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SO WHY ARE WE ANNOYED BY LOW FREQUENCY NOISE?

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INTRODUCTION

The practice of noise measurement and assessment of its impact upon the individual has, in large part, evolved in parallel with the dominant work technologies and practices of the day. In order to maintain effective assessment criteria and standards it is necessary to take into account emergent noise environments. An indication that new noise forms and environments have developed will be seen in the diminshed capacity of existing noise criteria and practices to account for an increasing number of instances of apparently anomalous noise annoyance complaints. Measures of noise annoyance will encounter a growing number of instances where the impact of the noise exceeds that predicted. This paper considers how such a gap between noise criteria and emergent noise forms/environments may occur and what it is about Low Frequency Noise (LFN) that may exacerbate this general problem. In order to address this general problem it is necessary to examine the type of performance demands that current technogies have contributed towards defining the work place. However, it will be argued that a fundamental characteristic of LFN is that of intrusiveness and it is this that will provide the basis from which annoyance responses will be experienced within a range of work and home environments. Quantifying the range of variables active within such noise environments has proven to be a continual challenge, but may well represent the most effective method of addressing the interactive and psychophysical nature of noise annoyance.

BACKGROUND

The Emergence of Noise Criteria: Quality of the Work Environment

One necessary aspect of the impact of work technologies and practices upon noise assessment measures has been to mark out for study those components of the noise environment which characterise the work place. Traditionally, these components have been likely to induce hearing loss rather than annoyance (Lampert & Henderson, 1973) being characteristic of heavy industry (Katz, 1994). From these studies came an increased understanding of the general risks of hearing loss, and as research continued a greater definition of the specific relationships responsible for occupational hearing loss followed. The distinct psychophysical properties of hearing sensitivity provided a basis for the development of successful hearing protection guidelines capable of accommodating different exposure pressure levels and duration and by combining measured hearing loss with sensitivity norms for age dependent presbyacusis it has been possible to predict likely consequences of noise exposure and to alter work practices accordingly. Formal application of these guidelines and relationships can be found in standardised criteria, including specific recommended dBA levels and general statements such as the 3-dB rule incorporated in the ISO 1999 (1990).

Changing Priorities

Improving the accuracy and the relevance of noise criteria in terms of the latest generation of technology related noise environments has meant a continual need to quantify predominant noise and task features. For example, criteria and scales for speech intelligibility have been produced and consistently revised as the components within the noise/speech intelligibility interaction have been elaborated (Kryter, 1962, Lazarus, 1994). Specific A-weighted sound pressure levels (SPL's) can now be recommended for particular environments as well as providing the basis for intelligibility curves. For example, under outdoor conditions at a distance of 1 metre, relaxed conversation can be conducted at approximately 54-56 dBA (Kryter,1970) while ISO 9921 states that 100% intelligibility will occur when the speech level exceeds the noise level by 15-18 dBA.

Transportation Noise Criteria: Quality of Living Environment.

Major environmental changes have been associated with industrial and technological developments and one major area that has dveloped in response to these demands of change has been that of transportation, with the corresponding impact upon individuals living environment. The results of a recent World Health Organisation study into the effects of community noise (Berglund & Lindvall, 1995) found that 25% of the European population was exposed to transport noise over 65 dBA (an average energy equivalent to continuous A-weighted sound pressure level over 24 hours) (Lambert & Vallet, 1994) and that although this figure varied between and within countries it was estimated that 20-25% of people in the countries of Great Britain, France, Germany and the Netherlands would experience traffic related noise annoyance with 30% of EU residents being exposed to night levels exceeding 55 dB LAeq. These figures are concerned primarily with road traffic noise although air traffic is predicted to grow by 50-80% in the U.K. (Large & House, 1989). The effect of much research into the impact of traffic noise has been to provide authorities with methods to augment the annoyance ratings derived from Leq measures, with various 'penalties' linked to particular acoustic features.

It has only been through the ability of research to pursue and identify those diverse acoustic components which contribute to elevated annoyance that has enhanced, in general, the effectiveness of noise criteria to parallel the growth of noise sources within the community. This can be seen by the attention now paid to variables such as; high-frequency hearing, Impulsive noise, duration/intensity interactions and ototoxic drugs (Collins, 1988). The rapid growth in machinery launched individuals into working with new noise forms and the paramount need for hearing protection has gradually evolved into hearing protection criteria that impose a form of behavioural manageability upon the work environment.

Speech Intelligibility

The studies directed towards criteria for work place verbal communication have been able to take account of speech processing requirements as part of the acoustic environment in such a manner that criteria are not only sensitive to masking levels but also to features such as; Indoors/outdoors, familiarity of content, content complexity, speech rate and listener attention span (Kryter, 1970). The approach has again been to study the fine detail of the component parts of the acoustic interaction (stimulus/background) in order to deliver a degree of control over the environment thereby promoting the desired behaviour.

Transportation Noise

The challenge posed by transportation noise to assessment criteria is one of continual change. Consequently, assessment criteria have evolved to take into account such variables as; engine size, road surface type, speed, time of day effects and magnitude of fluctuation in SPL. Indeed if the prediction from the OECD (1991) is accurate then the growth in geographical dispersion of noise sources, increasing spread of noise exposure over time and the expanding use of powerful noise sources will ensure the need for a further round of review and adjustment.

Loudness-Annoyance Model: Annoyance is a form of Damage

The capacity for noise control and assessment practices to maintain effectiveness derives largely from the ability of the intensity led model of noise annoyance to explain hearing damage, disturbance and annoyance effects experienced by individuals exposed to a range of noise environments/stimuli. It seems that where loudness is a clear feature, if not sole determinant, of the individual's response, noise criteria have met with the most widespread acceptance. The fundamental unit within this success has been dBA, based upon experimental methods designed to explicitly relate individual's hearing sensitivity (population norm) to noise impact. As the above sections have attempted to show, the analysis and elaboration of the variables associated with specific features of individual's behavioural responses to different noise forms and environments have relied upon this fundamental approach. Namely to identify the dominant feature of the noise environment, gauge the nature of its impact and then seek to control that impact by reducing exposure duration and/or SPL. However, as many researchers have noted, the measurement of annoyance responses based upon dBA makes the assumption that the loudness-annoyance relationship may assume an equally weighted contribution from across the noise spectrum, the loudness-annoyance model is

simply not sufficient, (Broner & Leventhall, 1983, Persson et al, 1985).
There has been a growing recognition that knowledge of the physical 'completeness' or 'sound character' of noise can mark out the type and magnitude of subjective response likely to occur (Benton, 1991). For example measures of SPL dBA may be augmented by incorporating assessment of features such as; tonal quality, impulsivity, and spectrum shape as well as by using comparative measures with dBC.

The pragmatic view of annoyance being that if a noise can be detected then with every increment in loudness there would be a greater likelihood of increased; damage (hearing loss), speech disruption (intelligibility) and annoyance (reduction in quality of living). In brief, when the auditory mechanisms are overloaded, damage may occur in a similar manner to when some loud sounds overload individuals tolerance where the hearing sensitivity curves would provide a bench mark of likely vulnerability.

However, we are increasingly becoming aware that tolerance to noise must usually take place within the context of competing demands and that individuals are able to impose 'tolerance' upon noise in a way that is both flexible and responsive to environmental task demands. This flexibility of response will be under pinned by a range of sensory/cognitive encoding processes designed to promote the ability to operate across a range of environmental conditions under differing levels of distraction. In order to achieve this flexibility the system is equipped with powerful sensory/cognitive processes and it is at this level that a separate view of annoyance, particularly relevant to LN, may be explored. The sensitivity of an individual may be related to a failure of these processes, and as these processes are sensory/cognitive the psychophysical attributes of a noise will play a major part in determining the likely response. Loudness will represent one attribute and depending on the overall processing demands will contribute to a greater or lesser degree to the formation of an annoyance response. For example, in the above cases of hearing damage and speech intelligibility, reduced loudness should lead to reduced damage and improved perception/reception respectively. However, what happens when SPL's of specific frequencies combine to challenge individuals 'flexibility' in such a manner that an overload of the sensory/cognitive system results, but the acoustic loading remains low?

Low Frequency Annoyance: Failure to Control
In what way and how is LFN different to other type of environmental noise? The effects of LFN are particularly problematic due to the wide spread incidence of LFN sources (e.g. air conditioning units and compressors), combined with efficient propagation characteristics and associated reduced capacity of structures to attenuate LFN (Leventhall, 1988).

It has been suggested by Lindberg and Backteman (1988) that LFN contributes to annoyance responses in three different ways (1) creates sensation of pressure in the ear (2) periodic masking effects on medium and high frequencies, with a strong modulation effect that can act to disturb conversation and (3) through secondary vibratory effects typically experienced within homes. The general, the form of symptoms reported associated with LFN have been well documented and would, in general seem to be consistent with the categories provided by Lindberg and Backteman above. The findings summarised in a wide ranging study by Persson-Waye (1995) gathered from a mixture of survey and experimental evidence confirms that LFN can lead to various negative symptoms at apparently innocuous dBA levels including; Task performance deterioration (e.g. secondary task errors with narrow band fc 70Hz at 25dB above individuals threshold matched to a 100Hz tone), reduced wakefulness (e.g poor vigilance with 42Hz at 70dB SPL), and sleep disturbance, headaches, irritation (e.g.with 55dB at 31Hz and 60dB at 16Hz).

Clearly LFN can act as a serious environmental pollutant and the primary feature of its impact would seem to be that it does not need to be perceived as 'loud' in order for it to cause various forms of annoyance. Moreover, research has shown that some of these (psychophysical) symptoms may increase in magnitude with decreasing SPL's. How might this corruption of the sensitivity model underlying annoyance criteria be achieved? What are the features of the sensory/cognitive interactions which mark LFN out as a special category of pollutant.

Intrusiveness and loss of controllability.

It is suggested that one essential element in any index of a noise to annoy should be a measure of its capacity to invade environments and in so doing to change individuals psychophysical behaviour. In broad terms the feature of intrusion has been recognised (e.g. speech intelligibility) but the strength of contamination is usually defined relative to Intensity levels. The notion of 'environment' being suggested here permits that low intensity levels may produce strong and unwanted effects because of the interactions which result between ongoing psychological operations and the psychophysical properties of LFN. The more transmissible a pollutant, the greater the resultant complexity of inter-environment intrusions. With each instance of intrusion the potential will be created for a change in the kind of impact likely to occur, produced through an interaction of environmental task demands and the capacity of LFN to invade individuals attention. At any given moment the individual will be processing information in order to calibrate internal operations to external requirements. A variety of complex information handling processes enable the individual to cope with the multi-dimensional task of meeting both explicit and implicit environmental demands. It is possible to do this because information may be utilized for both descriptive and inferential purposes. For example, any individual performing a task will be processing information within different environments, task, psychological state, psychological dimension (predisposition) and context. These environments are structurally dynamic (containing numerous gradations) and are also interactive. Consequently, any sensory intrusion is a multi-dimensional event with associated structural and dynamic effects. This is why the same noise may have a different impact upon an individual at any given moment. In order for the individual to negotiate these demands it is necessary for them to have the capacity to maintain selective attention, which permits them to identify and maintain priority responses. Processing of information will occur at different cognitive levels and in order to maximise processing definition (e.g. feature memory), non redundant stimuli/information will be given priority over redundant material. The boundary between the redundant and non redundant material is continually monitored. The manner in which material is organised is unclear, but it seems that the redundant material is held in some form of attenuated state, which is responsive to emergent needs while not intruding upon selected priorities. This ability to attenuate material may be the precursor to habituation, which is a powerful sensory/cognitive tool designed to protect limited directed attention space from incursions from low priority information.

Control: Sound Character

When LFN is of equal oudness to other noises it tends to be rated as more annoying (Benton and Leventhall,1985). This suggests, that for some reason, the sound character of LFN is found by individuals to be more difficult to ignore or to attenuate. Failed attenuation would lead to a reduction in our ability to control the impact that a stimulus might have while it could also lead to the occurrence of dishabituation. It is well documented that individuals suffering from LFN annoyance describe the noise as (1) omnipresent, all around, (2) cannot be ignored (3) worse in doors (4) cannot locate it and (5) tuned into it. It is likely that such complaints are indicative of a failing in the sensory/cognitive process to habituate to the signal.

Behavioural Control: Some examples (Benton, 1994)

Under such conditions complainants may seek to impose a behavioural control upon the noise by using the psychophysical information which appears to be available. Attempts to locate the noise source are inhibited by reduced head shadow cues, which serve to further focus the individual's attention upon the noise. While trying to reduce the sound's loudness by closing doors and windows will make the noise worse as a result of the propagation characteristics of LFN and the low-pass filtering effect of the structure. Moreover, masking of the LFN is made difficult by the asymmetric nature of the frequency masking curves. The individual will tend to become demoralised and anxious as attempts to control the noise fail and serve only to focus the noise within the individual attention span. The situation may become even more anxiety provoking for individuals if a low level low frequency noise is subjected to measures of dBA.

Conclusion

The progress and success of noise assessment criteria have been based upon an approach that has been prepared to re examine established practice in order to address emerging needs. The environment within which noise assessment has been characterised by a range of industrial and technology driven priorities. It is suggested that LFN may represent an important part of the emerging community noise priorities which are increasingly concerned with annoyance issues relating to quality of living.

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