ALARM VIGILANCE IN THE PRESENCE OF 80dBA PINK NOISE WITH NEGATIVE SIGNAL-TO-NOISE RATIOS

Buddhika Karunarathne[1], Richard H.Y. So[1] and Anna C.S. Kam[2]

[1]*Dept. of IELM, Hong Kong University of Science and Technology*
[2]*Dept. of Otorhinolaryngology, Head & Neck Surgery, Chinese University of HK*

Workers often have to be vigilant for critical auditory signals in the presence of loud noise. However this phenomenon appears to have received relatively less attention especially when the signal-to-noise ratios (SNRs) are less than unity (or –ve dB). In this study we focus on alarm vigilance in the presence of loud pink noise (80dBA) and with SNR of -18, -21, -24 and $-\infty$ dB. The results show that people with no known hearing impairments, were able to detect a 56dBA alarm in the presence of a noise level of 80dBA (i.e., a SNR of -24dB). The findings can help to establish threshold boundaries for audible alarm signal in the presence of loud noise.

Introduction

Auditory alarms have a wide variety of applications and the "better safe than sorry" principle has discouraged the use of alarms with loudness lower than the background noise (i.e., with negative signal-to-noise ratios, SNRs). Consequently, past studies on alarm perception with negative SNRs are few. On the other hand, after an alarm has been installed in the industry, levels of background noise could have increased over the years and gone beyond the original estimated levels resulting in negative SNRs. Authors of this paper were involved in an industrial consulting project where workers claimed to be able to detect alarms in which A-weighted sound pressure levels (in dBA) were 20 dB lower than that of the background noise. The testing was done in an actual industry setting. With the lack of literature studying the perception of alarm, with negative SNRs, in the presence of loud (80dBA) noise, the authors decided to conduct their own studies, hence this paper. In this study, both the alarm and the pink noise had similar spectral characteristics with those observed in the industrial study.

Alarm perception has been the subject of many studies. Guillaume *et al*. (2002) reported that a loud alarm is not necessarily a good alarm. Edworthy, Hellier and their colleagues investigated the effects of acoustic properties, such as pitch and harmonics on levels of perceived urgency of alarm in the absence of loud noise (Edworthy et al., 1991, Hellier et al., 1993). Carter and Beh (1987) reported that high level of background noise (92dBA) has adverse effects on performance of vigilance tasks.

Patterson studied about detection of tones in the presence of noise and found out that repeated signals are more detectable in uncorrelated noise than in repeated noise when the signal is 1.6 kHz (Patterson et al., 1982). Studying about detection of auditory signals in reproducible noise, Pfaflin and Mathews identified that the main determinant of detection behaviour was the energy increment produced by the signal (Pfaflin and Mathews 1965). However in these cases, the effect of SNR level on detectability has not been specifically looked into.

Pure tone detection (Elliot and Katz 1980) and warning signal detection (Haas and Casali 1995) with positive SNRs have been studied. However, studies focusing on the vigilance of alarms with negative SNRs in the presence of loud (80dBA or above) background noise could not be found. Therefore it is important to conduct more experiments on perception of alarms with negative SNRs. Data collected would be vastly useful in establishing the threshold boundaries within which an alarm is detectable in the presence of loud (about 80dBA) noise.

A recent industrial consulting study conducted by the authors on workers' vigilance provided motivation for this study. According to data collected from the field studies, even when an alarm was with a SNR of -18dB; listeners were able to successfully detect the alarms. Therefore the idea of determining the negative boundary of SNR level in which listeners start failing to detect the signals, formed the motivation of this study.

Methodology

Objective

The objective of this study was to determine the ability of the listeners to detect an alarm signal in the presence of loud noise (80dBA) with less than unity SNR.

Design, Apparatus, Stimuli and Procedures

The study had 4 stimuli conditions: (i) 80dBA pink noise plus an alarm at 62dBA (SNR = -18dB); (ii) 80dBA noise plus an alarm at 59dBA (SNR = -21dB); (iii) 80dBA noise plus an alarm at 56dBA (SNR = -24dB); and (iv) 80dBA noise only (the control condition with SNR = $-\infty$dB). In order to compare the spectra of the alarm and the noise directly, dB levels after filtered with a 1/3 octave band centred at 2kHz were measured for the noise (77dBA) and the alarms (59, 56 and 53dBA for SNR levels of -18, -21 and -24dB). Each stimulus lasted for 5 seconds. The three conditions with alarm were repeated 16 times and the control condition was repeated 12 times. This gave 60 stimuli and they were presented consecutively (in random order) without breaks. The total duration of the presentation was 300 seconds (5 seconds x [(3 alarm conditions x 16 repeats) + (control condition x 12 repeats)]). The order of presenting each stimulus was randomized. In this study, data from the repeats were averaged to get better mean estimations. We acknowledge if the control condition was also repeated 16 times would make the design full factorial.

The alarm was a recording of a real alarm used in the industry and the noise level of 80dBA was comparable to the background noise in the real situation. The choice of pink noise was made so that the spectrum of the noise was similar to that measured in the industrial consulting project. Figure 1(a) and 1(b) shows the waveform and the frequency spectrum of the alarm signal respectively.

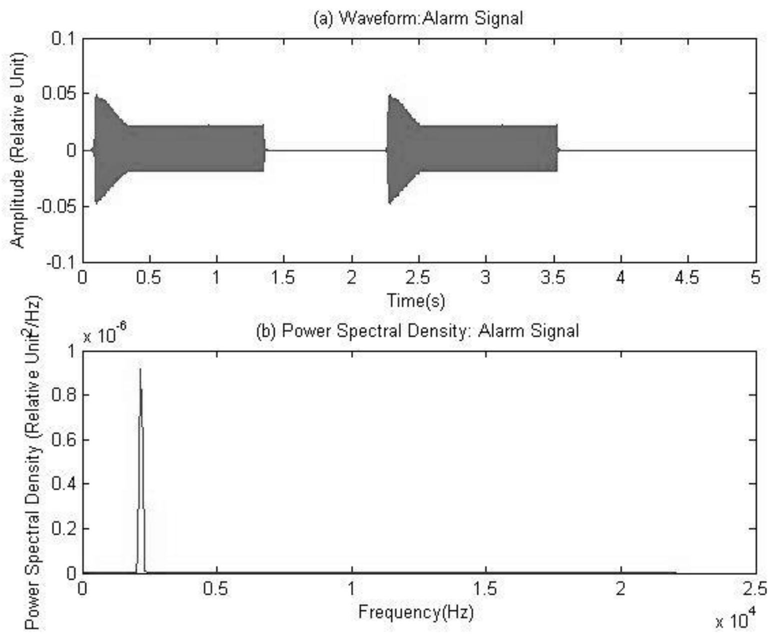

Figure 1: Temporal and spectral characteristics of the alarm signal (Power spectrum used FFT length of 512 and Hanning window)

Subjects were seated in front of a computer screen and listened to the audio clip presented. While listening, subjects used a hardware slider bar to rate the perceived loudness of the alarm in a scale from 0 to 100 (Figure 2). The position of the slide bar was sampled at 10Hz using the Phidget® system. As the alarm signals changed once every 5s (i.e., 0.2Hz), 10Hz sampling should be fast enough to measure the perceived changes of loudness as represented by positions on the sliding bar. Before the experiment, subjects were trained to anchor the 0 position to -∞dB condition in the presence of 80dBA noise and the 100 position to the -18dB condition in the presence of noise. The screen was only used to present the instructions before the experiment and we acknowledge that the screen can be replaced by a paper instruction.

Three speakers were used to present the audio stimuli. Two speakers placed on the left and right sides broadcasted the 80dBA pink noise (the 80dBA level was measured at the two ears of the subjects) and the third speaker in the front broadcasted the alarm signal (Figure 2). The positioning of the speakers was reconstructed from a real industry setting taken from a consulting study.

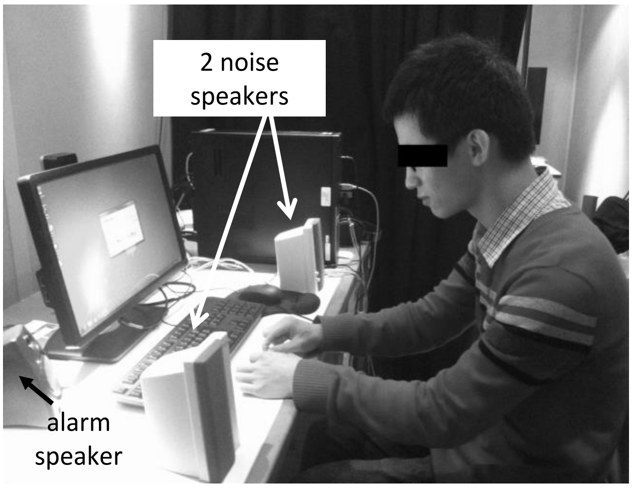

Figure 2: Experiment setup

Twelve subjects (7 male and 5 female) with no known hearing impairments participated in the experiment. The average age of the subjects was 25 years. They were tested to have hearing thresholds at 20dB or below at 500Hz, 1 kHz and 2 kHz for left and right ears, respectively. The deviation of hearing threshold of both ears was 5dB or less for all subjects.

Results

Data obtained from the first 8 subjects are analysed and reported in this paper. The full data set will be presented at the conference.

Figure 3 shows the average positions of the slide bar during the 5 second presentation of each of the four conditions. The starting positions for each condition were different because there was no break between the 60 stimuli and the starting position of the slide for each stimulus would be the ending position of the immediate preceding stimulus. Inspections of Figure 3 show that the positions for each condition asymptotically approached a final level.

To test the effects of convergence, average slider positions measured within each 0.5 second segments were extracted and compared using Friedman two-way ANOVAs and Wilcoxon signed ranked tests. Friedman and Wilcoxon tests were used so that data collected from the same subjects but in different time segments were directly compared with each other. Results of Friedman tests indicated that, at all levels of SNRs, time of measurement (within the 5 second measurement period) had significant main effects on the slider positions. This is consistent with Figure 3.

Results of Wilcoxon tests indicated that the slider positions collected in the last 0.5 second period were not significantly different from those collected between 4 and 4.5 seconds and between 3.5 and 4 seconds. This suggests that the slider positions had reached their asymptotical steady levels in the last one second. This is also consistent with Figure 3. Consequently, the slider positions of the last one second were extracted to determine the effects of SNR levels (Figure 4).

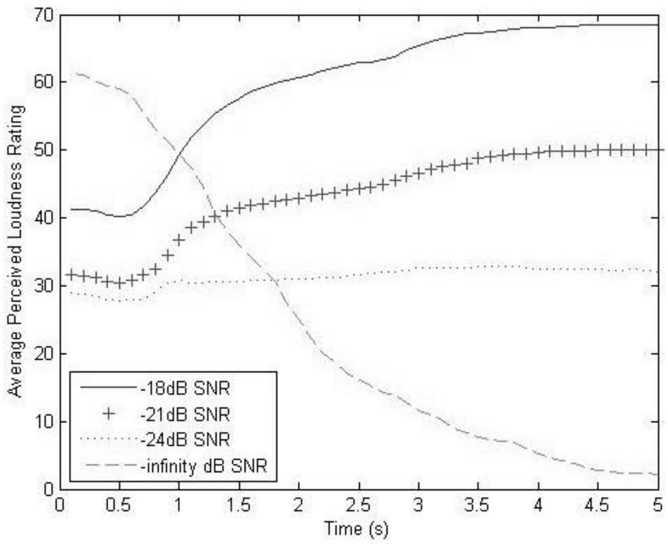

Figure 3: Average changes of slider positions (step responses) during the 5 second alarm stimulus at SNR levels of -18dB, -21dB, -24dB and -∞dB

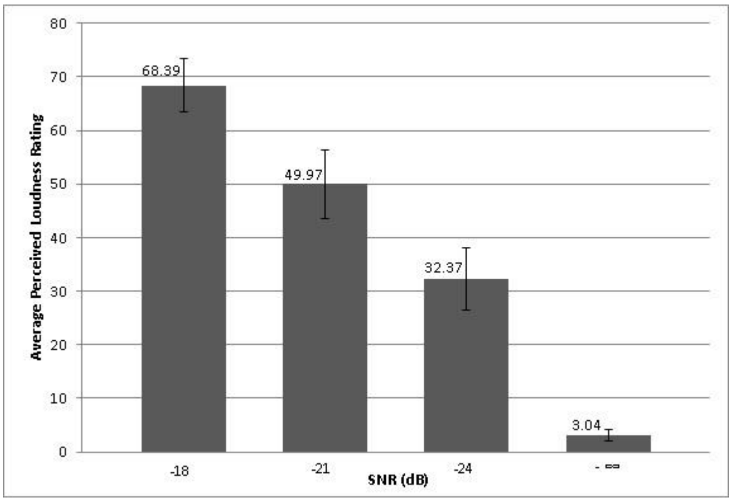

Figure 4: Average perceived loudness ratings as measured by the averaged slider positions in the last second of the 5 second measurement period as a function of different SNR levels (-18, -21, -24 and -∞dB)

A one-way ANOVA test was carried out to analyze the main effects of four SNR levels on the averaged slider positions during the last second of the stimuli. The result showed that the effect of SNR levels was statistically significant ($p<0.05$). Student-Newman-Keuls (SNK) post hoc testing revealed that data from all four SNR levels were significantly different from each other. This suggests that, in the presence of 80dBA pink noise, subjects were able to hear an alarm with SNR of -24dB and discriminated the presence of an alarm from the absence of an alarm.

Conclusion and Future Work

Persons with normal hearing are able to detect an alarm in the presence of 80dBA pink noise even with a SNR level of -24dB. This result helps towards the establishment of thresholds boundaries for audible alarms in the presence of loud noise. This is important in industrial safety procedures where the background noise levels are high and detecting alarms is critical.

Further studies with pure tones as signals will be conducted. Also an effort to simulate the reported phenomenon using an auditory model developed by Professor Raymond Meddis is continuing (Meddis, 2006a, b). The objective of the simulation is to examine the role of efferent feedbacks in alarm detection in the presence of loud noise.

Acknowledgement

The authors would like to thank the Hong Kong Research Grants Council for partially supporting this study. We are also thankful to Prof. Raymond Meddis

for his kind comments on the manuscript and support for latter computational analyses and modelling of the data.

References

Carter, N.L. and Beh, H.C. 1987, *The effect of intermittent noise on vigilance performance*. J. Acoust. Soc. Am., Vol. 82, No. 4, 1334-1341.

Edworthy, J., Loxley, S., and Dennis, L. 1991, *Improving auditory warning design: relationship between warning sound parameters and perceived urgency*. Human Factors, vol. 33, 205-231.

Elliot, L.L. and Katz, D.R. 1980, *Children's pure tone detection*. J. Acoust. Soc. Am. Vol. 67, No. 1

Guillaume, A., Drake, C., Rivenez, M., Pellieux, L., and Chastres, V. 2002, *Perception of urgency and alarm design*. Proceedings of the 8th International Conference on Auditory Display (pp. 357-361), Kyoto, Japan.

Haas, E.C. and Casali J.G. 1995, *Perceived urgency of and response time to multi-tone and frequency-modulated warning signals in broadband noise.* Ergonomics, 1995, Vol. 38, No. 11, 2313-2326

Hellier, E. J., Edworthy J., & Dennis I. 1993, *Improving auditory warning design: quantifying and predicting the effects of different warning parameters on perceived urgency*. Human Factors, vol. 35, no. 4, 693-706

Meddis, R. (2006a) *Auditory-nerve first-spike latency and auditory absolute threshold: A computer model*. J. Acoust. Soc. Am. 119, 406–417.

Meddis, R. (2006b) *Reply to comments on 'Auditory-nerve first-spike latency and auditory absolute threshold: A computer model'*. J. Acoust. Soc. Am. 120(3), 1192-1193.

Patterson, R. D., Milroy, R. and Lutfi, R. A. 1982, *Detecting a repeated tone burst in repeated noise*. J. Acoust. Soc. Am., Vol. 73, No. 3, 951-954.

Pfafflin, S.M. and Mathews, M.V. (1965) *Detection of auditory signals in reproducible noise*. J. Acoust. Soc. Am. 39(2), 340-345.