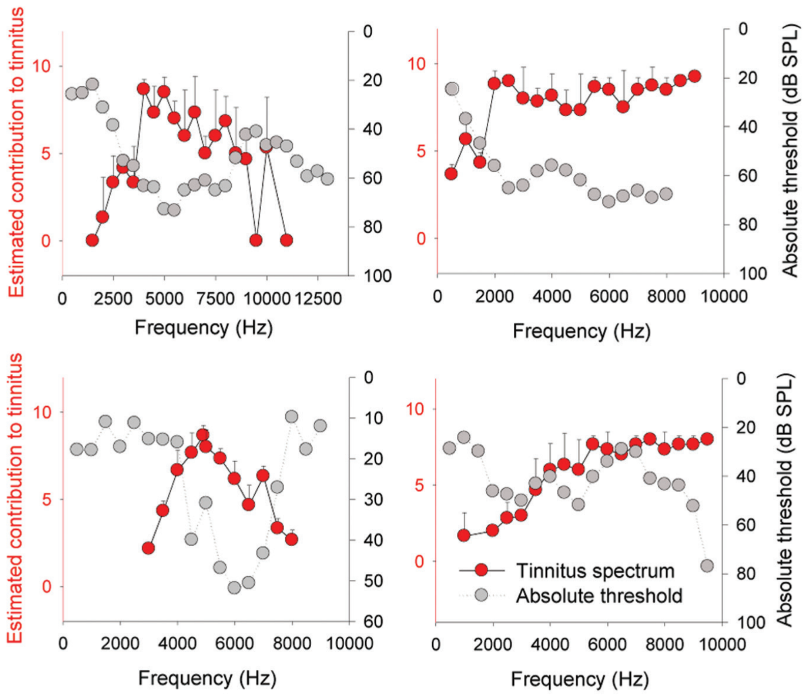

Figure 1: Data replotted from [9] showing absolute thresholds (grey circles, right y-axis) and estimated contribution of different frequency components to the tinnitus sensation (red circles, left y-axis). The error bars show ± one standard error.

[14]. Thus, the sound is louder by a factor of almost 20 for the person with hearing loss.

The conclusion from all of this is that loudness matches in dB SL are not related in a simple way to loudness in sones. Tinnitus can be moderately loud even when the SL of the matching stimulus is low.

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Declaration of Competing Interests
None declared.