INCREASING DETECTABILITY AND REDUCING ANNOYANCE OF ALARM DESIGN USING ACOUSTIC STRUCTURES OF MUSICAL INSTRUMENTS

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1 Introduction

Auditory alarms are critical to relaying crucial information in high-consequence industries. For example, in a healthcare context these alerts convey important information on patient physiologic status, with potentially catastrophic consequences for missed alarms. The current auditory alarm standard within hospitals [1] uses simplistic tones with non-temporally varied structures (flat tones), whose drawbacks have been discussed extensively [2]. Hospital alarm design have a 'better safe than sorry' approach, leading to an excess of sounds. Alarm rates in hospitals can hover around 350 alarms per patient per day [3], with only 0.5% indicating life threatening events [4]. This sheer numerosity of non-urgent alarms causes alarm fatigue which has led users to ignore or silence alarms, which can lead to negative consequences for staff and even patient deaths [5].

As many issues with alarms are intractable (i.e., numerosity), our team focuses on one specific and readily addressable issue—the lack of temporal and harmonic complexity. We have found that tones with varied amplitude envelopes and more complex harmonic structures reduce annoyance and increase detectability [6], although their relative scarcity in auditory psychophysics [7] seems to have led to lesser use in auditory interfaces [8]. The percussive triangle instrument is capable of piercing through the rich acoustic wall produced by large orchestras without being annoying, making it an interesting source of information on improving alarm efficacy.

In this study we test whether the complexity of musical triangle instrument can increase detectability (experiment 1) while reducing annoyance (experiment 2).

2 Methods

2.1 Participants

We conducted all experiments with psychology students at McMaster University in Hamilton, Ontario, who received course credit for completing in person and online experiments.

2.2 Apparatus

We used *Psychopy* [9] for the creation of all the experiments, which is hosted on the online experimental services *Pavlovia*.

For experiment 1 of detection, participants ran through trials in an IAC Controlled Acoustical Environment room to reduce any excess sounds and used Sennheiser HAD 200 over-ear monitor headphones throughout the study.

For experiment 2 on perceived annoyance, a new set of participants used their own computer and headphones and told to maintain the same volume level across the experiment.

2.3 Procedure

For experiment 1, we used a coordinated response measure (CRM) to test for detectability [10]. Participants listened to a target voice with an assigned callsign directing them to press one of the 16 coloured/numbered square on a computer monitor. Two additional voices 500ms prior and 500ms after the target acted as distractors. In addition to these three voices, participants listened for a tone, which sounded at one of six signal-to-noise ratios (SNRs, figure 2 left). Participants pressed the "space" key on their keyboards whenever they detected a tone. The triangle tone or the standard flat tone was presented randomly at each SNR level with a total of 216 trials, lasting 45 minutes.

For experiment 2, participants completed a two-alternative forced choice task evaluating the relative annoyance tones presented in pairs. Each tone was randomly presented to the participants, using the six signal amplitude levels measured in Root Mean Squared decibels (RMS dB, figure 2 right), the same levels used from the prior procedure. A randomly selected tone-RMS pairing was played and simultaneously the letter "A" was presented on screen. After three seconds the letter "B" appears on the screen and randomly plays another tone without replacement. A prompt asked the participant, "Which tone is more annoying?" and asked to press "A" or "B" on their keyboard to indicate the tone with higher perceived annoyance. The study continued until all comparisons of tones-RMS pairings are completed, with a total of 132 trials lasting 30 minutes.

2.4 Stimuli

Each experiment used a single set of stimuli, consisting of two kinds of sounds (a) "standard flat" and (b) "triangle inspired" tone seen in figure 1. We synthesized all sounds using the *MAESTRO* software [11], built in the *Supercollider* sound synthesis program [12].

The standard flat tone consists of a constant amplitude with a 20ms rise, 20ms fall, and 960ms sustain at every component containing a flat amplitude envelope. With five harmonic components at 261, 523, 783, 1046 and 1305 hertz (Hz), all components have equal energy.

The triangle inspired tone is based on a sample from *Spitfire Audio's BBC Orchestra* sample library [13]. We selected

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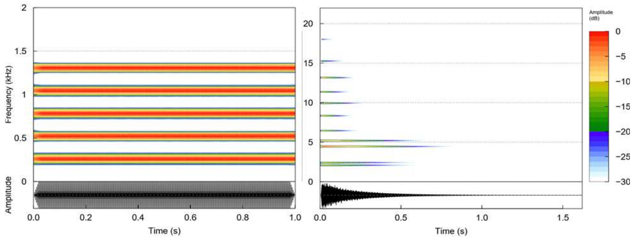

Figure 1: Power spectra and waveforms of the standard flat (left) and triangle inspired (right) tones. Y-axis for power spectra represents Frequency in kHz, and the Y-axis for the waveform represent relative amplitude. X-axis is time in seconds.

the twelve most prominent frequency peaks along with their durations and varied temporal amplitude changes. Its frequencies are 2093.0, 2430.01, 4462.1, 5202.8, 6462.5, 8344.9, 9941.7, 11361.0, 13161.9, 15265.6, 18010.5, and 20778.3 Hz, with relative amplitudes at 0.31, 0.32, 1, 0.6, 0.3, 0.35, 0.34, 0.31, 0.43, 0.17, 0.1, 0.01. The triangle inspired stimuli consist of a 5ms attack, 5ms sustain, 1.6s delay and an off curve of -10 for a percussive amplitude envelope. Both tones have equated RMS.

3 Results

3.1 Experiment 1 – Signal Detection

We used an analysis of variance (ANOVA) to analyze detection between the standard flat and triangle inspired tones, with a total of 31 participants. We analyzed the effect of SNR on tone detection with a 2x6 factorial ANOVA, revealing a significant effect on tone type F(1,408)=37.3, *p*=<.001, and SNR F(5,408)=4.19, *p*=<.01. We found no significant interaction between SNR and tone type F(5,408)=1.61, *p*=0.15.

We also analyzed the effect of each tone alone on SNR with a one-way ANOVA. We found a significant effect of SNR on the standard flat tone F(5,204)=7.06, *p*=< .001. However, there no significant effect of SNR on the triangle inspired tone F(5,204)=0.43, *p*=0.83.

3.2 Experiment 2 – Perceived Annoyance

For this second experiment, we used a chi-square test (X^2) to analyze perceived annoyance for all 34 participants. We found a significant effect for RMS $X^2(5, N=4488)=478.01$, $p<.001$ and for tone type $X^2(1, N=4488)=36.0$, $p < .001$.

4 Discussion

Reductions in energy lowered the detectability of the standard flat tone but had no effect on the triangle-inspired tone. Consequently, it appears sounds based on the triangle can be played at a greatly reduced volume without sacrificing detectability relative to standard designs—although they lead to significantly less annoyance.

5 Conclusion

This study shows one way in which musical sounds can offer useful insight to improve the efficacy of auditory alarms design in high consequence industries.

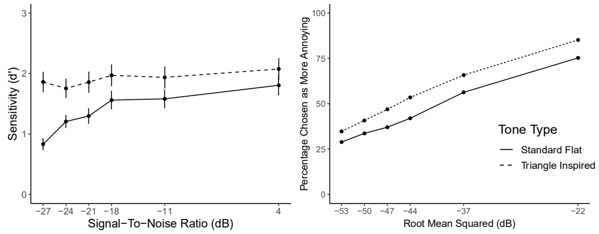

Figure 2: Experiment 1 (left), y-axis measures sensitivity measured in d prime, x-axis represents signal-to-noise ratio (SNR) in decibels (dBs). Error bars: 95% confidence interval. Experiment 2 (right), y-axis measures the percentage chosen as more annoying, x-axis represents root mean square (RMS) in decibels (dB).

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