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Chapter 61

Pre-Motor Response Time Benefits in Multi-Modal Displays

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ABSTRACT

The present series of experiments tested the assimilation and efficacy of purpose-created tactile messages based on five common military arm and hand signals. We compared the response times and accuracy rates to these tactile representations against the comparable responses to equivalent visual representations of these same messages. Results indicated that there was a performance benefit for concurrent message presentations which showed superior response times and improved accuracy rates when compared to individual presentations in either modality. Such improvement was identified as being due largely to a reduction in pre-motor response time and these improvements occurred equally in a military and non-military population. Results were not contingent upon the gender of the participant. Potential reasons for this multi-modal facilitation are discussed. The novel techniques employed to measure pre-motor response inform computational neuro-ergonomic models for multi-modal advantages in dynamic signaling. On a practical

level, these results confirm the utility of tactile messaging to augment visual messaging, especially in challenging and stressful environments where visual messaging may not always be feasible or effective.

Keywords: Visual Signaling, Tactile Signaling, Multi-Modal Advantage.

INTRODUCTION

Humans rely on their multiple sensory systems to continually integrate the environmental stimuli around them in order to build their perception of the world in which they live. While each sense is, in itself, remarkably adept at detection it is the combination and integration of these disparate sensory inputs which provide the rich tapestry of spatial, temporal, and object information on which humans rely to survive and thrive. The cross-modal fusion of these information sources is often more beneficial than simply increasing information from only one sensory modality. For example, Hillis, Ernst, Banks and Landy (2002) found that when combined, the value of multiple visual cues (e.g., disparity and texture gradients) did not produce as accurate performance as when visual and tactile cues were provided in an object property discrimination task. Comparing performance within the same modality versus combinations of two or more different modalities illustrates that information loss can occur during intra-modal presentations that does not occur with the fusion across different modalities. In the specific case of tactile and visual information there seems to be a highly efficient integration of the two sources (Ernst & Banks, 2002). This integration is especially beneficial when the cross-modal cues are congruent and match the top down expectancies generated by past experience.

Humans not only rely on their multiple sensory capacities to integrate different forms of stimuli, they also use these multiple sources to aid them in the initial process of orientation and the subsequent focus of their attention in space and time. When an individual directs their attention, regardless of the primary modality used in the process of detection, the other modalities are also frequently directed toward that same location. Indeed, it is the subject of an on-going debate as to the degree to which such orientation of attention is a multi-sensory construction (Spence & Driver, 2004) versus an over-dominantly visual process (Posner, Nissen, & Klein, 1976). In part, this issue can be approached from a neuro-physiological perspective. For example, Stein and Meredith (1993) have shown that bimodal and tri-modal neurons have a stronger cellular response when animals are presented with stimuli from two sensory modalities as compared with stimulation from only one modality. The combinations of two different sensory stimuli have been shown to significantly enhance the responses of neurons in the superior colliculus (SC) above those evoked by either uni-modal stimulus alone. Such an observation supports the conclusion that there is a multi-sensory link among individual SC neurons for cross-modality attention and orientation behaviors (see also Wallace, Meredith, & Stein,

1998). Multi-modal stimulation in the world is not always presented or received in a congruent spatial and temporal manner. This problem can be resolved in the brain by an over reliance on the one single dominant system which in humans is expressed in the visual modality (see Hancock, 2005).

To date, the exploration into the cross-modal attentional phenomenon has relied mainly on simple stimuli to elicit response (Spence & Walton, 2005). Gray and Tan (2002) used a number of factors (vibro-tactile actuators) spanning the length of the participant's arm with lights mounted on the individual factors. Using an appropriate inter-stimulus interval (ISI) and factor spacing (see Geldard, 1982) to create the illusion of movement, either up or down the arm, they found that response times were faster when the visual target was offset in the same direction as the tactile motion (similar to the predictive abilities one has to know the location of an insect when it runs up or down the arm). Reaction times were slower when the target was offset in the direction opposite to the tactile motion. Such a finding supports the idea that the cross-modal links between vision and touch are updated dynamically for moving objects and are best supported perceptually when the stimuli are congruent.

In another study, Craig (2006) had participants judge the direction of apparent motion by stimulating two locations sequentially on a participant's finger pad using vibro-factors. Visual trials included apparent motion induced by the activation of two lights sequentially. Some trials also were recorded with both visual and tactile stimuli presented together either congruently or incongruently. When visual motion was presented at the same time as, but in a direction opposite to tactile motion, accuracy in judging the direction of tactile apparent motion was substantially reduced. This superior performance during congruent presentation was referred to as 'the congruency effect'. A similar experiment conducted by Strybel and Vatakis (2004) who used visual apparent motion and found similar effects for judgments of auditory apparent motion. Auditory stimuli have also been shown to affect the perceived direction of tactile apparent motion (see Soto-Faraco, Spence, & Kingstone, 2004).

While all of these experiments with simple tasks are essential for understanding the psychological phenomena being studied, the extension of these findings into real-world conditions to embrace more applied stimuli is as yet largely unexplored. However, with advancements in tactile display technology and innovative signaling techniques, the importance of testing systems capable of assisting actual field communications is now both feasible and pragmatically important. Thus, the purpose of the present experiment was to examine combinations of visual and tactile communications of real-world operational signals in order to evaluate their efficacy for real-world applications. We also sought to distinguish whether multi-modal signal presentation led to performance advantages under such circumstances.

EXPERIMENTAL METHOD

EXPERIMENTAL PARTICIPANTS

To investigate the foregoing propositions, 72 participants (47 males and 25 females) ranging in age from 18 to 21, with an average age of 18.5 years, volunteered to participate. Of these individuals, 31 were from a large public southern metropolitan university and the remaining 41 were from a United States Military Academy. The latter group had prior experience with the visual form of the presented military visual signals, with the tactile form of the signals new to all.

EXPERIMENTAL MATERIALS AND APPARATUS

The vibro-tactile actuators (tactors) used in the present system were the model C2, manufactured by Engineering Acoustics, Inc (EAI). They are acoustic transducers that displace 200-300 Hz sinusoidal vibrations onto the skin. Their 17 gm mass is sufficient for activating the skin's tactile receptors. The tactile display itself is a belt like device with eight vibro-tactile actuators. Examples of the present belt system are shown in Figure 1. When stretched around the body and fastened, the wearer has an actuator over the umbilicus and one centred over the spine in the back. The other six actuators are equally spaced around the body; three on each side, for a total of eight (see also Cholewiak, Brill, & Schwab, 2004).

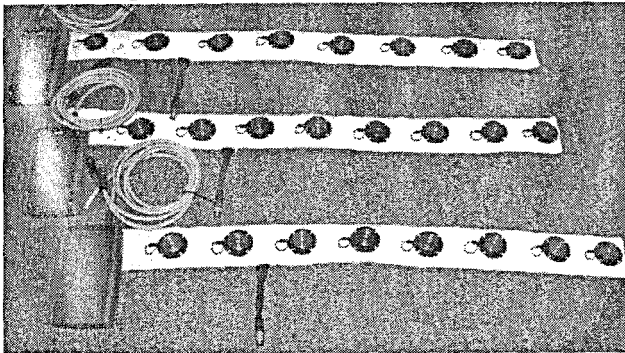


Figure 1. Three tactile displays belt assemblies are shown above along with their controller box.

The tactors are operated using a Tactor Control Unit (TCU) that is a computer-controlled driver/amplifier system that switches each tactor on and off as required. This device is shown on the left side of the tactile displays belts in Figure 1. The TCU weighs 1.2 lbs independent of its power source and is approximately one inch

thick. This device connects to a power source with one cable and to the display belt with the other and uses Bluetooth technology to communicate with the computer driven interface. Tactile messages were created using five standard Army and Marine Corps arm and hand signals (Department of the Army, 1987). The five signals chosen for the present experiment were, "Attention", "Halt", "Rally", "Move Out", and "Nuclear Biological Chemical Event (NBC)". The tactile representations of these signals were designed in a collaborative effort involving a consultant group of subject matter experts (SMEs) consisting of former US Soldiers and Marines.

Short video clips of a soldier in uniform performing these five arm and hand signals were edited to create the visual stimuli. Careful editing ensured the timing of the arm and hand signals closely matched that of the tactile presentations (see Figure 2). A Samsung Q1 Ultra Mobile computer using an Intel Celeron M ULV (900 MHz) processor with a 7" WVGA (800 x 480) liquid crystal display was used to present videos of the soldier performing the arm and hand signals. This computer ran a custom LabVIEW (8.2; National Instruments) application that presented the tactile signals via Bluetooth to the tactor controller board and captured all of the participant's responses via mouse input. Participants wore sound dampening headphones with a reduction rating of 11.3 dB at 250 Hz. This precaution was designed to mask any possible effects which could have accrued due to extraneous auditory stimuli produced by tactor actuation. As this is an issue which has caused some degree of controversy in the past, we were careful to control for this potential artifact in our own work (cf., Broadbent, 1978; Poulton, 1977).

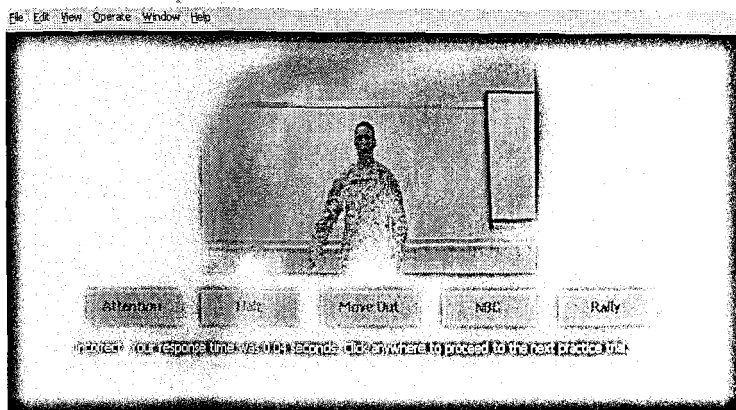


Figure 2. A computer screen shot showing what the participant viewed as the signals were presented. The participant mouse clicked on the appropriate signal name after each presentation.

EXPERIMENTAL DESIGN AND PROCEDURE

Participants first completed an informed consent document in accordance with the strictures of the American Psychological Association (APA). Participants then viewed a computer-based tutorial that described each arm and hand signal individually. For each signal, a short description was presented. Participants then viewed a video of a soldier in uniform performing the signal followed by a direct experience of its tactile equivalent. Finally, the participants were able to play the signals concurrently (both visual and tactile representation) together. Participants were allowed to repeat this presentation (i.e., visual, tactile, visual-tactile combined) as many times as they desired. Once the participant reviewed the five signals in the two presentation styles, a validation exercise was performed. Participants had to correctly identify each signal twice before the computer would prompt the experimenter that the participant was ready to begin.

The display of each signal was presented in one of three ways; i) a visual only (video presentation of the arm and hand signal), ii) a tactile only (tactile representation of the arm and hand signal), and iii) both visual and tactile simultaneously and congruent (i.e. exactly the same signal was presented both through the video and through the tactile system at the same time for all of these trials). The participants were presented each signal visually 8 times (8 trials x 5 different signals = 40 total trials to be visual only, tactile only, and combined visual and tactile presentations). This gave a grand total of 120 trials. The order that each participant performed the 120 trials was completely randomized. The entire experiment took less than an hour to complete.

Before each trial began, the mouse cursor had to be placed inside a small square in the center of the screen by the participant. The presentation of the signal, regardless of its modality, started the timer and the following performance responses were collected: i) the initial movement of the mouse, ii) the latency to name the received signal, iii) the signal named and accuracy of that choice. This formatting permitted us to parse the response into pre-motor time (the first movement of the mouse) and motor time (the time to place the cursor in the appropriate response box). It was these responses that were subjected to analysis.

RESULTS

Results were analyzed in terms of the speed of the response and the accuracy of the response under the respective conditions. We did conduct an initial analysis for any potential sex differences but found no significant influence upon any of the measures recorded. The subsequent analysis was therefore collapsed across sex. A one-way Analysis of Variance (ANOVA) was performed on the mean response times across the three experimental conditions of visual presentation, tactile presentation or visual-tactile concurrent and congruent presentation, with the

following results: $F(2, 213)=9.37, p<.01, (\eta^2_p = .961, \beta= 1.00)$. Post hoc analysis subsequently showed that simultaneously presented congruent signals resulted in significantly faster response times than visual signals presented alone $t(71)=3.15, p<.01$, see Figure 3. Also, as is evident from this illustration, responses to the congruent signals were also faster than tactile responses alone $t(71)=10.29, p<.01$. Additionally, the visual only presentation of the signal was significantly faster than the tactile only presentation of the signal $t(71)=-4.15, p<.01$.

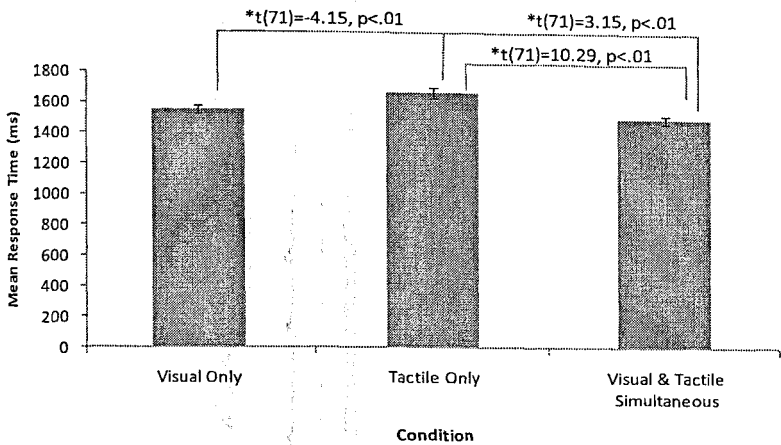


Figure 3. Response Time in milliseconds by signal presentation condition.

Analysis of the response accuracy data showed that there was a significant difference in the accuracy rate between the visual and tactile signals when presented alone $t(71)=-7.10, p<.01$. This difference was most likely due to the extraordinarily high accuracy visual performance rate since the military participants were already familiar with and already had some previous level of training for the visual presentation of the signals and no prior experience for the tactile presentations. There was also a significant difference in the accuracy rate when responses using the tactile modality were compared to the concurrent congruent presentation of the signals, $t(71)=7.47, p<.01$. Here, response to tactile signals proved less accurate than to the combined visual-tactile presentation. The overall lower accuracy rate for the tactile signaling is again attributed to the confusion between the tactile signal for "NBC" and "Halt". Analysis without the "NBC" tactile signal data again removed these significant differences in response accuracy. There was no significant difference between responses for the visual only condition and the combined condition.

A one-way Analysis of Variance (ANOVA) was performed on the mean response times for the pre-motor element (the time that elapsed from presentation of the signal to the first movement of the mouse) across the three experimental conditions of visual presentation, tactile presentation or visual-tactile concurrent and congruent presentation. This analysis produced a significant effect: $F(2, 213)=5.48, p<.01, (\eta^2_p = .961, \beta = 1.00)$. Subsequent pair-wise comparisons showed that simultaneously presented congruent signals resulted in significantly faster pre-motor response times than visual signals presented alone $t(71)=4.30, p<.01$, see Figure 4. Also, as is evident from the illustration, the congruent signals were faster than those pre-motor times for tactile alone $t(71)=-2.9, p<.01$. Additionally, the visual only presentation of the signal was significantly faster for pre-motor response than the tactile only presentation of the signal $t(71)=-2.89, p<.01$.

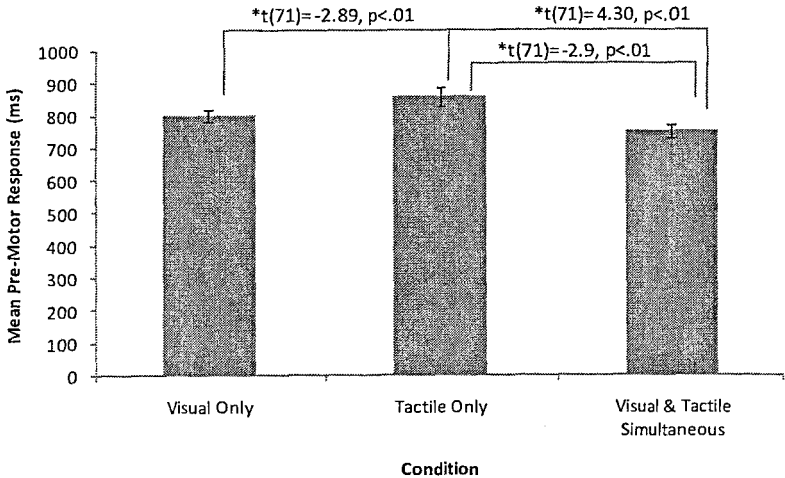


Figure 4. Pre-motor response time in milliseconds by signal presentation condition.

As previously stated, the presentation of the signal, regardless of its modality, started the experimental timer, allowing the capture of the latency from signal elicitation to the initial movement of the mouse, or pre-motor response. The latency to name the received signal, or in other words, the motor time, the time that it takes from the initial mouse movement to the time that the mouse resides in the appropriate response box was regarded to as the motor response time. There were no differences found across any of the experimental conditions for motor response latency.

It was further hypothesized that there could be some differences between the two respective groups of student and cadet participants due to their differential

experience with the hand signals communicated. The participants from the military academy had some prior experience with the visual form of message while the university students were encountering them for the first time. To a degree, any such difference should have been mitigated by the practice given. However, we chose to examine this eventuality analytically. A simple *t*-test did distinguish such a difference which was evident in the pre-motor response time to the tactile signals only (i.e., $t(70)=1.99$, $p<.01$ [military cadets = 785 ms vs. university students = 956 ms]). Potential reasons for this interesting outcome and an evaluation of all of the present results are discussed below.

DISCUSSION

From a simple 'horse-race' model of combinational processing, one would initially expect that the combined visual and tactile presentation of consistent signals would be equivalent to the faster of the two modalities (i.e., visual or tactile when presented alone). However, this simplistic conception was not supported by the data. Rather, the combinatorial condition was faster than either the visual alone or the tactile alone condition. Neither could enhanced processing speed be attributed to a tradeoff of speed for accuracy since the combined condition was significantly more accurate than the tactile alone presentation, although this latter result might have been affected by a confusion between two specific forms of tactile signal. However, in general, what emerges is a genuine advantage in performance for the multi-modal signal presentation. There are a number of potential reasons why this may occur. At the present, we must postulate some form of multi-signal reinforcement effect that derives from the facilitation due to cross-reinforcement of sensory signals. A more realistic source for the enhancement may lie in the neurophysiologic architecture linkages discussed at the start of this paper. It appears that cross-modal reinforcement has a direct effect on strength of synaptic transmission that is experienced early in the stimulus processing sequence. It was to explore this possibility that the experiment was conducted which parsed the response in order to isolate motor output components of the response sequence. Here, we found a strong confirmation first of the multi-modal presentation advantage and second of the isolation of that advantage into the early, pre-motor stages of response. At present, it is uncertain whether the primary advantage is to be found in the perceptual recognition phase of the response sequence or in the decision-making and response formulation element of that sequence. However, the distinction of such a difference is amenable to further empirical identification. From the assembly of present results it appears that a neuro-physiological argument underlying cross-modal stimulation provides the best candidate account for the early advantage offered by consistent multi-modal signaling.

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