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Cross-modal Effects In Tactile And Visual Signaling

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CROSS-MODAL EFFECTS IN TACTILE AND VISUAL SIGNALING

by

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ABSTRACT

Using a wearable tactile display three experiments were conducted in which tactile messages were created emulating five standard US Army and Marine arm and hand signals for the military commands, namely: “Attention”, “Halt”, “Rally”, “Move Out”, and “Nuclear Biological or Chemical event (NBC)”. Response times and accuracy rates were collected for novices responding to visual and tactile representations of these messages, which were displayed either alone or together in congruent or incongruent combinations. Results indicated synergistic effects for concurrent, congruent message presentations showing superior response times when compared to individual presentations in either modality alone. This effect was mediated by participant strategy. Accuracy similarly improved when both the tactile and visual presentation were concurrently displayed as opposed to separately. In a low workload condition, participants could largely attend to a particular modality, with little interference from competing signals. If participants were not given instructions as to which modality to attend to, participants chose that modality which was received first. Lastly, initial learning and subsequent training of intuitive tactile signals occurred rapidly with large gains in performance in short training periods. These results confirm the promise for tactile messages to augment visual messaging in challenging and stressful environments particularly when visual messaging is maybe preferred but is not always feasible or possible.

This work is dedicated to the Soldier, who above all must not fail, as his life and the lives and freedom of others depend on his performance.

ACKNOWLEDGMENTS

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LIST OF ACRONYMS/ABBREVIATIONS

ANOVA	Analysis of Variance
APA	American Psychological Association
dB	Decibels
GLM	General Linear Model
Hz	Hertz
IAW	In Accordance With
ISI	Interstimulus Intervals
LTM	Long Term Memory
MANOVA	Multivariate Analysis of Variance
PLLS	Posterolateral Lateral Suprasylvian
RT	Response Time
SC	Superior Colliculus
SA	Situation Awareness
SME	Subject Matter Expert
SPSS	Statistical Package for the Social Sciences (software)
STM	Short Term Memory, AKA Working Memory
TCU	Tactor Control Unit
UCF	University of Central Florida

CHAPTER ONE: INTRODUCTION

Humans rely on their multiple sensory systems, each with their different attributes for redundancy and confirmation, to continually integrate the stimuli around them to build their perception of the world in which they live. While each human sense is, in itself, remarkably adept at detecting things around us, the combination and integration of sensory input provides an extremely rich multi-sensory representation of spatial, temporal and object information that humans rely on to thrive and survive.

The cross-modal fusion or integration of information across different senses is better than more information within the same sensory modality. Consider the information from observing an orange from different angles versus sight and smell or sight and touch. Not surprisingly, Hillis, Ernst, Banks and Landy (2002) found that the value of multiple visual cues (disparity and texture gradients) combined, did not produce as accurate performance as when visual and tactile cues were combined in an object property discrimination task. Comparing performance within the same modality versus combinations of two different modalities illustrates that information loss can occur during intra-modal presentations that does not occur with the fusion of different modalities. Further studies have shown that in the case of tactile and visual information, there seems to be a highly efficient integration of the two information sources (Ernst & Banks, 2002). This optimal integration occurs naturally when cross-modal cues are congruent, matching top down expectancies and past experiences.

While not a common natural experience in one's environment, conflicts do occur between the senses. Magicians and illusionists often rely on such intra-modal failures of selective attention, while illustrations of the conflicting senses abound even in the early scientific literature. A good example is the Stroop effect, when words are written in different colors that do not match their semantic content, which is arguably one of the most quoted works in all of psychology, there is evident conflict (see Stroop, 1935). Similarly, crossing the sounds meant for the opposite ear produces Thompson's now infamous pseudophone effect (see Thompson, 1879).

The Stroop color and word confusion and its various derivatives have been the topic of myriad studies (Duncan-Johnson & Kopell, 1981; Dyer, 1973; Houston, 1969; Wheeler, 1977). Early versions of the Stroop test consisted of three different stimuli presentations. One type of stimulus was the words red, green, blue, brown, and purple all printed in different colored ink, none of which was congruent with the written word. The second type of stimulus or presentation involved the same five aforementioned colors printed as small triangles. The final type of stimulus involved the five color names written in standard black ink. What Stroop himself was most interested in was that the participants could "read" the colors in the same amount of time regardless of ink color. However, when participants were instructed to "name" the color of the ink used to print the word, the time to complete the task was almost doubled, a phenomena that came to be known as "the Color-Word Interference Effect", also known as "the Stroop effect".

Stroop interference is relatively easy to elicit in adults with normal reading skills, less so for children. Subsequent versions of the Stroop task used the original five colors, four colors or even as few as three colors with no significant difference found between the three different versions (Golden, 1975a, 1975b). Interestingly, researchers have used other stimuli in an attempt to create Stroop-like interference. For example, White (1969) presented cardinal directions in spatially incongruent locations represented by the corners of a square. While not as robust as the original Stroop interference, there was a significant increase in recognition times for the incongruent trials.

In a similar Stroop-like task, Shor (1970) presented arrows as stimuli that pointed to a particular direction (e.g. left, right, down, up), then used words presented next to the spatial presentation of the arrow in an incongruent manner (e.g. the arrow points right but the word reads left). Again, while not as disruptive as the color naming task, the incongruent trials did create a significant increase in recognition times. Arguably, colors and words seem to have some shared pathways, or at least share many of the same neuropsychological channels, resulting in performance conflicts when incongruent. The two nonverbal studies above show this same processing decrement with spatial tasks as well with the written word. Additionally, the automaticity of reading is so prevalent in the average adult, that words predominate, making the ability to ignore the visual reading cues difficult to suppress.

Ventriloquists similarly have relied on the failures of cross-modal selective attention in their efforts to give life to inanimate puppets and illustrations of multiple conflicting senses are also evident in numerous scientific and professional literature. When there is good visual localization and synchronization with the voice, vision will dominate and capture audition (i.e. the dummy talks, the actor's voice comes from his or her mouth, not the television speaker, etc.). However, with severely blurred or degraded visual stimuli, that are poorly localized, the reverse holds true: audition captures vision (Alais & Burr, 2004). In some cases neither sense dominates, and perception follows the mean position or the perceptual average, getting meaning from experience, not the from the sensory input. This precision of congruent bi-modal presentation is frequently better than either visual or the auditory uni-modal presentation alone. Alais and Burr (2004) have suggested that this simple model of synergistic combinations of visual and auditory information offers a better explanation of events like the 'ventriloquism effect', rather than the premise that one sense must always capture the other (also see Ernst & Banks, 2002; Gepshtein & Banks, 2003).

There are times though when the senses are in direct conflict, and this combination results in less than accurate perception. For example, when lip movements conflict with auditory stimuli creating misinterpreted phantom sounds, an illusion named the ‘McGurk effect’ (McGurk & MacDonald, 1976; Tiippana, Andersen, & Sams, 2004). Another example of incongruent crossmodal stimuli is in the aviation domain. Pilots often must rely on their visual system (i.e. their instruments) when their vestibular system becomes confused due to the varying effects of gravitational pull and acceleration of the aircraft and/or they become spatially disoriented (O'Hare & Roscoe, 1990), as is thought to have occurred in the fatality involving John F. Kennedy, Jr.

Shams, Kamitani, and Shimojo (2000) found a visual illusion that is induced by sound. When a single visual flash was accompanied by multiple auditory beeps, the single flash was incorrectly perceived as multiple flashes. Participants consistently and incorrectly reported seeing multiple flashes whenever a single flash was accompanied by more than one beep. In this case, the segmentation of the auditory stimuli drove the visual illusion. Saldana and Rosenblum (1993) found auditory misperceptions in participants audition when asked to report a pluck or bow in a string instrument that was incongruently matched between vision and audition with regards to its anticipated sound. Conversely, Omori, Kitagawa, Wada and Noguchi (2007) found that participants showed a reduction in the effects of the Hering and Wundt illusions (i.e. the optical illusion of parallel lines appearing bent) by allowing participants to feel the curvature or lack thereof in the lines that they were viewing.

Jousmaki and Hari (1998) demonstrated that they could change the perceived sound generated when a subject rubs their hands together, resulting in an illusionary effect or audio-tactile interaction called the ‘parchment-skin illusion’. A microphone recorded the sounds produced when the subjects rubbed their palms together in a back-and-forth motion at one to two cycles per second. The recorded sounds were played back to the subject through headphones and were presented either identically to the original sound or modified so that the high frequencies (above 2 kHz) were either dampened by or accentuated by 15 decibels (dB). When either the proportion of the high frequencies or the average sound level of the auditory feedback (higher frequencies) increased, the participants reported that their skin started to feel more paper-like (the perceived roughness/moisture of the hand decreased and the smoothness/dryness increased). The perceived incongruence of the auditory and tactile senses led to a perceptual change, based on the interaction or integration of cross-modal stimuli.

Guest, Catmar, Lloyd, and Spence (2002) showed a similar effect in tactile roughness perception of abrasive surfaces by modulating the frequency content of the auditory feedback. When higher frequencies were attenuated, subjects showed a bias towards an increased perception of tactile smoothness. Current research has explored these conflicts of incongruent cross-modal paradigms in many combinations of very basic visual, auditory, kinesthetic and tactile stimuli (Soto-Faraco, Lyons, Gazzaniga, Spence, & Kingstone, 2002; Soto-Faraco, Morein-Zamir, & Kingstone, 2005; Soto-Faraco, Spence, & Kingstone, 2004a; Spence & Driver, 1997; Spence & Walton, 2005).

The real gaps in the literature are these cross-modal congruent and incongruent effects when the stimuli are more complex and rich in context. The purpose of the present work is to explore congruency effects for actual tactile and visual signaling extending the phenomenon of the cross-modal congruency paradigm beyond simple laboratory stimuli. In the more applied settings, the cross-modal integration of visual and tactile information could improve effective single modality interpretation when one of the senses is unavailable or busy, and even greater cross-modal integration with both senses are available. In extreme conditions, such as military combat or fire fighting, the ability to have some form of redundancy gain is widely sought, given that missed or miss-interpreted signals or messages may have catastrophic consequences.

CHAPTER TWO: LITERATURE REVIEW

Cross-modal: The Integration of Multiple Senses

Humans not only rely on their multiple senses to integrate the different forms of stimuli around them, they also use the multiple stimuli to aid them in the orientation and focus of their attentional resources in space and time. When an individual directs their attention in space, regardless of the primary modality used to orient attention, the other modalities often tend to be directed toward a similar location. We all have been startled by a noise, only to turn our head in an effort to identify the origin of the auditory stimulus. Some researchers propose that attentional direction in space is most often a multi-sensory construction (Spence & Driver, 2004) while many still argue that we are largely a visual organism (Posner, Nissen, & Klein, 1976).

The psychophysical literature points to the empirical evidence of the strength of multi-sensory processing. 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 uni-modal stimulation. The combinations of two different sensory stimuli have been shown to significantly enhance the responses of superior colliculus (SC) neurons above those evoked by either uni-modal stimulus alone, supporting the conclusion that there is a multi-sensory link among individual SC neurons for cross-modality attention and orientation behaviors (Meredith & Stein, 1996; Wallace, Meredith, & Stein, 1998).

Recent literature continues to reinforce the assertion of multi-sensory processing is possible for 'uni-modal' neurons. Allman and Meredith (2007) used cellular recordings to measure responses of neurons in the posterlateral lateral suprasylvian (PLLS) of the cat. While uni-modal visual neurons did not respond when presented with only auditory stimuli, they did have an enhanced visual response with concurrently presented auditory stimuli. This finding suggests that bi- and tri-modal neurons are not the exclusive domain for multi-modal processing but that there is potentially a sub-threshold multi-sensory neuron that is contributing to an organism's processing of multi-modal stimulation. This may be a basis for behavioral responses to bi-modal stimuli found to be faster and more accurate than for uni-modal stimuli (Teder-Salejarvi, Di Russo, McDonald, & Hillyard, 2005).

Multi-modal stimulation in the world is not always presented or received in a congruent spatial and temporal manner. This is most often resolved in the brain by an over reliance on the visual system or by the brain registering a self-continuity in time (see Hancock, 2005). However, when the expectation that the multi-sensory information is congruent, and it is not, cognitive and perceptual errors can result. To date, the exploration into the cross-modal attention phenomenon has relied on simple stimuli eliciting a response from a simple paradigm. For example, Spence and Walton (2005) used a tactile stimulus and a light mounted at two elevations on a piece of foam and then placed in the vertical plane of the participant's hand (i.e. finger (up) versus thumb (down) of both hands). Participants made speeded elevation discrimination responses (up versus down) to visual targets (the mounted lights), while simultaneously trying to ignore task-irrelevant vibrotactile distractors presented independently to the finger (up) versus thumb (down) of either hand. Participants responded significantly more slowly, and somewhat less accurately, when the elevation of the vibrotactile distractor was presented deliberately incongruent with that of the visual target than when they were presented from congruent elevation.

Gray and Tan (2002) used a number of tactors (vibro-tactile actuators) spanning the length of the participant's arm with lights mounted on the individual tactors. Using an appropriate inter-stimulus interval (ISI) and tactor spacing (see Geldard, 1982; Geldard &

Sherrick, 1972; Helson & King, 1931) 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, thus, supporting 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.

Craig (2006) had participants judge the direction of apparent motion by stimulating two locations sequentially on a participant's finger pad using vibro-tactors. Visual trials included apparent motion induced by the activation of two lights sequentially. Trials were also conducted 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, 2004a, 2004b).

Bensmaia, Killebrew and Craig (2006) had participants make discrimination judgments comparing pairs of tactile stimuli with drifting sinusoids. On some of the trials a visual drifting sinusoid was presented simultaneously with one of the two tactile stimuli, serving as a distraction but to be ignored. When the directions of drift for the visual and tactile gratings display were congruent, the visual distractor increased the perceived speed of the tactile grating. When the two stimuli were incongruent, (i.e. they drifted in opposite directions) the distracting effect of the visual distractor was reduced or reversed, as was the perceived speed of the tactile grating slowed.

While all of these experiments with simple tasks are essential for understanding the psychological phenomena being studied, the extension of these findings to more applied stimuli is problematic. However, with the advancement of tactile display technology and innovative signaling techniques, the importance of testing systems capable of assisting communications is now possible and even more important.

Cutaneous Communication Systems

Cutaneous communication systems have enjoyed considerable success in many domains; including aircraft stick shakers, the ubiquitous cellular telephone vibratory alerts, and reading using Braille. Regardless of these successes, tactile displays are not as pervasive in military settings and may offer a relatively unexploited sensory channel for soldier communications, especially in the chaos of battle. Combat conditions can impose significant demands on Soldier senses, limiting their ability to communicate through normal auditory and visual pathways (Hancock & Szalma, 2008). Noisy (e.g., weapon fire, vehicle engines) and murky (e.g., smoke, sandstorm) conditions can hinder the ability to communicate critical data such as relevant threat information or simple squad movement instructions. In an environment replete with visual and auditory signals and noise, one way to circumvent this issue is to communicate through a relatively unused information channel: touch.

Tactile displays offer a relatively untapped channel for soldier communications. According to multiple resource theory (see Wickens, 1984, 2002), parsing information across the input modalities can alleviate sensory bottlenecks and reduce interference with visual and auditory channels. Tactile displays offer other advantages as well. First, they are non-illuminating and can be made to be acoustically covert, allowing the soldier to maintain a stealth advantage. Conversely, traditional visual and auditory displays can also mask important environmental information, such as distant enemy movement or approaching footsteps. Tactile displays offer the advantages of silent omni-presence and omni-directionality.

Our research group, in partnership with industry, has designed a wearable tactile display capable of remotely delivering patterns of vibratory stimulation at multiple loci (Merlo, Stafford, Gilson, & Hancock, 2006). This system has been shown to be able to convey information clearly beyond simple alerts or directional cueing. The display allows for precise control of frequency, gain, and onset times. With this level of stimulus control, consistent patterns can communicate more complex messages, as well as simple alerts. Stimulus parameters have been derived, based upon feedback from a group of subject matter experts (SMEs) consisting of retired US Soldiers and Marines, to tactually convey key hand and arm signals. The reason for this approach was three-fold. First, hand and arm signal movements have a spatio-temporal patterns that can be emulated and conveyed via comparable patterns applied to the skin. These tactile signals also can be presented covertly, without soldier movements that may signal their position to an enemy force. Second, the wireless transmission of these signals to the tactile display increases the likelihood that all squad members will receive a signal simultaneously. For example, when a team leader is informed of a potential threat and visually signals a "Halt" command, the soldiers in front of the team leader may not see the visual command while scanning their surroundings and maintaining local security. This can lead to an "accordion" effect, whereby soldiers do not immediately respond to halt and become spread out. Third, Soldiers are already well trained and tested for the use of hand and arm signals. Therefore, it is reasonable to expect a degree of transfer of training to learn the tactual form, provided that the tactile patterns are designed to closely approximate their intuitive visual counterparts. A short tactile lexicon was developed by the SME group based on commonly used commands of the existing U.S. Army hand and arm signals (Department of the Army, 1987) allowing eye-free and ear-free communication among display wearers (see Gilson, Redden, & Elliot, 2007). Concurrent with laboratory research, it was necessary to determine if such tactile displays could function in applied settings involving significant physical and cognitive demands. That is, to determine if the relative advantages of tactical displays remained as sensory and perceptual relief (see Calhoun, Draper, Ruff, Fontejon, & Guilfoos, 2003; Gilson & Fenton, 1974; Hopp, Smith, Clegg, & Heggestad, 2005; Oron-Gilad, Downs, Gilson, & Hancock, 2007; Pettitt, Redden, & Carstens, 2006; Raj, Kass, & Perry, 2000; Rochlis & Newman, 2000; Rupert, 2000; van Erp, 2005; van Erp, Groen, Bos, & vanVeen, 2006; Zlotnik, 1988).

For tactile displays that are based on vibration, the key skin receptors are primarily the Pacinian corpuscles, which consist of nerve endings surrounded concentrically by layers of non-neural connective tissue. Pacinian corpuscles respond most readily to vibration at frequencies around 200-300 Hz (Bensmaia, Hollins, & Yau, 2005; Verillo, 1966), whereas, the free nerve endings are sensitive to much lower frequencies between 50-100 Hz (Bear, Connors, & Paradiso, 2001). Researchers in the past have had problems when attempting to operationalize tactile displays with low frequencies since difficulties arise in the spread and localization of the signal. For example, Sklar and Sarter (1999) experienced difficulties with tactile signals being readily identified on the wrist and arm, where spread is linear. Gilliland and Schlegel (1994) reported that tactile communication applied to the head lowered performance on a concurrent task, mainly because of bone conduction. These aforementioned challenges, and similar issues, present significant hurdles to those seeking to use tactile displays in applied settings as tactile signals that are only recognizable in pristine, quiet conditions may have limited use in real-world military operations.

With reported difficulties of vibrotactile stimulator placement on the head and extremities, the torso appears to be the preferred placement site for a wireless, fieldable system (Cholewiak, Brill, & Schwab, 2004). The torso also offers the least opportunity for tactors to shift during demanding physical tasks and, based on SME input, would be the least likely location for it to impede other combat tasks while remaining easily perceptible.

Recent research has demonstrated that tactile cueing yields significantly faster and more accurate performance than comparable spatial auditory cues in laboratory tests. Further results have demonstrated this finding is relatively stable across a variety of body orientations, even when mental spatial translation is required (see Terrence, Brill, & Gilson, 2005) and under physiological stress such as running (see Merlo, Stafford, Gilson, & Hancock, 2006) or even under high acceleration (up to +9 G_z) (van Erp et al., 2007) . Near perfect accuracy rate, above 99%, displayed by the participants running in a physiological stress study was highly encouraging in respect to the potential of current tactile display designs (Merlo et al., 2006). The accuracy of the messages and the reported intuitiveness with which they were received also was a testament to the potential utility of the present '*language*' in the current tactile format.

Field studies at Fort Benning, Georgia have shown that response times were significantly faster with the tactile signals than with the hand signals, especially when the hand signals came from the Soldier's rear rather than the front. Results demonstrated Soldiers performing an obstacle course were able to receive, interpret and accurately respond to the tactile commands faster than when the information was passed by normal means (a leader in the front of a wedge formation or by a leader in the back of a wedge formation using conventional hand-and-arm signals). Soldiers also commented that they were better able to focus their visual attention on negotiating the obstacles and on local area situation awareness when receiving tactile signals than when maintaining visual contact with their leaders in order to receive standard hand and arm signals. Soldiers indicated the tactile system allowed them to focus more attention on negotiating obstacles, and that it would be useful in tactical situations in which they would need to focus on other tasks such as security. Soldiers also commented that it was very difficult to receive a visual hand and arm signal at certain points on the course where their full attention was given to negotiating the obstacle, or when they could not maintain visual contact with the leaders. Soldiers stated they knew immediately when they received a tactile signal no matter what obstacle they were negotiating (see Pettitt, Redden, & Carstens, 2006). Notably, there was no condition in this study where soldiers received both signals simultaneously.

The use of a tactile communication system may have the potential to improve infantry team performance beyond what was documented in this experiment. During the obstacle course used in the aforementioned study, the leaders in the front and rear of the Soldiers were not obscured by terrain, vegetation or light level. In other words, the conditions of this experiment were optimal for the Soldiers' ability to see the conventional hand and arm signals and they were expecting them. During combat situations, larger dispersions and obscurants (creating greater visual degradation) could greatly inhibit reception of visual hand and arm signals, especially when not expected. Visual barriers in an urban combat situation can impair hand and arm signaling. Additionally, hand and arm signals are traditionally passed along throughout the squad as a relay. The time that the first squad member receives, interprets, and relays the signal is obviously much quicker than the time that the signal is received by the last squad member. A tactile communication system would allow simultaneous reception of signals by all squad members. For example, a “halt” signal sent by visual signals could result in a wave or accordion effect during its relayed transmission so that the last squad member to receive the signal could still be moving well past the time when the squad needed to stop. A “halt” signal sent by a tactile system can be received by all squad members simultaneously. A further benefit provided by a tactile system is the increased local situational awareness (SA) experienced by the squad because the tactile system would free the visual channel to engage in other task directed activities (i.e., to watch for other pertinent visual stimuli like enemy movement, IEDs, etc. (see Smith & Hancock, 1995)). The tactile system also could act as a redundancy gain with Soldiers now having two means of receiving communications and might allow for better performance when signaling is presented in a multi-modal context.

In a simple reaction time (RT) task, participants responded faster to simultaneous visual and tactile stimuli than to a single visual or tactile stimulus (Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002). Similarly, in a computer simulated target cueing paradigm, participants responded faster and more accurately when there was both a visual and tactile cue presented (Oron-Gilad, et al., 2007).

A meta-analysis comparing visual and visual-tactile feedback found that visual-tactile feedback is particularly effective at reducing reaction time and increasing performance versus using only visual task feedback. In addition, greater performance for multimodality feedback was even more effective when workload was high and multiple tasks were being performed (Prewett et al., 2006).

Identification of Hypotheses

Three major hypotheses will be tested in these studies. First, the hypothesis that the tactile presentation of spatially based messaging or signaling (U.S. Army arm and hand signals) can produce similar performance levels, albeit potentially slower than their visual counterparts. Also, it is hypothesized that these two modalities will interact with one another so that performance will be better when both visual and tactile signals are presented simultaneously and congruently as measured by response time and signal identification accuracy. The comparison reference is against performance for signals presented in either modality alone.

Second, it is hypothesized that the simultaneous presentation in the different modalities of the signaling, that are incongruent in signal meaning (like the Stroop effect), will produce longer response times and greater error rates in signal identification. This effect will be exacerbated by instructions given to participants regarding the modality to which they focus their attention.

Third, if the performance variables for modalities are equated across signals, (i.e. made to match temporally according to baseline performance differences), the simultaneous presentation in the different modalities of the signaling, that are incongruent in semantic content, there will be a higher selection propensity for the modality that is presented first.

CHAPTER THREE: EXPERIMENT 1

Experimental Participants

To investigate the foregoing propositions, twenty participants from the University of Central Florida (ten males and ten females) ranging from ages 18 to 28, with a mean age of 19.7 years of age, volunteered to participate in the study. Participants each self-reported no surgical procedures, no significant scarring and no impediment that might cause lack of feeling in the abdomen or torso area. All participants provided informed consent and were treated in accordance with the APA standards regarding ethical principles (IAW 2002 Ethics Code).

The number of participants was based on a power analysis using (Cohen, 1988). The weighted effect size for a multimodal or visual-tactile benefit over a single modality is .84 under high workload and .68 for low workload (Prewett et al., 2006). Since the workload for the proposed paradigm is relatively low, the value of .70 was used as the calculational effect size. The estimated effect is medium or .70. Using the tables provided in (Cohen, 1988), the suggested N for an ANOVA with a value of $p \leq .05$ is not less than twenty participants for each between-participants condition.

Experimental Materials and Apparatus

The vibrotactile actuators (tactors) for the tactile system used in this work were model C2, manufactured by Engineering Acoustics, Inc. They are essentially acoustic transducers optimized for 200-300 Hz sinusoidal vibrations while impressed into the skin. Their 17 gram mass is sufficient for activating the skin's receptors and being easily detected by the touch senses. The C2's contactor is 7 mm, with a 1 mm gap separating it from the tactor's stationary aluminum housing. The C2 is a tuned device, meaning it operates well only within a very restricted frequency range, around 250 Hz.

The tactile display itself is a belt-like device with eight vibrotactile actuators, as shown below in Figure 1. The belt itself is made of elastic within high quality cloth similar to the material used by professional cyclist. When stretched around the body and fastened with velcro, the wearer has an actuator over the umbilicus and one centered over his spine in the back. The other six actuators are equally spaced, three on each side, for a total of eight, with one actuator at every 45 degrees from the navel around the body (see Cholewiak, Brill, & Schwab, 2004).

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

The tactors are operated using a Tactor Control Unit (TCU) which is a computer-controlled driver/amplifier system that switches each tactor on and off. This wearable device is shown on the left side of the tactile displays belts in Figure 1. The TCU weighs 1.2 lbs (.54 kgs) independent of its power source and it 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 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 experiment were, “Attention”, “Halt”, “Rally”, “Move Out”, and “Nuclear Biological Chemical event (NBC)”.

Table 1: *Arm and Hand Signals and Corresponding Tactile Signal Patterns. The illustrations are from US Army Field Manual 21-60.*

Arm / Hand Signal	Tactile Pattern	Visual Pattern
Attention	Sequenced activation of three forward tactors creating a linear motion back and forth across the front of the body	
Halt	Four tactors simultaneously actuated on the sides of the body	
Rally	Sequenced activation of all tactors creating a circular motion around the body	
Move Out	Sequenced back-to-front activation of tactors creating movement from each side of the body which converges in the front	
NBC	Sequenced activation on both sides simultaneously creating three distinct impulses on the sides of the body	

The tactile representations of these signals were designed in a collaborative effort of scientists at the University of Central Florida (UCF) and a consultant group of subject matter experts (SMEs) consisting of former United States Soldiers and Marines.

Short video clips of a soldier performing the five arm and hand signals were edited to show the visual stimuli. Careful editing ensured the timing of the arm and hand signals closely matched the tactile presentation. A Samsung Q1 Ultra Mobile computer using an Intel Celeron M ULV (900 MHz) processor with a seven inch 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 (8.5; National Instruments) application that presented the tactile signals via Bluetooth to the tactor controller board, and the same computer captured all of the participant's responses via mouse input (see Figure 2).

The display of each message or signal was presented in one of three ways:

- visual only (video presentation of the arm and hand signal)
- tactile only (tactile presentation of the arm and hand signal)
- both visual and tactile simultaneous and congruent (i.e. the same signals were presented both visually on the video and through the tactile system)

Participants wore sound dampening headphones with a reduction rating of 11.3 dB at 250 Hz to reduce the effects of any auditory stimuli emanated by the tactor actuation.

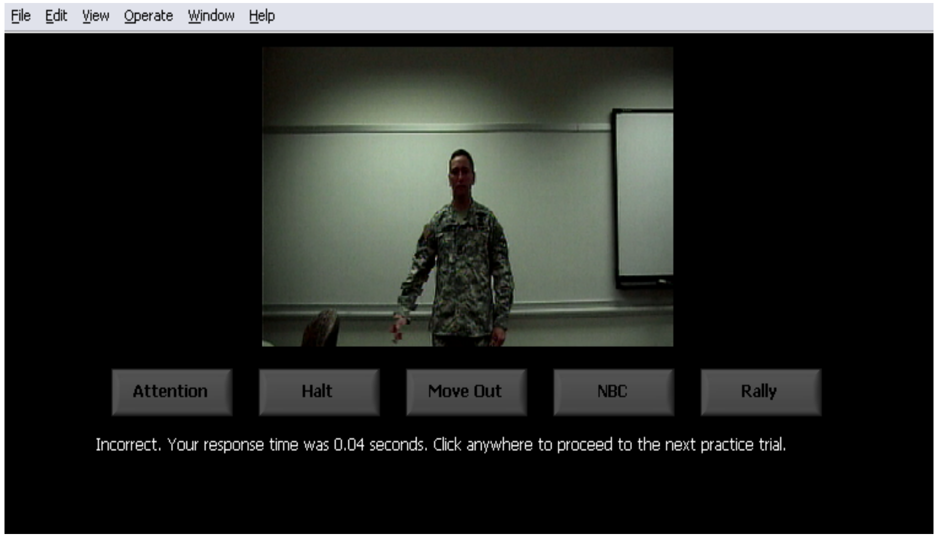


Figure 2. A screen shot of the computer display showing what the participant viewed as the visual signals were presented. The participants mouse clicked on the appropriate signal name below the image after each presentation.

<u>Experimental Design and Procedure</u>

Participants first completed a computer-based tutorial that described each arm and hand signal individually. For each signal, a short description was presented, which included the description of the signal from the Army and Marine Corps Field Manual. Participants then viewed a video of a soldier performing the signal and felt its tactile equivalent. Finally, the participants were able to play the five signals concurrently (visual and tactile). Participants were allowed to repeat the presentation (i.e., visual, tactile, visual-tactile) on a self paced basis. Once the participant reviewed the five signals in the three presentation styles, a validation exercise was performed. Participants had to correctly identify every congruently presented signal twice before the computer would prompt the experimenter that the participant was ready to begin.

Each participant performed 60 trials. The trials had four of each signal presented only visually (4 x 5 = 20 total), four of each signal with only tactile signals (4 x 5 = 20 total), and four of each signal performed simultaneously with both congruent visual and tactile presentation (4 x 5 = 20 total). The sixty total trials were randomized for each block by a random number generator function inside the LabVIEW application making the order of trials different for every participant.

Experiment 1 Results

All reported analyses were conducted using SPSS 11.5 for Windows with the alpha level set at $p \leq .05$ and with two-tailed t-test unless otherwise specified. All graphs include mean values and standard error bars unless otherwise noted. Mauchly's test for sphericity was conducted for all multivariate analyses. If the test results were not significant, the assumption for sphericity was used for subsequent tests, or else appropriate corrections were considered and reported for the subsequent analysis as to the type and results of the corrected results for those multivariate tests. Results were analyzed in terms of the speed of the accurate response and the accuracy of the response under the respective conditions. For incongruent conditions, the modality of the response was also considered. The mean response times for each modality are illustrated below in Figure 3.

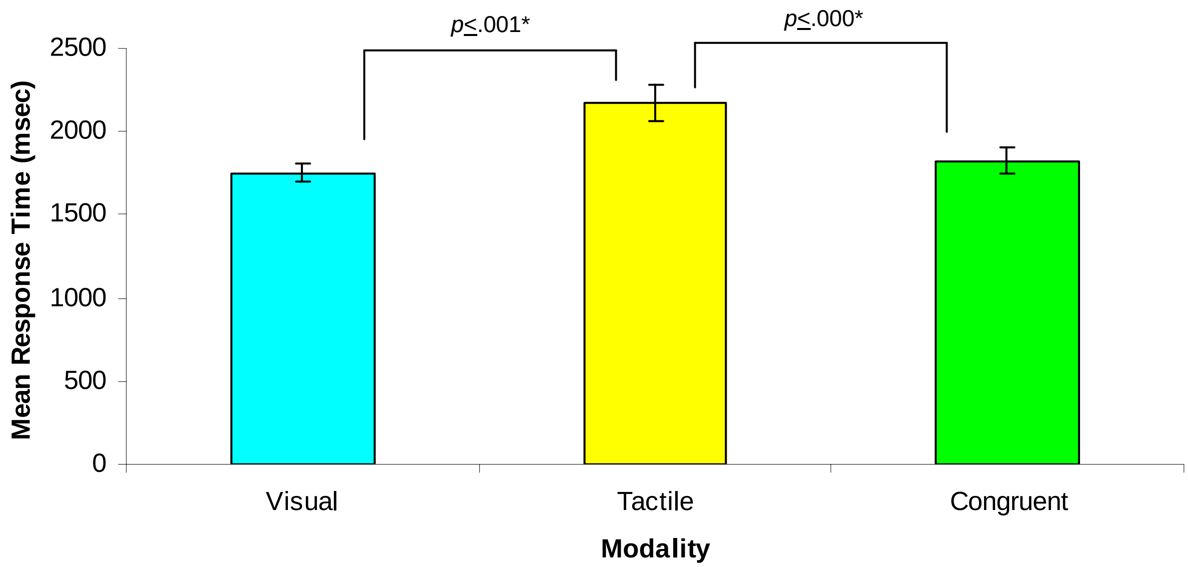


Figure 3. Mean response time (msec) by modality of signal presentation. Significant differences are noted with an "*".

Results of a general linear model (GLM) within-subjects analysis of variance of modality (visual, tactile and visual/tactile congruent) of presentation showed significant differences between the response time means, F (2, 38) = 16.576, p<.001, (η^2_p = .466, β= .999). Pairwise analysis, using a Bonferroni correction for multiple comparisons, showed a significant mean difference between the visual and tactile modalities, t(19) = -4.31, $p \leq .001$ as well as the congruent visual/tactile and tactile modality, t(19) = 4.98, $p < .000$. This difference is illustrated in Figure 3 above, as well as in the table of means (see Table 2 below). There was no significant difference between the congruent visual/tactile and visual presentation t(19) = -.692, $p \leq .497$.

Table 2. *Mean response times for three modalities.*

Modality	Mean	Standard Deviation
Visual	1754.50	234.22
Tactile	2148.06	500.36
Congruent	1795.86	347.35

A general linear model multivariate analysis of the within-subjects variables of modality (visual, tactile and visual/tactile congruent) and signal (attention, halt, move out, NBC and rally) was conducted for response time means, with the within-subjects factors of modality and signal passing assumptions for sphericity. However, Mauchly's test of sphericity was significant for the interaction of modality and signal, therefore the Greenhouse-Geisser correction was applied for the analysis of this interaction. There was no significant difference present between the differing signals; F (4, 76) = 1.93, $\underline{p} < .114$, ($\eta^2_p = .092$, $\beta = .557$). However, the interaction between modality and signal was significant F (4.39, 83.39) = 3.68, $p \leq .007$, ($\eta^2_p = .162$, $\beta = .886$). A pairwise analysis by signal was conducted using a Tukey'sTest to account for pooled error. The following abbreviated chart shows those comparisons which are significantly different. The complete table of all of the comparisons is shown in Table 5, Appendix D.

Table 3. *Significant pairwise comparisons between signals by modality.*

	Mean RT	STD DEV	Tactile Move Out	Tactile NBC
Visual NBC	1563	381.21	0.004*	0.003*
Visual-Tactile NBC	1580	367.67	0.005*	0.004*
Visual-Tactile Rally	1696	376.18	0.040*	0.031*

Note: For a complete table of all comparisons see Table 5 in Appendix D.
** denotes significant difference at p ≤ .05.*

The significant differences are between the fastest visual signals and multimodal congruent signals and the slowest tactile signals. As shown in Figure 4, only six of the 105 comparisons were significantly different. Notably, the few differences were between the extremes in performance. The signal that produced some of the fastest response times visually was the signal "NBC". This was the only visual signal of the five that was presented using both the left and right arms and hands. This made the visual recognition of this signal markedly different from the other four visual signals (as subjectively reported by participants), although not enough to create a statistical difference in response time means between the other visual signals. The few differences in response time between signals by modality are between the fastest visual and multimodal signals and the slowest tactile signals.

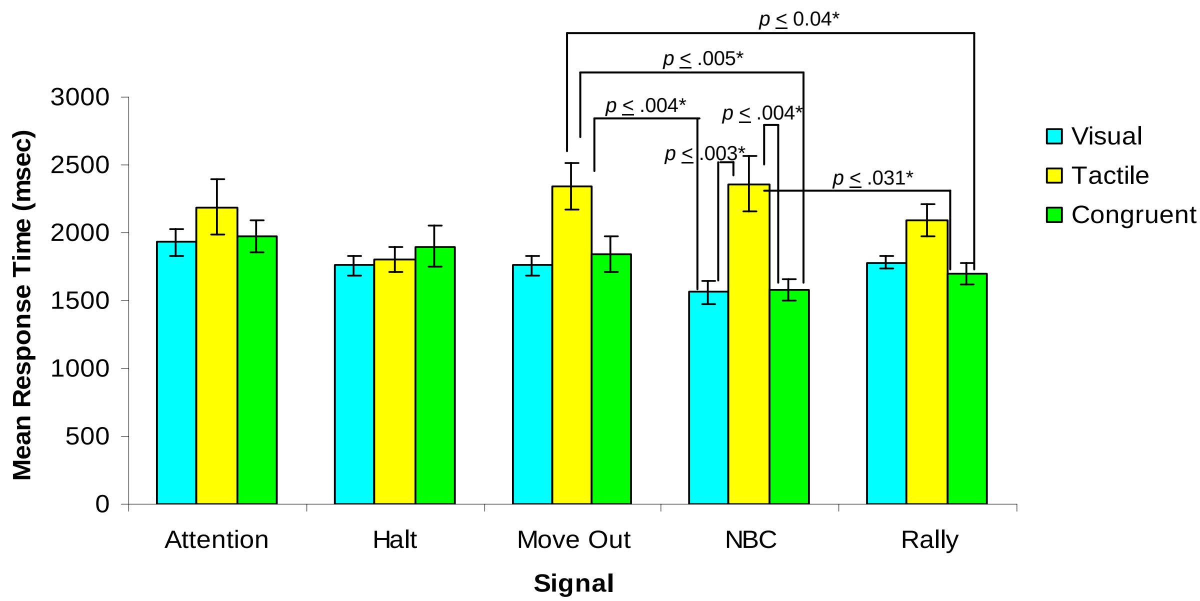


Figure 4. Mean response time (msec) by signal and modality. For complete table of all comparisons see Table 5 in Appendix D. * denotes significant difference at $p \leq .05$.

The accuracy of the participant's responses also differed by modality. Figure 5 illustrates the difference in the accuracy rates of the different modalities. Mauchly's test for sphericity was significant, so a Greenhouse-Geisser correction was made in the subsequent analysis. Results of a general linear model repeated measures within-subjects analysis of variance using modality (visual x tactile x congruent) shows significant differences between the response accuracy means, F (1.06, 20.19) = 13.805, $p \leq .001$, ($\eta^2_p = .421$, $\beta = .95$). Similar to response times analyses, pairwise analysis using a Bonferroni correction for multiple comparisons showed a significant mean difference only between the visual and tactile modality, $p \leq .005$ and the visual/tactile congruent and tactile modality, $p \leq .003$. Table 4 gives the mean percent correct by modality.

Table 4. *Mean response accuracy (%) for each modality.*

Modality	Mean Percent Correct	Standard Deviation
Visual	99.25	1.83
Tactile	87.50	14.28
Congruent	99.0	2.62

The difference between the accuracy of the different display modalities is illustrated in Figure 5 below. Notice the same trend in mean differences in accuracy to that of the comparisons of means response times (see Figure 3).

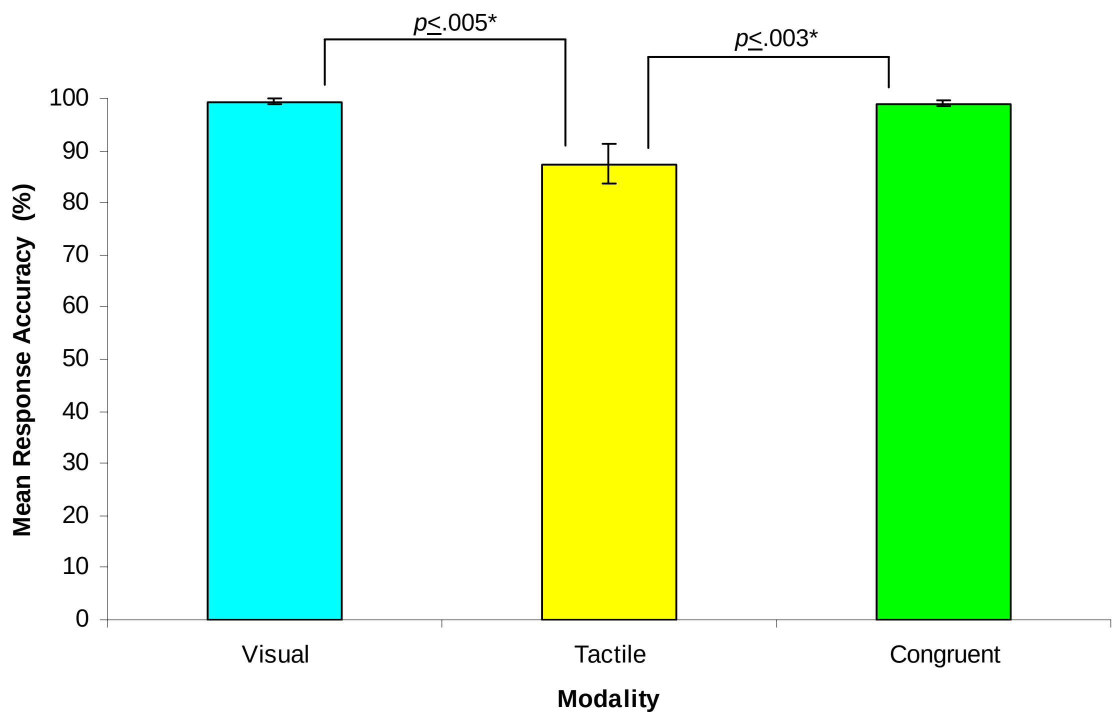


Figure 5. Mean accuracy rates (%) for the different modalities.

A general linear model MANOVA of the within-subjects variables of modality (visual, tactile, and congruent) and signal (attention, halt, move out, NBC and rally) was conducted for response accuracy means. Modality, signal and their interaction did not pass the assumptions for sphericity as Mauchly's test of sphericity was significant for all three. Therefore, the Greenhouse-Geisser correction was used for this analysis. There was a significant difference between signals F (3, 52) = 3.63, $p \leq .021$, (η^2_p = .161, β= .742). The interaction between modality and signal was also significant F (4, 67) = 4.51, $p \leq .004$, (η^2_p = .192, β= .903). A pairwise analysis by signal was conducted using a Tukey'sTest to account for pooled error. These mean differences by signal are illustrated in Figure 6 below.

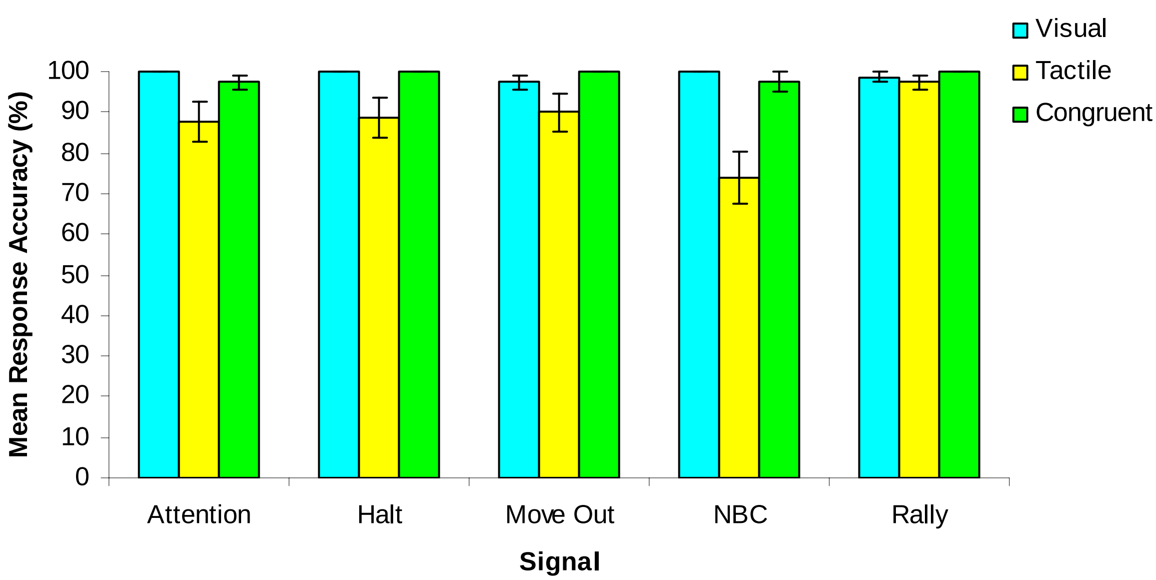


Figure 6. Mean response accuracy (%) by signal and modality. For the complete table of all of the comparisons see Table 6 in Appendix E. Those data with no SE bar represent conditions that were 100% accurate for all trials.

As shown in Figure 6 above, the only comparisons which are significantly different are the comparisons of the accuracy for the tactile signal for "NBC" (74%), which is significantly less accurate than all of the other signals in the other modalities and the tactile presentation of the signal "rally", which is more accurate than all of the other tactile signals. The tactile signal for NBC is not significantly different from the other three remaining tactile signals. The similarity between the two tactile signals "Halt" and "NBC" was one of the reasons for the low accuracy rate of the "NBC" signal. In almost every instance where there was an incorrect selection after the tactile signal "NBC" was presented, participants chose "Halt". The high accuracy rate for the tactile signal "Rally" was for the exact opposite reason. It was not easily mistaken with other signals as it fully utilized the tau phenomena (apparent motion) and had the tactile signal appearing to rotate completely around the body twice, almost completely analogous to its visual counterpart.

Lastly, the data were examined for any effects of gender in the different modalities. A general linear model MANOVA of the within-subjects variables of modality (visual, tactile, and congruent) and between-subjects variable of gender (male and female) was conducted for response time means, F (2, 36) =.642, $p \leq .532$, ($\eta^2_p = .034$, $\beta = .149$). As illustrated in Figure 7, there was no significant difference between females and males in any of the modalities.

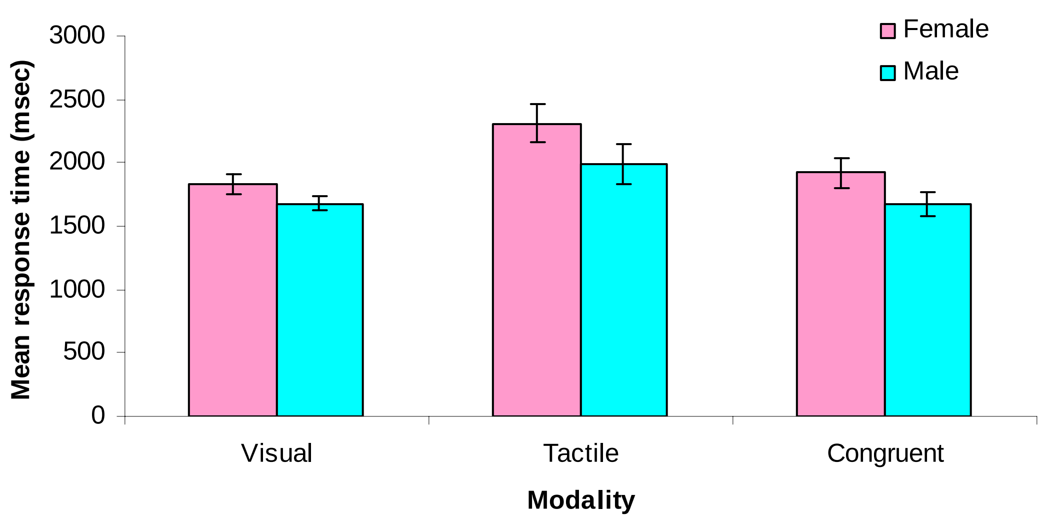


Figure 7. Mean response time in msec by modality and participant gender.

Analysis was also conducted on the accuracy of the response to the different signals by a general linear model MANOVA of the within-subjects variables of modality (visual, tactile, and congruent) and signal type (attention, halt, move out, NBC, and rally) and the between-subjects variable of gender (male and female), F (3.63, 65.39) =.925, $p \leq .448$, ($\eta^2_p = .049$, β= .265). Similar to the response latencies, there was no significant difference for accuracy by gender, see Figure 8 below.

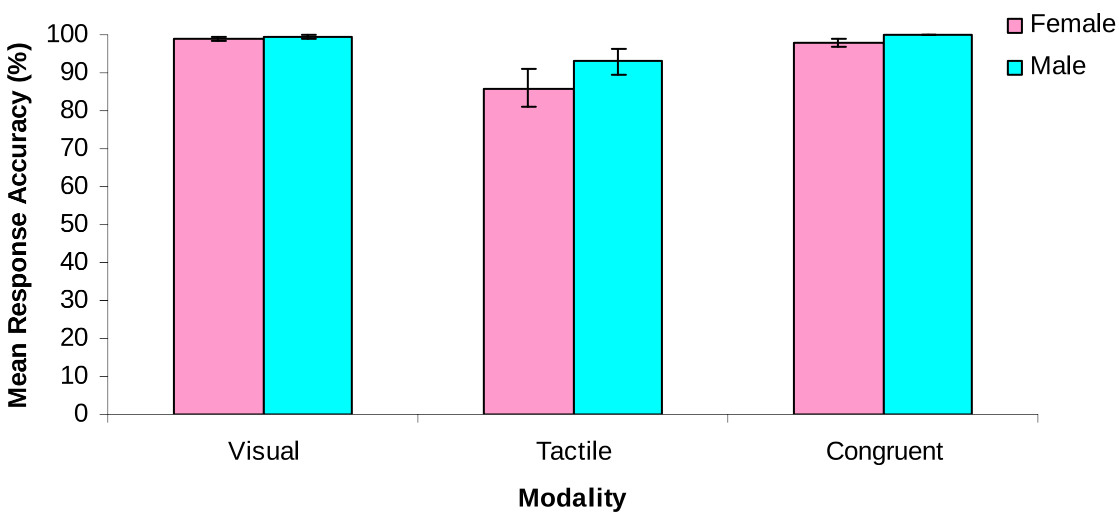


Figure 8. Mean response accuracy (%) by modality and participant gender.

Experiment 1 Discussion

The overall high accuracy rate displayed by the participants (over 87% in all modalities with under ten minutes of training) is highly encouraging for the eventual useful application of the current tactile display. Arguably, there was a marked advantage to the visual signals, as participants reported that three of the five visual signals were either already known or they would have guessed their meaning (e.g. attention, halt, and move out). The accuracy of the tactile messages and the reported intuitiveness with which they were received is a testament to the utility of the SME information and the present tactile 'language' transformation format. It also is a warning that thought for the design of intuitive signals is paramount. Similarities in both tactile and visual signals that cause confusion among similar signals were virtually eliminated in concurrent presentation. The rich multi-modal information for the congruent presentations produced equally fast and accurate performance as the single visual modality alone.

While the tactile signals are largely spatial emulations of their visual counterpart, it was not surprising to find a lack of significant performance differences between males and females. Gender differences often found in spatial cognition tasks are largely due to mental rotation and little to no mental rotation is required here for tactile signal comparison or interpretation (Voyer, Voyer, & Bryden, 1995). Additionally, some researchers have reported a decline in gender differences due to social and nurturing changes in today's more gender neutral environment (Feingold, 1988), while other factors such as athletic participation can mask or erase such differences (Hancock, Kane, Scallen, & Albinson, 2002). However, the sample size in this experiment was small (resulting in low power) for this between-subjects variable of gender, as gender differences still do exist for many spatial task and are well substantiated in the literature (Masters & Sanders, 1993).

While this initial experiment served to validate each signal's efficacy, it does not address other research questions that require a closer investigation into individual participant's response strategies. Are participants ignoring the tactile presentation during congruent multimodal presentation? Is this why there is no difference between the visual and congruent presentations in both response time and accuracy? For example, what are the effects of incongruent signaling (visual presentation that does not match tactile presentation)? One of the key characteristics of the Stroop phenomenon discussed earlier is that the participants had to either recognize the color of the font or read the word itself. The 'word effect' was demonstrated as participant's response times were slower when attempting to articulate the color of the word's font when the semantic content of the word was in conflict. Will this apparent automaticity of visual signaling cause a similar conflict?

In the follow-on experiment, some participants are free to choose what modality to attend when there is a multimodality presentation, while others are to be given instructions to attend to either one modality or the other. What is of issue is how well the participants can ignore one modality while attending to the other. Will there be a modality interference and will the instructed attention to a certain modality erase any benefits of the multimodal presentation during congruent trials? Additionally, will a forced strategy in modality effect the response time in that modality, as compared to a participant choosing his or her own strategy? It is to these follow-on propositions that we now turn.

CHAPTER FOUR: EXPERIMENT 2

Experimental Participants

To investigate the effects of incongruent signal presentation and the effects of instructions, sixty participants from the University of Central Florida (26 males and 34 females) ranging from ages 18 to 48, with a mean age of 21 years of age, volunteered to participate in the study. Participants each self-reported no surgical procedures, no significant scarring and no impediment that might cause lack of feeling in the abdomen or torso area. All participants provided informed consent and were treated in accordance with the APA standards regarding ethical principles (IAW 2002 Ethics Code).

The number of participants was based on a power analysis using (Cohen, 1988). The weighted effect size for a multimodal or visual-tactile benefit over a single modality is .84 under a high workload and .68 for a low (Prewett et al., 2006). Since the workload for the proposed paradigm is relatively low, the value of .70 was used as the effect size. The estimated effect is medium or .70. Using the tables provided in (Cohen, 1988), the suggested N for an analysis of variance with a value of $p \leq .05$ is not less than 20 participants for each between-subjects condition (i.e., 20 participants x 3 instruction types = 60 participants).

Experimental Materials and Apparatus

The experimental apparatus and materials used in the present procedure were the same as the first experiment.

Experimental Design and Procedure

Similar to the first experiment, participants first completed a computer-based tutorial that described each arm and hand signal individually. For each signal, a short description was presented, which included the description of the signal from the Army and Marine Corps Field Manual. Participants then viewed a video of a soldier performing the signal and felt its tactile equivalent. Finally, the participants were able to play the signals concurrently (visual and tactile). Participants were allowed to repeat the presentation (i.e., visual, tactile, visual-tactile) as many times as desired. Once the participant reviewed the five signals in the three presentation styles, a validation exercise was performed. Participants had to correctly identify each congruently presented signal twice before the computer would prompt the experimenter that the participant was ready to begin.

For this experiment, the display of each message or signal was presented in one of four ways:

- visual only (video presentation of the arm and hand signal)
- tactile only (tactile presentation of the arm and hand signal)
- both visual and tactile simultaneous and congruent (i.e. the same signals were presented both visually on the video and through the tactile system)
- both visual and tactile simultaneous and incongruent (i.e. the visually presented signal did not match the presented tactile signal).

Each participant performed two 60 trial blocks. The trials had two of each signal presented only visually (2 x 5 = 10 total), two of each signal with only tactile signals (2 x 5 = 10 total), four of each signal performed simultaneously with both congruent visual and tactile presentation (4 x 5 = 20 total) and four of each visual signal presented with an incongruent tactile signal simultaneously (5 x 4 = 20 total). The sixty total trials were presented in a randomized order for each participant.

Prior to their first experimental trial, participants were placed into one of three between subjects instructional conditions for the incongruent trials. While participants were not told overtly about the trials that would be presented incongruently (there were never any incongruent presentations in training), they were presented with one of the following instructions sets before beginning the experiment, representing the three between subjects conditions of instructions.

No Special Instructions:
At this time, signals will be presented either through the video, through vibration or through both. As quickly and as accurately as possible, respond by pressing the appropriate button that corresponds to the signal that you think you are receiving. If at any time you are unsure of what signal(s) you've been given, choose the one that comes to mind first.

Visual Instructions:
At this time, signals will be presented either through the video, through vibration or through both. As quickly and as accurately as possible, respond by pressing the appropriate button that correspond to the signal that you think you are receiving. If at any time you feel that the visual and tactile signals are not the same, choose the signal provided visually.

Tactile Instructions:
At this time, signals will be presented either through the video, through vibration or through both. As quickly and as accurately as possible, respond by pressing the appropriate button that correspond to the signal that you think you are receiving. If at any time you feel that the visual and tactile signals are not the same, choose the signal provided tactilely (vibration).

If participants asked about incongruence or visual tactile conflict in some signals they were again read the appropriate directions for their between-subject instruction condition. The purpose of these instructions was to guide the participant strategy when the incongruent conditions were presented. All other parts of the experiment remained constant with respect to the detail from the previous experiment. Participants were offered a break between blocks, although no participant actually took one, thus the elapsed time between blocks was approximately one minute. The entire experiment took approximately 35 minutes to complete.

Experiment 2 Results

All analyses reported were conducted using SPSS 11.5 for Windows with the alpha level set at $p \leq .05$ and with two-tailed t-test conducted unless otherwise noted. Results were analyzed in terms of the speed of the response and the accuracy of the response under the respective conditions. For incongruent conditions, the modality of the response was also considered.

Since the incongruent condition raised a number of issues in analysis, the first comparison of results are from the other three conditions only (i.e., visual, tactile or tactile/visual congruent) when participants' responses were accurate. The two 60 experimental trials were separated into two blocks. No participant took more than a one minute break between blocks. Additionally, no feedback on performance was given between blocks. Analysis of performance by block is considered here; however, initially performance will be analyzed by combining blocks unless otherwise stated.

A multivariate analysis of variance was performed on the mean response times across the three experimental conditions of visual presentation, tactile presentation or visual-tactile concurrent and congruent presentation, when there was no specific instructions to drive the participant strategy (i.e. the between subject variable of instructions was the condition that was not specific about modality), with the following results: $F(3, 57)=2.85$, $p<.04$, ($\eta^2_p = .130$, $\beta= .653$). Subsequent pairwise analysis showed that, simultaneously presented congruent signals resulted in significantly faster response times than visual signals presented alone $t(19)=-2.25$, $p\leq.04$. This effect is shown in Figure 9. Also, as is evident, the congruent signals were faster than tactile alone $t(19)=-3.98$, $p\leq.01$. Further, the visual only presentation of the signal was significantly faster than the tactile only presentation of the signal $t(19)=-2.16$, $p\leq.04$. More stringent adjustments or corrections for multiple comparisons, such as the Bonferroni correction for multiple comparisons, resulted in this difference in the congruent and visual comparison not being significantly different. However, the difference between the tactile and the other two modalities remains significantly different. These results are consistent with the first experiment where no incongruent trials were introduced. Any confusion caused by the incongruent trials does not slow down the congruent trials mean response time, in fact, the congruent trials seem to actually show benefit for the multimodal presentation as compared to single modality presentation. Participants subjectively reported greater confidence in responding to signals that were presented in both modalities congruently.

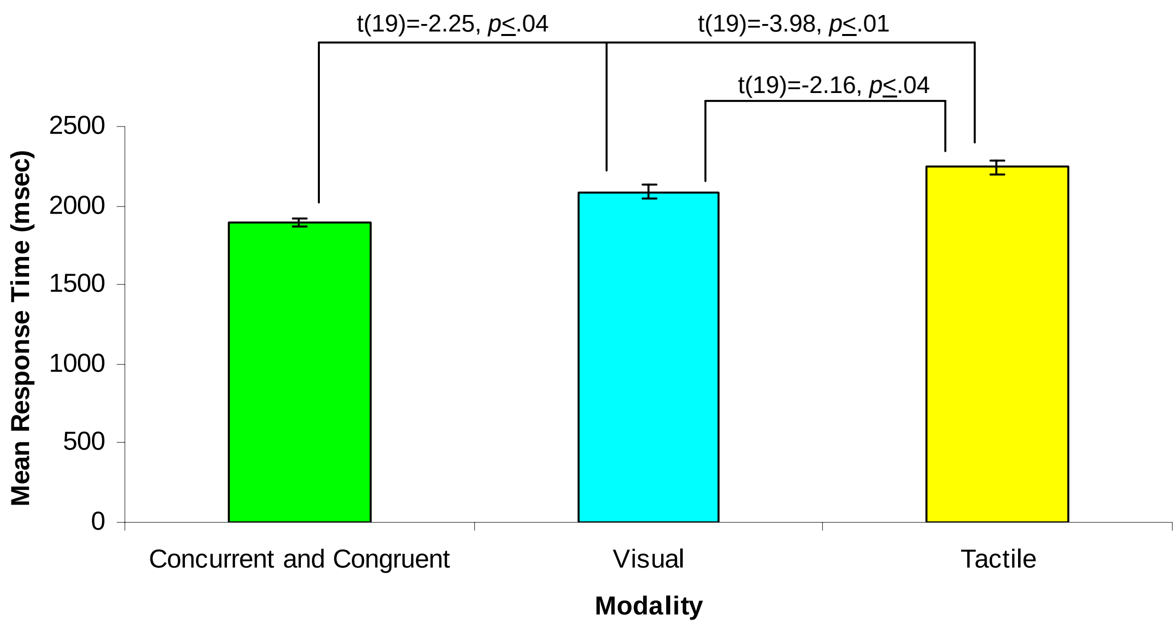


Figure 9. Mean response time (msec) by signal presentation condition. Comparisons are paired t-tests with no corrections.

Results for the incongruent trials were analyzed in terms of the speed and accuracy of the response under their respective conditions. During incongruent trials participants chose either their preference for tactile or visual presentation (in this condition, no specific instructions were given to the participants to deal with this conflict of signals). If neither of the presented signals were selected, the response was coded as a “response not matching either presentation”, with nine out of twenty participants making this type of error. Participant’s selections were examined during incongruent trials to determine which signal modality they responded to most frequently (again no instructions were given on which signal to choose during incongruent presentations). There was an overall preference for choosing the visual presentation over the conflicting tactile signal during both experimental blocks, with an increase in tactile selection during the second block (see Figures 10 and 11). This apparent increase in participants’ choosing the tactile signals during the second block was significant for both modalities $t(19)=-2.66$, $p\leq 0.02$ (tactile) and $t(11)=2.45$, $p\leq 0.02$ (visual), however, the number of visual modality responses were still greater than for tactile across both blocks.

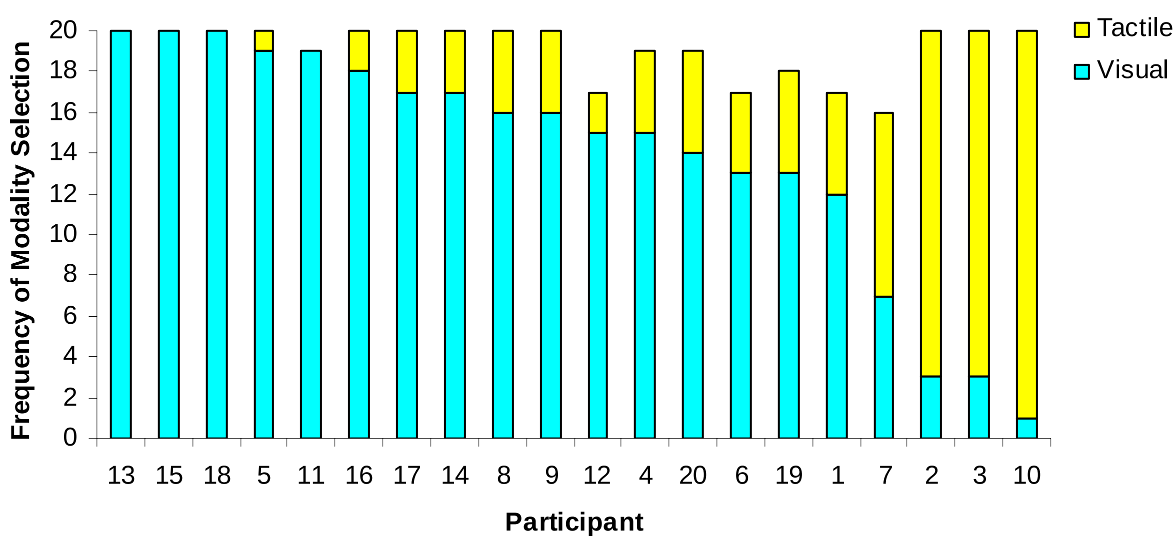


Figure 10. Frequency of signal modality selection during incongruent trials in block 1.

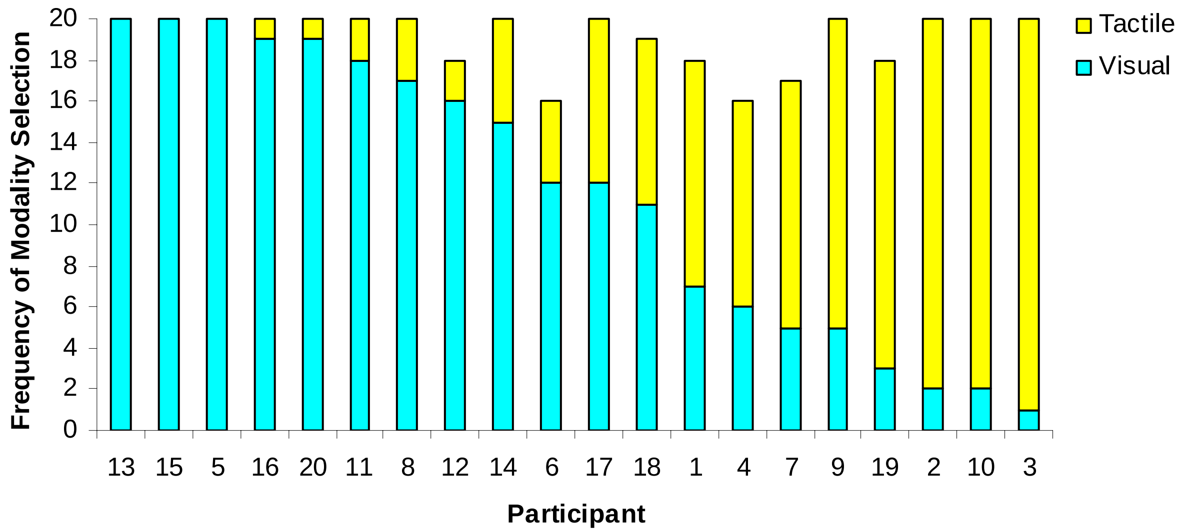


Figure 11. Frequency of signal modality selection during incongruent trials in block 2.

The mean response time for the incongruent trials compared to the other modalities is shown below in Figure 12.

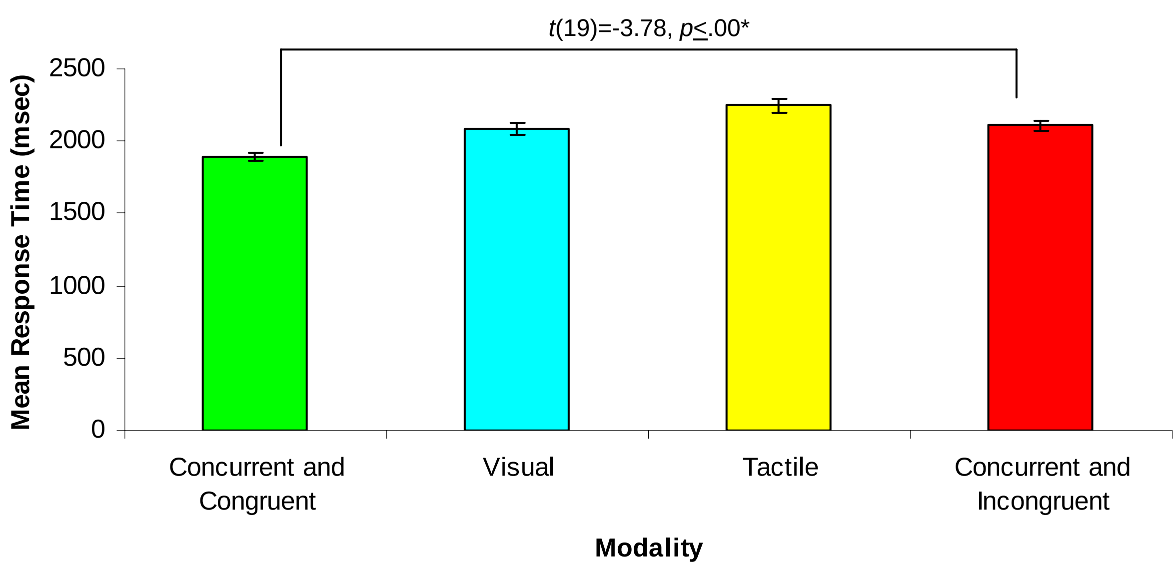


Figure 12. Mean response time in milliseconds by modality of presentation.

While not significantly slower than visual presentations $t(19) = -.150$, $p<.88$, or the tactile presentation $t(19) = 1.43$, $p \leq .17$, incongruent presentations are significantly slower than the concurrent and congruent presentations, $t(19)=-3.778$, $p \leq .00$.

Responses that did not correspond with either modality presented were not considered in this comparison (i.e., 36 out of 800 trials). This omission of these rare events means that the selection percentages do not always equal 100% in Figures 10 and 11. If neither of the presented signals were selected, the response was coded as a "response not matching either presentation", with nine out of twenty participants making this type of error. Figure 13 shows that slower response times were associated with the responses that did not match either of the incongruent modalities presentations. Participants reported confusion when not being told which modality took precedence. Most participants stated that they would pick a modality and try to be consistent, but many reported that they would still often choose the alternate modality. The responses not matching either presentation (there was a 40% chance to getting it right just guessing) apparently caused a longer than normal decision making process before selection as can be noted by the longer average response time with greater variability.

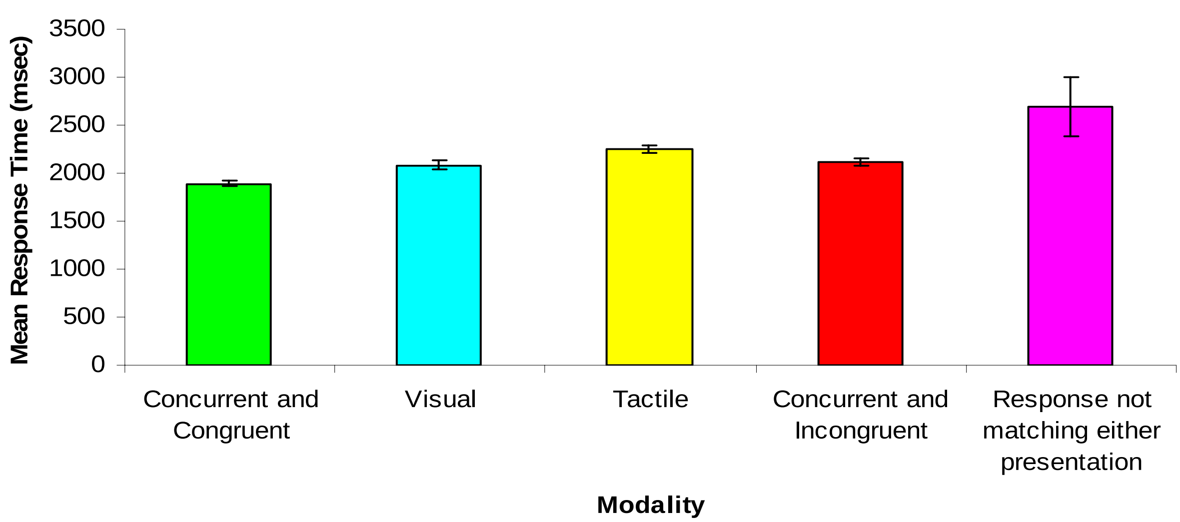


Figure 13. Mean response time (msec) by modality.

Although, there was no significant difference in the accuracy rates observed between the visual and tactile signals when they were presented alone $t(19)=1.61$, $p \leq .125$, there was a significant difference in the error rates when the tactile modality was compared to the concurrent-congruent presentation of the signals, $t(19)=-3.55$, $p \leq .002$, see Figure 14 for these mean correct response percentages.

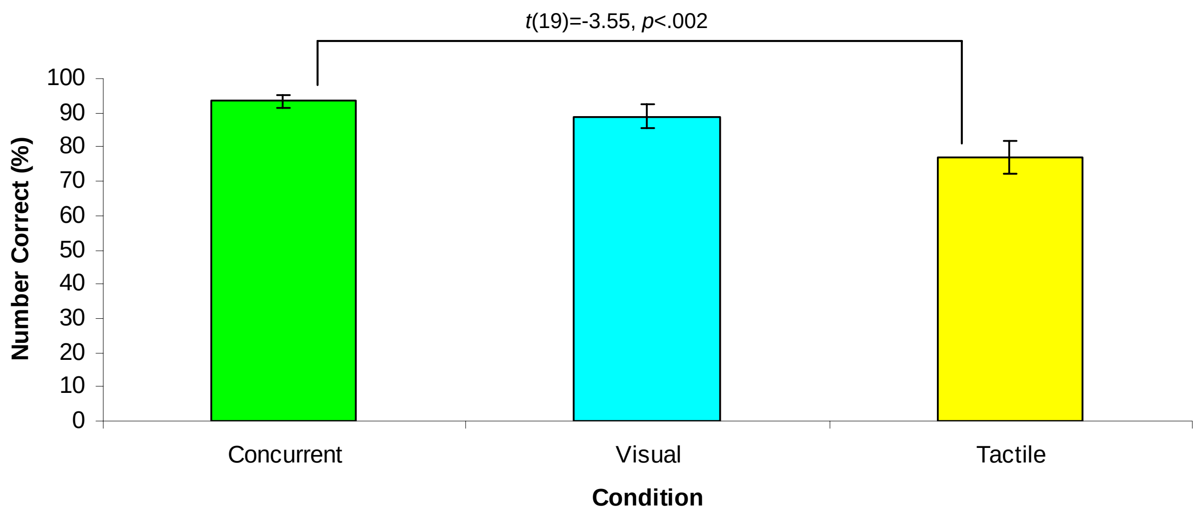


Figure 14. Mean percentage of correct responses by signal presentation.

In a manner similar to that shown in experiment number one, the overall lower accuracy rate for the tactile signaling was due to an apparent confusion between the tactile signal for "NBC" and "Halt", which have similar tactile characteristics but, in contrast, low visual similarity.

All of the aforementioned results were presented for the experimental condition with no specific instructions. In other words, participants were not influenced overtly for their attention to be focused on any particular modality. Analysis was conducted for the other between-subjects variables of instruction. Results of the mean response times for correct responses during the experimental condition of no special instructions, visual instructions, and tactile instructions are presented in the following analysis.

Figure 15 shows the mean response time in milliseconds for correct responses of signal presentation modality by the between subjects experimental condition of instruction.

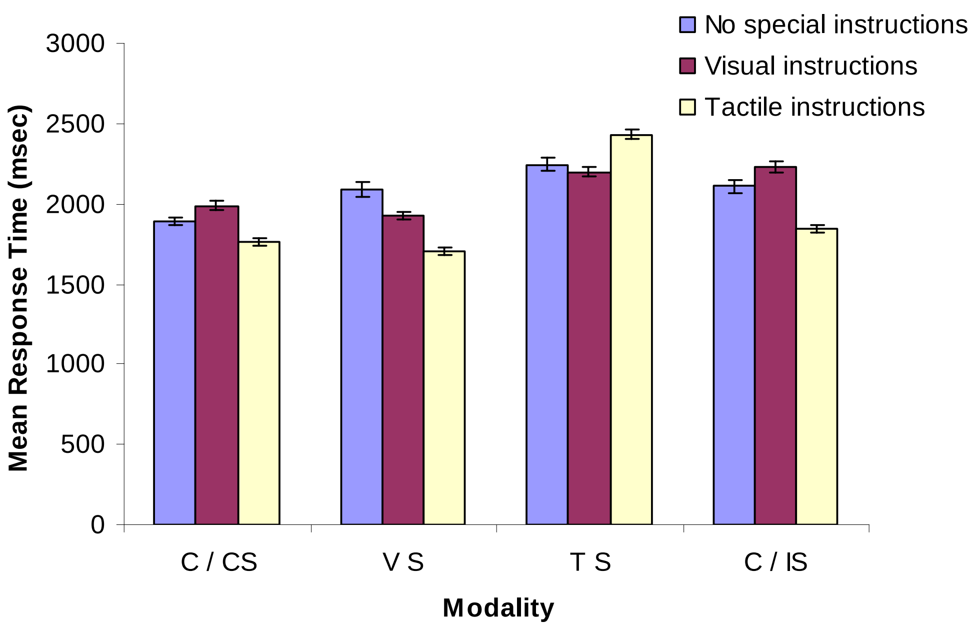


Figure 15. Mean response time (msec) for modality of signal presentation by between subjects experimental condition of instructions. Abbreviations for modalities are as follows: Concurrent and Congruent Signals (C / CS), Visual Signals (VS), Tactile Signals (TS), Concurrent and Incongruent Signals (C / IS)

A general linear model MANOVA was conducted on the variables of modality (visual, tactile, tactile/visual congruent or tactile/visual incongruent) by instructions (no special instructions, visual instructions or tactile instructions), $F(4.29, 122.27)=6.12$, $p \leq .000$, ($\eta^2_p = .177$, $\beta = .998$). The entire list of comparisons can be found in Table 7 located in Appendix F. Comparisons of interest include a significantly faster response times for concurrent and congruent signals when given instructions to prioritize tactile signals, also faster performance for visual signaling under either instruction condition, visual or tactile, as compared to the no instruction condition. Lastly, there was slower tactile signal response when given instructions to attend to the tactile signals and faster performance under the incongruent condition when told to attend to the tactile signals. This last finding was exact opposite for incongruent signaling when given visual instructions as performance actually slowed.

While accuracy is affected by the modality of the signaling as seen in experiment one and in this experiment, illustrated below in Figure 16, there is no effect for accuracy in the interaction of modality and instructions $F(2.63, 75.04)=.645$, $p \leq .569$, ($\eta^2_p = .022$, $\beta = .17$).

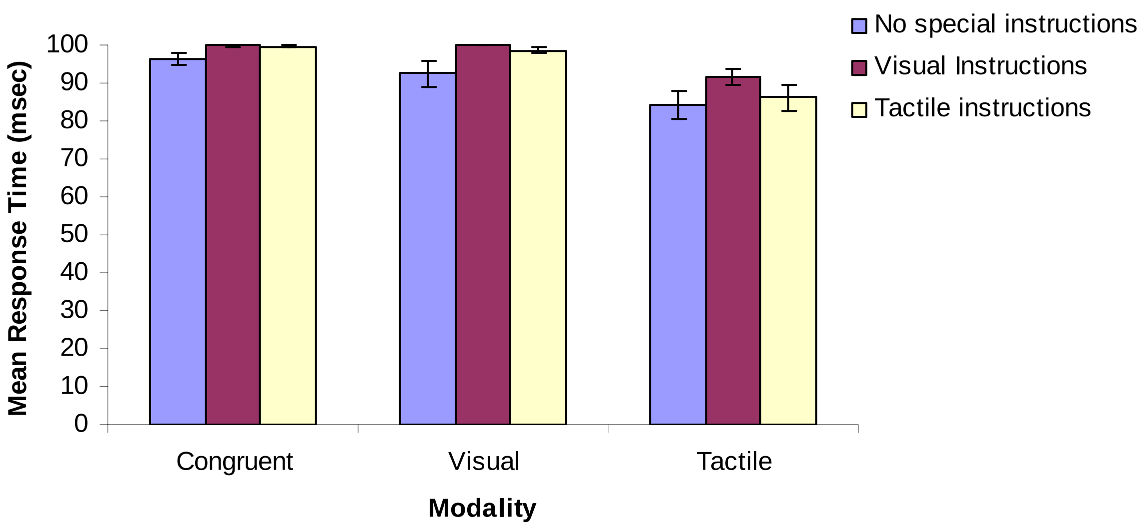


Figure 16. The mean percent accuracy for modality by the between subjects variable of instruction.

Results for the incongruent trials were analyzed in terms of the speed and accuracy of the response under the respective instruction sets. During incongruent trials participants chose either the appropriate tactile or visual presentation (in this case, the instructions the participants were given were specific on how to respond if there was a conflict of signals). If neither of the presented signals were selected, the response was coded as a "response not matching either presentation", with seven out of twenty participants making this type of error in the visual instructions condition and thirteen participants make this type of error in the tactile instruction condition. Participant's selections were examined during incongruent trials to determine which signal modality they responded to most frequently (again instructions were given on which signal to choose during incongruent presentations). These data are presented by experimental block and the figures for each block (Figure 17 for visual instructions and Figure 18 for tactile instructions) are placed in close proximity to one another so that the comparison can be made by participant. Participant data has been ranked from highest visual selection to lowest from left to right. Participants are numbered so that any differences in selection of the signal modality across blocks can be compared.

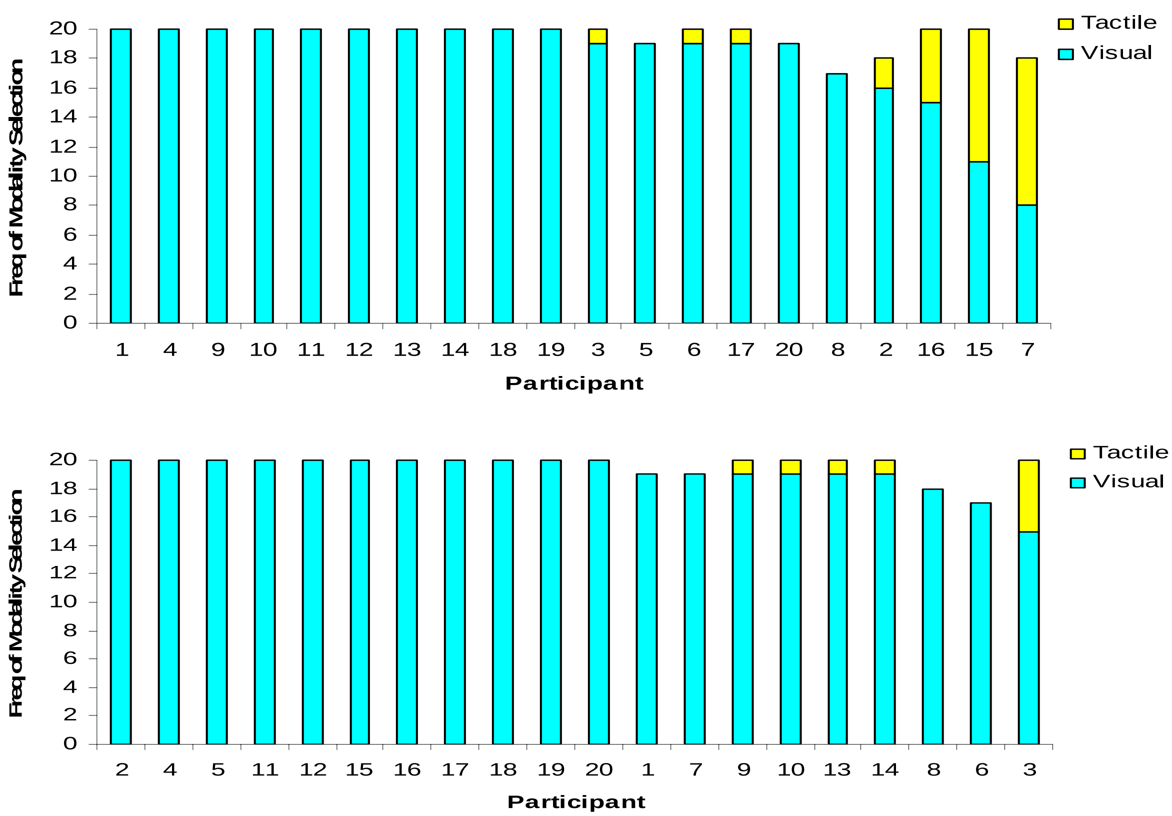


Figure 17. Frequency of modality selection when given visual instructions by participant and block. Block one is on the top graph and block two is on the bottom.

There was an overall preference for choosing the visual presentation over the conflicting tactile signal during both experimental blocks, for the visual instruction condition. There was a slight increase in visual selection during the second block (see Figure 17), but this increase was not significant $t(19)=-1.36$, $p \leq .189$. While the no instruction group also largely presented a visual preference (see Figures 10 and 11), there was significantly more visual choices when instructed to use that modality over the no special instructions condition $t(19) = -2.93$, $p < .009$.

A similar preference for the tactile modality was shown for the tactile instruction condition. However, in this condition, the movement in the second block to more tactile selection of conflicting or incongruent signals was significant, $t(19)=-3.38$, $p \leq .003$, see Figure 16.

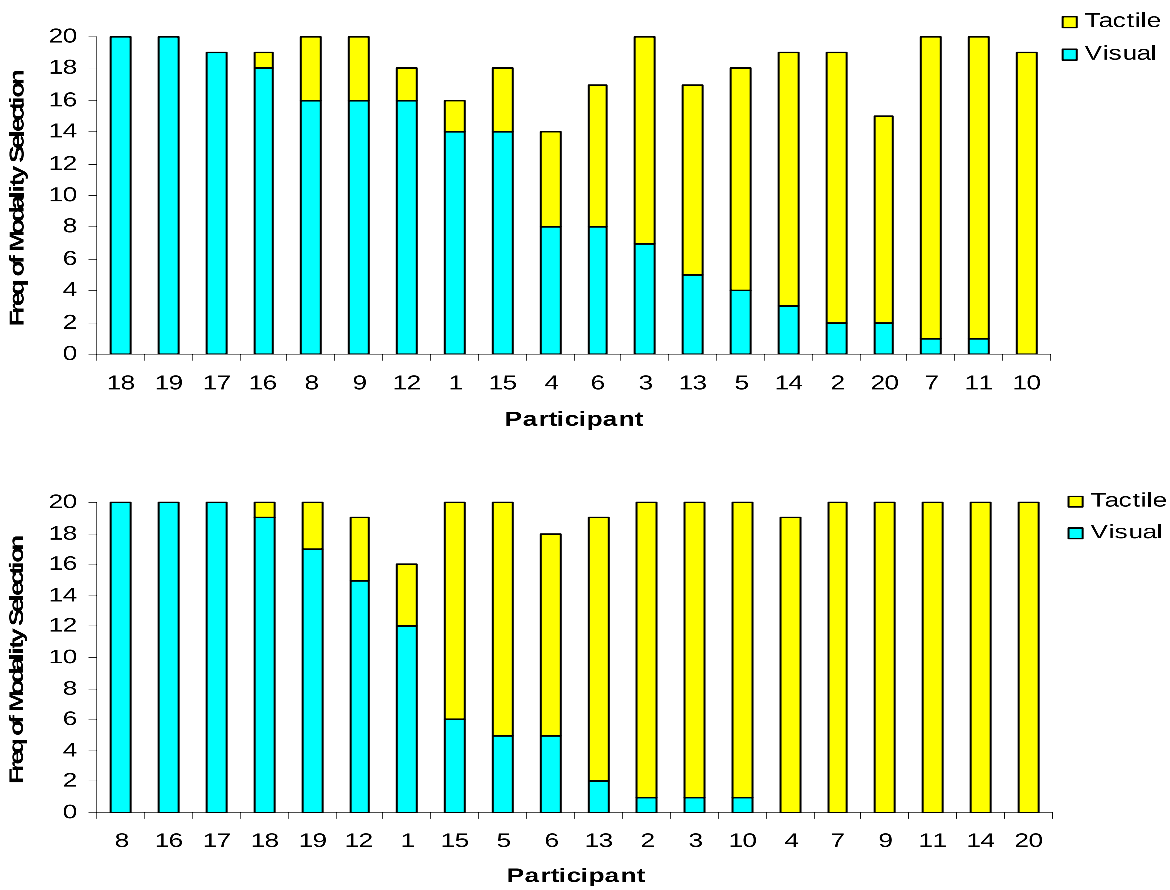


Figure 18. Frequency of modality selection by participant and block. Block one is on top graph and block two is on the bottom.

With the exception of the visual instructions condition, there were more tactile responses for the incongruent trials by participants in the second experimental block. For a complete comparison of signal selection by instructions during the single modality and congruent and incongruent trials see Table 8 in Appendix G.

As mentioned previously, there was a difference between response times for all modalities between blocks (see Figures 17, 18, 19 and 20) and this difference was significant, $F(2.54, 144.88)=19.06$, $p \leq .000$, ($\eta^2_p = .251$, $\beta = 1.00$).

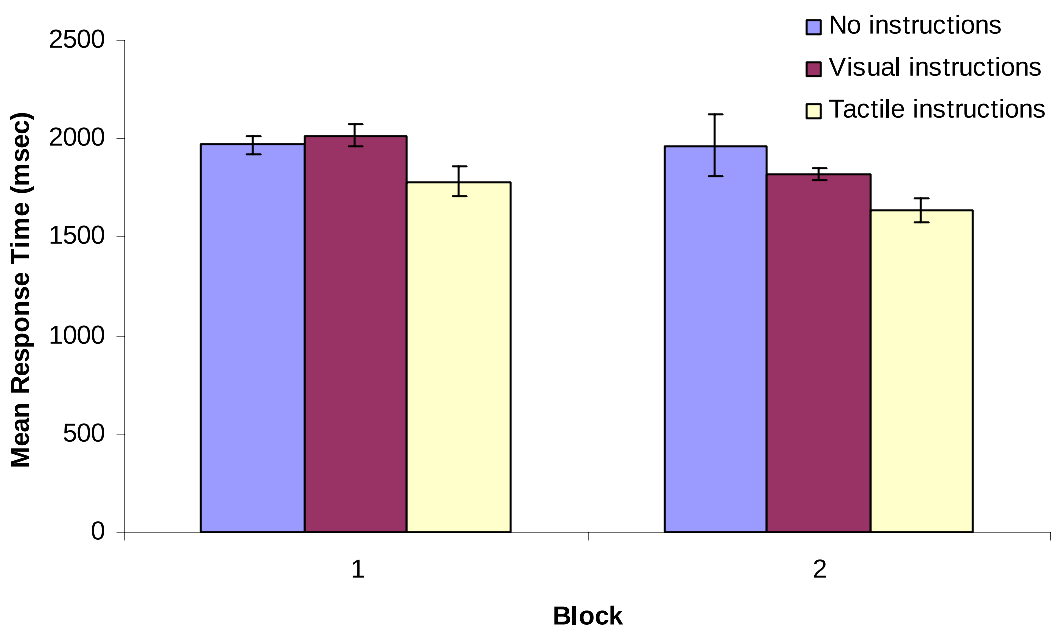


Figure 19. The mean response time (msec) for visual signaling by the between subjects variable of instruction across blocks.

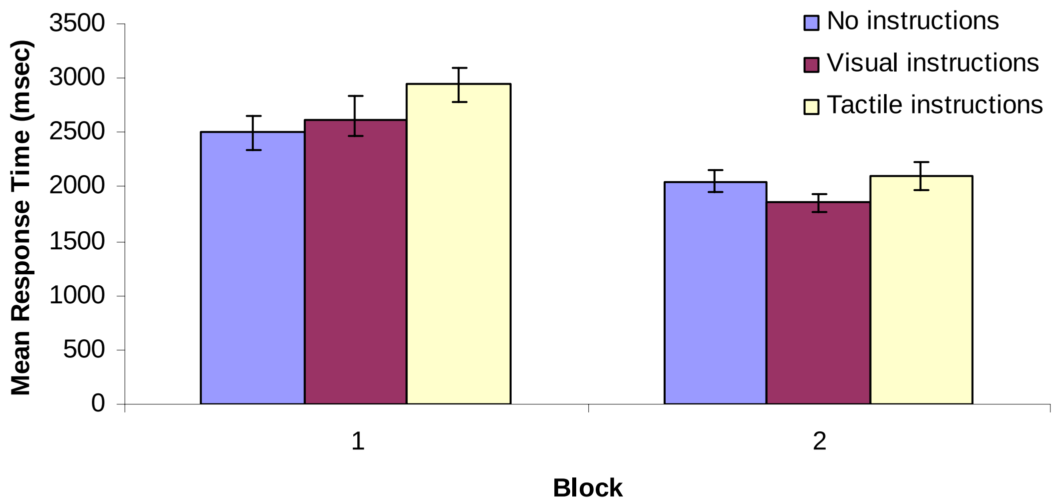


Figure 20. The mean response time (msec) for tactile signals by the between subjects variable of instructions across blocks.

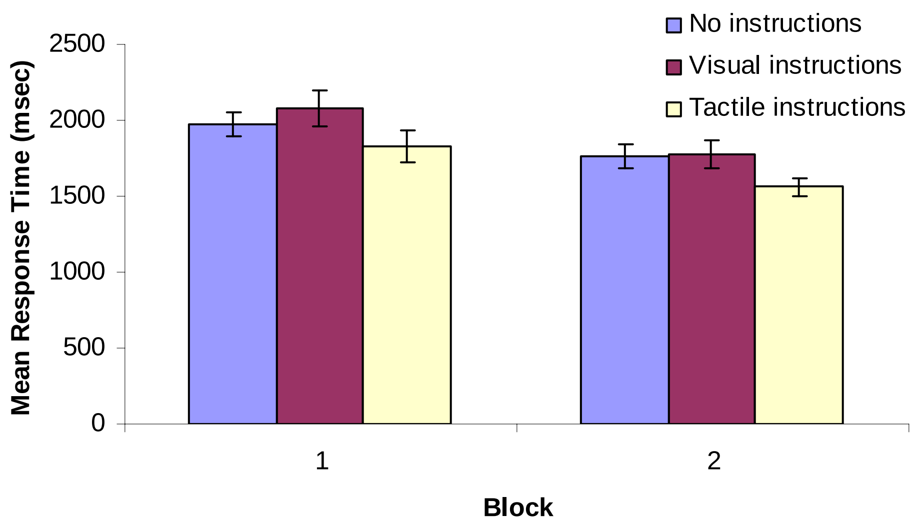


Figure 21. The mean response time (msec) of visual/tactile congruent signals by the between subjects variable of instructions across blocks.

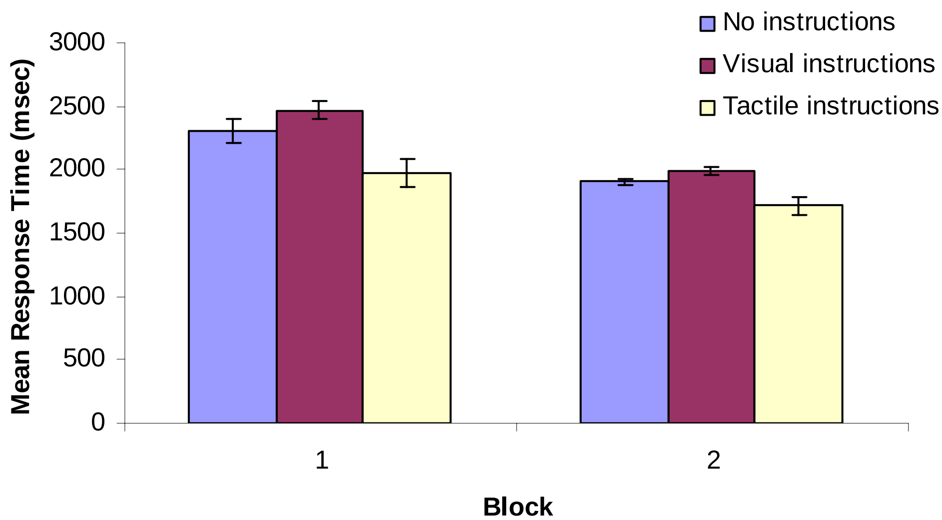


Figure 22. The mean response time (msec) of visual/tactile incongruent signals by the between subjects variable of instructions across blocks.

While participants did get faster in most all cases during the second block, the interaction between modality, block and instruction was not significant $F(4, 114)=.804$, $p\leq.525$, ($\eta^2_p = .027$, $\beta = .255$).

There were no significant interactions for gender across any of the experimental within or between conditions, including modality, signals and blocks.

Experiment 2 Discussion

The introduction of the incongruent multi-modal presentation proved to be disconcerting for most participants. The majority of participants would ask for clarification when the first or second incongruent trial was presented (all 60 trials were randomized for each participant). In an effort to support experimental fidelity, this questioning by the participant was answered with a repeat of the instructions that they were to follow. By the second block, participants were well aware of the incongruence and resolved to follow one strategy or the other. This increase in resolve is evident in the faster response times in the second block as well as a movement towards more selection of visual and tactile stimuli in the visual and tactile instruction conditions respectively. The use of instructions to drive participant strategy was largely successful. The majority of the participants were able to attend to the single modality during the incongruent trials, although some made no cross-modal selections. The reason that participants chose more tactile stimuli in the second block of the no special instructions condition is especially interesting. As the results showed, participants chose more visual signals during the no special instructions condition, but started to move towards more tactile signals during the second block.

There are two reasons that this migration towards the tactile stimuli might have occurred. First, the participants were suffering from some confusion created by the lack of understanding on which signal modality to report. This could have (and was subjectively reported) to have increased the participants' perceived workload. Previous studies have shown that the real benefits for multi-modal displays are during periods of high workload (Prewett et al., 2006), a condition that did not exist in the other conditions in that the participants' cognitive dissonance could be rectified by the adherence to the instructions of priority to one modality over the other. Secondly, the perceived workload increase could have been from fatigue during the second block, but this was not seen in the other conditions when performance improved during the second block and adherence to the prescribed modality actually increased slightly in the visual condition and significantly in the tactile instruction condition. Additionally, during the no special instructions condition, there were significant effects for multi-modal congruent presentations. Again, in the effort of reducing the confusion created by the incongruent presentations and with no instructions on how to deal with them, the presence of a multi-modal congruent stimulus was reported as a reassuring sight to the participants. Many participants anecdotally reported a higher confidence in their answers during the multi-modal congruent presentations.

Finally, the performance itself (regardless of modality and instruction) increased as a function of learning the paradigm, illustrated by the performance increase in each modality across blocks (see Figures 19-22) . The alphabetically arranged computer screen buttons and the movement of the computer mouse all are skills that routinely show an improvement in performance over time, up to the point of fatigue effects. However, no participant subjectively reported any fatigue and the experimental blocks were quite short (less than five minutes).

While participants were able to largely adhere to the visual signals during the visual instructions conditions, there was much less strict adherence to the modality instruction during the tactile instruction condition. As stated previously, there was a reported visual advantage to at least three of the five visual signals as the visual signals seemed logically and intuitively based on Western societal norms (e.g. a waving extended arm and hand means “I need your attention”!). Since no participant had ever been exposed to this form of tactile signaling before, it was doubtful that the ten minutes of training before the experiment was going to make them as familiar with the tactile signaling as twenty plus years of using similar visual signaling. In an effort to equate the stimuli, a method of stimulus matching needed to be employed.

CHAPTER FIVE: EXPERIMENT 3

Experimental Participants

Twenty participants (10 males and 10 females) ranging from ages 18 to 28 years, with a mean age of 20 years, volunteered to participate in the study. Participants each self-reported no surgical procedures, no significant scarring and no impediment that might cause lack of feeling in the abdomen or torso area. All participants provided informed consent and were treated in accordance with the APA standards regarding ethical principles (IAW 2002 Ethics Code).

Experimental Materials and Apparatus

The experimental apparatus and materials used in the present procedure were the same as the first two experiments.

Experimental Design and Procedure

In the final experiment, baseline data for participants was collected to allow a performance matching by modality adjustment. In other words, if a participant was faster with a particular signal visually, that modality was slowed in its presentation rate to make it equal to the other modality. This was done in an effort to create a bit of a bottleneck in processing, as the stimulus in the slower modality has been given a head start, to potentially create more conflict in the incongruent conditions. Additionally, the baseline data will give an opportunity to measure any performance benefits gained from additional training.

All parts of the experiment were the same as in the first experiment, with the exception of the following steps. After the training, each participant performed 60 randomized trials that consisted of four of each signal presented only visually (20 total), four of each signal with only tactile signals (20 total), and four of each signal performed simultaneously with both visual and tactile congruently presented (20total). The trials were completely randomized for each participant.

The data that were collected from these trials were averaged for the visual and tactile presentations. The modality by signal condition that resulted in the fastest accurate trials (e.g. visual halt versus tactile halt) was slowed down by that amount. For example, if the participant responded to the visual presentation of halt faster than the tactile presentation of halt, the video presentation latency was slowed down by that difference. If the tactile presentation of the signal resulted in a faster response time, that tactile signal was slowed down by that difference. These timing adjustments, tailor made for each participant, were now implemented in the same paradigm as in the second experiment, when the visual and tactile signals were presented incongruently. No special modality instructions were given to participants in this experiment.

Experiment 3 Results

Results were analyzed in terms of the speed of the accurate response and the accuracy of the response under the respective conditions. For incongruent conditions, the modality of the response was also considered. The mean response times for each modality are illustrated below in Figure 23.

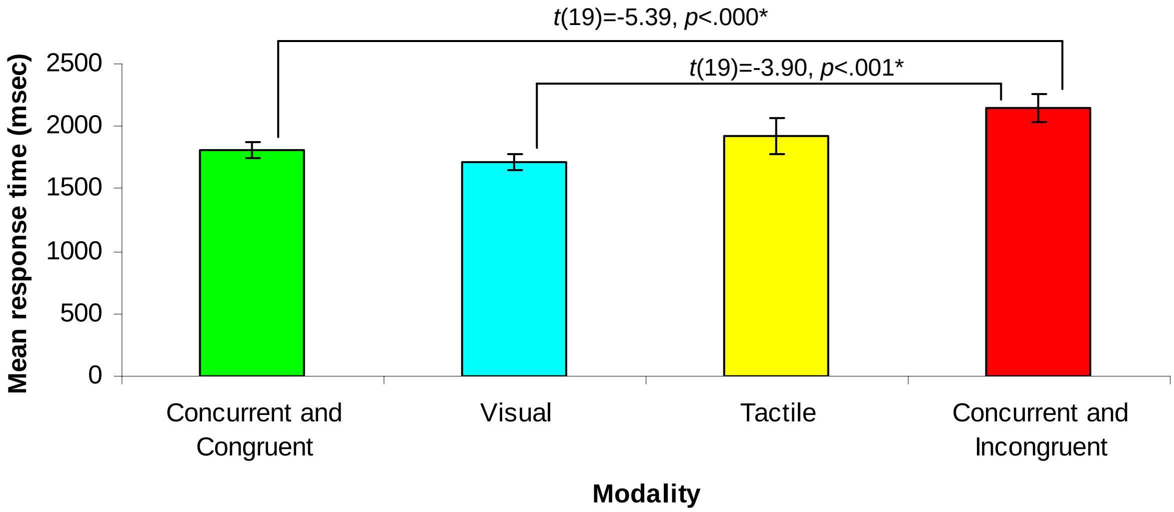


Figure 23. Mean response time (msec) by modality.

A general linear model MANOVA was conducted on the variables of modality (visual, tactile, tactile/visual congruent or tactile/visual incongruent) by signal (attention, halt, move out, NBC and rally) by block (one and two). As in the previous experiments, there was a significant difference between the different modalities, $F(2.22, 42.14)=6.75$, $p \leq .002$, ($\eta^2_p = .262$, $\beta = .918$), however, this difference disappeared when the incongruent condition is removed from the comparison, $F(2, 38)=1.96$, $p \leq .155$, ($\eta^2_p = .093$, $\beta = .380$). Subsequent pairwise analysis using a Bonferroni correction shows that the only significant difference between any of the modalities is when comparison is made between multi-modal incongruent trials to multi-modal congruent $t(19) = -5.39$, $p \leq .000$, or multi-modal incongruent trials to visual trials $t(19) = -3.90$, $p \leq .001$.

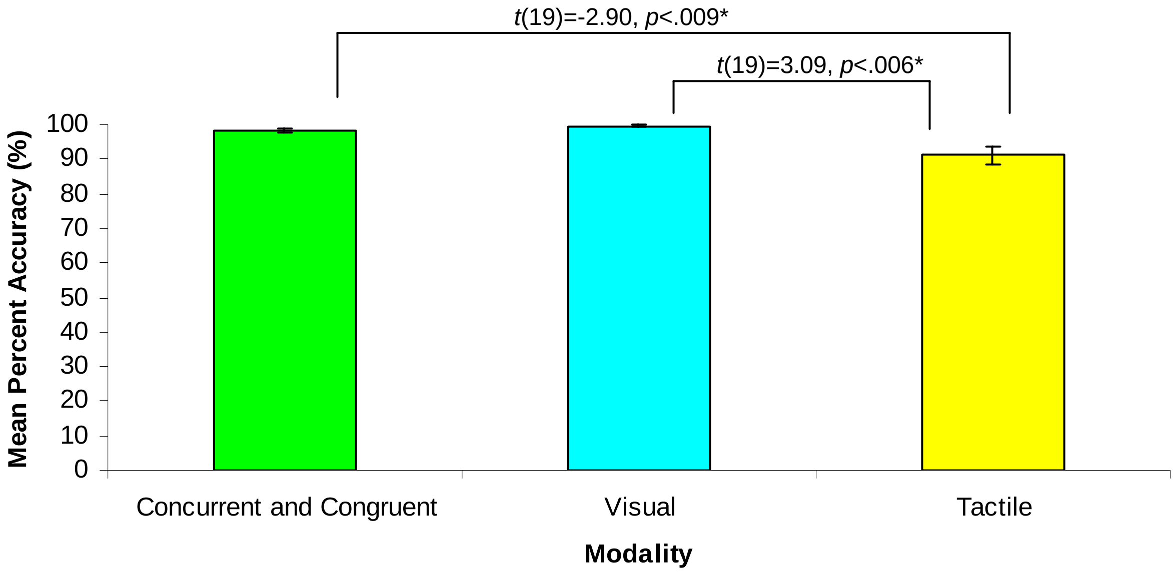
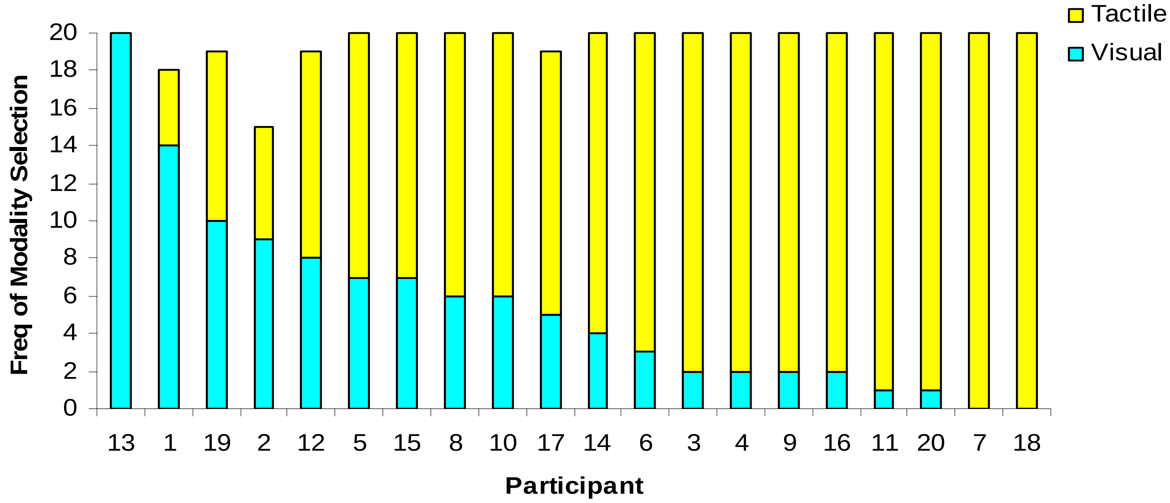


Figure 24. Mean percent accuracy by signal modality

The accuracy of the trials was again above 87 % in all modalities. There was a significant difference between the modalities, $F(1.12, 21.24)=8.75$, $p\leq.006$, ($\eta^2_p = .315$, $\beta = .833$) as illustrated above in Figure 22, however, there was no significant change in accuracy between blocks or significant interactions among signal, modality or block. Pairwise comparison using a Bonferroni correction shows a significant difference between visual and tactile signal accuracy $t(19) = 3.09$, $p\leq .006$, and multi-modal congruent signals and tactile signals $t(19) = -2.90$, $p\leq .009$.

The temporal performance matching of the visual and tactile stimuli caused a major shift in participants choosing the tactile presentation during incongruent multi-modal signaling. Out of the 800 trials across the two blocks, there were 568 trials (71%) that involved a visual delay (average video delay was 525 msec with a range of 975 msec and *SD* of 278 msec). There were 232 times (29%) that the visual presentation was delayed (average tactile delay was 295 msec with a range of 672 msec and *SD* of 224 msec). As illustrated in Figure 25 below, there was a primacy effect for signal selection (i.e. that signal that started its presentation first was usually selected).



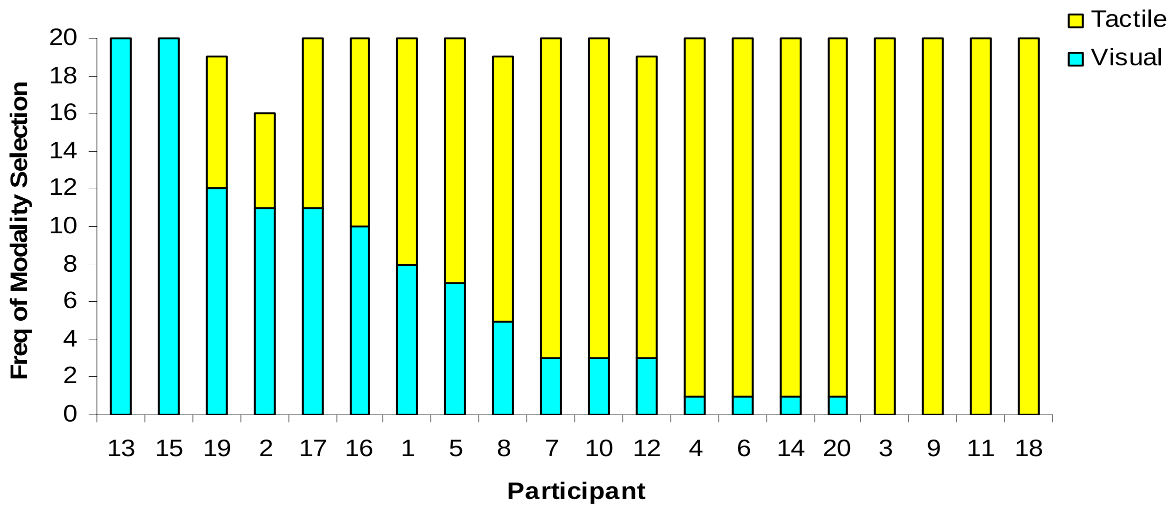


Figure 25. The frequency of modality selection by participant. Block one is shown on the top graph and block two is illustrated in the second graph below.

When the tactile signal was the signal presented first, it was selected over 77% of the time, whereas for the 29% of time that the visual signals were presented first there was only a 48% selection rate. This preference for tactile signals did not significantly change in the second experimental block $t(19)=.677$, $p<.51$, as illustrated in Figure 25 above.

Experiment 3 Discussion

In an effort to make the timing adjustments to the signals two, 30 trial blocks were performed by the participants. These sixty trials included exposure to all of the signals presented visually, tactile and multi-modal congruent. Participants were given feedback at the end of this calibration run. The results of this extra training clearly showed up in the results of the visual, tactile and multi-modal presentation. This small amount of extra training (as compared to experiments one and two which had no extra training), as well as no confusion from incongruent trials during their first experimental blocks, removed all differences in the participants' response times for the different modalities. The perfect accuracy rates for the visual signals was an additional indicator that the extra exposure to the signals helped participants learn the signals better (at least during the brief experimental trials) and the increased tactile accuracy and performance is even more encouraging towards the intuitiveness and simplicity that the tactile signals seemed to show in participant performance.

The stimulus matching by equating the participants' temporal performance by signal had an interesting primacy effect for signal selection, as the tactile signals were selected at a much higher rate than the visual signals during incongruent trials. The response time performance difference between incongruent trials and single modality tactile trials disappeared, as participants were able to respond to the tactile signal as fast as if it was presented alone, erasing signs of visual interference.

The primacy effect displayed by participants was extremely compelling and would prove interesting across the different instructional conditions. However, what is lacking in these experimental trials is context, which should contribute a larger amount to the perception of conflicting signals, especially for trained personnel in highly stressful conditions.

CHAPTER SIX: DISCUSSION

The question of learning complex tactile communication signals, especially for use in adverse or unusual circumstances is liable to be an important future issue and not just for military operations alone. The tactile system acts as a redundancy gain as the participants now have multiple means of receiving communications since the visual hand and arm signals would still be available (Hale & Stanney, 2004).

There were three major hypotheses tested in this study. First, the hypothesis that the tactile presentation of spatially based messaging or signaling (U.S. Army arm and hand signals) can produce similar performance levels, albeit potentially slower than their visual counterparts. While this was found to be true, the third experiment showed results suggesting that for more deliberate practice, the difference in the performance between the visual and tactile signals can virtually be eliminated. As far as the interaction of the two signals when presented simultaneously and congruent, the results showed only performance benefits with no loss during congruent cross-modal presentation. This confirms the results throughout the literature of potential cross-modal benefits (Ernst & Banks, 2002; Ferris & Sarter, 2008; Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002), but in this case with more advanced stimuli.

Second, it was hypothesized that the simultaneous presentation in the different modalities of the signaling, that are incongruent in signal meaning (like the Stroop effect conflict between words and colors), would produce longer response times and greater error rates in signal identification. This did not prove to be as problematic as predicted, largely due to the presented signals not being as automatic or well rehearsed, like reading is to adults (Dyer, 1973; Shor, 1970; White, 1969). With no instructions to drive their strategy, participants largely chose the visual signals. The cross-modal incongruent trials resulted in largely visual preference selections with a significant trend towards more tactile selections in the second block, although still predominantly a visual preference. When given instructions to direct attention to one modality over the other, the ability to completely ignore the alternate modality was only possible for some of the participants, with greater ability for the visual modality than for tactile, although all of the participants got better at choosing the directed modality over time. During some of the experimental trials, participants got so confused by the incongruence of signals that they chose a signal that was not presented in either of the modalities and these selections were significantly longer in response time than any single or congruent modality presentation. This inability to ignore other modalities, in this case vision or touch, is well documented (Spence & Driver, 1997; Spence & Walton, 2005). This lack of ability to completely disregard the alternate modality could actually get worse if the alternate modality was well known or rehearsed (again Stroop like interference) or naturally as is the case in pilots attempt to ignore vestibular cues over aircraft instruments (O'Hare & Roscoe, 1990).

Third, it was hypothesized that if the performance variables for modalities are equated across signals, (i.e. made to match temporally according to baseline performance differences), for the simultaneous presentation in the different modalities of the signaling, that are incongruent in semantic content; there will be a higher selection propensity for the modality that is presented first. This was largely the observation. Most participants performed faster in the visual trials during the baseline, thus the tactile signals were presented first by that average difference. During the incongruent conditions, participants chose tactile signals over visual when the tactile signals were presented with this temporal advantage (Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002). Also interesting, the small amount of extra practice that was received to achieve the baseline timing data resulted in the removal of any significant difference between visual and tactile signaling and resulted in improvement within the cross-modal presentation as well.

While testing seems to result in superior performance for tactile communication and traditional arm and hand signals combined, the challenge of a universal input device remains a significant hurdle. Stimulus response compatibility will have to be analyzed carefully to maximize performance as different types of inputs are considered for use with tactile displays.

However, when individuals are faced with extreme challenges and the traditional sources of information are for some reason, either diminished or eliminated altogether, the tactile system provides an important alternative communication channel. The opportunity to create a new tactile language is one that should be exploited as we move beyond the passive Braille system to active whole-body signalling. The overall high accuracy displayed by the participants (over 87% in all modalities with fewer than ten minutes of training) is extremely encouraging for this first iteration of advanced tactile signalling. The accuracy of the messages and the reported intuitiveness with which they were received is also a testament to the utility of the subject matter expert guidance and the present tactile 'language' transformation format. Potential confusion for tactile and visual signals is virtually eliminated by concurrent, congruent presentation.

Design Implications and Recommendations

The results obtained in these three experiments help to illustrate the utility of tactile signalling, especially when augmenting of visual signals. The results also offer some practical considerations in the design of future tactile displays. Meticulous care went into the design of the tactile signals as visual counterparts and these and several other experiments conducted in our lab in related tactile signalling areas have shed light on the most efficient ways to design tactile messages and signalling.

- *The spatial qualities of the visual signal must be closely replicated by the tactile signal as closely as possible, especially dynamic movement.*

This is potentially why there was considerable confusion between the two signals "halt" and "NBC". The visual signal halt involved the least amount of movement of the arm to position the hand and then became a totally stagnant signal from that point. The representation of that signal should have had longer onset times so that the lingering of the tactor in the "on" position would have been more representative of the static hand in the visual signal. Additionally, the tactile signal for halt was presented on both sides of the participants' body, where as the visual signal only involved the one hand and arm all located on the body's right plane. "NBC" was actually well replicated both spatially and temporally by its tactile signal equivalent, but became confused with the tactile signal for "halt" because of its spatial and temporal similarity in the tactile modality. In an effort to make sure that "halt" maintained a strong presence (*i.e. four tactors going off simultaneously, because SMEs stated that this signal could not be missed*) it lost much of its spatial similarity to its visual counterpart. Spatial characteristics seemed to outweigh temporal characteristics.

- *Use knowledge in the world.*

The transfer of training, in this case previously learned visual signalling by military personnel, must be high. The subjective acceptance of the current display by both military and civilian personnel was high because the messaging was commonly known or understood. The military signal for halt is the same as that used by civilian traffic police. There was a high transfer due to the tactile similarity, and the visual counterpart was already a known entity. Cross-modal benefits are gained immediately when concurrent modality presentation can be used in the instruction and subsequent training.

- *Primacy matters. That which is received first is usually processed first.*

As a result of these experiments, we have found that participants can largely attend to one modality over the other, however, if there are potentials for incongruence, primacy seems take precedent. If the tactile and visual signals are coming from different sources, and those sources reliability differs, it might prove useful to present that modality that represents the highest reliability first. However, this recommendation might only hold under low workload conditions, as this was not tested under high workload conditions.

Recommendations for Future Research

Since the goal of the majority of tactile communication research is not to replace traditional forms but to improve performance when other modalities might be compromised, more research needs to be conducted under conditions where the tactile modality prevails. For example, high visual workload conditions would not only force participants to use touch, but also to push the envelopes of performance to see what can truly be achieved with multimodal influence. The degree to which a college freshman can be trained in a laboratory task and their motivation to excel in that task, quickly hit a point of diminishing returns, thus applied studies with some degree of trained expertise might shed light on the true benefit of multi-modal presentation.

While spatial congruence has shown to be extremely important in intuitive tactile signal presentation, the importance of the temporal differences between tactile and visual stimuli has yet to be determined. While the temporal limits of the phi phenomena with vision and the tau phenomena with skin are well known(Geldard, 1982; Geldard & Sherrick, 1972), what are the perceptual effect when one modality does not match the other, and how important are these temporal differences to intuitive signalling? Touch might involve its own “gestalt” where as context might drive it well beyond its current sensory limits. The value of communication with others through sight and sound is invaluable in remote hostile environments like soldiering or mountaineering. The psychological benefits of a reassuring communicated “touch” might make an even greater difference. It is not a matter of if the tactile sense will be used to communicate in more traditional ways like the eyes and ears; it is a matter of when.

APPENDIX A: INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Expedited Review and Approval for a New Protocol with Consent Documentation

From : **UCF Institutional Review Board**
FWA00000351, Exp. 5/07/10, IRB00001138

To : **James Merlo**

Date : **May 16, 2007**

IRB Number: **SBE-07-05007**
Study Title: **A multimodal approach to uninhabited vehicle operations in dynamic environments**

Dear Researcher:

Your research protocol noted above was approved by **expedited review** by the UCF IRB Chair, Vice-chair or designated reviewer on 05/16/2007. **The expiration date is 05/15/2008.**
Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The category for which this study qualifies as expeditable research is as follows:

> #4 Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed they must be cleared/approved for marketing.
>
> #7 Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

All data, including all signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Use the Unanticipated Problem Report Form or the Serious Adverse Event Form (within 5 working days of event or knowledge of event) to report these events to the IRB. Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. Electronic submission of all these forms is available at http://iris.research.ucf.edu/ .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, IRB Chair, this letter is signed by:

Signature applied by Janice Turchin on 05/16/2007 03:25:39 PM EDT

IRB Coordinator

APPENDIX B: INFORMED CONSENT STATEMENT

INFORMED CONSENT STATEMENT

Project Title: A Multimodal Approach to Unmanned Vehicle Operations in Dynamic Environments

Primary Investigator(s): James Merlo

Overview: This experiment is intended to examine how people interpret tactile signals on the body. A series of tactile signals will be presented in different locations and arrangements during the experiment. After the tactile signals are presented, participants will be asked to make judgments about the presented sequence.

If I choose to participate, what will I be asked to do?
You will be asked to provide a brief medical history to make sure you are eligible for participation in the study. The history primarily asks about conditions or medications that might be related to sensation and perceptual deficits (e.g., reduced skin sensitivity) and motor ability. **You do not have to answer any questions that you do not wish to answer.**

To ensure accurate placement of the tactors, your abdomen will need to be measured using a cloth measuring tape. The researcher will then fit you with the tactor belt.

The researcher will then seat you in the display system, and you will be provided with more specific instructions on how to perform the experimental tasks. **You will have the opportunity to ask for clarification if any aspect of the task is confusing.**

You will be given a debriefing sheet which gives information about the experiment, and an opportunity to have any of your questions regarding the experiment answered.

What steps are being taken to ensure my privacy?
All information you provide will be kept confidential. Written information (e.g., surveys, forms, etc.) is kept in a locked file cabinet. A numerical code will be used for all electronic information (e.g., performance data) so that your identity cannot be linked with the data file.

Are there any risks associated with participating in this experiment?
The experiment does not require you to perform actions beyond those which you would probably experience in everyday life. The tactors used for vibration stimuli are commercially available and are similar to devices used in vibrating cell phones and pagers. Therefore, this protocol is deemed minimal risk.

What if I have questions about the experiment or its procedures?
You may ask questions about the experiment at anytime. If you have questions after the experiment session has ended, you may contact James Merlo at james.merlo@us.army.mil or (407) 242-7589.

Who do I contact if I have questions about participants' rights?
Questions or concerns about the research participants' rights may be directed to the UCFIRB Office, University of Central Florida Office of Research, Orlando Tech Center, 12443 Research Parkway, Suite 302, Orlando, FL 32826. The phone number is (407) 823-2901.

How long will the experiment last?
It varies from person to person, but a typical time commitment is approximately 1 hour.

Where will the experiment take place?
The experiment will take place in the Psychology Building on main campus.

Will I receive any compensation for participating in this experiment?
Some instructors offer extra credit for participating in experiments, but this is at your instructor's discretion. The experimenter will show through the SONA system that you have participated in this study and provide you with the appropriate research credits. Your participation in this study is voluntary and the researchers cannot provide you any financial compensation for your participation in the project.

Is there anything else I need to know?
You are free to withdraw from the experiment at anytime without any negative consequences. You must be 18 years or older to participate.

If you believe you have been injured during participation in this research project, you may file a claim with UCF Environmental Health & Safety, Risk and Insurance Office, P.O. Box 163500, Orlando, FL 32816-3500 (407) 823-6300. The University of Central Florida is an agency of the State of Florida for purposes of sovereign immunity and the university's and the state's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the university's and the state's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.

Information regarding your rights as a research volunteer may be obtained from:
IRB Coordinator
Institutional Review Board (IRB)
University of Central Florida (UCF)
12443 Research Parkway, Suite 302
Orlando, Florida 32826-3252
Telephone: (407) 823-2901

Please check one:

- ❑ **I am 18 years of age or older.**
- ❑ **I am under 18 years of age.**

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant's Signature	Date	Participant's Printed Name
Witness' Signature (Research Assistant)	Date	PI's Signature Date

Dr. Peter Hancock

APPENDIX C: PRETEST QUESTIONNAIRE

PRETEST QUESTIONNAIRE

Demographics Information

1. Age: _______ years of age

2. Sex:
   - ❑ Female
   - ❑ Male

3. Have you previously participated in any experiment involving tactile or vibrational stimulation?
   - ❑ Yes
   - ❑ No

4. If you answered yes to Question 3, please describe the experiment:

5. Is your body's sense of touch currently affected by any medication, drugs, or alcohol?
   IF YOU ANSWER YES, ***DO NOT*** INDICATE WHICH SUBSTANCE(S).
   - ❑ Yes
   - ❑ No

6. Do you have any scarring, lesions or any other characteristic that limits your sense of touch or vibration in and around your abdomen?
   - ❑ Yes
   - ❑ No
   - ❑

APPENDIX D: TABLE OF COMPARISONS OF MEAN RESPONSE TIME (MSEC) OF SIGNAL MODALITY BY SIGNAL TYPE

Table 5. *The pairwise analysis of the response time means (msec) of signal modality by signal type using a Tukey's Test.*

										Signal by Modality							
Signal by Modality	Mean (ms)	SD	V NBC	VT NBC	VT Rally	V Halt	V Move Out	V Rally	T Halt	VT Move Out	VT Halt	V Attention	VT Attention	T Rally	T Attention	T Move Out	T NBC
V NBC	1563	381.21	--	1.000	1.000	0.999	0.999	0.997	0.990	0.965	0.871	0.775	0.607	0.215	0.058	0.004	0.003
VT NBC	1580	367.67		--	1.000	1.000	1.000	0.999	0.995	0.980	0.909	0.828	0.672	0.260	0.074	0.005	0.004
VT Rally	1696	376.18			--	1.000	1.000	1.000	1.000	1.000	0.998	0.993	0.965	0.681	0.317	0.040	0.031
V Halt	1759	329.17				--	1.000	1.000	1.000	1.000	1.000	1.000	0.997	0.878	0.546	0.103	0.080
V Move Out	1761	322.32					--	1.000	1.000	1.000	1.000	1.000	0.997	0.884	0.556	0.106	0.083
V Rally	1781	210.16						--	1.000	1.000	1.000	1.000	0.999	0.93	0.634	0.139	0.110
T Halt	1806	416.59							--	1.000	1.000	1.000	1.000	0.961	0.728	0.191	0.154
VT Move Out	1843	610.42								--	1.000	1.000	1.000	0.989	0.847	0.291	0.241
VT Halt	1898	666.33									--	1.000	1.000	1.000	0.955	0.483	0.417
V Attention	1931	427.68										--	1.000	1.000	0.984	0.612	0.543
VT Attention	1977	533.59											--	1.000	0.998	0.779	0.719
T Rally	2090	541.93												--	1.000	0.986	0.974
T Attention	2188	912.96													--	1.000	1.000
T Move Out	2343	778.33														--	1.000
T NBC	2361	914.65															--

APPENDIX E: TABLE OF COMPARISONS OF MEAN ACCURACY (%) OF SIGNAL MODALITY BY SIGNAL TYPE

Table 6. The pairwise analysis of mean accuracy (%) of signal modality by signal type using a Tukey's Test.

	M		Signal by Modality														
	Accuracy	*SD*	T NBC	T Attention	T Halt	T Move Out	V Move Out	T Rally	VT Attention	VT NBC	V Rally	V Attention	V Halt	V NBC	VT Halt	VT Move Out	VT Rally
T NBC	74%	381.21	--	0.305	0.181	0.104	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T Attention	88%	367.67		--	1.000	1.000	0.791	0.791	0.791	0.791	0.622	0.454	0.454	0.454	0.454	0.454	0.454
T Halt	89%	376.18			--	1.000	0.912	0.912	0.912	0.912	0.791	0.636	0.636	0.636	0.636	0.636	0.636
T Move Out	90%	329.17				--	0.972	0.972	0.972	0.972	0.905	0.791	0.791	0.791	0.791	0.791	0.791
V Move Out	98%	322.32					--	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
T Rally	98%	210.16						--	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
VT Attention	98%	416.59							--	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
VT NBC	98%	610.42								--	1.000	1.000	1.000	1.000	1.000	1.000	1.000
V Rally	99%	666.33									--	1.000	1.000	1.000	1.000	1.000	1.000
V Attention	100%	427.68										--	1.000	1.000	1.000	1.000	1.000
V Halt	100%	533.59											--	1.000	1.000	1.000	1.000
V NBC	100%	541.93												--	1.000	1.000	1.000
VT Halt	100%	912.96													--	1.000	1.000
VT Move Out	100%	778.33														--	1.000
VT Rally	100%	914.65															--

APPENDIX F: TABLE OF COMPARISONS OF MEAN RESPONSE TIME (MSEC) OF SIGNAL MODALITY BY INSTRUCTION TYPE

Table 7. *The pairwise analysis of mean response time (msec) of signal modality by instruction type using a Tukey's Test.*

	M Response Time (msec)	Tactile Instructions / Visual Signaling	Tactile Instructions / Concurrent and Congruent Signaling	Tactile Instructions / Concurrent and Incongruent Signaling	No Instructions / Concurrent and Congruent Signals	Visual Instructions / Visual Signaling	Visual Instructions / Concurrent and Congruent Signaling	No instructions / Visual Signals	No Instructions / Concurrent and Incongruent Signals	Visual Instructions / Tactile Signaling	Visual Instructions / Concurrent and Incongruent Signaling	No Instructions / Tactile Signals	Tactile Instructions / Tactile Signaling
Tactile Instructions / Visual Signaling	1706.26	--	1.000	0.634	0.170	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tactile Instructions / Concurrent and Congruent Signaling	1758.5		--	1.000	0.684	0.277	0.022	0.000	0.000	0.000	0.000	0.000	0.000
Tactile Instructions / Concurrent and Incongruent Signaling	1843.0			--	1.000	1.000	0.513	0.012	0.000	0.000	0.000	0.000	0.000
No instructions / Concurrent and Congruent Signals	1890.9				--	1.000	0.978	0.113	0.044	0.000	0.000	0.000	0.000
Visual Instructions / Visual Signaling	1928.5					--	1.000	0.394	0.201	0.003	0.000	0.000	0.000
Visual Instructions / Concurrent and Congruent Signaling	1990.1						--	0.992	0.834	0.063	0.016	0.006	0.000
No instructions / Visual Signals	2086.4							--	1.000	0.881	0.573	0.367	0.000
No instructions / Concurrent and Incongruent Signals	2108.4								--	1.000	0.819	0.615	0.000
Visual Instructions / Tactile Signaling	2199.6									--	1.000	1.000	0.020
Visual Instructions / Concurrent and Incongruent Signaling	2228.3										--	1.000	0.076
No instructions / Tactile Signals	2246.8											--	0.158
Tactile Instructions / Tactile Signaling	2433.4												--

APPENDIX G: TABLES OF COMPARISON OF SIGNAL SELECTION (%) BY TRIAL AND INSTRUCTION TYPE

Table 8. *Signal selection (%) by signal presentation for the no instructions condition.*

Signal Presentation	Signal Selection				
	Attention	Halt	Moveout	NBC	Rally
Visual Attention	96.25	0.00	1.25	0.00	2.50
Visual Halt	15.00	82.50	0.00	1.25	1.25
Visual Moveout	10.00	1.25	88.75	0.00	0.00
Visual NBC	11.25	2.50	1.25	85.00	0.00
Visual Rally	13.75	1.25	0.00	0.00	85.00
Tactile Attention	77.50	2.50	7.50	7.50	5.00
Tactile Halt	2.50	81.25	2.50	11.25	2.50
Tactile Moveout	10.00	1.25	75.00	6.25	7.50
Tactile NBC	7.50	25.00	3.75	62.50	1.25
Tactile Rally	3.75	1.25	3.75	2.50	88.75
Attention / Attention	93.13	1.25	2.50	1.25	1.88
Attention / Halt	57.50	40.00	0.00	2.50	0.00
Attention / Moveout	70.00	0.00	27.50	0.00	2.50
Attention / NBC	57.50	7.50	0.00	35.00	0.00
Attention / Rally	55.00	0.00	2.50	2.50	40.00
Halt / Halt	2.50	90.63	0.00	6.88	0.00
Halt / Attention	37.50	60.00	0.00	2.50	0.00
Halt / Moveout	5.00	65.00	27.50	2.50	0.00
Halt / NBC	2.50	75.00	0.00	22.50	0.00
Halt / Rally	2.50	42.50	2.50	0.00	52.50
Moveout / Moveout	3.75	0.63	92.50	1.88	1.25
Moveout / Attention	42.50	0.00	55.00	0.00	2.50
Moveout / Halt	2.50	27.50	62.50	7.50	0.00
Moveout / NBC	2.50	10.00	62.50	25.00	0.00
Moveout / Rally	2.50	2.50	62.50	0.00	32.50
NBC / NBC	0.00	5.63	0.63	93.75	0.00
NBC / Attention	25.00	0.00	0.00	75.00	0.00
NBC / Halt	0.00	22.50	0.00	77.50	0.00
NBC / Moveout	2.50	0.00	25.00	72.50	0.00
NBC / Rally	0.00	0.00	0.00	75.00	25.00
Rally / Rally	1.25	0.00	0.00	0.00	98.75
Rally / Attention	30.00	0.00	0.00	0.00	70.00
Rally / Halt	0.00	45.00	0.00	5.00	50.00
Rally / Moveout	7.50	0.00	25.00	0.00	67.50
Rally / NBC	5.00	5.00	0.00	32.50	57.50

Note: For the incongruent signal presentations, the first signal listed was the signal presented visually.

Table 9. *Signal selection (%) by signal presentation for the visual instructions condition.*

Signal Presentation	Signal Selection				
	Attention	Halt	Moveout	NBC	Rally
Visual Attention	96.25	1.25	0.00	0.00	2.50
Visual Halt	0.00	95.00	1.25	1.25	2.50
Visual Moveout	1.25	0.00	97.50	0.00	1.25
Visual NBC	1.25	0.00	1.25	95.00	2.50
Visual Rally	0.00	1.25	0.00	1.25	97.50
Tactile Attention	88.75	2.50	3.75	5.00	0.00
Tactile Halt	0.00	88.75	5.00	5.00	1.25
Tactile Moveout	7.50	1.25	78.75	10.00	2.50
Tactile NBC	2.50	17.50	3.75	75.00	1.25
Tactile Rally	1.25	2.50	2.50	2.50	91.25
Attention / Attention	96.25	1.25	0.00	0.63	1.88
Attention / Halt	95.00	2.50	0.00	0.00	2.50
Attention / Moveout	97.50	2.50	0.00	0.00	0.00
Attention / NBC	90.00	0.00	2.50	7.50	0.00
Attention / Rally	95.00	2.50	0.00	2.50	0.00
Halt / Halt	0.63	96.88	1.88	0.63	0.00
Halt / Attention	7.50	90.00	0.00	2.50	0.00
Halt / Moveout	7.50	85.00	7.50	0.00	0.00
Halt / NBC	0.00	92.50	5.00	0.00	2.50
Halt / Rally	2.50	87.50	2.50	0.00	7.50
Moveout / Moveout	0.63	1.88	97.50	0.00	0.00
Moveout / Attention	0.00	2.50	97.50	0.00	0.00
Moveout / Halt	0.00	10.00	87.50	0.00	2.50
Moveout / NBC	0.00	2.50	90.00	7.50	0.00
Moveout / Rally	0.00	2.50	82.50	0.00	15.00
NBC / NBC	0.00	0.63	0.63	98.13	0.63
NBC / Attention	7.50	0.00	0.00	92.50	0.00
NBC / Halt	0.00	2.50	2.50	95.00	0.00
NBC / Moveout	7.50	0.00	2.50	90.00	0.00
NBC / Rally	0.00	0.00	0.00	95.00	5.00
Rally / Rally	1.25	0.00	0.63	0.63	97.50
Rally / Attention	0.00	2.50	0.00	0.00	97.50
Rally / Halt	0.00	2.50	0.00	2.50	95.00
Rally / Moveout	2.50	0.00	2.50	2.50	92.50
Rally / NBC	2.50	0.00	2.50	5.00	90.00

Note: For the incongruent signal presentations, the first signal listed was the signal presented visually.

Table 10. *Signal selection (%) by signal presentation for the tactile instructions condition.*

Signal Presentation	Signal Selection				
	Attention	Halt	Moveout	NBC	Rally
Visual Attention	97.50	1.25	0.00	0.00	1.25
Visual Halt	0.00	100	0.00	0.00	0.00
Visual Moveout	2.50	2.50	95.00	0.00	0.00
Visual NBC	0.00	1.25	2.50	96.25	0.00
Visual Rally	2.50	1.25	1.25	0.00	95.00
Tactile Attention	81.25	6.25	6.25	5.00	1.25
Tactile Halt	7.50	83.75	2.50	6.25	0.00
Tactile Moveout	1.25	6.25	81.25	8.75	2.50
Tactile NBC	15.00	20.00	3.75	61.25	0.00
Tactile Rally	1.25	1.25	2.50	0.00	95.00
Attention / Attention	97.50	0.63	0.63	0.63	0.63
Attention / Halt	37.50	57.50	0.00	5.00	0.00
Attention / Moveout	42.50	0.00	52.50	5.00	0.00
Attention / NBC	47.50	10.00	0.00	42.50	0.00
Attention / Rally	42.50	0.00	0.00	0.00	57.50
Halt / Halt	1.25	97.50	0.00	1.25	0.00
Halt / Attention	55.00	42.50	2.50	0.00	0.00
Halt / Moveout	0.00	37.50	62.50	0.00	0.00
Halt / NBC	0.00	65.00	2.50	32.50	0.00
Halt / Rally	5.00	25.00	2.50	2.50	65.00
Moveout / Moveout	0.63	0.63	95.63	2.50	0.63
Moveout / Attention	50.00	2.50	47.50	0.00	0.00
Moveout / Halt	5.00	57.50	35.00	2.50	0.00
Moveout / NBC	2.50	10.00	45.00	42.50	0.00
Moveout / Rally	2.50	0.00	42.50	0.00	55.00
NBC / NBC	0.00	3.13	0.63	95.63	0.63
NBC / Attention	50.00	0.00	5.00	45.00	0.00
NBC / Halt	5.00	50.00	0.00	45.00	0.00
NBC / Moveout	0.00	0.00	52.50	47.50	0.00
NBC / Rally	0.00	0.00	2.50	35.00	62.50
Rally / Rally	0.63	0.00	0.63	0.00	98.75
Rally / Attention	57.50	0.00	2.50	0.00	40.00
Rally / Halt	2.50	52.50	0.00	7.50	37.50
Rally / Moveout	2.50	0.00	45.00	2.50	50.00
Rally / NBC	7.50	5.00	0.00	52.50	35.00

Note: For the incongruent signal presentations, the first signal listed was the signal presented visually.

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