DETECTSOUND VERSION 2: A SOFTWARE TOOL FOR ADJUSTING THE LEVEL AND SPECTRUM OF ACOUSTIC WARNING SIGNALS

Y. Zheng, C. Giguère, C. Laroche, C. Sabourin
Programme d'audiologie et d'orthophonie, Université d'Ottawa, Ottawa, Ontario K1H 8M5

1. INTRODUCTION

Improper uses of warning signals are quite common in the workplace. In a study carried out in a steel plant [1], 93 different conditions where warning signals are used were surveyed. Results revealed that in 40% of the cases, the signals were not properly adjusted to effectively warn of safety hazards when hearing protection was worn. Another quite common problem was to deliberately set the warning signals at excessively high levels. Other researchers have reported that the signal level could be 20 dB above necessary in some cases [2].

Organizations focusing on health and safety in the workplace have proposed some theoretical models for designing warning signals [3], but none provides a comprehensive solution to this problem. Detectsound Version 1 released in 1991 [4] seems to be the first of practical software tool for predicting the detectability of acoustic warning signals in real-life conditions, taking into account the hearing status of the target population, the background noise in the workplace and the wearing of hearing protection.

Since it was developed, Detectsound has been used to design safer warning signals and to propose modifications for existing signals in term of spectral content and overall sound pressure level. Despite its success, the needs for new features and improvements have been emerging in the past decade. This article presents a comprehensive revision of Detectsound to update the main algorithm and to expand the available options to account for the hearing status of workers.

2. METHOD

In Version 2, an algorithm reflecting the direct estimation of masked thresholds is adopted, instead of the loudness estimation procedure used in Version 1. As proposed by Moore et al. [5], the estimation of masked thresholds is based on the background noise spectrum and the frequency selectivity data (K & ERB) for the target worker. The equation is:

$$P_s = K\int_0^{\infty} N_{(f)} W_{(f)}\, df \qquad (1)$$

where P_s is the power of the signal at the detection threshold in noise, $N(f)$ is the masker spectrum, K is the detection efficiency constant, and $W(f)$ is the auditory filter shape of the worker. The latter can be described by:

$$W(g) = (1+pg).exp(-pg) \qquad (2)$$

where $g = |f - f_0|/f_0$ is the normalized frequency, $p = (4\times f_0)/ERB$ is the slope of the auditory filter, f_0 is the centre frequency of the filter, f is the frequency (Hz), and ERB (Hz) is the Equivalent Rectangular Bandwidth of the auditory filter.

This improvement avoids the complexity and estimation errors arising from loudness estimation procedures and facilitates individualized estimation. $W(f)$ and K can describe the frequency selectivity data of either a specific individual or worker, or a statistical population of workers.

The latest normative data on hearing sensitivity shift [6] (ISO 1999-1989) and frequency selectivity change with hearing loss have been integrated into Detectsound. ISO 1999 allows predicting the effect of long-term noise exposure and aging on hearing loss for otologically normal population. Frequency selectivity can also be estimated based on published normative data [7,8].

A software tool, Detectsound Version 2, reflecting the algorithmic improvements over the previous version has been developed, complete with a new and improved graphic user interface [9].

3. RESULT

Individual hearing status can now be accounted for in Detectsound Version 2. Figure 1 gives an example of Detectsound's application to analyzing the functional requirements of a specific worker Y. The measured hearing status for this worker is shown in Table 1. The background noise is machinery room noise at a level of 87.2 dBA, and no hearing protection is used.

Table 1. Measured hearing status of worker Y (Left ear)

Frequency (Hz)	250	500	1000	2000	3000	4000
THR(dB HL)	6	3	2	6	6	18
ERB (Hz)	57	93	173	321	487	1013
K (dB)	3.9	3.4	-0.7	1.0	-1.2	-

The predicted optimal range (Design window) of warning signal levels at various frequencies is shown in Figure 1 for the above worker Y. To facilitate recognition of warning signals, a level of 10-15 dB above masked thresholds has been proposed [3]. Thus, in Detectsound, the lower and upper boundaries of the design window are defined to be 12 dB and 25 dB above the estimated masked thresholds respectively, with a maximum of 105 dB SPL to prevent overly loud sounds. The frequency components falling within the design window are optimally adjusted. If the number such components is three or more, the signal is considered to be effective for worker Y.

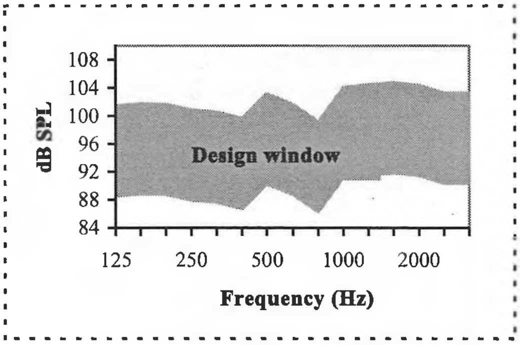

Figure 1: Warning signal design window applicable to worker Y

Detectsound Version 2 can also be used to find optimal signalization solution for several workers sharing a common work area, or for populations of different hearing status. A comparison conducted between the two versions of Detectsound also suggests that Version 2 gives out more accurate predictions [9]. Figure 2 illustrates the comparison result. The target population consists of 6 normal hearing subjects, and the background noise at white noise of 80 dB SPL. The observed data are measured masked thresholds from an independent validation study.

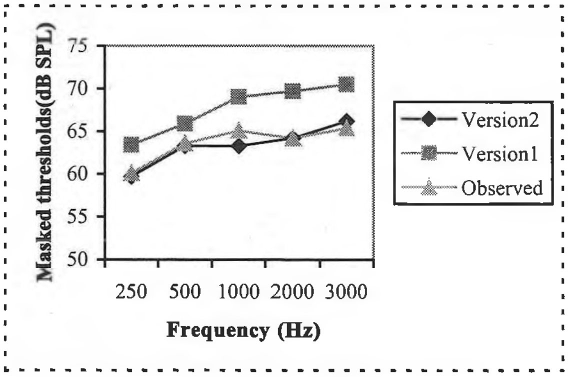

Figure 2. Prediction accuracy for two versions of Detectsound

An average overestimation of 4 dB is found for Detectsound Version 1 across frequencies from 250 to 3000Hz, while Version 2 carries an average underestimation of only 0.3dB.

4. DISCUSSION

Detectsound Version 2 provides a more complete solution for warning signalization in the workplace. If the hearing status of a specific worker is fully known, the analysis result is tailored to meet the functional requirements of that worker. The analysis result can also be made to suit the needs of a population of workers if the hearing status of this population is considered. Detectsound Version 2 can also make predictions based on estimated hearing thresholds and frequency selectivity data, and this expands its application to situations where the hearing status of the workers are unavailable (such as planning a new plant). The predictions by Version 2 are also more accurate.

One current limitation of Detectsound Version 2 is that it cannot be applied when the background noise spectrum is unspecified. The integration of Detectsound with a sound propagation model inside industrial plants is proposed. The latter could predict the noise distribution within a workplace given the noise sources, and provide Detectsound with the required background noise data needed for the design of acoustic warning signals.

[Work funded by an NSERC Collaborative Health Research Project Grant, Canada].

5. REFERENCES

1. Tran Quoc, H., Hétu, R., and Laroche, C. (1992). "Computerized assessment and prediction of the audibility of sound warning signals for normals and hearing-impaired individuals", in M. Matilla and W. Karwowski (eds.), *Computer applications in ergonomics occupational safety and health* (Elsevier, Amsterdam), pp. 105-112.

2. Patterson R.D., & Milroy, R. (1980). "The appropriate sound level for auditory warnings on civil aircraft", J. Acoust. Soc. Am. 67, S58.

3. ISO 7731 (1986). "Danger signals for work places -- Auditory danger signals", International Organization for Standardization, Geneva.

4. Laroche, C., Tran Quoc, H., Hétu, R., and McDuff, S. (1991). ""Detectsound": A computerized model for predicting the detectability of warning signals in noisy workplaces," Applied Acoustics, 32: 193-214.

5. Moore, B.C.J., & Glasberg, B.R., (1987). "Formulae describing frequency selectivity as a function of frequency and level, and their use in calculating excitation patterns", Hearing Res., 28:209-225.

6. ISO 1999 (1989). "Acoustics – Determination of occupational noise exposure and estimation of noise-induced hearing impairment", International Organization for Standardization, Geneva.

7. Laroche, C., Josserand, B., Tran Quoc, H., Hétu, R., and Glasberg, B.R. (1992). "Frequency selectivity in workers with noise-induced hearing loss," Hearing Research 64: 61-72.

8. Moore, B.C.J., & Glasberg, B.R., (1996). "A revision of Zwicker's loudness model", Acta Acustica, 82, 335 –345.

9. Zheng, Y. (2003). "Development of new "Detectsound" – A computerized model for adjusting the level of acoustic warning signalization in workplaces", Master's Thesis, University of Ottawa, Canada.