Achieving Balance between Benefits and Costs:
Finding Appropriate Levels for Alarm Sounds in a Nursing Unit

Introduction and Background

Each decision we make, being a simple or difficult one, has its benefits and costs. For example, the designer of the smoke detector in my kitchen has decided to make the beep as loud as possible to ensure I can hear it once it is activated. However, the beep is so loud that I cannot focus on what has happened to my stove while it is on; I have to turn the alarm off before I can save my kitchen. The benefit of the designer's decision is that I immediately become aware of a potential fire, while the cost is that my normal function is interrupted by the annoying loud sound.

Similar situations exist in a hospital. The workstation of a nurse is equipped with various alarm sounds indicating that an emergency may have occurred. Of course, these alarm sounds should be clearly audible to the nurse, so she can immediately pay attention to the patient, but the level of the alarm cannot simply be set as loud as possible, like the smoke detector in my kitchen. This is because first we do not want the nurse to be startled by the alarm, as I am by the smoke detector. More importantly, a nursing station is not far away from patient rooms. If alarm sounds are too loud, they will be heard by the patients, which may result in some negative effects for patient care.

The current study attempts to determine scientifically an appropriate level for an alarm sound, aiming to balance the benefits and costs in the above nursing unit situation. One may think that the loudness of an alarm sound can be adjusted as simple as adjusting the volume of one's music on an iPhone. However, it may not be possible to set the level by trial and error, as the problem is complicated by several issues. First, a hospital is not a quiet environment. The average ambient noise level can be as high as 72 dB(A) (Choiniere, 2010). Ambient noise can make the detection of alarm sound difficult if the alarm is not loud enough. This phenomenon is known as *auditory masking*. An analysis of the noisy environment where alarm detection occurs is needed in determining the lower limit of the appropriate level of alarm sounds. Second, there is a critical level beyond which alarm sound detection performance is good enough. This critical level is called the *auditory threshold*. Beyond threshold, further increase of the alarm level does not help detection, but the costs associated with increasing level continue to rise. Therefore, finding the auditory threshold in a certain noisy environment is vital for achieving the balance between costs and benefits in the current situation.

Patterson (1982, 1990) has developed several guidelines for auditory warning systems on civil aircraft and in general working environment. The rationale behind the guidelines is the *power-spectrum model of auditory masking*. This type of model may not be perfect, but it could be very useful. It is based on psychoacoustic studies conducted over the past several decades. Before any human subject is involved, Patterson's guidelines based on the power-spectrum model will be used to predict the auditory threshold imposed by a relatively steady-state noisy background. The lower limit and upper limit of the appropriate alarm level are then determined based on the threshold. Finally, human subjects could be involved to validate or modify the alarm settings based on the prediction.

Specific Aims, Methodology and Anticipated Results

The environment for this study is the nursing unit and patient rooms on the 6th floor of Richard M. Ross Heart Hospital. The alarm sounds are four different alarm sounds installed on the nursing workstation computers there.

Phase I: Laboratory Analysis

The first step is to do a *spectral analysis* of the environmental noise and the alarm sounds, respectively. (Hospital ambient noise and alarms are complex sounds in which multiple *frequency components* exist. Each frequency component has its unique power. Spectral analysis produces the *power spectrum* of a complex sound.) Before we can do spectral analysis of the noise, we need to sample the noise in the nursing unit. Past study (Choiniere, 2010) suggests that daytime noise levels are higher than nighttime noise levels, thus the sampling will occur several times a day to account for the variation. During daytime, there should be a time interval with the highest noise level. If threshold is derived and alarm level is set simply according to this highest noise level, the alarm could be too loud at night, and patient sleep may be disturbed.

To do spectral analysis of the alarms, we will play alarm sounds through computer loudspeakers that are like those on the nurse workstation. The alarm sounds will be analyzed in isolation by reproducing them in an anechoic chamber. The spectral analysis will be done using a Brüel & Kjær sound level meter (type 2270) coupled to an acoustic manikin (KEMAR). Using the KEMAR manikin allows us to account for the filtering characteristics of the ears of a typical adult listener.

After the spectra of alarm sounds and work area noise environments are obtained, auditory threshold will be predicted based on the power-spectrum model (Patterson, 1982). Further, the lower limit of the appropriate level will be determined as 15 dB above the threshold and upper limit will be 25 dB above threshold according to the guidelines. Note that this upper limit only accounts for the annoying effect that an alarm may have on a nurse. Our other important goal is not to allow the alarm to be audible to patients in patient rooms located several meters away from the nursing station. Therefore, the upper limit may be further constrained by this factor. Further analysis of alarm detection in the patient room is needed here.

Phase II: Evaluation in Clinical Setting

Comparison between the range of appropriate level found in the previous step and the power of frequency components of each alarm sound will be made to adjust levels individually for each alarm sound. After this has been done, alarms set to the recommended levels will be tested with human subjects (nurses and patients) in the Ross Heart Hospital. Phase II will require IRB approval, but Phase I will not. An application for approval will be submitted and revised as needed before any human experimentation is undertaken. Further adjustment may be needed to make sure the benefits and costs are indeed balanced.

Interdisciplinary Nature of the Project

The design and evaluation of alarm sound should consider human factors to take advantage of human strengths. The psychology of hearing serves as part of the knowledge base. For example, the power-spectrum model of auditory masking applied in finding appropriate levels for alarm sound is a product of acoustics, biology and psychology. The interdisciplinary nature of the current project is obvious.

More generally, alarm sound helps a control system to convey information to operators. Numerous human-centered research questions could guide the future direction of the current project. For example, how to enable alarm sounds to convey different levels of urgency, how to assist operators' learning and retention of alarm sounds and how do operators react to alarm sounds under conditions of uncertainty. The investigation of these topics requires some modeling work of signal detection / identification and decision-making processes. Thus, the expertise of Dr. Feth (Psychoacoustics) and Dr. Rayo (Human Factors and Alarm Design) are combined in the mentorship of this project.