Low Frequency Noise and phantom sounds

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1. INTRODUCTION

Since the 1970's annoyance from low frequency (LF) noise has been a topic investigated by acoustic researchers. Acoustic experts were involved because of the difficulties in determining the LF sound or its source, and LF sound was expected to be more intrusive than mid and high frequency sound because it is not screened or absorbed as easily. The puzzling character of the often elusive sound and the intensity of suffering displayed by complainants probably contributed to the efforts of authorities and acoustic investigators to try and solve this problem. Complaints about LF noise were made in a variety of situations, ranging from individual dwellings where sometimes the noise was evident for the investigator but in other cases even house mates were not able to hear the sound, to communities in which a number of people reported low pitched sounds of unknown origin. In the US and UK the latter cases have become known as a 'Hum' preceded by a topographical name: Taos Hum, Bristol Hum, Kokomo Hum, etc. There are probably many more places where such Hums are heard, but never reached fame because they were not reported in the popular media. In the Netherlands there have been several cases where one or more people reported hearing an intrusive low pitched sound in a local newspaper which subsequently led to confirmation and support from others. When a number of people in the same area hear an unidentified low pitched sound (though not all of them are complainants), complainants assume that it must have the same source. Low Frequency Noise (LFN), written in capitals, has become an ominous concept, a confrontation between sufferers asking for understanding and a solution and often experts who cannot help. It has been suggested by several authors that in some cases tinnitus or internal sounds could be the source of LF noise. This paper explores this probability in more depth.

2. RESULTS FROM EARLIER STUDIES ON LF NOISE

The acoustical environment in the dwellings of individual complainants has been investigated in a number of studies (see Pedersen et al [2008] for an overview of relevant studies). The results can be summarized as follows:

1. In a minority of cases a sound below 200 Hz can be identified as the certain or probable cause of the complaints; in some, but not all cases the investigator was able to hear that sound. When the sound has been identified, the sound source may still be unknown or it may be known but comply with limits on permissible levels.
2. In the majority of cases a specific sound could not be identified as a likely cause of the complaints. In a number of these cases there was doubt about the audibility of components of the LF spectrum for the complainant at times of complaints, so the case was not definitely resolved. In the remaining cases it was concluded that the LF part of the spectrum was below the hearing threshold of the complainant or a reference

threshold, so any LF sound present could not or probably not cause the sound perceived by the complainant.

3. Overall sound levels and 1/3 octave spectra in dwellings of complainants are, on average, not clearly different from those in dwellings of controls. With broad band sound levels of less than 25 dB(A), dwellings are usually quiet.
4. When compared to the median threshold of young adults, there is (almost) never audible sound present at frequencies below approximately 40 Hz, but there is (almost) always (soft) audible sound above 100 Hz. Infrasound is thus not at stake.
5. Complainants are usually elderly people (> 50 years of age) and do not have exceptionally good hearing. In fact their hearing threshold is often not as good as the median hearing threshold at that age. Using the median threshold of young adults as a reference threshold will usually overestimate the capacity of complainants to hear sound at low level.

The results indicate that external, physical sound in many cases cannot explain the complaints. A similar conclusion seems to apply to the collectively perceived hums. The earliest reported 'Taos hum' remains a mystery and is now rated number one on the 'Top Ten Unexplained Phenomena' on the LiveScience website. Also the cause of the 'Kokomo Hum', first reported in 1999, appears to be unresolved. Although several causes have been suggested, including electromagnetic fields and shifting sands, to my knowledge no physical sound source has been identified that did cause a 'Hum'.

3. PHANTOM SENSATIONS

In medical literature there is an abundance of information about sensory sensations perceived by persons without an external stimulus. The general term for such a perception is hallucination which can be visual, aural, tactile (feeling), olfactory (smell), gustatory (taste), equilibroceptive (balance perception), proprioceptive (posture perception) or nociceptive (pain). Aural hallucinations include voices, music and meaningless sounds; the former are more usually referred to as hallucinations proper, the latter as tinnitus. Hallucinations can be caused by specific events (brain damage, amputation of limb, detonation) or can occur without apparent cause.

In the last two decades there is increasing evidence that the brain is always involved in 'producing' hallucinations or 'phantom' sensations. Even when physiological damage is apparent, the brain can contribute to a new sensation in reaction to the damage. A well-known example is phantom pain in a lost limb. Even though the subject is quite aware that the limb is no longer there, the inner feeling (propriocepsis) of that limb can be very realistic, in some cases leading to persistent pain.

3.1 SOUND

According to the Encyclopaedia Britannica [2008] sound can be defined in two ways, viz. as "a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium", or as "that which is perceived by the ear". The first definition is, though in more abstract terms, what many people suppose is the nature of a LF sound. This paper will highlight the second definition although, according to the Britannica, this definition "is not particularly illuminating and is unduly restrictive, for it is useful to speak of sounds that cannot be heard by the human ear, such as those that are produced by dog whistles or by sonar equipment."

Merriam-Webster's dictionary [2008] gives similar definitions: sound is "mechanical radiant energy that is transmitted by longitudinal pressure waves in a material medium (as air) and is the objective cause of hearing" or "a particular auditory impression" or "the sensation perceived by the sense of hearing". The last definition includes the brain as part of the hearing system.

In sound one can thus distinguish between sound as a physical phenomenon and sound as a (personal) perception. The Britannica and Merriam-Webster's seem to favour the physical definition, as many complainants do, but allow for a subjective definition of sound. As the examples in the Britannica show physical sound may not be audible. This is especially true for low and very high frequencies where human hearing is less sensitive or not sensitive at all. In contrast, tinnitus is within the frequency range of normal hearing but usually is not the result of a physical sound, though for those who perceive it, it is a very real sound.

3.2 TINNITUS

The term tinnitus is used for a range of aural sensations with different causes. Tinnitus can be a physical sound produced by blood flow, oto-acoustic emissions, or muscle tension, in which case it is called an objective tinnitus. In the majority of cases tinnitus cannot be objectified or measured and is then called subjective.

Tinnitus can be perceived as very different, although usually meaningless sounds: ringing, crickets, whooshing, pulsing, ocean waves or buzzing; but also as dial tones or music [ATA]. Matching experiments, where a sound is presented to a subject who adjusts the sound in pitch and/or level to the perceived tinnitus sound, show that usually tinnitus is high pitched, but it can be low pitched too. It is often not a steady, single tone, but can consist of a number of frequencies which can also vary over time. In 28% of 1400 subjects the tinnitus sound could be matched to a tone with a frequency below 1000 Hz; most prevalent however was a pitch equivalent to a frequency above 8000 Hz (31%) [Savastano 2004].

When the tinnitus is matched in level, the sensation level is often higher than that of the matching sound: the level of the matching sound is lower than would be expected from the loudness of the matched (tinnitus) sound. In an investigation of 1400 subjects (persons with tinnitus asking for a specialist examination) Savastano [2004] found that the loudness level (level above threshold) of a sound matched to the tinnitus sound was less than 10 dB for 59% of the subjects, and above 15 dB for 17%. This was not correlated to the perceived discomfort of the sound, as table I shows: at all loudness levels there were subjects that perceived the tinnitus intensity as low, medium or high. According to Savastano the masking experiments show that there is no correlation between the subjective description and objective (matched) sound levels.

Tinnitus in the 1400 subjects was monaural (55%), binaural (41%) or central/'in the head' (3.4% of cases). In 23% of cases it was reported to be the

Table 1 Perceived tinnitus intensity in relation to loudness level of sound matched to the tinnitus sound [Savastano 2004]

	Tinnitus intensity		
Matched loudness level	**low**	**medium**	**high**
<10dB	9	71	20
10-15dB	21	64	14
>15dB	28	47	25

result of elevated noise levels (at work or environmental). There was no clear sex difference: woman have tinnitus as often as men do. There was however a clear age effect: the probability of tinnitus onset increased with age and was highest at an age of 40 - 50 years.

In a review paper Moller [2007] concludes that different studies show that 4.4% to 15.1% of people of all ages perceive tinnitus, and all studies agree that prevalence is higher for people aged 50 and more, where 7.6% to 20.1% of the people perceive tinnitus. According to Penner et al [1996] 6.4% of the population of the USA have troublesome tinnitus and 7.2% of the British population have consulted a doctor because of tinnitus.

According to Hazell [2002] the difference between those who experience a persistent tinnitus but do not find it a burden and those who do, is not in the sound itself, because the tinnitus sounds in both groups are very similar. It is rather the reaction to the tinnitus that makes the difference: the sufferers perceive the tinnitus as a threat or an intrusion, whereas the others think it is of little consequence. The impact of tinnitus on a person's life can be estimated with the Tinnitus Handicap Inventory (THI), a 25 item questionnaire to be completed by the patient ([McCombe et al, 2001], see also [Soundidears, 2004]). Using available reference scores for a shortened THI for screening purposes (THI-S), the score can be classified in four ranges from 'no handicap' to 'serious handicap' [Newman et al, 2008]. The THI(-S) could be used for LFN sufferers as well to assess the severity of the impact.

3.3 SOUNDS IN SILENCE

Tinnitus is correlated to impaired hearing, either as a result of ageing or after an acoustical trauma. It also occurs in normal hearing persons, especially when in a quiet environment or after exposure to loud sound. Moller [2007] states that in a quiet environment most elderly perceive tinnitus sounds, but only a few are disturbed by it. In a famous experiment Heller and Bergman [1953] showed that when asked to remain in a very quiet room, within five minutes 94% of 80 adults with normal hearing (no history of deafness or tinnitus) and age between 18 and 60, reported hearing a sound. The same experiment was performed with 100 people with a hearing impairment, and 73% of these reported a sound. The sounds reported (written down when sitting in the quiet room) were widely different, but can be classified as low frequency sounds (buzz, drone, hum, roar, truck, fog horn, rumble, surf, throbbing, thumping), high frequency (HF) sounds (bell, hiss, ring, whistle, squeal, squeak) or undecided (steam, click, tap, falling water, etc.). Of the sounds reported by the normal hearing subjects 43% were LF and 25% HF, whereas the hearing impaired reported 30% LF and 45% HF sounds. It thus appears that most of the normal hearing subjects heard a sound in a very quiet environment, which was more often than not in the LF domain. In the same conditions hearing impaired people less often heard a sound and that sound was more often then not in the HF domain. In a similar experiment Tucker et al [2005] found that 77.5% of 80 normal hearing, young (18 to 30) Caucasian adults heard a sound when in quiet room. Here 25% of the sounds described can be characterized as LF and 39% as HF (most of which was ringing: 37%), with again the rest undecided. African American adults in this same study less often heard a sound in quietness (37.% of 40 people) and they equally often reported a LF and a HF sound (each 27% of the sounds described).

Knobel and Sanchez [2008] added to these experiments by having the subjects (66 persons aged 18 to 65) perform a task when sitting in a 'sound-treated' (apparently very quiet) booth. In one task subjects were asked to perform a game of skill, in the second task subjects were asked to pay attention to possible light changes, in the final task subjects were asked to pay attention to possible sounds. In fact no light or sound changes were applied. After each task subjects were asked to write down the visual and auditory perceptions during the task. After the game 20% of the subjects reported an auditory perception. When attention was asked for light changes, 46% reported an auditory perception. And when attention was focused on sound, 68% reported an auditory perception. The authors remark that in the first two tasks typical tinnitus sounds were mentioned (hiss, ring and hum), while in the task where attention was driven to hearing, more unusual sounds were heard such as a slamming door, crying baby, barking dog, cuckoo clock, or a washing machine.

Hearing voices (without someone present talking) is known to be associated with psychiatric disorders, but Pennings et al [1996] found that people with no history of a disorder and leading a normal life, also hear voices. These subjects were not known, but in a television program the investigators invited people hearing voices to contact the team and 15 persons (non-patients) did. It appeared that patients with a dissociative disorder more often (10 out of 15) could not talk with the voices, whereas most schizophrenic patients and non-patients could (12 out of 18 and 10 out of 15, respectively). However, the most important difference was that none of the non-patients was afraid of the voices, whereas most patients (25 out of 33) were. The reason for this could be that most of the non-patients (13 out of 15) could control the voices and all could refuse orders, while for most of the patients (29 out of 33) the voices controlled them and 26 of them could not refuse orders.

3.4 TINNITUS MODEL

In 1990 Jastreboff proposed a model for the perception of and reaction to tinnitus, though the model seems to be applicable to any perceived sound. In this model (figure 1) the perception and evaluation of a sound is a result of detection of that sound and of the emotions associated with it. The emotional association is not the result of a conscious process, but is a result of earlier learning and adapting to a sound. When a sound is heard for the first time it has no meaning or associations and the sound receives attention to establish its source. People do not passively 'record' sound, but interpret it, mostly

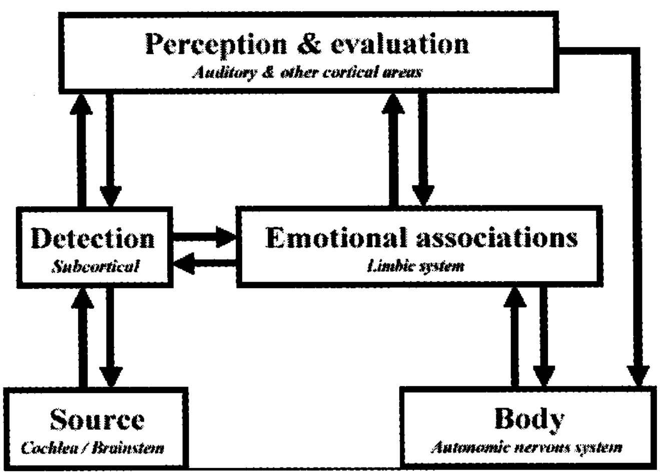

Figure 1. *Jastreboff neurophysiological model of tinnitus [Hazell, 2002]*

unconsciously: the sound is coming from a source and the nature of the source is established (a plane, music from a neighbour, the garbage collector, etc.) [Fowler, 1991]. If a negative emotion is attached to the sound, perhaps because the listener is frustrated when they cannot establish the source or because the sound is threatening, this association can present itself autonomously the next time the sound is heard and may lead to a stronger negative evaluation of the sound. Through the limbic system the detected sound can directly evoke, unconsciously, an emotional association such as fear or a feeling of frustration or powerlessness, influencing the conscious evaluation of the signal. In this way a feedback loop is created, in which the perceived loudness of the signal is determined by the detected signal and the emotions resulting from earlier evaluations. A continued tinnitus perception thus may be the result of fear conditioning [Cacace, 2003] if the sound is associated with anxiety about its origin (is there something wrong in my ears or brain?) or the possible future development of the sound (will this go on in keeping me awake? will it get worse?).

3.5 TINNITUS IMPACT AND REMEDY

Tinnitus, as yet, cannot be cured, though patients can learn to cope better with it. The aim of Tinnitus Retraining Therapy (TRT), a quite successful therapy, is to change the patient's thoughts about tinnitus and to reduce the distress caused by it. To this aim cognitive behaviour therapy is provided and a small noise generator, worn by the patient, is used (now commercially available, either separate or combined with a hearing aid). The generator does not mask the tinnitus but is intended to draw attention away from the tinnitus sound. Berry et al [2002] report a significant improvement in self-perceived disability in 32 patients following TRT, measured as a reduction in THI score before treatment and after 6 months. In that same period loudness discomfort level (the level at which sound causes discomfort) significantly improved but loudness matching level (the level of a presented sound matching the tinnitus) did not change. Hatanaka et al [2008] also found a significant reduction in the THI score, already after one month of tinnitus retraining therapy (TRT). Their subjects were originally 217 tinnitus patients but most patients could not tolerate the Tinnitus control instrument (= noise generator) or failed in a TRT trial. So, TRT does not offer a solution for all tinnitus sufferers. 79 patients who did receive TRT were followed for 6 months. The average THI score at the beginning of the treatment was 48.8 (moderate handicap), decreasing to 36.3 one month after starting the treatment and 28.3 (mild handicap) after 6 months. Leventhall et al [2008] introduced psychological treatment and relaxation therapy to eight sufferers of LFN. All eight felt they had derived benefit from this approach, but the number of sufferers was too low to obtain general conclusions from this study. In a further paper [Benton et al, 2008] the same authors put the LFN health problem in a broader health care and demographic perspective, and announce the development of an internet based 'distance learning' package (www.copingwithnoise.org).

As subjective tinnitus is related to neural activity without external stimulus, some therapeutic interventions are based on changing this activity. Methods investigated are Transcranial Magnetic Stimulation (TMS) and electrical stimulation including cochlear stimulation (see, e.g., [Mennemeier et al, 2008; Quaranta et al, 2004); Dobie et al, 1986; Kleinjung et al, 2008]). Most methods are experimental and are tried clinically with a varying success rate. As their relevance to LFN is unclear they are not within the scope of this article.

3.6 AUDITORY SEX DIFFERENCES

No obvious sex differences in hearing have been found due to neurological differences. According to some studies both the left and right primary auditory cortices (PAC) are larger in women than men, but this was not found in all studies; many studies emphasize the variability between subjects in size and location of these PACs [Ruytjens et al, 2007]. In some studies women depend less on the left hemisphere of the brain for language processing, but in other studies the opposite was found or no sex differences were obvious [Ruytjens et al, 2007]. Ruytjens et al studied the activity of the left and right PAC when subjects (10 male, 10 female) were in a PET scanner and were presented with acoustic stimuli binaurally through in-ear phones (music or white noise at 75 dB sensation level) or no sound. Both stimuli are broad band; music was used as a dynamical stimulus and noise as a static one (continuous and uniform spectrum). Activity in the PAC due to a stimulus was determined by subtracting the activity when no stimulus was presented from the activity when the stimulus was presented. There was no difference in activity between men and women when listening to music. But there was a difference when listening to white noise: the female PAC was significantly more active. Also, in the male group only, there was a deactivation in the right prefrontal cortex when listening to noise (compared to no sound). According to the authors, the prefrontal cortex is known to be involved in auditory tasks requiring sustained or selective auditory attention. They hypothesize that it is the difference in attention that causes the difference in deactivation of the right prefrontal cortex, which again influences the activation of the PAC. In short: women pay more attention to meaningless noise than men do and this activates their auditory processing.

3.7 PERSONAL FACTORS

ln In general, individuals who are noise sensitive or who feel fear associated with a noise source, report more noise annoyance. Miedema and Vos [1999] investigated the effect of several demographic and attitudinal factors on annoyance from transportation noise (aircraft, road traffic and rail) for a large number of respondents. In this study the average score of highly noise sensitive individuals (22% of 15171 respondents) was 16 points higher on a 0-100 point noise annoyance scale than for low noise sensitive individuals (46%). Here, highly sensitive was the upper third of three categories: low (0-32 of maximum noise sensitivity rating), medium (33-66), and high (67-100). Individuals who expressed fear associated with the source also scored higher: 17% of respondents were in the 'high fear' category (scores 67-100 on a scale with increasing feelings of fear) and their noise annoyance rating was on average 27 points higher than the 'low fear' individuals (62% of 17494 respondents). In this study Miedema and Vos showed that age and education level also had an influence on the noise annoyance score, but far less than sensitivity and fear had.

Bartels [2008] investigated the relation between tinnitus and Type-D personality. Type-D (Distressed) personality is correlated to perceived as well as objective health and has been shown to be correlated to several health factors such as mortality, cancer, cardiac diseases, anxiety and depression [Denollet, 2005]. Type-D is assessed with a standard questionnaire and depends on two personal traits: negative affectivity (NA) and social inhibition (SI). Increased NA is the tendency to feel more negative emotions and distress and to be more sensitive for negative signals from their environment. Increased SI is the tendency to not express negative emotions in social interactions and to feel tense, uncomfortable, and insecure with others. Type D patients "tend to worry, take a gloomy view of life, scan the world for impending trouble, and feel tense and unhappy" [Tulloch and Pelletier, 2008]. Bartels et al [2007] found that tinnitus patients had statistically significant and clinically relevant higher levels of neuroticism (related to Type-D) and type-D traits (NA and SI), and were more likely to have a type-D personality. Tinnitus patients also showed lower levels of extraversion and emotional stability. Controls for this were other patients with minor illnesses or health complaints (not tinnitus), but due to the different disease characteristics the matching between cases and controls was considered problematic. It was concluded that help-seeking tinnitus patients had a significantly higher prevalence of type-D personality than the general population visiting the Ear, Nose and Throat clinic.

3.8 VISUAL PHANTOM SENSATIONS

An interesting parallel to the typical LFN complaints is the Charles-Bonnet Syndrome (CBS). People with CBS experience visual hallucinations (and no hallucinations in the other senses) but are aware of their unreal nature. Teunisse et al [1996] investigated the prevalence and characteristics of CBS in a group of 505 visually handicapped persons. Most of these were 'low vision' patients and none had a psychiatric diagnosis, according to a second paper [Teunisse et al, 1995]). 63 subjects (13%) had experienced visual hallucinations in the 4-week period before screening, either daily (17 cases), weekly (19), monthly (22) or less often or unknown (5). A hallucination most often lasted from a minute to over an hour (68%), contained people (80%), but also animals (35%), plants or trees (25%) and other objects or scenes. The contents were most often not familiar (65%) and not recurring (60%). Favourable conditions for seeing a hallucination were evening and night time (reported by 58% of cases), poor lighting (60%), when being inactive (85%), and when at home (72%). Patients were aware that the hallucinatory images were unreal, though some were of such normal appearance (e.g. cows in a real meadow) that they were taken for real until corrected by others. Though the hallucinations were of little consequence to the patients, all were glad to hear it could be diagnosed and was not considered a mental disorder. Many patients had not consulted a doctor for it, though most concealed it for others. The authors suggest that sensory deprivation and a low level of arousal are triggers for CBS hallucinations. In their second paper Teunnise et al [1996] show that CBS is age related: CBS is rare amongst visually handicapped adults below 50 years off age (3%) and prevalence increases with age until 75 where it is approximately 14%. Also, most (70%) are female.

Of people suffering from migraine about 30% have visual hallucinations ('aura') [Dodick and Gargus, 2008]. According to Dodick and Gargus a new theory for migraine is that it results from an electric wave travelling through the brain, stimulating the visual cortex and pain receptors. An alternative theory is that migraine originates in the brain stem. During migraine three nuclei (clusters of cells) in the brain stem, that normally inhibit pain neurons in the brain membrane, are active. These same nuclei control sensory information towards the cortex and could thus influence sensory perception (in a migraine attack sufferers can be more sensitive to light, sound and smell). Finally the activity of these nuclei depends on the emotional state of the person by receiving input from cortical areas that regulate arousal, attention and mood.

4. DISCUSSION

The experience with phantom perceptions shows that they occur for all the senses. Subjective tinnitus, a phantom sound, is in fact quite common. There can be an event that led to the (first) perception of a phantom, but often there is not. In most cases people are aware that a phantom perception must be unreal, and most people seem not to be bothered by it. On the other hand, people may suffer seriously from phantom perceptions when they fear them, perhaps because the perceptions are uncomfortable or because they may be the precursor of a serious illness.

Fear is also an important factor contributing to annoyance from actual (transportation) noise sources. With respect to aural perceptions, it appears that in fact quite often 'normal' (no hearing impairment, no psychiatric disorder) people perceive a sound in a quiet environment without an external stimulus. In a quiet environment most elderly perceive tinnitus sounds. The common cause that is suspected in a 'Hum' may therefore not be a specific sound source, but the quietness of the area and the age of its inhabitants.

There is a direct visual analogy to the aural sensation of (not physical) LFN: the Charles-Bonnet Syndrome. People having visual hallucinations are usually elderly people with reduced vision and when at home in poorly lit conditions. LFN sufferers are often elderly people with reduced hearing and when at home in quiet conditions. In both cases there is a reduced sensitivity to stimuli and the environment does not or hardly presents stimuli.

Tinnitus occurs more often in elderly people (>50 years) as LFN complaints do. The perceived loudness is not an indication of the level of an external sound that matches the tinnitus. When the objective level (level of matched sound) is low, the sensation can be of an intense sound. The recent discovery that women pay more attention to meaningless (white) noise then men do, may in part explain why more women then men are suffering from LFN.

Many LFN complaints cannot be explained by a physical sound, and occur in quiet home environments. It is probable that a larger number of people hear a hum when in their quiet home, but many of them never complain. When in the media attention is focused on such a sound, usually a number of people confirm that they too hear a low pitched sound, and then -sometimes- a 'Hum' is born. A probable explanation for this phenomenon is tinnitus, and as yet other explanations that have been proposed all seemed to be wrong or speculative. In the 14th century William van Ockham proposed a criterion to choose from different explanations: take the simplest explanation. This explanation is not necessarily the right one, but it is the most obvious to start with. In the 20th century Popper proposed another criterion for the best theory: one must not look to verify a theory, but one must try to falsify it. In our context this would mean that one must try to show that tinnitus cannot be the cause. Many LFN sufferers use the pre-Popper philosophy and collect information that confirms their theory.

A major obstacle to helping most of the LFN sufferers (those where no physical sound can be demonstrated) seems to be their determination that the perceived sound must have a physical source. This blocks the way to solve or at least relieve the suffering. Whatever the cause, to sufferers the LF noise is a burden and they often demonstrate feelings of anxiety. In my experience sufferers may feel this anxiety because of several reasons:

- the source is unknown but the noise sounds very real; that LF sound can be heard over considerable distance and is not easily reduced is common experience, so it is plausible there is a source somewhere. Sufferers think there must be a source somewhere but are not able to find it.
- the noise intrudes into their home and even their body and cannot be controlled. (the noise is there when sufferers want it to be quiet).
- often no other persons or perhaps a few people are able to hear the (same?) noise and sufferers feel left alone and not taken seriously; often sufferers remark that they are not insane and do not make up the noise.

Feelings of anxiety add to the negative evaluation of the LF noise and may even increase the perceived level.

Different ways to help 'normal' tinnitus sufferers are to:

- expose them to more sound when the tinnitus is more disturbing, which is usually in quiet conditions; sometimes people put on a hearing aid to reduce the tinnitus.
- offer cognitive behavioural therapy to help them to accept the sound by reducing negative associations.
- respect the sufferer and respect the suffering, acknowledge the perception is real for the sufferer. In fact this help is useful irrespective of the actual source: it may be subjective tinnitus, or a real sound of unknown origin, or a real sound of a known source but not within control.

5. RECOMMENDATIONS

It has been shown that the cause of LF noise complaints can be real sound sources. In that case, mitigation measures are in principle -though maybe not in practice- possible. However, in many cases of LF noise complaints the source of the perceived noise is not a physical sound. In that case 'Ockham's razor' points out what line to pursue first: the most likely explanation. When a physical source is improbable and/or acoustically implausible (the acoustical characteristics causing the perception are contradictory to physics), tinnitus is a likely cause. If so, the sufferer should be directed towards medical or psychological support.

Whether the sound is physical or not, it is important to respect the person suffering from LF noise. The suffering does not depend on the actual source, although knowing the actual source may offer relief and be a step towards a solution.

To relieve the complaints, add sound to the environment where complaints are most intense (often the sleeping room). Possibilities are opening a window (to allow outdoor sound into the room) or having sound producing appliances in the room (fan, aquarium, music, recordings of natural sounds or music, radio). A CD with low frequency noise ('brown noise' and 'black noise', with respectively a 1/f and 1/f2 dependency of one third octave band levels on frequency) that was offered to complainants, has helped most of them at least for some time, though a few disliked this noise (as of now, I have only anecdotal evidence of a score of cases). The supply of a distracting sound in combination with psychotherapeutical help (such as to be provided for LFN sufferers on www.copingwithnoise.org) are similar to TRT, a therapy that in many cases successfully reduces the negative impact of tinnitus.

It may help to convince sufferers of the non-physical nature of the noise (if that is probably the case) by matching the sound in their home with a sound from a frequency generator or a number of pre-recorded sounds. When the matching sound is obvious to others, whereas they cannot hear the matched sound, this may help to accept that the disturbing sound is of a different nature. This experiment may be more convincing if a person trusted by the sufferer is present.

A similar attempt is to record the sound in a room when the LF noise is heard, and then play it back. The LF noise -if present as real sound- should be better audible when the sound is amplified. The recording must have a high signal-to-(instrumental) noise ratio, as otherwise the instrument noise is amplified and the result is not just the originally recorded sound.

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