Using the method of adjustment to enhance collision warning perception

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The psychophysical method of adjustment procedure was used in two experiments to examine parameters necessary for a sound to be perceived as an urgent warning. In the first, participants were only able to adjust one parameter at a time and in the second participants were allowed to adjust all four parameters simultaneously. Participants’ adjusted frequency, pulse duration, inter burst interval, and pulses per burst of a standard sound in ascending and descending order. Both studies revealed highly similar results indicating that collision warning sounds might be more effective if they have a base frequency of approximately 1000 Hz, consist of three pulses per burst and if pulse is no more than 500 ms in duration with a 20 ms onset and offset time and no more than 410 ms between each burst. Further examination of these parameters in simulated and on-road driving is warranted.

Keywords: auditory warnings, method of adjustment, warning design, psychophysical methods

1. Introduction

In recent years we have seen a steady increase in the amount of technology in modern vehicles. In-vehicle systems can provide various types of information to the driver ranging from highly critical information like collision warnings to less important information such as navigational cues or incoming phone calls. Considerable literature now exists demonstrating a wide array of beneficial effects of these in-vehicle systems (Ben-Yaacov, Maltz, & Shinar, 2002; Lee, McGehee, Brown, & Marshall, 2006). Warnings have been shown to help recapture drivers’ attention and reorient them to potentially hazardous events (Ho, 2005; Ho & Spence, 2009; Spence & Santangelo, 2009). Due to the proliferation of informational systems in the modern vehicle it is vital to consider what properties are associated with a signal being perceived as a warning versus some less urgent signal.

Warnings can be presented in various modalities, however research indicates that safety critical warnings should have an auditory component (see reviews in Baldwin, 2012; Barfield & Dingus, 1998. Auditory warnings have the advantage of being perceptible when a driver is not looking at any one specific location (Spence & Ho, 2008). Auditory signals can vary on a multitude of parameters such as frequency, duration, intensity, tempo, and many others. Patterson (1990) note that warnings should have some sort of ramp/build up before being presented at full intensity, suggesting a rise time of 20 ms. Additionally, Patterson (1990) suggest that a warning have a grouped cluster of pulses separated by a relatively short period of time with a subsequent group of pulses following. Lastly Campbell, Richard, Brown & McCallum (2007) suggest that for a warning to be considered urgent it should have a high frequency, contain multiple harmonics, be played at a relatively fast pace, and contain multiple pulses per burst. Understanding these parameters and how they impact urgency is vital for collision warning development.

Psychophysical methods have been employed recently to help understand and investigate the relationship between physical stimuli and their subjective perceptions (Baldwin & Lewis, 2014; Lewis & Baldwin, 2012). Psychophysical methods have been used in a variety of domains for urgency mapping. Urgency mapping is used to ensure that the perceived urgency of a given alert matches the hazard level of the situation (Hellier & Edworthy, 1999). Urgency scaling allows researchers to systematically determine changes in perceived urgency associated with changes in the physical parameter of a given modality. Another potential method that can be used to determine perceptions of particular sounds is interval scaling, or sorting (Hellier, Edworthy, & Dennis, 1995). This method can be used to rapidly sort any number of stimuli into meaningful categories (Block, Buss, Block, & Gjerde, 1981; Bonebright, Miner, Goldsmith, & Caudell, 2005; Viswanathan, Johnson, & Sudman, 1999). Categories can be either predefined or open-ended. By using sorting methodologies it is possible to find commonalities between sounds placed in the same categories. Another way to determine what parameters are needed for a sound to be perceived a certain way is the psychophysical method of adjustment. This method allows individuals to adjust specific stimuli by
increasing or decreasing particular values until a given objective is met. Generally the presented stimulus is distinctly above or below a certain hypothesized criteria and participants are asked to adjust the stimulus until it meets that criteria. This method provides a means of determining the range and average levels of a given parameter that are associated with perceptions of stimuli matching a given criteria.

1.1 The Present Study

The current study utilized the psychophysical method of adjustment to determine the point at which individuals began to perceive an abstract tone as a highly urgent, time-critical collision warning sound. Using a series of ascending and descending parameter adjustments we were able to determine values for acoustic parameters that were critical to a sound being perceived as a collision warning.

2. Methods Experiment 1 – Single Parameter Adjustment

2.1 Participants

Twenty people (13 Female) with an average age of 22.44 provided written informed consent and voluntarily participated. All participants had normal self-reported hearing.

2.2 Warning Stimuli

The base warning tone consisted of a 300 Hz tone consisting of 5 harmonics, with a single pulse that lasted 200 ms. Tones had 20 ms onset and offset times. The base tone was repeated approximately eight times with a 118 ms inter burst interval (IBI) resulting in a total play time of roughly 2500 ms. Sounds were played through Sennheiser headphones via a Matlab program. The Matlab program allowed participants to adjust the base sound on frequency, pulse duration, IBI, or pulses per burst. Each parameter was adjusted one at a time while all other values were held constant. Table 1 shows the maximum and minimum values for each parameter as well as the adjustment increments. During adjustment, the maximum length of the sound was capped at 2500 ms. If an additional pulse would put the max time over 2500 ms then silence was played instead.

Table 1. Warning Stimuli Descriptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Adjustment Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>200 Hz</td>
<td>2500 Hz</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>160 ms</td>
<td>800 ms</td>
<td>40 ms</td>
</tr>
<tr>
<td>IBI</td>
<td>10 ms</td>
<td>800 ms</td>
<td>40 ms</td>
</tr>
<tr>
<td>Pulses Per Burst</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

2.3 Procedure

When participants arrived they signed a consent form and were asked to verify that they had normal or corrected to normal hearing. Then participants were informed that they would be presented with a single sound and that their task was to adjust that sound on either frequency, pulse duration, inter burst interval, or pulses per burst, depending on what the instructions on the screen indicated they should adjust. They were instructed that they were to adjust the sound to either make it sound like a highly urgent, time-critical collision warning or to adjust it until it no longer sounded like a highly urgent, time-critical collision warning. Participants adjusted each parameter a total of six times. Three times they were instructed to make the sound seem like a warning and three times they were to make it no longer seem like a warning. The order of the parameters to be adjusted were completely randomized. Participants were given feedback as to what the current adjustment sounded like in real time such that every time they increased or decreased the value the resulting sound was played. Participants were told that they could adjust the sound as many times as they liked until they were satisfied with their final sound. When participants were making an adjustment on one parameter all other parameters was held constant at their base values.

3. Results
Table 2 shows the mean value for each parameter as well as the value at which 90% of participants agreed that the sound seemed like a highly urgent, time-critical collision warning.

Table 2. Mean values for each parameter and value when 90% of participants found the resulting sound to be a warning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
<th>90% Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>955 Hz</td>
<td>1200 Hz</td>
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<tr>
<td>Pulse Duration</td>
<td>470 ms</td>
<td>360 ms</td>
</tr>
<tr>
<td>IBI</td>
<td>340 ms</td>
<td>240 ms</td>
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<tr>
<td>Pulses Per Burst</td>
<td>2.80</td>
<td>4</td>
</tr>
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</table>

4. Discussion of Experiment 1 – Single Parameter Adjustment

Participants were asked to adjust individual parameters of a base sound to make the resulting sound seem either like a highly urgent, time-critical warning or to make it no longer sound like a highly urgent, time-critical warning. The resulting averages provide specific values at which a sound begins to switch from being a non-urgent, time-critical warning to an urgent, time-critical warning sound. These results indicate that a 950 Hz tone with 3 pulses per burst with each pulse being 470 ms in length and each burst being separated by 340 ms would be perceived as a collision warning for most individuals. However as suggested by the 90% values in order to reach a consensus amongst the majority of people all these parameters would need to be enhanced by increasing frequency and pulses per burst, while shortening pulse duration and inter burst interval.

In this experiment participants were only allowed to adjust one parameter at a time. Allowing participants to adjust only one parameter at a time has several limitations. Most importantly, the interaction of specific parameters can not be examined and the possibility exists that some of these acoustic parameters may have a stronger role in overall perceptions than the others. Additionally it could have been possible that no matter what value a participant adjusted a sound too they may have never been able to make it seem like or unlike a warning. For example, if frequency was the dominant parameter associated with perceived urgency, then all levels of other parameters may be perceived as either warning like or not warning like, depending on the base frequency of the sound being adjusted. In order to resolve these issues and provide some insight into the parameters that might be most important we conducted a second experiment. In Experiment 2 participants were able to adjust all four parameters for a given sound in any order. This was expected to account for the potential of some parameters to dictate overall perceptions.

5. Methods Experiment 2 – Multiple Parameter Adjustment

5.1 Participants

Twenty participants (11 Female) with an average age of 21.32 who had not participated in Experiment 1 provided written informed consent and voluntarily participated in Experiment 2. All participants had self-reported normal hearing.

2.2 Warning Stimuli and Procedure

The base sound was the same sound used in Experiment 1. For this experiment participants were able to adjust all four parameters at the same time. Just like in Experiment 1 the max sound length was 2500 ms and if an extra burst would result in the total sound length being over the max, silence was presented instead of that burst. Sounds were again played through a pair of Sennheiser headphones through a similar Matlab program. The procedure was the exact same as Experiment 1 except that for this experiment, participants were instead instructed to adjust all four parameters as they saw fit to make the sound seem like a highly urgent, time-critical collision warning or to no longer seem like a highly urgent, time-critical collision warning.

6. Results

Table 3 shows the mean value for each parameter as well as at what value 90% of participants thought that parameter resulted in a highly urgent, time-critical collision warning.
Table 3. Mean values for each parameter and value when 90% of participants found the resulting sound to be a warning

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
<th>90% Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1025 Hz</td>
<td>1400 Hz</td>
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<tr>
<td>Pulse Duration</td>
<td>540 ms</td>
<td>400 ms</td>
</tr>
<tr>
<td>IBI</td>
<td>490 ms</td>
<td>360 ms</td>
</tr>
<tr>
<td>Pulses Per Burst</td>
<td>3.03</td>
<td>5</td>
</tr>
</tbody>
</table>

7. Discussion of Experiment 2 – Multiple Parameter Adjustment

In this experiment participants were allowed to adjust all four parameters in order to make the resulting sound seem like a highly urgent, time-critical warning or to make it no longer sound like a highly urgent, time-critical warning. Based upon the resulting averages and 90% values we can see that, for the most part, results were similar to those obtained in Experiment 1. Frequency, pulse duration, and pulses per burst all were within 2 adjustments from the scores obtained from Experiment 1. The only parameter that increased by more than two adjustments was IBI, which had an average value that was four adjustments (160 ms) different than those obtained in Experiment 1. However, this is most likely due to the fact that we did not manipulate inter pulse interval (IPI) so when multiple pulses were added per burst the only perceived pause between each pulse was derived from the 20 ms onset and 20 ms offset times, giving the sound an overall fast tempo. Furthermore by not allowing extra bursts to play if the overall signal time would exceed 2500 ms, the final average sound created for most participants may have only consisted of one burst.

8. General Discussion

Identifying the parameter values that result in a sound being perceived by most individuals as a highly urgent signal is critical for effective collision warning design. The psychophysical method of adjustment procedure used in these two experiments resulted in highly similar values for parameters thought to be critical components of an auditory warning. Similar results were obtained from both experiments whether participants were allowed to adjust only one or multiple parameters at a time. Overall results suggest that a sound is more likely to be perceived as a highly urgent, time-critical collision warning if it has a base frequency of approximately 1000 Hz with 5 harmonics and if it consists of at least three pulses per burst with each pulse being no more than 500 ms in duration with a 20 ms onset and offset time with no more than 410 ms between each burst.

These findings show the important role psychophysical methods have in helping to determine preliminary criteria for collision warning design. By using this method of adjustment we were able to obtain cutoff points for frequency, pulse duration, pulses per burst, and inter burst interval. Furthermore by using the multiple parameters method of adjustment we were able to see the impact pulses per burst had on the inter burst interval parameter. Due to the fixed sound duration whenever participants added extra pulses per burst they never actually got to hear multiple bursts. In future examinations when there are multiple pulses per burst, instead of looking at IBI it would be more advantageous to look at the amount of time between the actual pulses that create the burst (inter pulse interval).

Our results are also in-line with previous recommendations. Campbell et al. (2007) recommended that the frequency of an urgent warning should be high, recommending about 800 Hz. Our findings support the recommendation of having a high fundamental frequency suggesting that a frequency around 1000 Hz may be more effective in warning perception. Other recommendations stated the need for multiple pulses per burst (Campbell et al., 2007; Patterson, 1990). Again our results show support for the notion of needing multiple pulses per burst, with our data suggesting that having at least three pulses per burst will help a warning be more effective. While our pulse duration and inter burst interval criteria didn’t exactly match prior recommendations, we feel this is due in part to there being no true inter pulse interval resulting in a fast tempo which is still in-line with prior recommendations (Campbell et al, 2007).

While the method of adjustment shows great benefit it is not without its limitations. One limitation being that, even though we have fairly consistent findings for the lower range values of each parameter we do not have any idea as to the upper limits of those parameters. It is possible that each parameter could have a value, that when exceeded, causes the sound to no longer be perceived as a collision warning. This
issue could be solved by using another method of adjustment procedure where adjustments toward non-warnings are made using the values obtained here as starting points.

Another potential limitation of this method is an overall lack of actual driving context for the experiment. While participants were told to make the sounds seem either like or unlike a collision warning sound they did so while sitting in a silent lab room. Further follow-up studies are being conducted to determine how well these parameters hold up in richer context as well as when used for an actual collision warning system.

Further research is still needed to verify the results of this current study. Overall the psychophysical method of adjustment serves as a relatively simple and easy to use tool for the development criteria that could help improve the probability of a sound being perceived as a collision warning. One great benefit of this method is that it can also be used by other modalities such as visual and tactile stimuli as well as bimodal combinations. Currently, auditory warnings serve as the primary modality for alerting drivers to a critical situation, however the tactile modality constitutes a rapidly growing area of investigation. Using this method of adjustment could allow for a preliminary investigation into perceptions of tactile cues as collision warnings.

Acknowledgements

The authors would like to acknowledge the funding support of the National Highway Traffic Safety Administration (under Westat led Task Order No: DTNH22-11-D-00237/0001).

References


