MEASUREMENT OF PERCEIVED ANNOYANCE DUE TO LOW FREQUENCY CONTENT IN BROAD SPECTRUM NOISES

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1. INTRODUCTION

Environmental noise is a growing problem in the workplace and in homes, inducing annoyance and hearing loss, and affecting productivity and well-being. Current by-laws and regulations use SL measured in the dBA to assess both annoyance and potential hearing loss. While dBA-based measurements are fairly effective in assessing risk of hearing loss, noise annoyance arises from many factors other than loudness (Guski 1999) which cannot be measured using only this weighting. Annoyance is especially difficult to assess when the noise in question contains significant energy with Low Frequency (LF) content.

In the past, a number of experiments have tried to correlate annoyance with LF content with rather specific methods, using pure tones (Moller, 1987; Nakamura and Inukai, 1998), verbal scales for judgment (Inukai et al, 2000), or field data with real noises and assessments (Broner and Leventhall, 1983). While individually, useful results are often obtained, it is difficult to generalize such specific results into a versatile method of assessing LF annoyance in the field. In the present work, we generate and use a set of broadband noises of continuous spectra similar in shape to common pink noise. Subjects listen to each noise followed by a reference white noise of a known level and adjust the volume of the test noise until both noises reach equal annoyance. The idea is to quantitatively determine how LF spectral content contributes to noise annoyance.

Our goal is to develop a means to assess the annoyance of a noise by measuring it in both dBC and dBA. The difference dBC-dBA is an index of low frequency energy in a noise. Since dBA understates low frequencies while dBC does not, a greater proportion of noise energy in the LF region will show a larger difference between dBC and dBA. Furthermore, dBC and dBA are both easily measured in the field using any sound level meter. Thus, an attractive way to assess noise annoyance while account for low frequency content may be to use the standard dBA measurement result and add a "penalty" based on the measured C-A value.

This C-A idea has been explored in the past by Kjellberg (1997) where it was suggested that any C-A value of greater than 15 should incur a +6 dBA penalty. Our approach differs by seeking an appropriate penalty for each C-A value through the testing of subjects in the laboratory. We present an experimental method that is straightforward and scalable, and which may eventually offer a simple means to adjust for LF content in assessing noise annoyance.

2. METHOD

Test noises used were generated artificially for simple control of desired spectra and levels. Noise generation was done via MATLAB by the Inverse Fast Fourier Transform of a random-phase, 1 / (f ^ n) shaped spectrum. For the spectra, n is referred to as the 'slope' of the spectrum and corresponds to the amount of low frequency content. The spectra were band-limited between 31.25Hz and 8kHz, representing a total 8 octave bands: 6 octaves focused on the pertinent region of hearing around 1kHz, while extending 2 extra octaves in the LF direction. The noises were balanced in software to the level in dB linear. The .wav files were then stored at Fs=22050Hz for later playback. Table 1 contains the four spectra used and their values under different indices of LF content.

Table 1. Various noise spectra used in preliminary tests

Slope(n)	dB/octave	dBC-dBA
0.5	-3	2.00
1.0	-6	9.94
1.5	-9	18.33
2.0	-12	24.35

The calibration and experiment were both performed inside an IAC Audiometric Cabin. The noise signals were sent from the computer through a Digital Audio Labs CardDeluxe sound card into a Rotel RA-810A power amplifier, after which the signal was binaurally reproduced via AKG K301xtra circumaural headphones, worn by the subject inside the sound cabin. Calibration of the noise levels were performed by measurement through an artificial ear setup consisting of a human head mannequin containing a Bruel & Kjaer Type 4134 microphone connected through a B&K 2804 amplifier to a B&K 2231 sound level meter. Adjustments were made directly in software.

For the preliminary tests, 6 young adult subjects, 3 male and 3 female were asked to adjust pairs of noises to obtain the same annoyance. The noise pairs were presented as one reference white noise and one "coloured" noise for which the LF content varied. After each listening, the subject adjusted the volume of the "coloured" noise and listened to the noise pair again, repeating until both noises appeared equally annoying. Each of six subjects performed three runs of the experiment. Each run consisted of 20 pairs of noises, with 5 slopes (Table 1) at 40, 50, 60, and 70 dB linear.

To assist our subjects, “annoyance” was elaborated as “disturbance”, “unpleasantness”, or “nuisance” as these terms best represent annoyance according to noise research experts from seven nations (Guski, 1998).

3. PRELIMINARY TESTS

The tests conducted were intended to establish the performance of a straight dBA measurement of noise annoyance. The results show dBA tending to underestimate annoyance in noises with high LF content. Total variability in the limited data was large, making quantitative claims difficult. However, these differences arose mostly between subjects. Figure 1 shows each subject’s results with the n=2.0 “coloured” noise. The dotted line through each figure represents when A-weighting correctly measures annoyance. 4 of 6 subjects had found LF content more annoying, 1 was neutral, 1 found it less annoying. The relative consistency within each individual suggests that the method is reasonably reliable and may hold potential.

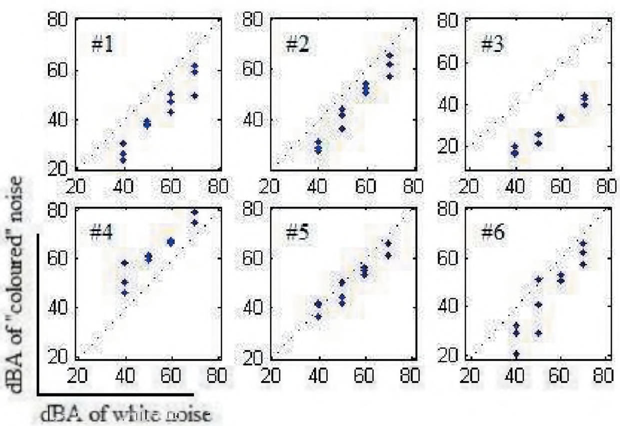

Fig. 1. Plots of equal annoyance between “coloured” and white noises. Each point represents one observation.

A second observation was that overall level of the noises did not have any discernable effect on the annoyance of LF content. This result suggests that following tests should reduce the number of levels used, hence reducing testing time per subject, freeing up time to test more subjects.

Variability is the main concern. To reach our goal of a dBC-dBA assessment method, more coherent results are required. The source of variations likely includes the set of personal moderators proposed by Guski (1999) which include sensitivity, anxiety and personal evaluation of noise source, and coping capacity. Of these, sensitivity and evaluation of the noise source are the primary contributors to variability. In a controlled laboratory, anxiety about noise source and coping capacity are unlikely to be real concerns as the subject has full control over delivery of the noise dose.

Feedback from subjects indicated that association with memories and environments directly influence their response to noise. From figure 1, subject 4 described the LF noises as sounding like a soothing waterfall, while subject 1 was reminded of the noise inside an airplane cabin. This has clearly introduced a large discrepancy between the subjects’ responses. Thus, any further experiment should include a simple survey component to allow subjects to describe their associations with the noise, separating subjects into positive and negative responder groups. Because only one in six of the subjects had found “coloured” noise less annoying than white noise, and since the noises are typically encountered in workplaces or homes where they tend to distract or disturb, positive responses to LF noise will be uncommon. It is logical to use only data from individuals with negative associations, thus providing more coherent data in determining our dBC-dBA penalty values. Finally, figure 2 is an idealized example of the dBC-dBA penalty plot using only the mean values of the limited data collected thus far.

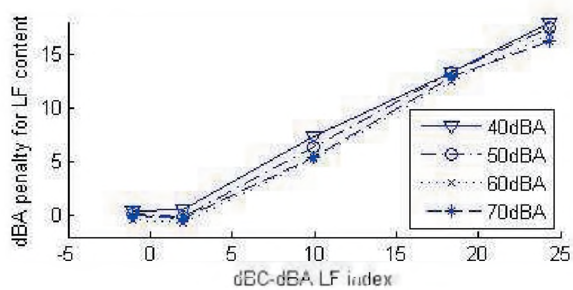

Fig. 2. Plausible end application of LF annoyance data. An operator can use dBC and dBA measurement of real noise to determine the dBA penalty due to LF energy.

4. CONCLUSION

The method developed here confirmed the inadequacy of the dBA system in measuring LF noise annoyance. Suggestions were made to further improve the method toward tighter results. Further testing is required to gather enough data to realize a dBC-dBA approach to noise annoyance assessment for LF-intensive noises.

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