

Vibrotactile Stimuli Parameters on Detection Reaction Times

Eric T. Chancey¹, J. Christopher Brill¹, Adam Sitz¹, Ulrike Schmuntzsch², & James P. Bliss¹

Old Dominion University, Norfolk, Virginia¹
Berlin Institute of Technology, Berlin, Germany²

Signaling system designers are leveraging the tactile modality to create alarms, alerts, and warnings. The purpose of this research was to map detection reaction times (RT) toward tactile stimuli with various parameter manipulations. We employed a 3 (wave form) \times 3 (inter-pulse interval) \times 3 (envelope) within subjects design. The dependent measure was detection RT. Twenty participants (15 female) responded to 270 tactile stimuli. ANOVAs indicated three two-way interactions. Generally, shorter inter-pulse intervals led to quicker RT and the fade-in envelope led to longer RT, when compared to envelopes starting at the maximum amplitude. Square and sinusoidal waves tended to prompt quicker RT than the noise wave. The strength of these relationships, however, depended upon the presence of the other parameters. Designers can use the results of this study to effectively and appropriately assign tactile parameter manipulations to signals that require varied levels of response urgencies.

INTRODUCTION

With the relatively recent advancements in technology, sensor-based signaling system designers are beginning to leverage the tactile modality to present vibrotactile alarms, alerts, and warnings. Indeed, applications and research incorporating vibrotactile signals have begun to appear in cell phones, videogame controllers, driver-vehicle interfaces (Baldwin & Lewis, 2014), collision avoidance systems (Scott & Gray, 2008), tactile warnings in dismounted military operations (Bliss, Liebman, & Brill, 2012), multimodal action-specific warning gloves (Schmuntzsch, Sturm, & Rotting, 2014), military hand signal communications (Brill, Terrence, Stafford, & Gilson, 2006), pilot spatial orientation systems (Rupert, 2000), and navigation systems (Cholewiak, Brill, & Schwab, 2004).

Researchers have provided suggestions for how to design tactile stimuli to effectively convey information (e.g., Brown, Brewster, & Purchase, 2005; Jones & Sarter, 2008). Yet, frequently, a critical aspect of signaling system design is to present signals that elicit timely responses from the operator. Several lines of research have compared inter-modal reaction time differences among auditory, visual, and tactile signals within different domains. In the context of vehicular collision avoidance systems, evidence suggests that tactile signals lead to quicker braking reaction times than auditory warnings (Mohebbi, Gray, & Tan, 2009) and visual warnings (Scott & Gray, 2008). Ng and Chan (2012) reported quicker reaction times for tactile stimuli than auditory or visual stimuli, in a simple choice reaction time task. Alternatively, Bliss et al. (2012) found that visual alerts presented during a simulated reconnaissance mission yielded significantly quicker reaction times than auditory alerts, whereas reactions to tactile alerts fell between those two modalities. Although these studies provide some evidence to suggest a reaction time benefit for vibrotactile signals over signals presented in other modalities (at least in some contexts), manipulating tactile signals to produce differential reaction times is still an inexact science.

Researchers have also manipulated the parameters of visual and auditory signals to prompt timely responses (e.g., Adams & Trucks, 1976; Wogalter, Conzola, & Smith-Jackson, 2002). In the interest of designing effective vibrotactile

signals, it would also make sense to map tactile parameters to reaction times.

An obvious parameter manipulation, that could likely lead to quicker vibrotactile signal reaction times, would be to elevate signal amplitude, wherein higher amplitude results in a stronger sensation due to the greater number of mechanoreceptors being activated (Asamura, Yokoyama, & Shinoda, 1998). Yet, signaling system designers could choose to avoid more intense tactile stimuli, potentially sacrificing faster reaction times, and opt for less intense signals to reduce instances of the user becoming annoyed or startled. Similarly, patterns of the amplitude could be manipulated to convey differences in waveform (e.g., sinusoidal, square, saw, or triangle) that are perceived differently (Self, van Erp, Eriksson, & Elliott, 2008) and may prompt different reaction times.

Recent research efforts (Baldwin & Lewis, 2014; Baldwin et al., 2012; Pratt et al., 2012) have investigated aspects of urgency coding for vibrotactile signals by manipulating temporal pulse patterns (i.e., the length of silence between pulses or the inter-pulse interval; IPI). The results from these studies suggest that signals with shorter IPIs produce the perception of greater associated urgency. This may also translate to quicker reaction times toward vibrotactile stimuli with short IPIs.

Purpose and Hypotheses

The purpose of this study was to manipulate the levels of different vibrotactile parameters and measure detection reaction times toward those stimuli. Although there are numerous vibrotactile parameters to manipulate (e.g., frequency, duration, spatial location, and wave form complexity; Brown et al., 2005), we chose to narrow the scope of this study to focus on the effects of IPI, amplitude onset/offset (envelope), and waveform.

Based on previous urgency mapping research (i.e., Baldwin & Lewis, 2014; Baldwin et al., 2012; Pratt et al., 2012) we hypothesized that shorter IPIs would lead to quicker detection reaction times than longer IPIs. Additionally, we predicted that the less intense amplitude onset (fade-in) would lead to longer detection reaction times than when the amplitude started at the maximum level. This prediction was

based on the expectation that participants would simply not be able to immediately detect the onset of the stimulus. Because limited previous research has been conducted on investigating detection reaction time differences for various waveforms, we did not make a prediction for this manipulation.

METHOD

Design

We employed a 3 (waveform) x 3 (IPI) x 3 (envelope) within subjects design. The dependent variable for this experiment was stimulus detection reaction time (RT; recorded in milliseconds).

Stimuli

After manipulating parameters to reflect independent variable manipulations, there were a total of 27 individual vibrotactile stimuli. The resulting stimuli were suprathreshold, but not uncomfortable. All stimuli were approximately 2,500 ms in duration (see Figure 1).

Waveform. Tactile stimuli were manipulated to present three waveforms: sinusoidal, square, and noise. Sinusoidal and square waveforms were tuned to 250 Hz, and the third waveform level was broadband white noise, tuned to remain within a 200 – 300 Hz range. We chose a frequency of 250 Hz because of the frequency sensitivity range of Pacinian corpuscles, which are most sensitive to vibrations approaching this frequency (Weisenberger, 2005). Pilot testing using magnitude estimation was undertaken to ensure subjective intensities were relatively equal across waveforms.

IPI. We manipulated IPI in a manner similar to that of Baldwin et al. (2012; Baldwin & Lewis, 2014; Pratt et al., 2012). Participants were presented with 4, 8, or 12, 200 ms pulses, during each 2,500 ms stimulus. This roughly corresponded to IPIs (i.e., silence between each pulse) of 475 ms, 118 ms, and 9 ms, respectively. In the results section, we refer to these as long, medium, and short IPIs. We should note, however, that the amount of silence at the tail of each stimulus varied according to IPI manipulation, as the pulse-to-pulse duration (pulse duration + IPI) did not divide evenly within 2,500 ms. Therefore, the duration of each stimulus varied slightly.

Envelope. We also manipulated the amplitude onset and offset to “fade-in,” “fade-out,” or maintain a consistent amplitude throughout, which we refer to as the stimulus envelope. For the fade-in envelope, the onset of the stimulus amplitude started at zero and steadily elevated to a constant maximum suprathreshold level at 500 ms. For the fade-in envelope, the onset of the stimulus amplitude started at a constant maximum suprathreshold level and began to steadily reduced to zero at 2,000 ms. For the no-fade envelope, the amplitude remained at a constant maximum suprathreshold level throughout the stimulus presentation. The maximum amplitude was equal for each envelope.

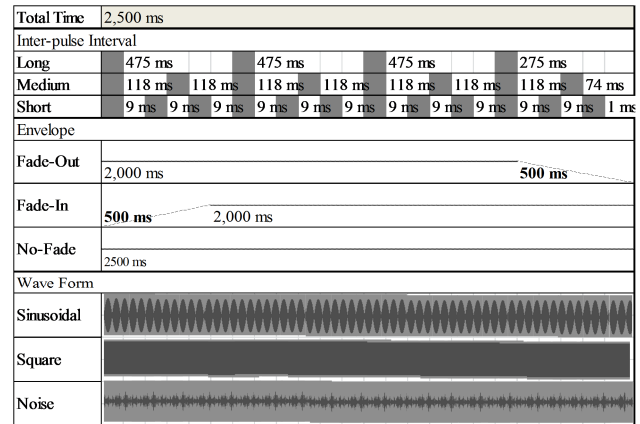


Figure 1. Graphical depiction of tactile parameter manipulations. Note: Under Inter-pulse Interval, gray areas indicate a 200 ms pulse and white areas are denoted with the amount of time (ms) between each pulse. Under Envelope, the line angle indicates a 500 ms fade-in (positive angle), 500 ms fade-out (negative angle), or no-fade (straight line). Under Wave Form, each line indicates the visual representation of each wave form.

Participants

Twenty undergraduate students from Old Dominion University (15 females) participated in this study for class credit. The participants indicated an average age of 20.95 years ($SD = 4.25$). No participant reported having any sensory or cognitive impairment that would impact performance.

Equipment

A desktop computer running Microsoft Windows XP (2 GB RAM) and a Dell ST2210 21.5" LCD monitor was used for this experiment. SuperLab software version 4.5 (Cedrus, Inc., San Pedro, CA) controlled stimulus presentation and recorded participants' responses. Vibrotactile stimulation was presented using an EAI model C2 Tactor (Engineering Acoustics, Inc., Casselberry, FL). The C2 tactor (3 cm diameter, .08 cm height, 17 g weight) used a moving plunger and stationary surround to present vibration patterns. A Velstretch® band held the tactor against the posterior side of participants' left wrist (side opposite palm). All participant responses were made using a Cedrus model RB-530 response pad and standard computer mouse (see Figure 2).

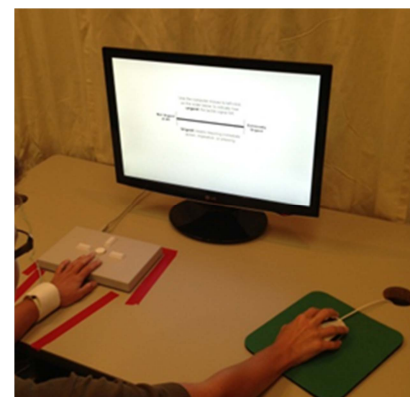


Figure 2. Picture of experimental setup.

Procedure

Participants were seated at a computer workstation and asked to complete an informed consent form. Upon completion of the consent form, a brief medical questionnaire was administered evaluating participants for sensorimotor

deficits that might preclude participation. Participants were then outfitted with the tactor on the posterior side of their left wrist using the cloth band. Tape markings on the surface of the workstation desk standardized participants' resting hand position throughout the duration of the experiment.

Participants then completed four practice trials to familiarize themselves with the type of stimuli and method of response (Cedrus response pad). Practice vibrotactile stimuli were not presented during subsequent experimental blocks. After completing the practice session, participants began the experiment. Beginning each trial, participants were textually prompted to press a designated button on the response pad upon detection of a vibrotactile stimulus. To prevent participants from rote responding based upon a rhythm, a randomly selected inter-trial interval of 1,000 ms, 1,500 ms, or 2,000 ms was presented before each trials. Each subsequent trial automatically began after a participants' response input. A total of 270 trials (10 repetitions for each of the 27 stimuli) were presented using the method of constant stimuli (Fechner, 1966). Upon completion of these trials, participants were debriefed, thanked, and dismissed.

RESULTS

The data were inspected to ensure that each group had equal numbers, no outliers, and that the data had a normal distribution. We conducted multiple repeated measures ANOVAs to identify differences among the dependent measures. If sphericity was violated, Greenhouse-Geisser corrections were made. Significant simple effects were followed up with Bonferroni adjusted pairwise comparisons. An alpha level of $p < .05$ was established to indicate statistical significance.

Envelope \times IPI: There was a significant interaction between envelope and IPI on RT, $F(2.588, 46.577) = 39.263$, $p < .001$, $partial \eta^2 = .686$. A follow-up analysis on simple effects indicated that there was a significant effect of IPI on RT, but only for the fade-in condition, Wilk's $\lambda = .079$, $F(2, 17) = 98.677$, $p < .001$, $partial \eta^2 = .921$ (see Figure 3). Pairwise comparisons indicated that for the fade-in condition, the longest IPI resulted in a significantly longer RT than both the shortest ($p < .001$) and the medium IPI ($p < .001$).

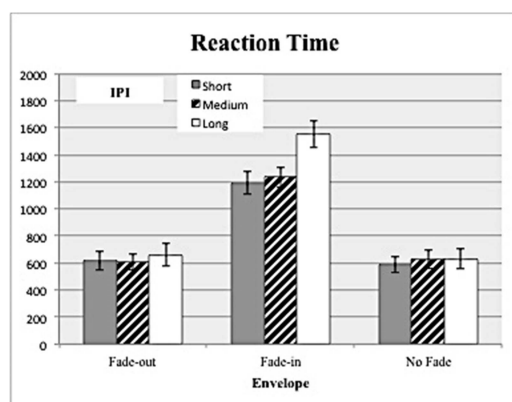


Figure 3. Mean reaction times for the three levels of IPI nested within each level of envelope. Note: Reaction time in milliseconds.

Alternatively, envelope had a significant effect on RT for all IPI's (see Figure 4). Simple effects of envelope were significant at the short IPI, Wilk's $\lambda = .064$, $F(2, 17) =$

124.989, $p < .001$, $partial \eta^2 = .936$, medium IPI, Wilk's $\lambda = .048$, $F(2, 17) = 169.164$, $p < .001$, $partial \eta^2 = .952$, and long IPI, Wilk's $\lambda = .029$, $F(2, 17) = 284.691$, $p < .001$, $partial \eta^2 = .971$. Pairwise comparisons indicated that the fade-in condition resulted in significantly longer RT's than the fade-out and no fade conditions for all IPI's ($p < .001$).

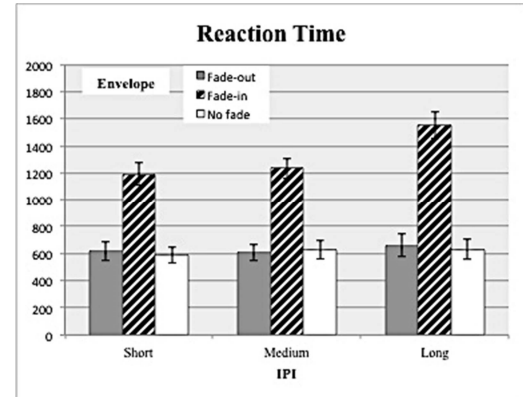


Figure 4. Mean reaction times for the three levels of envelope nested within each level of IPI. Note: Reaction time in milliseconds.

Envelope \times Wave: There was a significant interaction between envelope and wave on RT, $F(4, 72) = 7.464$, $p < .001$, $partial \eta^2 = .293$. Wave type had a significant effect on RT in all envelope conditions (see Figure 5). Simple effects of wave were significant for the fade-out, Wilk's $\lambda = .327$, $F(2, 17) = 17.478$, $p < .001$, $partial \eta^2 = .673$, fade-in, Wilk's $\lambda = .134$, $F(2, 17) = 55.026$, $p < .001$, $partial \eta^2 = .866$, and no fade conditions, Wilk's $\lambda = .404$, $F(2, 17) = 12.516$, $p < .001$, $partial \eta^2 = .596$. Pairwise comparisons indicated that for the fade-in condition, the noise wave resulted in significantly longer RT's than the square ($p < .001$) and sinusoidal ($p = .009$) waves. For the fade-in envelope, all three wave forms were different from each other, where the square wave resulted in the shortest RT followed by the sinusoidal wave and then noise wave (both $p < .001$). For the no-fade envelope, the noise wave resulted in a longer RT than the square wave ($p < .001$) and the sinusoidal wave ($p = .046$).

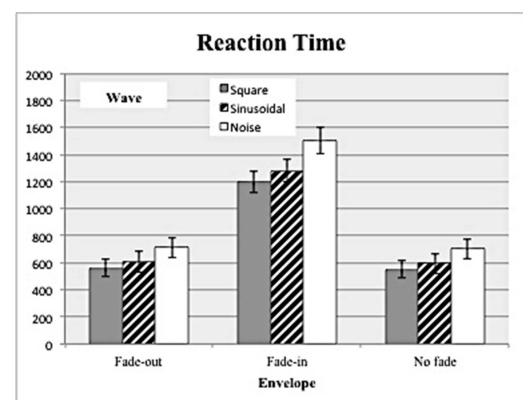


Figure 5. Mean reaction times for the three levels of wave form nested within each level of envelope. Note: Reaction time in milliseconds.

Alternatively, envelope had a significant effect on RT in all wave conditions (see Figure 6). Simple effects of envelope were significant for the square wave, Wilk's $\lambda = .043$, $F(2, 17) = 186.979$, $p < .001$, $partial \eta^2 = .957$, sinusoidal wave, Wilk's $\lambda = .047$, $F(2, 17) = 171.994$, $p < .001$, $partial \eta^2 = .953$, and

noise wave, Wilk's $\lambda = .038$, $F(2, 17) = 215.379$, $p < .001$, $\text{partial } \eta^2 = .962$. Pairwise comparisons indicated that the fade-in condition resulted in significantly longer reaction times than the fade-out and no fade condition for all wave conditions ($p < .001$).

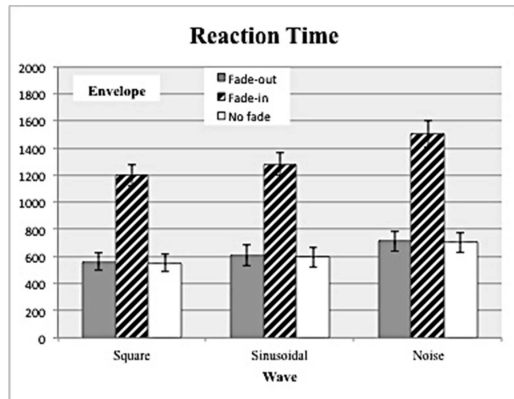


Figure 6. Mean reaction times for the three levels of envelope nested within each level of wave form. Note: Reaction time in milliseconds.

IPI \times Wave: There was a significant interaction between envelope and wave on RT, $F(2.774, 49.933) = 3.768$, $p = .019$, $\text{partial } \eta^2 = .173$. Wave type had a significant effect on RT in all IPI conditions (see Figure 7). Simple effects of wave type were significant for the short IPI, Wilk's $\lambda = .230$, $F(2, 17) = 28.478$, $p < .001$, $\text{partial } \eta^2 = .770$, medium IPI, Wilk's $\lambda = .184$, $F(2, 17) = 37.574$, $p < .001$, $\text{partial } \eta^2 = .816$, and long IPI, Wilk's $\lambda = .291$, $F(2, 17) = 20.693$, $p < .001$, $\text{partial } \eta^2 = .709$. Pairwise comparisons indicated that for the short IPI condition the noise wave resulted in the longest RT ($p < .001$). For the medium IPI the square wave resulted in a quicker RT than the sinusoidal wave ($p = .017$) and the sinusoidal wave resulted in a quicker RT than the noise wave ($p = .009$). For the long IPI, the square wave resulted in a quicker RT than the sinusoidal wave ($p = .010$) and the sinusoidal wave resulted in a quicker RT than the noise wave ($p = .037$).

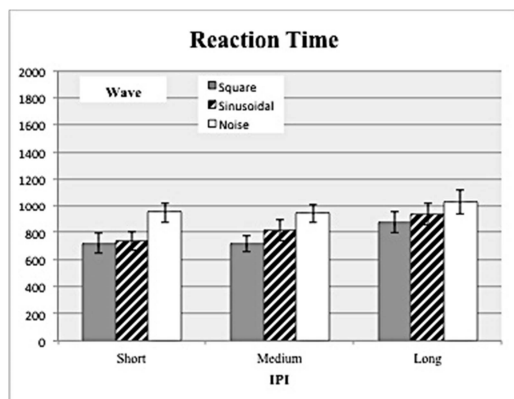


Figure 7. Mean reaction times for the three levels of wave form nested within each level of IPI. Note: Reaction time in milliseconds.

Alternatively, IPI had a significant effect on RT in all wave type conditions (see Figure 8). Simple effects of IPI were significant for the square wave, Wilk's $\lambda = .222$, $F(2, 17) = 29.760$, $p < .001$, $\text{partial } \eta^2 = .778$, sinusoidal wave, Wilk's $\lambda = .241$, $F(2, 17) = 26.787$, $p < .001$, $\text{partial } \eta^2 = .759$, and noise wave, Wilk's $\lambda = .635$, $F(2, 17) = 4.896$, $p = .021$, $\text{partial } \eta^2 = .365$. Pairwise comparisons indicated that for the

square wave condition, the long IPI resulted in the longest RT ($p < .001$). For the sinusoidal wave, the short IPI resulted in a quicker RT than the medium IPI ($p = .016$) and the medium IPI resulted in a quicker RT than the long IPI ($p < .001$). For the noise wave, only the medium and long IPI's differed ($p = .014$).

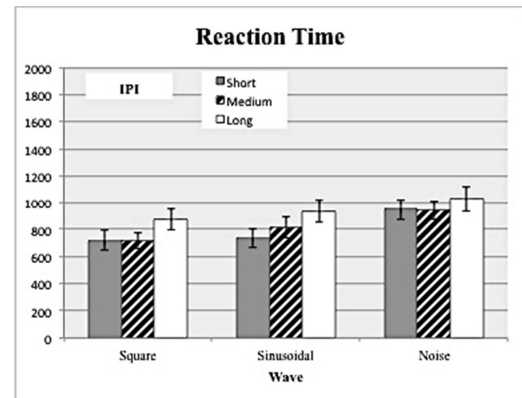


Figure 8. Mean reaction times for the three levels of IPI nested within each level of wave form. Note: Reaction time in milliseconds.

DISCUSSION

Clearly, detection RTs were affected by the parameters manipulated. Supporting our hypotheses, shorter IPIs led to quicker RTs and the fade-in envelope led to longer detection RTs when compared to envelopes starting at the maximum amplitude. Additionally, the square and sinusoidal waves tended to prompt quicker detection RTs than the noise wave. However, our analyses indicated that the effects of all parameter levels on detection RTs tended to depend upon the presence of each other (i.e., multiple two-way interactions).

Envelope on Detection RT

It is not surprising that envelope had the largest effect on RT, as the fade-in condition was intentionally less intense at the onset of the stimuli. Although quick reaction times are often desired, the purpose of signaling systems is not to always elicit a time-critical immediate response *per se*, but simply to issue a signal that makes the operator aware of a condition. To this point, Bliss and Gilson (1998) present a signaling system taxonomy that separates *warnings*, which indicate that a danger may exist given certain circumstances, *alarms*, which require immediate action to escape negative consequences, and *alerts*, which simply indicate a condition exists. To prompt quick reaction times, designers sometimes attempt to use very intense signals. Yet, it is not always appropriate to present signals that represent extreme dimensions, as this could prompt a startle response in the operator, and actually impede performance. To circumvent startle responses, a less intense preemptive signal, such as the fade-in envelope, could be used for warnings and alerts.

IPI on Detection RT

Generally, shorter IPIs resulted in quicker detection RTs, although the strength of this effect was modulated by the presence of the other parameter manipulations. However, these results seemed to correspond well with studies of tactile urgency coding (Baldwin & Lewis, 2014; Baldwin et al., 2012; Pratt et al., 2012). Taken together, tactile signals with

short IPIs will likely result in not only a greater sense of urgency, but also quicker reaction times. This makes IPI an important consideration for alarm signal design, which requires immediate response from the operator to avoid negative consequences.

Wave Form on Detection RT

The square wave inconsistently led to quicker RTs than the sinusoidal wave, where this effect largely depended on the envelope and IPI. The noise wave, however, consistently produced longer RTs than the sinusoidal or square waves. A potential reason for this is likely due to the fact that this wave form was less uniform in frequency. Because the noise wave was tuned to remain within a 200-300 Hz range, it may have been at a disadvantage for consistently activating Pacinian corpuscles at their peak sensitivity.

Further Research and Considerations

Because the skin varies greatly in the density and type of mechanoreceptors according to location (Weisenberger, 2005), if the stimulus site were changed, so too may these results. We presented stimuli to the posterior side of the wrist, as previous research has demonstrated this location is sensitive to vibrotactile stimulation (e.g., Baldwin & Lewis, 2014; Baldwin et al., 2012; Bliss et al. 2012; Cholewiak & Collins, 2003). For application purposes, evidence suggests that individuals are better able to localize vibrotactile stimulation on the body when it is presented near anatomical landmarks such as joints (Cholewiak & Collins, 2003). Our results could be applicable to displays that rely upon localization to convey directionality (e.g., signals presented to the left or right wrist to cue attentional shifts in direction). Yet, we presented stimuli to only one wrist. Additional research should be conducted to test the interaction of parameter manipulations and directional cueing. Practitioners wishing to apply or generalize these results to tactile signals should be mindful of signal presentation location when implementing tactile signals for a particular display application.

Additionally, it is important to realize that this was a simple reaction task; i.e., participants were not required to make a response choice and made the same response to all signals. Participants were not required to perform a secondary task, which is frequently not the case in applied settings. Moreover, as a psychophysical investigation this study lacked a context, as we were simply attempting to provide very general information about tactile parameter effects on detection RTs. Designers wishing to apply these results should realize that reaction times are greatly affected by these variables (Van der Molen & Keuss, 1979; cf. Bliss et al. 2012 and Ng & Chan, 2012).

Conclusion

Signaling system designers are beginning to engage the tactile modality to communicate alarms, alerts, and warnings. Yet, little information exists to inform tactile parameter manipulation to ensure timely responses from the operator. This study represents a continued effort to map RT to different kinds of tactile signals. Designers can use the results of this study to effectively and appropriately assign tactile parameter manipulations to signals that require varied levels of response urgencies.

REFERENCES

- Adams, S., & Trucks, L. (1976). A procedure for evaluating auditory warning signals. *Proceedings of the 6th Congress of the International Ergonomics Association and Technical Program for the 20th Annual Meeting of the Human Factors Society*, (pp. 166-172). Santa Monica, CA.
- Asamura, N., Yokoyama, N., & Shinoda, H. (1998). Selectively Stimulating Skin Receptors for Tactile Display. *Computer Graphics and Applications, IEEE*, 18 (6), 32-37.
- Baldwin, C. L., & Lewis, B. A. (2014). Perceived urgency mapping across modalities within a driving context. *Applied Ergonomics*, 45, 1270-1277.
- Baldwin, C. L., Eisert, J. L., Garcia, A., Lewis, B., Pratt, S. M., & Gonzalez, C. (2012). Multimodal urgency coding: Auditory, visual, and tactile parameters and their impact on perceived urgency. *Work*, 41, 3586-3591.
- Bliss, J. P., & Gilson, R. D. (1998). Emergency signal failure: Implications and recommendations. *Ergonomics*, 41 (1), 57-72.
- Bliss, J. P., Liebman, R., & Brill, J. C. (2012). Alert characteristics and identification of avatars on a virtual battlefield. *Intelligent Decision Technologies*, 6, 151-159.
- Brill, J. C., Terrence, P. I., Stafford, S., & Gilson, R. D. (2006). A wireless tactile communication system for conveying U.S. Army hand-arm signals. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*, (pp. 2247-2249).
- Brown, L. M., Brewster, S. A., & Purchase, H. C. (2005). A first investigation into the effectiveness of Tactons. *First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems*, (pp. 18-20). Pisa, Italy.
- Cholewiak, R. W., Brill, J. C., & Schwab, A. (2004). Vibrotactile localization on the abdomen: Effects of place and space. *Perception and Psychophysics*, 66 (6), 970-978.
- Cholewiak, R. W., & Collins, A. A. (2004). Vibrotactile localization on the arm: Effects of place, space, and age. *Perception and Psychophysics*, 65 (7), 1058-1077.
- Fechner, G. T. (1966). *Elements of Psychophysics*. New York: Holt, Rinehart, and Winston. (Original work published 1860).
- Jones, L. A., & Sarter, N. B. (2008). Tactile displays: Guidance for their design and application. *Human Factors*, 50 (1), 90-111.
- Mohebbi, R., Gray, R., & Tan, H. Z. (2009). Driver reaction time to tactile and auditory rear-end collision warnings while talking on a cell phone. *Human Factors*, 51, 102-110.
- Ng, A., & Chan, A. (2012). Figure response times to visual, auditory, and tactile modality stimuli. *Proceedings of the International MultiConference of Engineers and Computer Scientists*. 2. Hong Kong: IMECS.
- Pratt, S. M., Lewis, B. A., Penaranda, B. N., Roberts, D. M., Gonzalez, C., & Baldwin, C. L. (2012). Perceived urgency scaling in tactile alerts. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, (pp. 1303-1306). Boston, MA.
- Rupert, A. H. (2000). Tactile situation awareness system: Proprioception prostheses for sensory deficiencies. *Aviation, Space, and Environmental Medicine*, 71, A92-A99.
- Schmuntzsch, U., Sturm, C., & Roetting, M. (2014). The warning glove - Development and evaluation of a multimodal action-specific warning prototype. *Applied Ergonomics*, 45, 1297-1305.
- Scott, J. J., & Gray, R. (2008). A comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving. *Human Factors*, 50 (2), 264-275.
- Self, B. P., van Erp, J., Eriksson, L., & Elliott, L. R. (2008). Human factors issues of tactile displays for military environments. In J. F. van Erp, & B. P. Self (Eds.).
- Van der Molen, M., & Keuss, P. (1979). The relationship between reaction time and intensity in discrete auditory tasks. *Quarterly Journal of Experimental Psychology*, 31, 95-102.
- Weisenberger, J. M. (2005). Cutaneous Perception. In *Blackwell Handbook of Sensation and Perception* (pp. 558-566). Blackwell Publishing.
- Wogalter, M. S., Conzola, V. C., & Smith-Jackson, T. L. (2002). Research-based guidelines for warning design and evaluation. *Applied Ergonomics*, 33, 219-230.