AUDIBILITY OF SIGNALS AND ALARMS IN A COAST GUARD ENVIRONMENT

Chantal Laroche
Audiology and Speech Pathology
Faculty of Health Sciences
University of Ottawa
Ottawa, ON K1N 6N5

Murray Hodgson
Occupational Hygiene Program
Dept. of Mechanical Engg.
University of British Columbia
Vancouver, BC V6T 1Z3

Laurel Ritmiller
BC Research Inc.
3650 Wesbrook Mall
Vancouver, BC V6S 2L2

Stanley Forshaw
3958 Sherwood Rd.
Victoria, BC V8N 4E6

1. INTRODUCTION

This paper is a report on one phase of a research project aimed at developing occupational hearing criteria for the Canadian Coast Guard (CCG). The overall objective was to propose reliable criteria specifying whether or not CCG ship personnel have adequate hearing abilities to carry out their jobs proficiently. In three companion papers (Ritmiller *et al.*, 1999, Hodgson *et al.*, 1999, Forshaw *et al.*, 1999), details are given about the prediction of speech intelligibility in noise, one of the most important hearing abilities necessary to perform CCG duties safely. An additional concern addressed in this paper is the audibility of signals (e.g., sound of telephone ringing) and alarms (e.g., radar alarm). In CCG environments, the perception of auditory signals and alarms is crucial to ensure safety of people and equipment. The assessment of the different auditory signals and alarms collected on the CCG vessels (Ritmiller *et al.*, 1999) were performed with a computerized model, called DETECTSOUND™ (Laroche *et al.*, 1991). This model has been used previously in different environments (Laroche and Lefebvre, 1998; Proulx *et al.*, 1995).

2. DETECTSOUND ™ MODEL

DETECTSOUND™ allows users to determine the characteristics of warning sounds to be used in a specific environment or to evaluate the effectiveness of the warning sounds currently used in an environment. The foundations of the model have been presented in a previous paper (Laroche *et al.*, 1991). DETECTSOUND™ considers the following information:

- the background noise at each workstation (1/3 octave band levels from 25 to 12,500 Hz);
- the hearing protectors worn by a standard individual or by specific individuals (attenuation in dB from 63 to 8,000 Hz);
- the audiogram of a standard individual or the actual individuals assigned to a workstation (hearing thresholds from 125 to 8,000 Hz);
- all warning sounds that can be heard at the station (1/3 octave band levels from 25 to 12,500 Hz).

The loss of frequency selectivity (i.e., the ability of the ear to extract a sound signal in a background noise) is also taken into account in the software. It is statistically related to the loss of sensitivity.

These factors are analyzed together and the results are displayed in a graphic or a table form. Figure 1 is an example of a graphic display. In Figure 1, the frequency content is presented on the x axis and the level of each 1/3 octave band of the noise or the warning sound is on the y axis. The full horizontal line corresponds to the background noise level at the workstation. The vertical lines correspond to the spectral content of the signal heard at this workstation. The dark zone represents the "hearing window" (i.e., the spectral and level region in which at least three spectral lines of a warning sound should be in order to attract attention and be recognized among different warning sounds). This zone is based on the masked threshold (i.e., hearing threshold in noise) computed for each third octave band to which 13 to 25 dB is added. These last values are extracted from the ISO 7731 standard (1986) and other publications (Patterson, 1982).

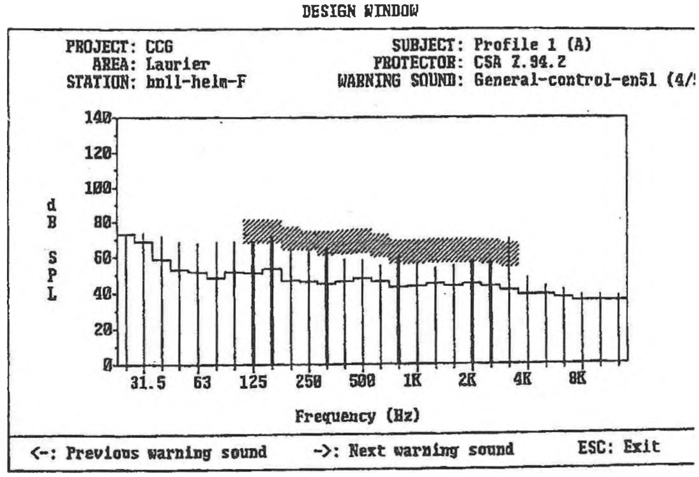


Figure 1: Graphical display of the "hearing window" for a particular workstation and a particular sound signal

According to the ISO standard (1986), at least one spectral component should reach the "hearing window". In order to address fluctuations in background noise common in work environments, many authors have suggested that more than one component must reach the "hearing window". This ensures that if one component is temporarily masked by the background noise other components would then be available. In Figure 1, the alarm should be well perceived and recognized by people with normal hearing because six spectral lines are inside or at the borders of the "hearing window". If all the spectral lines would have been below the design window, modifications would have been required. For example, the spectral content of the warning sound should have been changed, the signal level increased or the background noise reduced. If the lines would have been over the design window, the warning sound level would have been too high and could have caused hearing damage, interference with communication or a startle reaction. Based on these facts, a specific method of analysis was developed.

3. METHOD

The purpose of this phase of the project was to estimate the low fence for auditory signal-perception in terms of sensorineural hearing loss. Hence, an array of hearing losses was prepared to encompass the range within which the low fence was likely to occur. As explained in a companion paper (Forshaw *et al.*, 1999) twenty hearing threshold level (HTL) profiles were defined, based on the epidemiological data published in ISO Standards 7029 (1982) and 1999 (1988), and represent typical manifestations of noise-induced and age-related hearing losses. The resulting HTLs at .5, 1, 2 and 4 kHz are shown in Table 1 of the companion paper (Forshaw *et al.*, 1999) for five of the profiles.

In order to run DETECTSOUND™, the 1/3 octave-band levels of each signal or alarm and each background noise (for the same position in space) have to be entered. The data were collected using a Rion Type 1 sound level meter and a digital audiotape recorder at each workstation where an alarm or signal was used.

For the hearing protectors requirement of DETECTSOUND™, the attenuation values of a Type A protector (CSA Z94.2 Standard, 1994) were used. These values were used only for workstations where hearing protectors were normally worn. The CSA Z94.2 Standard was used because of the variability in the type of hearing protectors used on CCG vessels. By using Type A values, we were confident that the predictions would be conservative.

To determine the low fence for signal perception, each alarm or signal was analysed according to the following decision matrix (Table 1).

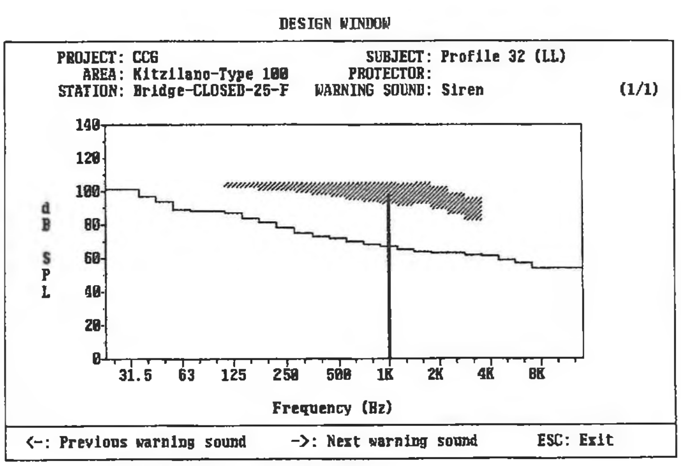
Table 1: Decision matrix for signal and alarm perception using the DETECTSOUND™ model

(++)	3 or more components in the "hearing window"
(+)	1 or 2 components in the "hearing window" and some under, but above noise level
(+-)	1 or 2 components in the "hearing window"
(-)	All components under the "hearing window" but above noise level
(--)	All components under noise level

The low fence was set at the lowest HTL profile for which the (+-) label was met, for each alarm and signal. This decision represents a compromise and was motivated by the ISO 7731 standard (1986) which states that one component should at least be well over the background noise, and the fact that the (++) label would be the ideal situation. In fact, in this project, the (++) label was not achieved in many situations, mainly due to high background noises, low levels of signal or a limited number of spectral components in the signal. In certain background noises, DETECTSOUND™ predicted that it was even impossible for people with HTL Profile 1 (best hearing profile) to perceive the signal.

4. RESULTS AND DISCUSSION

Figure 1 showed an example of a (++) label for a specific alarm on a specific vessel. Figure 2 shows an example of (+-) label, which would represent the low fence HTL profile for this specific alarm.



Overall, the minimum signal perception HTL profile was less than the minimum speech perception profile. This finding is not surprising as speech perception in noise refers to much more complex auditory abilities than signal perception. This phase of the project has nevertheless shown that many alarms or signals have not been designed or chosen as a function of the background noise, worker hearing loss and the wearing of hearing protectors. It is important to mention that all these results are based on prediction models and would have to be validated on human subjects in order to propose hiring criteria which takes into account more than just hearing sensitivity.

5. ACKNOWLEDGEMENT

This work was supported by Transport Canada-Transportation Development Centre (TDC) and the Canadian Coast Guard (CCG) under contract T8200-5-5567/A. The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official TDC or CCG policy or decision unless so designated by other documentation.

6. REFERENCES

C.S.A. (1994) *Hearing Protectors.* Canadian Standards Association, Standard Z94.2.

Forshaw, S., Ritmiller, L., Hodgson, M., Laroche, C. (1999). Estimates of speech intelligibility based on equivalent speech- and noise-spectrum levels and hearing thresholds. *Canadian Acoustics*, 27(3).

Hodgson, M., Forshaw, S., Ritmiller, L., Laroche, C. (1999). Characterizing ship acoustical environments for speech communication. *Canadian Acoustics*, 27(3).

ISO (1982). *Acoustics-Threshold of Hearing by Air Conduction as a Function of Age, Sex for Otologically Normal Persons.* International Organisation for Standardization, Standard 7029.

ISO (1986). *Danger signals for workplaces-Auditory danger signals.* International Organisation for Standardization, Standard 7731.

ISO (1988). *Acoustics-Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment.* International Organisation for Standardization, Standard 1999.

Laroche, C., Lefebvre, L. (1998). Determination of optimal acoustic features for reverse alarms. *Ergonomics*, 41, 1203-1221.

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

Patterson, R. (1982). Guidelines for auditory warning systems on civil aircraft. *CAA Paper 82017*, Civil Aviation Authority, London.

Proulx, G., Laroche, C., Latour, J.C. (1995). Auditory problems with fire alarms in apartment buildings. *Proceedings of the Human Factors and Ergonomics Society*, 39th Annual Meeting, San Diego, 2, 989-993.

Ritmiller, L., Forshaw, S., Hodgson, M., and Laroche, C. (1999). Development of bona fide occupational requirements for hearing in Canadian Coast Guard operations. *Canadian Acoustics*, 27 (3).