THE EFFECTS OF TACTILE DISPLAYS ON THE PERCEPTION OF TARGET DISTANCE

by

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ABSTRACT

Because vital information can be missed by Soldiers in combat environments that tax the eyes and the ears, it is imperative that alternative techniques be investigated to determine their potential in relaying this information in an effective way. This research investigated the use of a tactile display for providing distance and azimuth information about enemy targets. In a series of three experiments, participants were asked to engage enemy targets while utilizing cues that provided location information. In Experiment 1, two tactile cueing techniques (i.e., varying intensity and varying pulse rate) and three auditory cueing techniques (i.e., non-spatial speech, varying frequency of 3-D tones, and varying pulse rate of 3-D tones) were used to provide distance and azimuth information about enemy targets. Findings indicated that more participants preferred the tactile pulse cue and the non-spatial speech cue. There were no significant differences in performance among the tactile and the auditory cues, respectively. However, both the tactile cue types resulted in better performance and lower mental workload than the three auditory cue types. In Experiment 2, performance was investigated among the preferred tactile pulse cue and the non-spatial speech cue as well as a tactile direction only cue (i.e., no distance information), a visual cue, and a no cueing control. Findings indicated that both the tactile cue types resulted in better performance and lower mental workload than the other cue conditions. Experiment 3, was a multimodal investigation in which performance was investigated among combinations of the non-spatial speech, visual, and tactile pulse cues employed in Experiment 2. Findings indicated that cue combinations that included the tactile pulse cue resulted in better performance and lower mental workload than the cue combination without the tactile pulse cue. Overall, the findings support the notion of employing tactile displays as a communication means

to provide azimuth and distance information to Soldiers about enemy targets, either as a unimodal cue or in concert with other cue types.

This work is dedicated to the Soldiers in the United States Army who unselfishly serve our nation. I also dedicate this work to my family for their undying support, especially my mother and father, John White Jr. and Willie White, and my siblings, Ava Scott, Sandra Powe, John K. White, and Carleton White.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE
INTRODUCTION

Advances in technology currently provide Soldiers with an abundance of information about the battlefield in order to accomplish their set mission goals. Such completion is facilitated by situation awareness (Endsley, 1995; Smith & Hancock, 1995). In addition to this wealth of information and the persistent threat posed by the enemy, the dynamics of the battlefield pose a number of additional environmental demands such as operational time of day, noise pollution and masking, terrain constraints, and adverse weather that all impact such situation awareness, and cognitive workload, in addition to critical performance levels (Hancock & Szalma, 2008). It is imperative then to understand what information is vital and what information is superfluous for any given Soldier at any given moment in time. Careful consideration must also be given as to which sensory channel, or combination of sensory channels, are best suited through which the Soldier receives such vital information. In military environments, there are a grave costs associated with the transgression of such limits. Such costs are measured in terms of injury and loss life. Improving upon the transmission of vital information and the identification of the best sensory modalities to promises to will reduce these operational costs. Therefore, the present dissertation seeks to address the use of tactile displays to communicate vital information to Soldiers.

The completion of a combat mission rests upon the survival of those that are tasked with such challenge. Therefore, the ability for Soldiers to detect and appropriately respond to the presence of enemy targets in a dynamic battlefield environment is of utmost importance. As a result, designers need to develop systems that reliably aid Soldiers in locating enemy targets in an inconspicuous manner. These systems must be versatile enough to be functional and reliable in dynamic battlefield environments (i.e., rugged and resilient). Such systems could require the use of a single perceptual modality or employ several perceptual modalities in concert. There may be times when a given modality is masked of for some other reason inoperative. There may also be times when redundancy is needed to ensure that vital information is not missed. For example, an auditory display may not be well suited for noisy environments in which a Soldier may miss the critical aural information. On the other hand, a visual display may not be well suited for very sunny outdoor conditions. Although a backlight would enable such visual displays to be seen in the dark, the illumination of the display could reveal the position of the Soldier to the enemy. Furthermore, there may be times when the visual channel is fully consumed by another task like scanning perimeters. In consequence, it may be unavailable to view and assimilate further visual display. Redundancy can also potentially alert the Soldier of impending danger. Wickens (2002) has asserted that two tasks can be timeshared if they do not employ the same perceptual modality for information input. Therefore, if one perceptual modality is consumed with another task, then an alternative modality should be employed wherever feasible. Tapping into various perceptual modalities is thus essential for the versatility necessary for a hardened system suitable for combat.

Perhaps the most vital piece of information that a Soldier can have regarding the battlefield is the location of the enemy. Although the localization of enemy targets in the 360 degree periphery is useful for situation awareness, an indication of the distance of those targets from a Soldier would also increase situation awareness and have a positive impacts on their decision making. Such a spectrum of positional knowledge allows Soldiers to better prioritize the engagement of enemy targets. For example, an enemy target that is closer in proximity to a given Soldier should be prioritized above a target that is located at a far greater distance.

Soldiers will also be able to make, as well as adapt, other mission critical decisions based on the location of enemy targets.

Distance and azimuth information about enemy targets is currently provided via auditory and visual modalities via two fielded systems: the Boomerang and the Shoulder Worn Acoustics Targeting System (SWATS). The Boomerang is a device that detects small arms gunfire using an array of microphones. It can be mounted to a vehicle, mounted on a stationary object, or worn by a Soldier. When enemy gunfire is detected, the hostile shooter's location is currently provided aurally (e.g. "shot, five o' clock, seven hundred sixty meters") via a speaker or visually via a display panel. This device was developed by Defense Advanced Research Projects Agency (DARPA) and BBN Technologies, and is currently fielded (see Figure 1). The SWATS is device that detects and locates a hostile shooter's gunfire and provides the user with the azimuth and distance of the enemy either visually or auditorily (see Figure 2). This device is worn by an individual Soldier. This has been developed by QinetiQ North America. The hostile shooter's location is currently provided aurally to the user with earphones using spatial language (e.g. "five o' clock, seven sixty meters" or "five o' clock, seven hundred sixty meters"). When the visual modality is used, the fob displays various pieces of information to the user (see Figure 3). The device uses a global positioning system (GPS), tilt, heading, and accelerometer sensors to provide 95% accurate location (+/- 7.5) accurate location information about enemy shooters. In open terrain, it can detect gunfire at a range greater than 700 meters. This system has been fielded in combat zones from Afghanistan and Iraq. The equipment used for the present dissertation is based on the design of the SWATS.

Figure 1. Boomerang developed by DARPA and BBN Technologies.

Figure 2. SWATS developed by QinetiQ North America.

Figure 3. Visual display of the SWATS showing distance (in meters) and icon representing the azimuth location of an enemy shooter.

As previously mentioned, there are a variety of situations in which the auditory and visual modalities are not suitable to transmit information. At such times, the tactile modality has been shown to be a viable alternative (Merlo et al., 2006). The tactile modality is useful for providing cues that indicate the azimuth location, but it may also be useful for providing distance information. The present work is thus focused on investigating the effects of tactile displays on the perception of distance. The tactile modality is examined in comparisons to auditory and visual modalities as well as multimodal displays. The theoretical foundation of this research is predicated upon theories in situation awareness (Endsley, 1995) and mental workload (Hancock & Meshkati, 1988) as well as the Multiple Resource Theory (Wickens, 2002; Wickens, 2008).

Endsley (1995) defined situation awareness (SA) "*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" (p. 36) (see also Hancock & Diaz, 2002). In order to sustain situation awareness, humans must perceive and comprehend the elements in their current, as well as, their prospective environment. Due to the dynamics of the battlefield, Soldiers must be able to adapt to such variability in order to make appropriate decisions to achieve their mission (Smith & Hancock, 1995, p. 120). These decisions are based on an individual's "*intent drawn from hedonistic decision-making, past experience, and also due to the intent conveyed through the environment*" (Hancock & Diaz, 2002). One way to maintain SA is to employ automated aids. In the present work, the tactile modality is explored as a method to provide distance information about enemy targets in addition to azimuth location.

SA can be assessed either directly or indirectly (cf., Saner, Bolstad, Gonzalez, & Cuevas, 2009). Direct measurement is a product-oriented approach in which real-time probes and/or subjective questionnaires are employed. These measures are considered direct because the human for which SA is being measure is directly asked questions about their environment or asked to assess their own perception of their SA. Indirect measurements are largely process-oriented approaches in which measures of physiological state, behavior, and performance are assessed. For the purposes of the present dissertation, the indirect approach is used where objective primary and secondary task performance are the featured measures. More specifically, this encompasses the acquisition rate of enemy targets, the number of times such targets are missed, and the accuracy of navigating a specific path.

Mental workload is defined as *"the level of attentional resources required to meet objective and subjective performance criteria, which may be mediated by task demands, external* *support, and past experience"* (see Young, Brookhuis, Wickens, & Hancock, 2015; see Hancock & Meshkati, 1988; Proctor & Van Zandt, 2008). During high cognitive load, operators may not attend to all elements in the environment. Therefore, if the elements of the environment are not perceived, they cannot be comprehended; nor can any future projections upon them be made. Mental workload can be assessed through behavioral measures, secondary tasks, physiological measures and subjective measures (Young et al., 2015; Wickens, Hollands, Banbury, Parasuraman, 2013). For the present purpose, the National Aeronautics and Space Administration Task Load Index (NASA-TLX) subjective measure are administered (see Hart & Staveland, 1988). The NASA-TLX is described in the methodology section of Experiment 1 (and see Appendix A).

The Multiple Resource Theory is an approach that can predict both human performance in a multi-task environment and interference among dual tasks (Wickens, 2002). This is of upmost importance because human resources to perform multiple tasks are both limited and allocatable. This theory can be applied using a 4-dimensional model (see Figure 4). The four dimensions are stages, sensory modalities, codes, and visual information. Stages are either perceptual or cognitive. Sensory modalities are either auditory or visual. Codes as either visual or spatial. Visual information is either focal or ambient. Employing this model can aid in determining when it is best to employ a given modality. While the multiple resource theory model does not include the tactile modality, it still provides implications of when to utilize it. The theory suggests offloading information from one overtaxed modality onto another can reduce excessive mental workload (Wickens, 2002; Wickens, 2008). More specifically, when task demands fall into the same cells of the figure, a performance decrement is likely.

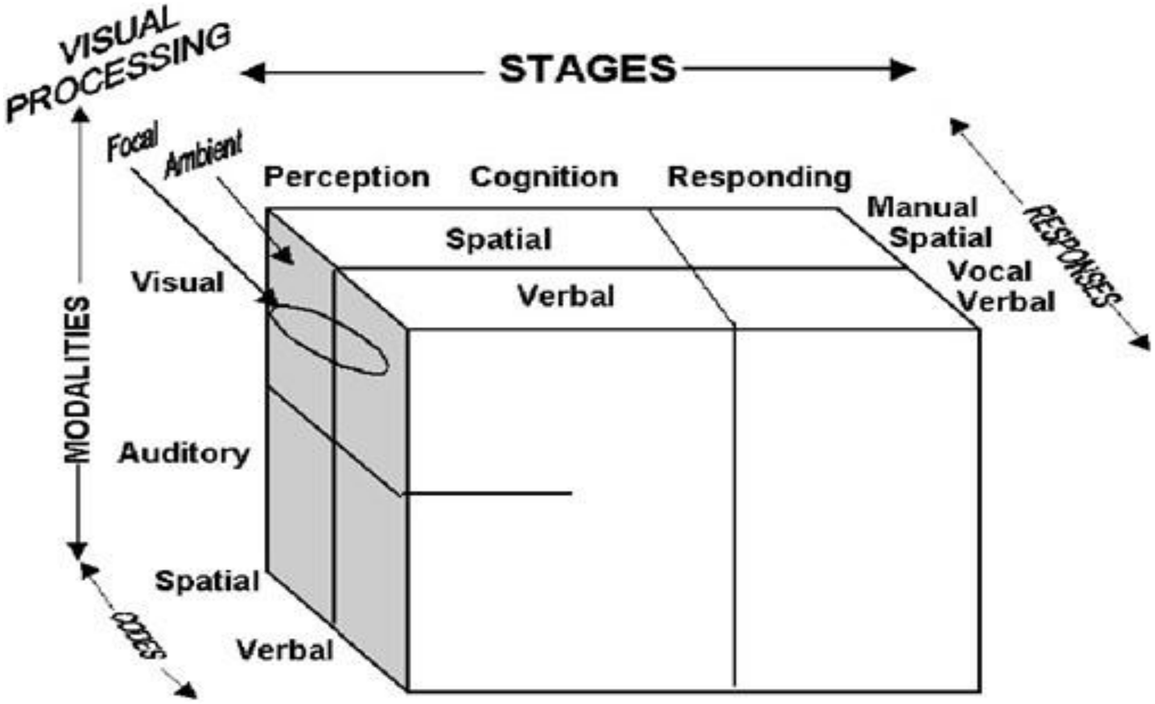


Figure 4. Wickens' Multiple Resource Model.
Source: Adapted from "Multiple Resources and Mental Workload" by C.D. Wickens, 2008, *Human Factors, 50* (3), p. 450. Copyright 2008 by the Human Factors and Ergonomics Society.

In order to investigate the use of a tactile display for providing distance and azimuth information about enemy targets, a series of three experiments were conducted. In each experiment, participants were asked to engage targets while utilizing cues that provided location information about those enemy targets. The objective of Experiment 1 was to investigate the effects of two tactile cueing techniques and three auditory cueing techniques on the perceived location of enemy targets. Findings of this experiment identified the tactile cueing technique and the auditory cueing technique that provided the best performance. These cueing techniques were employed in Experiment 2. The objective of Experiment 2 was to investigate the effects of a no cueing control, an auditory cue, a visual cue, and a tactile cue on the perceived location of enemy targets. Findings of this experiment quantified how the tactile cue compared to the auditory and visual cues as well as no cueing at all. The objective of Experiment 3 was to investigate the effects of combinations of the cues employed in Experiment 2 on the perceived location of enemy targets. Findings of this experiment quantified how the multimodal cues compared to each other and the advantages of the multimodal cues over the unimodal cues in Experiment 2.

CHAPTER TWO
REVIEW OF RELEVANT LITERATURE

The ability to communicate information to Soldiers regarding the battlefield on which they are actively engaged is of grave importance. It is therefore imperative that researchers examine all possible means and modalities of such communication to ensure that this vital information is successfully received, and in a manner that is inconspicuous to the enemy. One of the most common means of communicating information is by way of the auditory displays. Audition occurs as a result of vibrations known as airborne sound pressure that travel to the ear (Szalma & Hancock, 2011). The brain then processes these signals and the exposed individual experiences auditory sensation (Fastl & Zwicker, 2007). In military-relevant communications, these sound waves are produced by different technologies such as headphones or speakers to transmit such information. This information can come in the form of a simple tone or sound, a sequence of tones, 3-D tones, or speech. Simple tones or sequence of such tones are best suited to simple information such as warnings or alerts, but speech is better for the transmission of more complex information (Proctor & Van Zandt, 2008).

Another common means of communicating vital information in military environments is by way of the visual modality. Visual information is presented to the human through either a static or dynamic display. A static display is fixed and does not change, but a dynamic display, by definition, changes over time (Proctor & Van Zandt, 2008). In order for military personnel to maintain an accurate understanding of the battlefield, visual displays are mainly dynamic. Some of the means by which information is presented visually to Soldiers is via handheld devices, head-up displays, helmet-mounted displays, and displays that are integrated into vehicles (see Hancock, Sawyer, & Stafford, 2015). Visual displays vary in size, and the time that information appears may vary in duration. Hancock et al. (2015) found that performance decreases and mental workload increases systematically with displays size and information presentation rate. Some of the types of information that can be presented on a given display are symbols, codes, colors, shapes, and/or text. (Proctor & Van Zandt, 2008; Rasmussen, 1983). Although there are other means of presenting visual information, when it comes to Soldiers is in combat situations, the aforementioned types are best to ensure that the visual channel is not overtaxed with monitoring for extended periods of time and the associated problem of vigilance (Hancock, 2013). Monitoring a visual display for long periods of time leaves less capacity for Soldiers to scan the battlefield. Focused monitoring can also compromise safety, especially for example while having to control a moving vehicle on the battlefield. Thus, there is an essential search for balance in information processing modality as we seek to generate the optimal profile for Soldier information assimilation.

Tactile Communication

Due to the diversity of information sources being presented to Soldiers, researchers are exploring how to best communicate vital information without inducing cognitive overload, stress, and associated performance degradations (Hancock & Warm, 1989). Another rationale for exploring alternative communication means is revealed when the auditory and visual channels are either masked or exhausted. The sense of touch is an area that has been promoted as a means of mitigating the negative effects of massive amounts of information being presented to the auditory and visual channels (Van Erp, 2007; Chen & Terrence, 2008; Merlo & Hancock, 2011; Mercado, White, Sanders, & Wright, 2012). The premise for examining the tactile modality is essentially founded in the multiple resource theory. The tactile modality can potentially reduce mental workload that is associated with the overtaxed auditory and visual modalities. Scerra and Brill (2012) found that performance was decreased and workload increased due to limited mental resources when participants performed dual tasks, where each task employed the tactile modality. However, a decrease in workload was revealed when participants performed the dual tasks crossmodally (i.e., the tactile modality was employed in the primary task and either the visual or auditory modality was employed in the second task) (Scerra & Brill, 2012).

Gibson (1962) categorized the sense of touch of as being either active or passive. Active touch is defined as touching, exploratory in that stimulation to the skin is caused by the independent motor activity of the participating individual. Passive touch is defined as being touched, receptive in that the stimulation is initiated by some object in the environment (Gibson, 1962). Tactile communications involve the use of display systems that are used to communicate information via the skin (i.e., passive touch). A tactile display can be defined as any device that presents information by stimulating the skin (Gemperle, Ota, & Siewiorek, 2001). An everyday example of a tactile display is a cell phone. The vibration feature of such a phone provides tactile stimulation. Although the vibratory information of a cell phone is simple, this still alerts the user of an incoming call or message. The value of the tactile display of a cell phone is realized when the user is anticipating an important call or message in an environment where they must remain quiet (e.g., during a religious service, at a movie at the theater, or in an important lecture). Such constraints also pertains when the user is in an extremely noisy environment that masks the sound of the ringer. Another example of a tactile display, coming from the automotive industry, are safety features available in modern production vehicles in which the seat vibrates to alert the driver of a potential collision (Fitch, Kiefer, Hankey, & Kleiner, 2007). These examples show how beneficial tactile displays can be and it is anticipated that many more applications will be enacted soon.

Tactile communications occur by employing the sense of touch. Although the sense of touch is mainly associated with the skin, there are receptors in the muscles, tendons, and joints that contribute to the sense of touch (Fulkerson, 2014). However, for the present dissertation, the skin is of primary concern. Jablonski (2006), stated that "*touch involves the stimulation of skin by mechanical, thermal, chemical, or electrical means and the resulting sensations of pressure, vibration, temperature, or pain.*" The sense of touch has been coined by some as the "Mother of Senses" (Jablonski, 2006; Montagu, 1986). This is because the sense of touch is the first sense to be developed and all other senses are founded upon it. In less than six weeks, the sense of touch is developed in a human embryo (Montagu, 1986). At this stage the eyes and ears are not yet developed. Montagu (1986) highlights evidence of the early development of the sense of touch: at about six weeks, stroking the lips causes the bending of the neck and truck and at about 9 weeks, applying pressure to the base of the thumb will cause a fetus to open its mouth and move its tongue. The fetus is continuously massaged by amniotic fluid during the entire nine months of a mother's pregnancy (Field, 2001). Even during childbirth, the massaging action of the uterine contractions and movement through the birth canal aid in the development of the respiratory system (Field, 2001). After birth, in order to survive, infants must continue to experience touch. Holding and wrapping an infant helps to regulate temperature, breathing, and blood flow (Montagu, 1986). When infants are deprived of touch, this can result in difficulty sleeping, suppressed immune system, and stunted growth and development (Field, 2001). Therefore the importance of the sense of touch must not be minimized.

The skin, the largest organ of the body, has a surface area of about 1.8 m^2 for an average individual. The human cannot survive if this organ is absent. According to Greenspan and Bolanowski (1996), there are three types of skin: glabrous, hairy, and mucocutaneous. The glabrous skin is found on the palms of the hands and the soles of the feet while the mucocutaneous skin is found on entrances to the interior of the body. However, the vast majority of the body is covered by hairy skin. The skin is made up of numerous types of mechanoreceptors (Sherrick & Cholewiak, 1986; Van Erp, 2007). The mechanoreceptors of the skin sense the deformation of the skin thereby allowing sensations such as vibration, pressure, and pain to be received (Sekuler & Blake, 1990). Since mechanoreceptors vary in their characteristics and their distribution throughout the skin, the perceptional resolution and sensitivity of the skin varies across the body (Cholewiak & Collins, 2003; Gemperle et al., 2003). Specifically, the Pacinian corpuscles are very sensitive to vibration (Mortimer, Zets, Mort, & Shovan, 2011). Tactile impulses from the skin receptors travel via the spinal cord to the brain. In the cortex of the brain, the precentral gyrus is concerned with sensory information and the postcentral gyrus is concerned with motor information (Montagu, 1986). The tactile representation of parts of the human body in the cortex can be seen in the sensory (precentral gyrus) and motor (postcentral gyrus) homunculi. These bodily representations closely correspond to each other. Also, the precentral gyrus and the postcentral gyrus are connected in the cortex. Because the development of the sense of touch begins during the embryotic stage of human life and because it is largely represented in the brain, it seems reasonable that it would be a suitable means for communication.

Careful consideration must be taken when determining the optimal body locations to provide tactile stimuli as well as the parameters of such stimuli. These investigations date back to the 1800s to the work of those such as Weber (1834/1978) on the perceptual resolution of the whole body. Weber found that perceptual resolution was best for the fingertips and the tip of the tongue. Weinstein (1968) furthered this work by assessing the detection, discrimination, and localization of pressure stimuli being applied to the different locations on both the male and female bodies. Findings of this research revealed that the tactile sensitivity of women is generally higher for women than for men (Weinstein, 1968). However, for the purposes of this research, the hairy skin of the torso will be employed.

Currently, when it comes to providing stimuli for tactile display systems, instead of pressure, vibratory stimuli are almost ubiquitously employed (Cholewiak & Collins, 2003). The way in which the mechanoreceptors respond to tactile stimuli depends on the frequency, amplitude, duration, and location of those stimuli (Jones & Sarter, 2008). Other parameters that can affect the response of mechanoreceptors include waveform, patterns, and inter-stimulus interval. Teuber (1960) determined that there are more perceptual dimensions than stimulus parameters. Because there are a number of parameters that can be manipulated with tactile stimuli, there a numerous perceptual dimensions or tactile sensations that the human can experience by manipulating those parameters. However, this requires that caution be used when selecting appropriate parameters for a given application. Jones and Sarter (2008) determined that although tactile stimuli can be perceived at frequencies between 20 and 500 Hz, the most effective range of frequencies lie between 150 and 300 Hz. Mortimer et al. (2011) identified 250 Hz as the optimal frequency to provide vibrations via tactors with a linear design. It is thought that the amplitude and frequency should be not manipulated simultaneously since, if the amplitude is increased at a constant frequency, both an increase in amplitude and an increase in frequency are perceived (Jones & Sarter, 2008). With regard to duration of tactile stimuli, one study indicated that participants prefer durations between 50 and 200 ms (Kaaresoja & Linjama, 2005). However other studies have used longer durations. This question remains unresolved.

Tactile stimuli to communicate information is usually provided via tactors. The placement of these tactors is not solely dependent on the perceptual resolution or sensitivity of the skin. Other factors that affect the placement of tactors include the presence garments or equipment worn on the body and the type of tasks that the user must complete. For example, a piece of heavy, body-worn equipment can dampen the vibration of any given tactor, and thereby cause the communication to be misinterpreted. Also, tactors should not be placed at body locations at which they will interfere with the user completing his or her task. For example, tasks that require the use of the hands will likely negate the hands as a feasible body location for tactor placement. With regard to military operations, for dismounted Soldiers, the torso has been found to be the best location to place tactors because it is stable, body-centered, and 3-D (Gilson, Redden, & Elliot, 2007; Van Erp, 2007). However, body parts are actually 4-D, with time as the fourth dimension (Hancock, 2015). The torso is also an especially suitable location based on its perceptual resolution and sensitivity. Tactors have normally been mounted on the torso with a belt that contains an array of such tactors (see Figure 5). Previous research has investigated the number of tactors that prove optimal for the torso. Cholewiak, Brill, and Schwab (2004) found that eight equidistantly placed tactors provided that most effective localization performance. However, in military domains, directional information is provided based on twelve clock positions in many cases. So for the present research, a twelve channel tactile belt will be employed. Whether additional, vest like matrices of tactors improve tactile communications substantially has yet to be unequivocally established.

Figure 5. Tactile system developed by Engineering Acoustics Inc. Shown is an adjustable belt that contains twelve C-2 tactors and the control unit.

Tactile stimuli has been shown to be effective in challenging outdoor environments and in conditions of high cognitive and visual workload (Hancock et al., 2015). However, the environment is a very important constraint when it comes to the perception of tactile stimuli. When users are negotiating obstacles, tactile communications can be easily missed; particularly when the torso is in contact with an external surface (Redden, Carstens, Turner, & Elliott, 2006; White & Krausman, 2015). Also the vibrations of moving vehicles have the potential of masking effects on all forms tactile stimuli (Van Erp & Self, 2008; Krausman & White, 2008). There are also times when tasks may actually distract users from recognizing tactile cues. Oakley and Park (2007) found that performance effectiveness on tactile recognition decreased while participants performed a transcription task, data-entry, and during concurrent walking. Therefore the parameters of tactile stimuli must be carefully considered in light of the user's current operating environment. Communications must be easily perceived in the operating conditions presented by each environment if the advantages of tactile communication are to be realized (Elliott et al., 2006).

There are numerous tactile communication studies to date. Some of these studies have employed simple tactile signals, while others have been used to provide more complex information (Rothenberg, Verrillo, Zahorian, Brachman, & Bolanowski, 1977; Piateski & Jones, 2005; Jones, Kunkel, & Piateski, 2009; White & Krausman, 2015). Simple tactile signals normally provide information like simple alerts to some event or directional information, as well as, navigation relevant information (Calhoun, Draper, Ruff, Fontejon, & Guilfoos, 2003; Calhoun, Draper, Ruff, & Fontejon, 2002; Elliott, Duistermaat, Redden, & Van Erp, 2007; Van Erp, J.B.F., Van Veen, Jansen, & Dobbins, 2005). A series of studies have revealed that tactile cues are useful in alerting platoon leaders of incoming messages (Krausman, Elliott, & Pettitt, 2005; Krausman, Pettitt, & Elliott, 2007). Brill, Terrence, Downs, Gilson, Hancock, and Mouloua (2004) found that the tactile modality was useful for directional cueing without imposing any additional demands upon the visual and auditory modalities. The tactile modality has been found to be useful in directing visual attention to targets by reducing response time, reducing missed signals, as well as reducing false positives (Merlo & Hancock, 2011). Tactile cues have also been found to be useful for interruption management (Hameed, Ferris, Jayaraman, & Sarter, 2009; Lu, Wickens, Prinet, Hutchins, Sarter, & Sebok, 2013). Research conducted by White, Kehring, and Glumm (2009) revealed the tactile modality provided significant performance advantages in target acquisition. Another investigation found that the tactile stimulation is useful in providing directional information for visually impaired pedestrians (Gustafson-Pearce, et al, 2007). More recently, researchers have begun exploring the use of tactile stimuli on the head in which one study indicated that participants are able to localize tactile signals on different areas of the head (Binseel & Kalb, 2013).

Tactile cueing has also been explored in various types of vehicle applications (Mohebbi, Gray, & Tan, 2009; Fitch et al., 2007). Research using a simulator that replicates vehicle movements, indicated that participants are able to localize tactile signals while in motion (Krausman & White, 2008). The potential of in-vehicle tactile communications has also been revealed by a study which compared speech messages against tactile messages in providing warnings to drivers (Martens & Van Winsum, 2001). Ho, Tan, and Spence (2005) reported that tactile cues were useful in shifting visual attention during a driving task. Another study indicated that operators were able to perceived tactile waypoint information in both boat and helicopter operations (Van Erp, Jansen, Dobbins, & Van Veen, 2004). Tactile cues were useful in aiding pilots in a hovering task (McGrath, Estrada, Braithwaite, Ray & Rupert, 2004; Raj, Kass, & Perry, 2000; Van Erp, Veltman, Van Veen, & Oving, 2002; Kelley et al., 2013). During both night and day conditions, the tactile modality increased the performance of pilots in maintaining aircraft altitude (Van Erp, Veltman, & Van Veen, 2003). In a comparison of well-rested versus fatigued pilots, Curry, Estrada, Webb, and Erickson (2008), tactile cueing was also useful increasing maneuver performance near the ground in a degraded visual environment by indicating drift information. Researchers have also reported that tactile cues are useful in directing attention without disrupting information processing in an aircraft-based multitask environment (Hopp, Smith, Clegg, & Heggestad, 2005).

Tactile communications have also been used to provide more complex information through the use of tactile patterns. One study has shown that participants were able to identify tactile patterns on the forearm (Piateski & Jones, 2005). Researchers have been able to successfully translate Army arm and hand signals into tactile patterns and successfully relay such patterns to participants (Pettitt, Redden, & Carstens, 2006; Merlo, Stafford, Gilson, & Hancock, 2006; and also Merlo et al., 2006). Research with a tactile grammar has indicated that participants are able to learn a tactile grammar that consists of 56 patterns (Fuchs, Johnston, Hale, & Axelsson, 2008). Using a torso mounted tactile display (i.e., STRAP), it has been found that participants are able to complete a room clearing task with the aforementioned tactile grammar at performance levels equivalent to that of verbal communications (Johnston, Hale, & Axelsson, 2010). In a recent study conducted by White and Krausman (2015), manipulating the intensity and inter-stimulus interval (i.e., speed) of tactile patterns each may be candidates for urgency indications. A similar framework could be employed to encode azimuth location and distance information into tactile cues. Therefore the present research program examined how the tactile modality compares with the auditory and visual modalities for cueing location and distance. Given the range of empirical tactile investigations, the information that tactile displays can communicate ranges from simple alerts to a complex grammar.

Multimodal Communication

Multimodal systems are those that output information to provide stimulation to more than one single sensory channel. The benefits of such multimodal systems is that they provide synergy, redundancy, and an increased bandwidth for information transfer (Sarter, 2006). The present research seeks to capitalize particularly on such redundancy benefits. Based on the operating environment, the appropriate sensory mode is often context contingent. Coovert, Gray, Elliott, and Redden (2007) for example, determined that multimodal communications are a means of through which to mitigate cognitive overload, improve situation awareness, and reduce performance decrement. Using a tracking task, researchers found that visual and tactile modalities can be combined when they present equivalent qualitative information (Van Erp & Verschoor, 2004). Another study revealed that the combined visual and tactile cues yields lower response time than unimodal visual and tactile cues (Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002). Sklar and Sarter (1999) found that visual and tactile cues increased detection and decreased response time by directing participant attention while performing a visual task. Findings concerning another visual search task indicated that a combined auditory and tactile cue improved performance and reduced mental workload versus a non-cued condition (Hancock, Mercado, Merlo, & Van Erp, 2013). A meta-analysis that compared visual to combined visual and tactile cues indicated that the combined visual and tactile cues enhanced task effectiveness more than visual cues alone (Prewett et al., 2006). In the military domain, multimodal cues have been studied as a means to improve target localization and acquisition. White, Kehring, and Glumm (2009) conducted a series of target acquisition studies that yielded increases in target acquisition performance and decreases in mental workload with multimodal cues as compared to no cueing. A study that examined localizing targets in flight revealed that the auditory and visual cues increase performance and reduce mental workload versus both the non-cueing and auditory conditions (Tannen, Nelson, Bolia, Warm, & Dember, 2004). A further investigation that employed a 3-D audio cue, a tactile cue, and a combined 3-D audio and tactile cue to direct participants toward threats while in a vehicle, showed that the multimodal cue yielded better performance than the 3-D audio cue alone (Carlander & Eriksson, 2006; Oskarsson, Eriksson, Lif, Lindahl, & Hedström, 2008). Multimodal cues are also useful in navigation tasks. It has been shown that that participants are able to accurately navigate a specified path using a tactile display with a hand held GPS (Elliott et al., 2007). Van Erp and Van Veen (2004) conducted a driving study in which a visual and auditory cue providing greater improvements in navigation above either the visual and auditory cues alone. In the area of communications, the combination of Army arm and hand signals combined with a tactile pattern equivalent resulted in improvements in both response time and accuracy demonstrating that vibrotactile cues extend beyond any simple speed-accuracy trade-offs (Merlo, Duley, & Hancock, 2010). Being able to provide azimuth location and distance information through combinations of the tactile, auditory, and visual modalities may therefore provide effective and efficient forms operational redundancy. This redundancy can mitigate performance degradations potentially caused by the events within dynamic environments. Therefore this research that characterizes the battlefield examined all possible pairings of the tactile, auditory and visual cues for location and distance.

Hypotheses

Contingent upon the prior formal investigations, I offered three hypotheses. First, the tactile modality was hypothesized to be an effective indicator of target distance as a single modality or as part of a pairing with other sensory modalities. The tactile modality was expected to improve performance in the target acquisition task by increasing the number of hits and reducing the number of misses, suppressing the number of false alarms, and decreasing response time. Second, the tactile modality was expected to reduce the number of errors in a concurrent navigation task. Finally it was hypothesized is that the tactile modality would decrease overall mental workload. The tactile modality was expected to provide a significant performance advantage over the visual modality in particular because of the amount information that it receives. The tactile modality was hypothesized to have a significantly higher number of hits, a lower number of misses, reduced response time, a lower number of navigation errors, and reduced mental workload. Additionally, because of the time required to relay a non-spatial speech cue, the tactile modality was expected to have a lower response time than the non-spatial speech modality. These hypotheses are formally given in Table l.

Table 1

Primary Hypotheses

Measure	Hypothesis
Hit Rate (%)	Tactile > No Cueing Tactile > Visual
False Alarm Rate (%)	Tactile < No Cueing
Response Time (ms)	Tactile < No Cueing Tactile < Non-Spatial Speech Tactile < Visual
Navigation Errors	Tactile < Visual
Mental Workload	Tactile < No Cueing Tactile < Visual

The first subsidiary hypothesis of Experiment 1 is that the moving condition would decrease the number of hits and increase the number of misses and false alarms when both the tactile cue types are employed. For the auditory modality, it was expected that the 3-D audio tones would yield better performance in response time than the non-spatial speech cue due to the time needed translate the linguistics of the non-spatial speech cue into meaning (Loomis, Lippa, Klatzy, & Golledge, 2002). However, it was hypothesized that mental workload was expected to be highest in the moving conditions, and it was expected to be the lowest in the stationary conditions. With regard to participant preference, it was expected that participants would favor the 3-D audio tones over the non-spatial speech as they will require the time to translate linguistics into operational directions. These hypotheses are formally given in Table 2.

Table 2

Experiment 1 Subsidiary Hypotheses

Measure	Hypothesis
Hit Rate (%)	Stationary > Moving (Tactile)
False Alarm Rate (%)	Stationary < Moving (Tactile)
Response Time (ms)	3-D Audio < Non-Spatial Speech
Mental Workload	Stationary < Moving

CHAPTER THREE
EXPERIMENT 1

The objective of the present experimental procedures was to investigate the effects of two tactile cueing techniques and three auditory cueing techniques on the perceived distance and azimuth location of enemy targets in a simulated environment. This investigation examined these cues in both stationary and moving conditions. Cues provided information about the location and distance of enemy targets firing weapons in a 360-degree field. Participants were asked to locate and engage such targets with the aid of the cues. Current findings could serve to indicate whether the tactile modality is a feasible means of communicating distance information and, if so, whether manipulating the intensity of a single pulse or the speed of a series of pulses yielded a significantly substantive performance benefit in order to invest further resources in such practical implications. The present findings also indicated whether the 3-D audio tones provided advantages over non-spatial speech in the perceived location and distance of auditory stimuli.

Experimental Method

Experimental Participants

A power analysis using GPower 3.1 software was conducted to determine that seventeen participants were needed for this study. Seventeen male infantry Soldiers from the 101st Airborne Division of Ft. Campbell, KY volunteered to participate in this investigation. The age of participants ranged from 18 – 28 years of age (*M* = *22*.2 years, *SD* = 3.2). Ten of the participants had combat experience.

Experimental Apparatus

Immersive Environment Simulator

The Immersive Environment Simulator (IES) is a facility which is located at Aberdeen Proving Ground, Maryland (see Figure 6). It provides a multi-sensory immersion in a laboratory setting to investigate Soldier performance. There are three major components of this simulator: a visual interface, an auditory interface, and a mobility interface. The visual interface is a 4-sided RAVE display that enables a 360-degree field of view. Each side or screen is 12.5’ width x 10’ height. The auditory interface is driven by forty four speakers strategically placed in the facility. Speakers were used to generate background noise during the stationary conditions. The walls have been treated with materials to create an anechoic environment. The final component of this simulator, the mobility interface, is the omni-directional treadmill. This omni-directional treadmill allows users to walk, jog, or crawl in any direction. It differs from a traditional treadmill in that the speed and heading is completely controlled by the movements of the user. These movements are tracked using a camera based tracking system. The omni-directional treadmill has an 8’ x 8’ working surface. So the user can walk in any direction and the treadmill continuously acts to bring the user back to center (i.e., to ensure that the user does not walk over the edge of the treadmill itself). While the user walks on the treadmill the virtual environment updates its relative visual location in order to simulate walking in the real world. The software used in the IES is Soldier Visualization System (SVS). This software was developed by AIS-RBD. Some of the features of the software include, but are not limited to, 3-D audio, night vision and thermal modes, weather, and time-of-day.

Figure 6. Immersive Environment Simulator.

Tactile Belt

A tactile belt developed by Engineering Acoustics Inc. (EAI) is to be used in the present investigations (see Figure 5). The belt is adjustable belt and contains twelve EAI C2 tactors (acoustic transducers) positioned at 30-degree intervals and a tactor control unit. The transducers are approximately 1.2 inches in diameter. The belt connects to a tactor control unit, which receives commands via wireless Bluetooth technology and translates them in to vibratory stimuli with the tactors in the adjustable belt. The tactor control unit is capable of varying frequency, gain, and duration of vibratory signals, and consequentially can output simple tactile signals as well as more complex tactile patterns. It is powered by a 7.2 V, 2.6 Ah Li Ion battery. Participants wore an undershirt with belt loops sewn in to ensure that the tactile belt remained in place during data collection.

Cell Phone

A Samsung Galaxy S4 cell phone that uses the Android operating system was used in the present investigations to present visual cues. The cell phone was programmed to mimic the visual display of the aforementioned SWATS (see Figure 3). The cell phone is powered by a 3.6-V Li-ion battery. It was enclosed in a Juggernaut Phone Case and attached to each participants forearm with a forearm mount (see Figure 7).

Figure 7. Samsung Galaxy S4 cell phone enclosed in a Juggernaut phone case. Shown on the display of the cell phone is a 10 ‘o clock, near cue.

Earbuds

Stereo earbuds developed by Tok Tok Designs were used to provide auditory cues and enemy gunfire. Each participant received a new pair of earbuds to utilize during data collection. The earbuds plugged into 3.5 mm audio jack on the Samsung Galaxy S4.

Custom Software

Custom software developed by EAI was used in the present investigations to present cues. The aforementioned SVS software in the IES facility communicated target information (i.e., target presentation, target azimuth, and target distance) information to the custom built software using a local network. The custom software then triggered cues via the tactile system and the cell phone (i.e., visual and auditory cues) using Bluetooth technology. The cues employed were specified in the design of each experiment.

Questionnaires

NASA-TLX

The NASA-TLX is a widely used subjective workload assessment. This assessment provides an overall workload score based on a weighted average of six subscales (Hart & Staveland, 1998). The subscales are i) mental demand, ii) physical demand, iii) temporal demand, iv) performance, v) effort, and vi) frustration. Participants are asked to rate each of the subscales on a scale of 0 to 100. Each of the subscales are then assigned a weight contingent on the fifteen possible pairwise comparisons among each of them. Here, each individual is asked to choose the subscale that contributes most to their own workload experience. A computerized version of this assessment was employed in this line of research. However, a printed version is provided in Appendix A.

Demographics Survey

A demographic-based survey is used to obtain pertinent information about the participants in each study (see Appendix B). Particular areas of interest are age, years of military service, and combat experience.

Cue Preference

In Experiment 1, because two differing tactile cue conditions and three differing auditory cue conditions were employed, participants were asked to indicate their preference of the two tactile cue types and their preference of the three auditory cue types. In Experiments 2 and 3, participants were asked to indicate their preference of cuing modality. Participants were also allowed to provide other open-ended comments about their experience with the various cueing modalities.

Experimental Design

The present investigation was a 5 x 2 within participant design in which cue condition and status represented the within-participant factors. The cue conditions included three auditory cueing conditions and two tactile cueing conditions. The auditory conditions were non-spatial speech, 3-D audio frequency, and 3-D audio pulsing; the tactile conditions were tactile intensity and tactile pulsing. The status levels were represented by stationary and moving. In the stationary condition participants completed the target acquisition task while standing, and in the moving condition participants completed the target acquisition task while navigating a path in the virtual environment. Each participant completed a block in each of the five conditions twice, once while stationary and once navigating the virtual environment. The conditions were counterbalanced across participants using the latin square design. Eight dependent variables were measured: hits, misses due to inaccurate target engagement, misses due to targets not being detected, false alarms, response time to accurate target engagement, navigation errors (i.e., the number of wrong turns made during navigation in the moving condition), and mental workload.

Experimental Procedures

After participants arrived, they received a brief overview of the study and administered the informed consent form (see Appendix E). They were then asked to a demographics survey to obtain pertinent information about them. The participants then received a vision screening and a hearing screening. Before the experimental runs begin, participants were trained on each of the cue modalities to ensure that they comprehended the localization and distance information that they provided. They were also shown an example of the enemy target. The target azimuth location was provided based on clock positions. The distance of targets ranged from 20 to 100 meters, with 20-59.9 meters representing a “near” range and 60-100 meters representing a “far” range. There were three types of auditory cues: non-spatial speech, 3-D audio frequency, or 3-D audio. The non-spatial speech cue was presented verbally with a pre-recorded voice (e.g. “five o’ clock, seven sixty meters”). There were two types of 3-D audio cues: (1) a single 900 ms tone was manipulated with two sound frequency levels to indicate distance, where a 500 Hz frequency level indicated an enemy target at a “near” range and a 250 Hz frequency level indicated an enemy target at a “far” range (2) or a series of three 500 Hz tones 200 ms pulses with varied speed to indicate distance where a 10 ms inter-stimulus interval (ISI) indicated an enemy target at a “near” range and a 300 ms ISI indicated an enemy target at a “far” range. The 3-D audio cues were created using the head related transfer function (HRTF) of a standard headform. Tactile cues were presented as vibrations about the torso of participants. The tactile There were two types of tactile cues: (1) a single 900 ms vibration was manipulated with two intensity levels to indicate distance, where a gain of 255 (113.96 dB) indicated an enemy target at a “near” range, and a gain of 64 (101.96 dB) indicated an enemy target at a “far” range or (2) as series of three 200 ms vibrations at a gain of 255 with varied speed to indicate distance where a 10 ms inter-stimulus interval (ISI) indicates an enemy target at a “near” range and a 300 ms ISI indicates an enemy target at a “far” range. The tactile cues had a frequency of 250 Hz. Participants were then trained on the omni-directional treadmill to ensure that they can maneuver safely. The participants were required to walk for a minimum of five minutes. Extra time was provided when needed. Participants were then asked to engage targets while navigating a path using a map while received each of the cue types to familiarize them with the task.

During each experimental block, forty eight enemy targets (i.e., two targets at each clock position at each distance range) appeared on the screen at random intervals and fire a weapon. Participants were asked to engage those enemy targets as quickly as possible by firing a mock weapon (see Figure 8). Enemy targets appeared for 5 seconds in the stationary conditions and 6 seconds in the moving conditions. The additional second provided for target exposures in the moving scenarios was due to the difficulty associated with engaging targets located in between buildings in the scenarios. A slight reduction in the speed of the omni-directional treadmill’s responsiveness when a user side steps or walk backwards made it more difficult to engage targets within 5 seconds. This delay was implemented in the software that controls the omni-directional treadmill and could not be altered. In the stationary condition, participants stood at the centermost point of the omni-directional treadmill and were allowed to turn their bodies 360 degrees from the specified 12 o’clock position to engage targets. In the moving condition, participants were asked to engage targets while navigating a map of a Middle Eastern urban environment. Each of the moving blocks of the study employed a unique path. Each path was approximately 890 meters (.553 miles). If participants got off the navigation path, the error was counted as a navigation error and the experimenter directed them back to the specified path. Background noise was provided during all of the stationary conditions of the study. This background noise was a recording of the noise generated by the omni-directional treadmill when in motion for consistency with the moving conditions. Background noise was played at approximately 80 dB. Participants completed the NASA-TLX workload assessment after each block. Upon completion of the study, participants were asked to identify their preferred cue modality and were allowed to make open-ended comments about their experience with the various cue modalities.

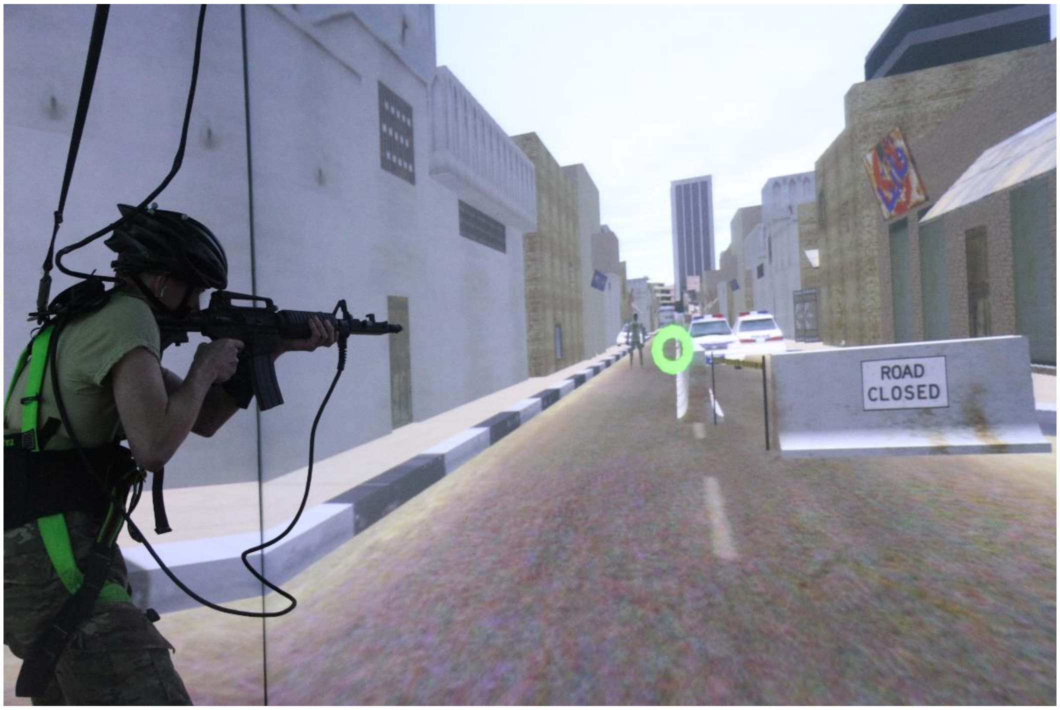


Figure 8. Participant engaging targets in the virtual environment using a mock weapon.

Results

Separate repeated measures analyses of variance (ANOVA) were conducted on each of the dependent variables ($\alpha = 0.05$). Post hoc tests were performed using the Bonferroni method. Effect sizes are reported as Cohen's D.

Hits

A repeated measures ANOVA revealed a significant main effect of cue condition, Wilks' Lambda = .095, F (4, 13) = 31.018, $p < .001$, $n_p^2 = .905$, on the percentage of targets hit (see Figure 9). Post hoc comparisons indicated that the tactile intensity and the tactile pulse cues yielded a significantly higher hit rate than the non-spatial speech, the 3-D audio frequency, and the 3-D audio pulse cues (all $p < .001$). The analysis also revealed a significant main effect of status, Wilks' Lambda = .223, F (1, 16) = 55.699, $p < .001$, $n_p^2 = .777$, on the percentage of targets hit. A higher percentage of targets were hit in the stationary conditions than in the moving conditions (see Figure 10).

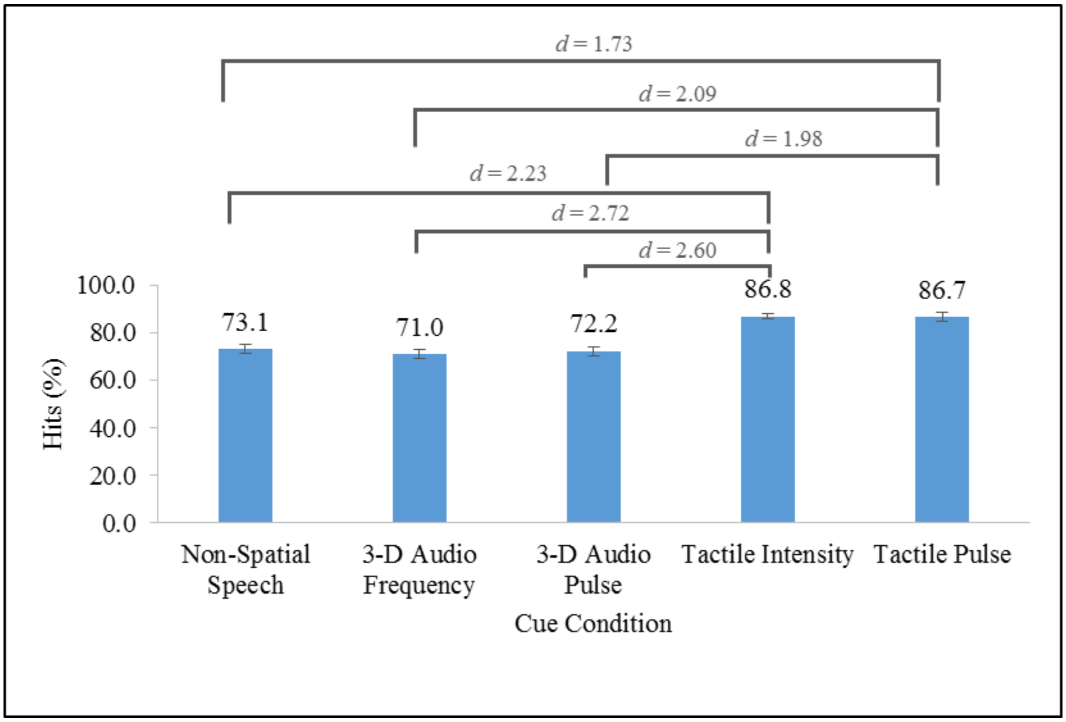


Figure 9. Experiment 1 Main effect of cue condition on the Percentage of hits.

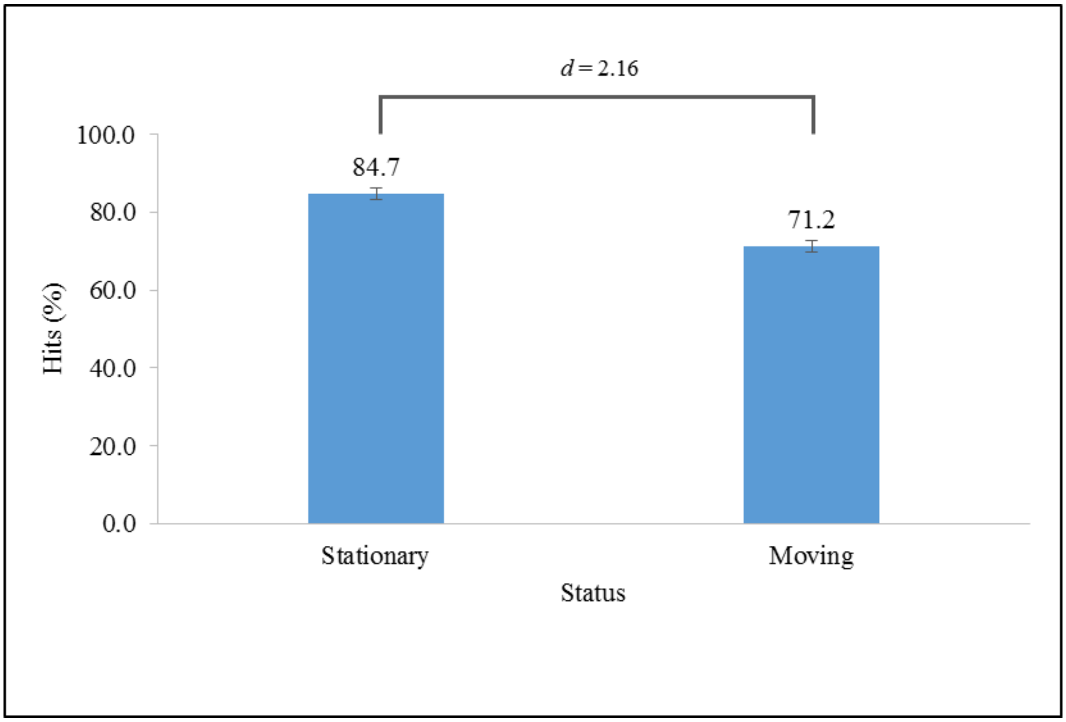


Figure 10. Experiment 1 Main effect of status on the percentage of hits.

Misses

Inaccurate Engagement

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .471, F (1, 16) = 17.948, p = .001, n_p^2 = .529, on the percentage of targets missed because they were not accurately engaged. A greater percentage of targets were missed in the moving conditions (see Figure 11).

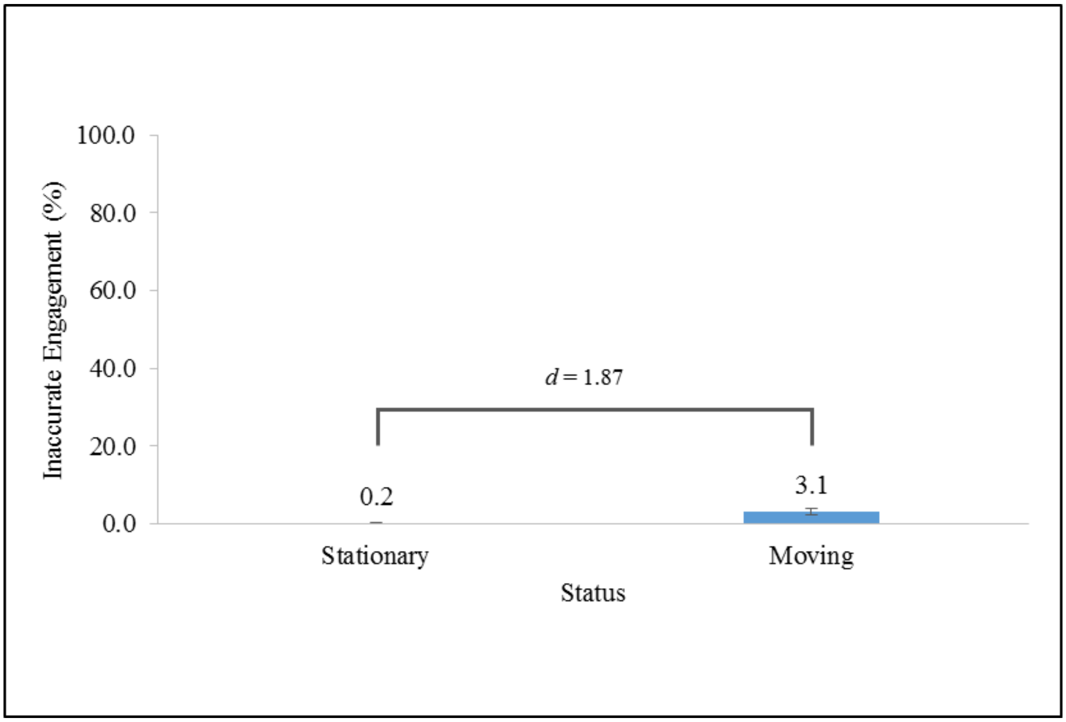


Figure 11. Experiment 1 Main effect of status on the percentage of inaccurate engagement.

Targets Not Detected

A repeated measures ANOVA revealed a significant interaction between cue condition and status on the percentage of targets missed because they were not detected, Wilks' Lambda = .489, F (4, 13) = 3.400, p = .041, $n_p{}^2$ = .511 (see Figure 12). An analysis of simple effects revealed that in the stationary condition, the tactile intensity cues yielded a significantly lower number of targets not detected than the non-spatial speech (p < .001, d = 1.28), the 3-D audio frequency (p < .001, d = 2.08), and the 3-D audio pulse cues (p < .001, d = 1.83). The tactile pulse cues yielded a significantly lower number of targets not detected than the non-spatial speech (p = .001, d = 0.96), the 3-D audio frequency (p < .001, d = 1.61), and the 3-D audio pulse cues (p < .001, d = 1.38). For the moving condition, the tactile intensity cue yielded a significantly lower number of targets not detected than the non-spatial speech (p < .001, d = 1.99), the 3-D audio frequency (p < .001, d = 2.05), and the 3-D audio pulse cues (p < .001, d = 2.12). The tactile pulse cue also yielded a significantly lower number of targets not detected than the non-spatial speech (p < .001, d = 1.79), the 3-D audio frequency (p < .001, d = 1.84), and the 3-D audio pulse cues (p < .001, d = 1.90). The analysis of simple effects also revealed that a significantly higher percentage of targets were not detected in the moving conditions than in the stationary conditions with the non-spatial speech (p < .001, d = 1.45), the 3-D audio frequency (p = .003, d = 0.98), the 3-D audio pulse (p = .001, d = 1.41), the tactile intensity (p < .001, d = 1.48), and the tactile pulse cues (p = .034, d = 0.68).

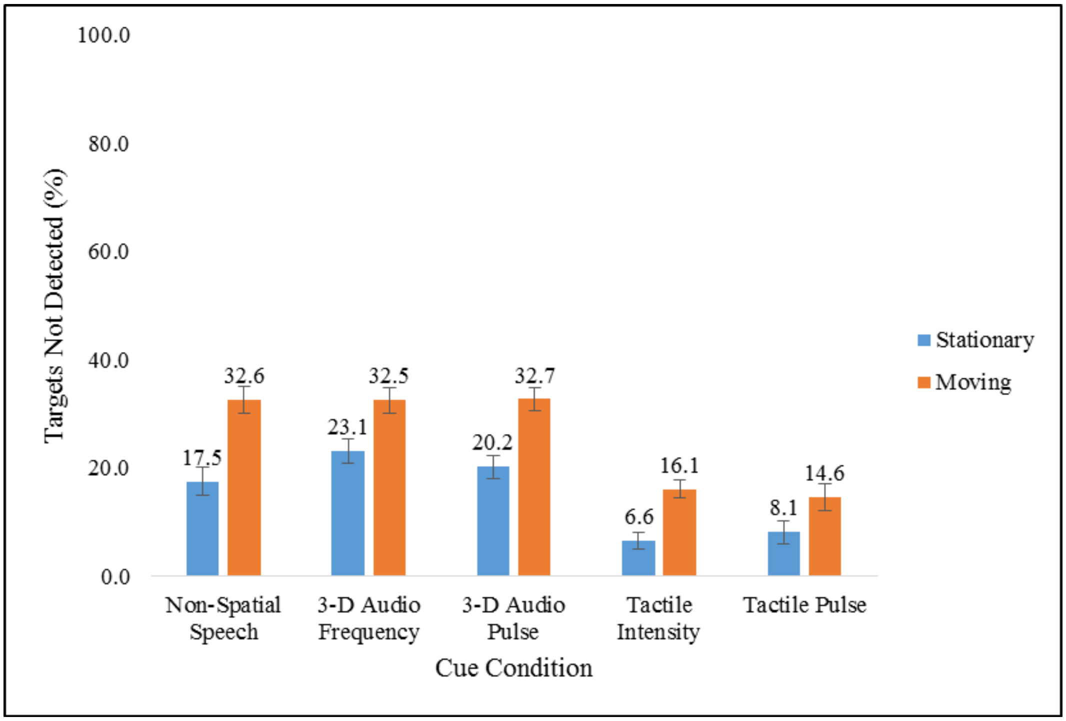


Figure 12. Experiment 1 Status condition X cue condition on the percentage of targets not detected.

False Alarms

There were no false alarms in this experiment.

Response Time

A repeated measures ANOVA revealed a significant main effect of cue condition Wilks' Lambda = .111, *F* (4, 13) = 26.038, *p* < .001, n_p^2 = .889, on response time (see Figure 13). Post hoc comparisons indicated that the tactile intensity cue yielded a significantly shorter response time than the non-spatial speech, the 3-D audio frequency, and the 3-D audio pulse cues (all *p* < .001). The tactile pulse cue yielded a significantly shorter response time than the non-spatial speech (*p* < .001), the 3-D audio frequency (*p* < .001), and the 3-D audio pulse cues (*p* = .002).

The analysis also revealed a significant main effect of status, Wilks' Lambda = .094, *F* (1, 16) = 153.541, $p < .001$, $n_p^2 = .906$, on response time. Response time was significantly longer in the moving conditions than in the stationary conditions (see Figure 14).

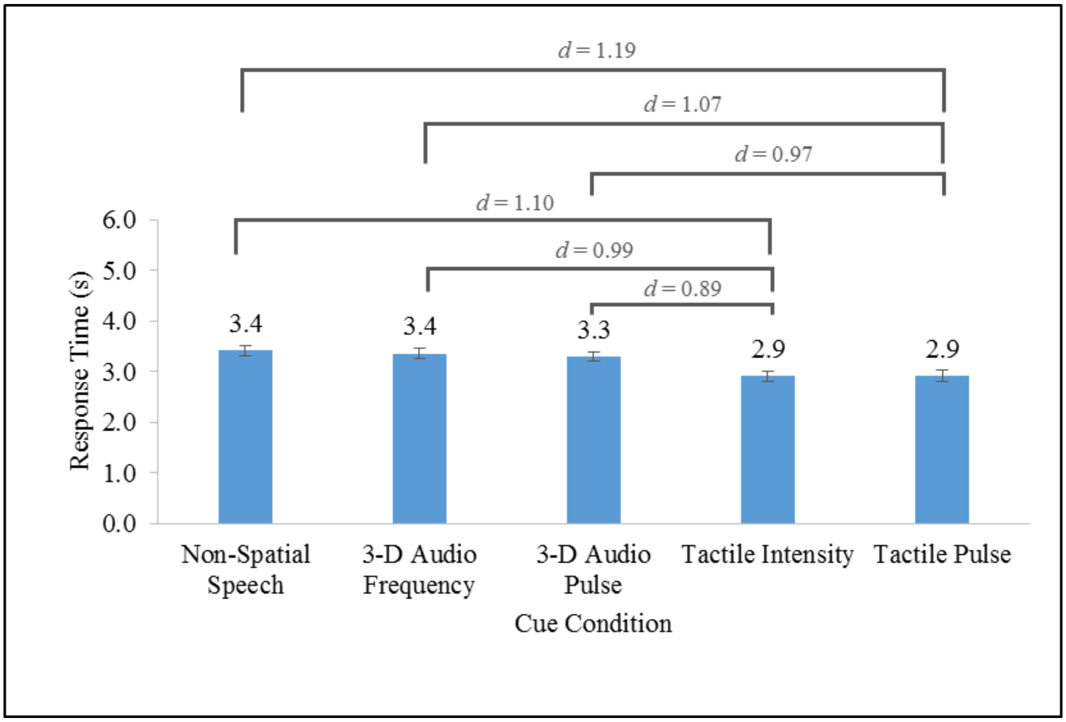


Figure 13. Experiment 1 Main effect of cue condition on response time.

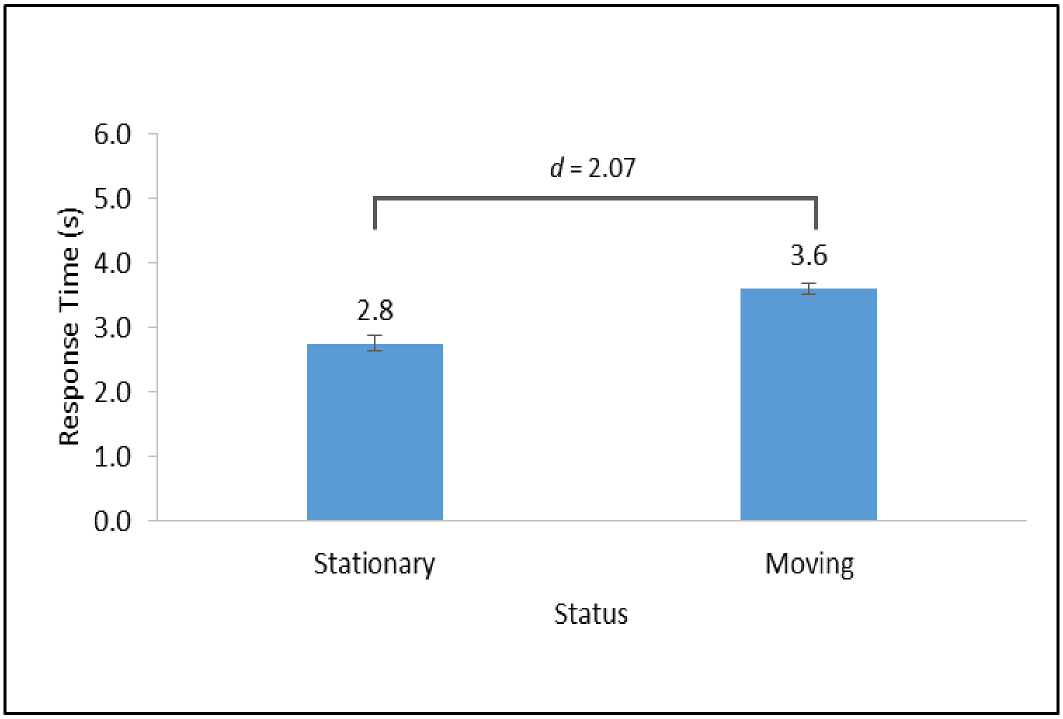


Figure 14. Experiment 1 Main effect of status on response time.

Navigation Errors

A repeated measures ANOVA did not reveal any significant effects of cue condition on the number of navigation errors.

Mental Workload

In addition to global mental workload scores, raw workload scores for each of the six subscales were analyzed.

Global Workload

A repeated measures ANOVA revealed a significant interaction between cue condition and status on global mental workload, Wilks' Lambda = .351, *F* (4, 13) = 6.017, $p = .006$, $n_p^2 =$

.649 (see Figure 15). An analysis of simple effects revealed that in the stationary condition, global mental workload was significantly lower with the tactile intensity cues than with the non-spatial speech (*p* = .004, *d* = 0.78), the 3-D audio frequency (*p* < .001, *d* = 1.85), and the 3-D audio pulse cues (*p* < .001, *d* = 1.86). Mental workload was significantly lower with the tactile pulse cues than with the non-spatial speech (*p* = .013, *d* = 0.68), the 3-D audio frequency (*p* < .001, *d* = 1.70), and the 3-D audio pulse cues (*p* < .001, *d* = 1.70). Mental workload was also significantly lower with the non-spatial speech than with the 3-D audio frequency (*p* = .005, *d* = 1.06) and 3-D audio pulse cues (*p* = .001, *d* = 0.99). For the moving condition, global mental workload was significantly lower with the tactile intensity than with the non-spatial speech (*p* = .004, *d* = 0.87), the 3-D audio frequency (*p* = .010, *d* = 0.95), and the 3-D audio pulse cues (*p* = .021, *d* = 0.89). Mental workload was significantly lower with the tactile pulse cues than with the non-spatial speech (*p* = .002, *d* = 0.85), the 3-D audio frequency (*p* = .006, *d* = 0.93), and the 3-D audio pulse cues (*p* = .013, *d* = 0.86). The analysis of simple effects also indicated that global mental workload was significantly higher in the moving condition than in the stationary condition, with the non-spatial speech (*p* = .001, *d* = 0.87), the tactile intensity (*p* = .003, *d* = 0.67), and the tactile pulse cues (*p* = .002, *d* = 0.70).

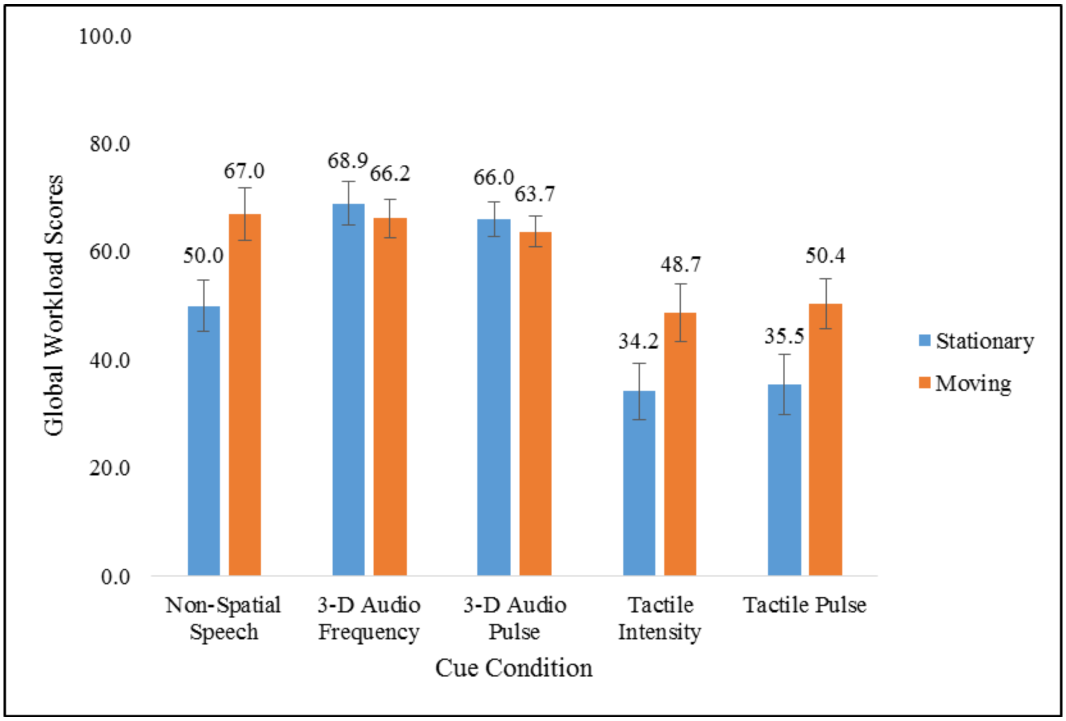


Figure 15. Experiment 1 Cue condition X status interaction on global mental workload scores.

Raw Subscale Workload

A repeated measures ANOVA revealed a significant main effect of cue condition, Wilks' Lambda = .339, *F* (4, 13) = 6.336, *p* = .005, n_p^2 = .661, on mental demand (see Figure 16). Post hoc comparisons indicated that the tactile intensity cue yielded significantly lower mental demand scores than the non-spatial speech (*p* = .012), the 3-D audio frequency (*p* = .002), and the 3-D audio pulse cues (*p* = .011). The tactile pulse cue yielded significantly lower mental demand scores than the non-spatial speech (*p* = .003), the 3-D audio frequency (*p* = .002), and the 3-D audio pulse cues (*p* = .005). The analysis also revealed a significant main effect of status, Wilks' Lambda = .693, *F* (1, 16) = 7.088, *p* = .017, n_p^2 = .307, on mental demand. Mental demand scores were significantly lower in the stationary conditions than in the moving conditions (see Figure 17).

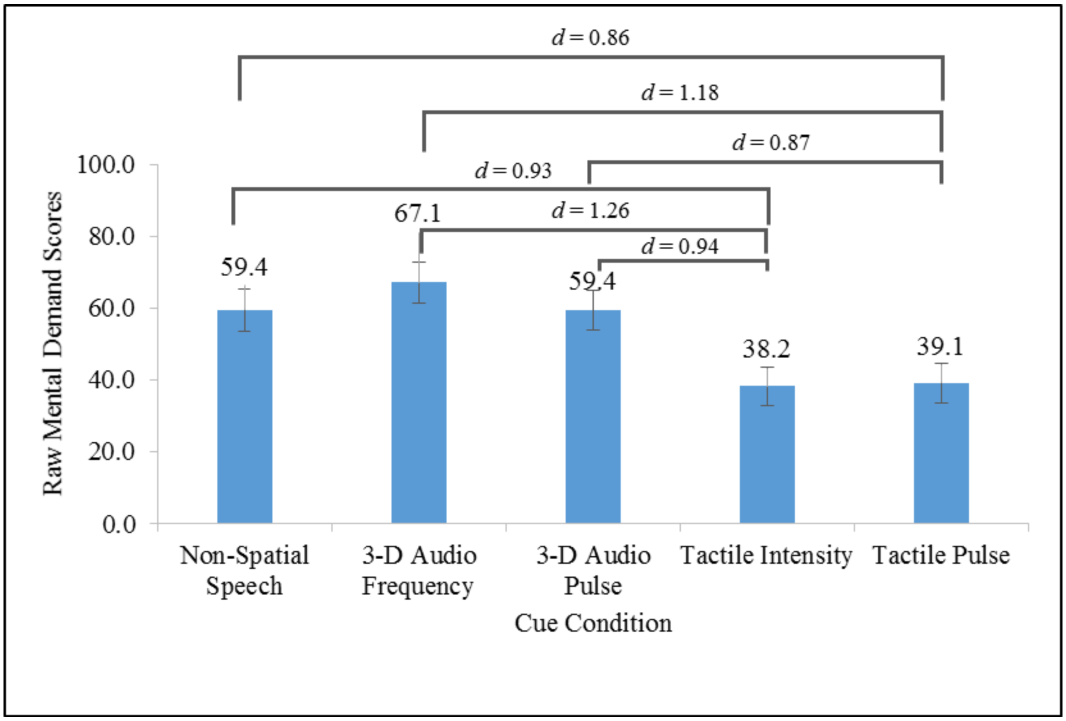


Figure 16. Experiment 1 Main effect of cue condition on raw mental demand scores.

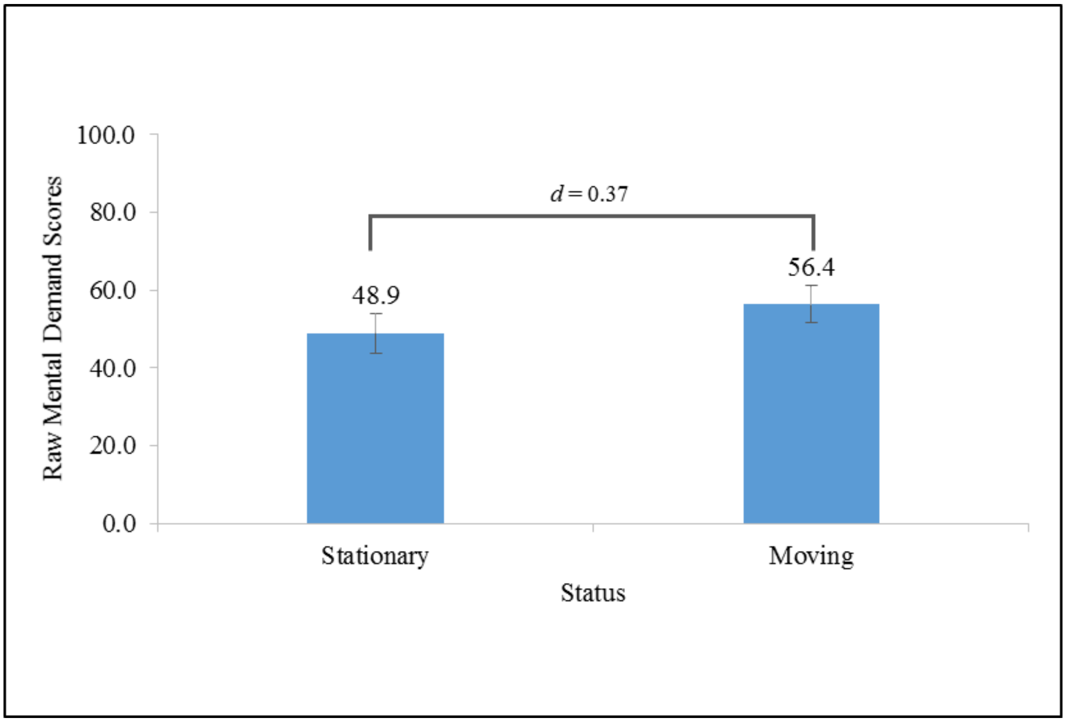


Figure 17. Experiment 1 Main effect of status on raw mental demand scores.

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .518, *F* (1, 16) = 14.874, *p* = .001, n_p^2 = .482, on physical demand. Physical demand scores were significantly lower in the stationary conditions than in the moving conditions (see Figure 18).

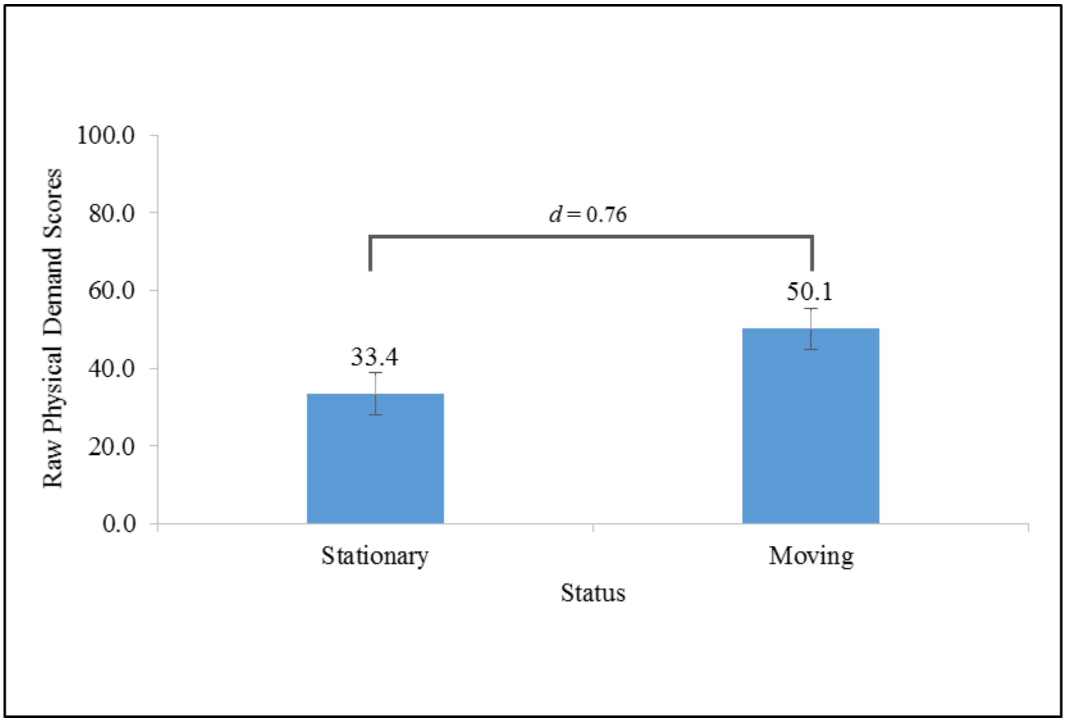


Figure 18. Experiment 1 Main effect of status on raw physical demand scores.

A repeated measures ANOVA revealed a significant main effect of cue condition, Wilks' Lambda = .477, *F* (4, 13) = 3.556, *p* = .036, n_p^2 = .523, on temporal demand (see Figure 19). Post hoc comparisons indicated that the tactile intensity cue yielded significantly lower temporal demand scores than the 3-D audio frequency (*p* = .011) and the 3-D audio pulse cues (*p* = .021). The tactile pulse cue yielded significantly lower temporal demand scores than the non-spatial speech (*p* = .047), the 3-D audio frequency (*p* = .018), and the 3-D audio pulse cues (*p* = .026). The analysis also revealed a significant main effect of status, Wilks' Lambda = .631, *F* (1, 16) =

9.366, p = .007, $n_p{}^2$ = .369, on temporal demand. Temporal demand scores were significantly lower in the stationary conditions than in the moving conditions (see Figure 20).

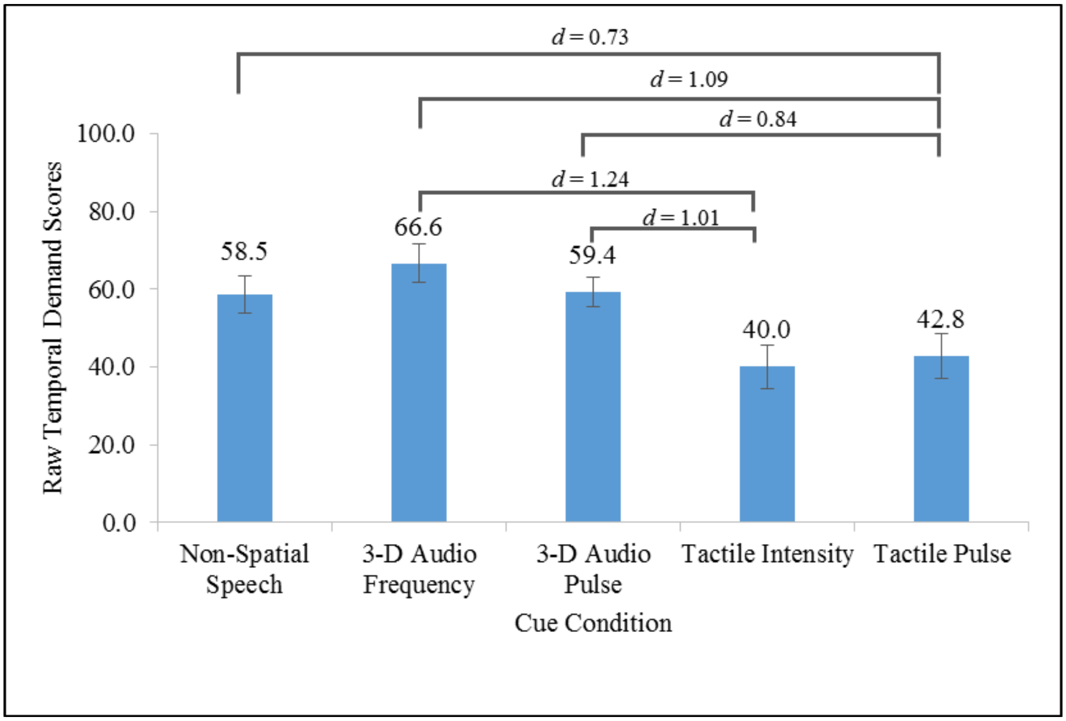


Figure 19. Experiment 1 Main effect of cue condition on raw temporal demand scores.

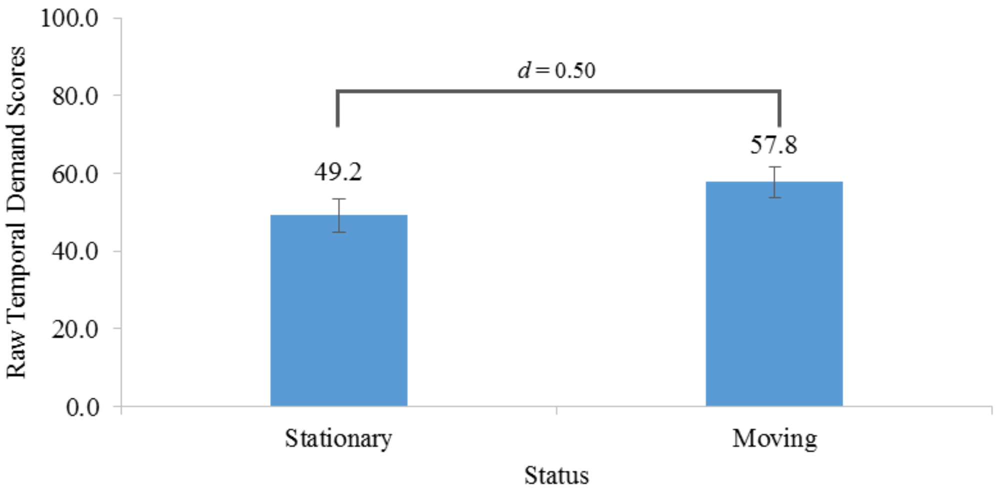


Figure 20. Experiment 1 Main effect of status on raw temporal demand scores.

A repeated measures ANOVA revealed a significant interaction between cue condition and status on performance, Wilks' Lambda = .292, F (4, 13) = 7.873, p = .002, n_p^2 = .708 (see Figure 21). An analysis of simple effects revealed that in the stationary condition, performance was significantly better with the tactile intensity cues than with the 3-D audio frequency (p = .002, d = 1.28) and the 3-D audio pulse cues (p < .001, d = 1.48). Performance was significantly better with the tactile pulse cues than with the non-spatial speech (p = .028, d = 0.73), the 3-D audio frequency (p = .001, d = 1.42), and the 3-D audio pulse cues (p < .001, d = 1.66). Performance was also significantly better with the non-spatial speech than with the 3-D audio frequency (p = .015, d = 0.68) and 3-D audio pulse cues (p = .023, d = 0.80). For the moving condition, performance was significantly better with the tactile intensity than with the non-spatial speech (p = .011, d = 1.04), the 3-D audio frequency (p = .009, d = 0.88), the 3-D audio pulse cues (*p* = .029, *d* = 0.60), and the tactile pulse cues (*p* = .015, *d* = 0.24). Performance was significantly better with the tactile pulse cues than with the non-spatial speech (*p* = .043, *d* = 0.80) and the 3-D audio frequency (*p* = .047, *d* = 0.65). The analysis of simple effects also indicated that performance was significantly poorer in the moving condition than in the stationary condition, with the 3-D audio pulse (*p* = .004, *d* = 0.52) and the tactile pulse cues (*p* = .032, *d* = 0.62).

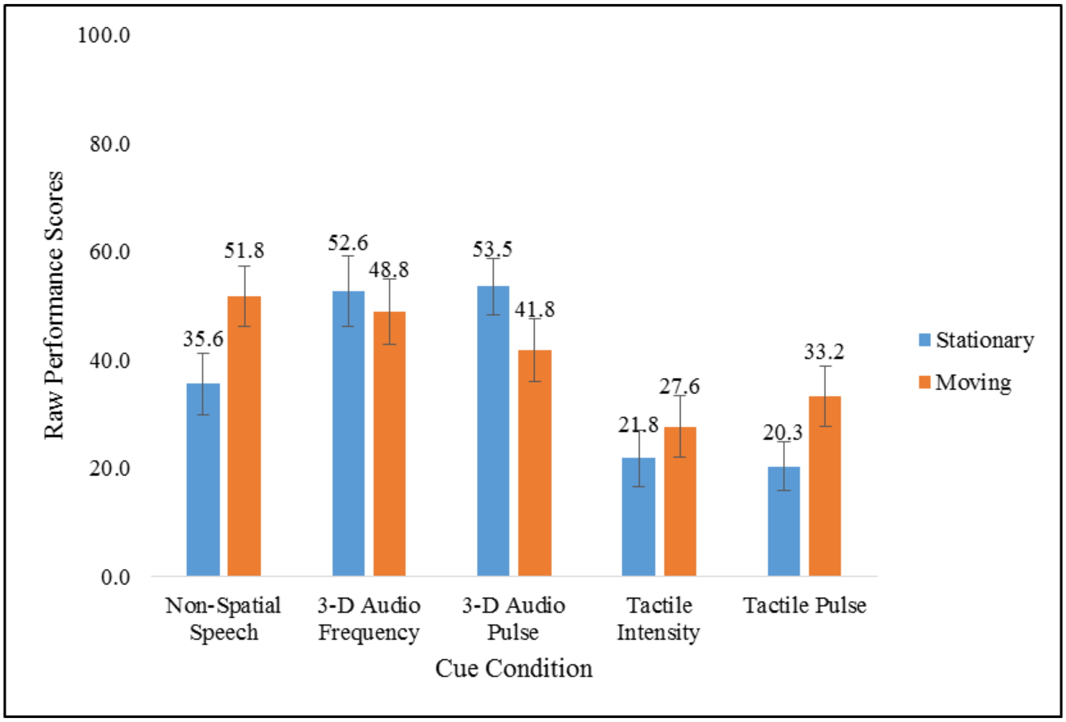


Figure 21. Experiment 1 Cue condition X status interaction on raw performance scores.

A repeated measures ANOVA revealed a significant main effect of cue condition, Wilks' Lambda = .422, *F* (4, 13) = 4.449, *p* = .017, n_p^2 = .578, on effort (see Figure 22). Post hoc comparisons indicated that the 3-D audio pulse cue yielded significantly higher effort scores than the tactile intensity (*p* = .005) and the tactile pulse cues (*p* = .004). The analysis also revealed a significant main effect of status, Wilks' Lambda = .761, *F* (1, 16) = 5.037, *p* = .039, n_p^2 = .239, on effort. Effort scores were significantly lower in the stationary conditions than in the moving conditions (see Figure 23).

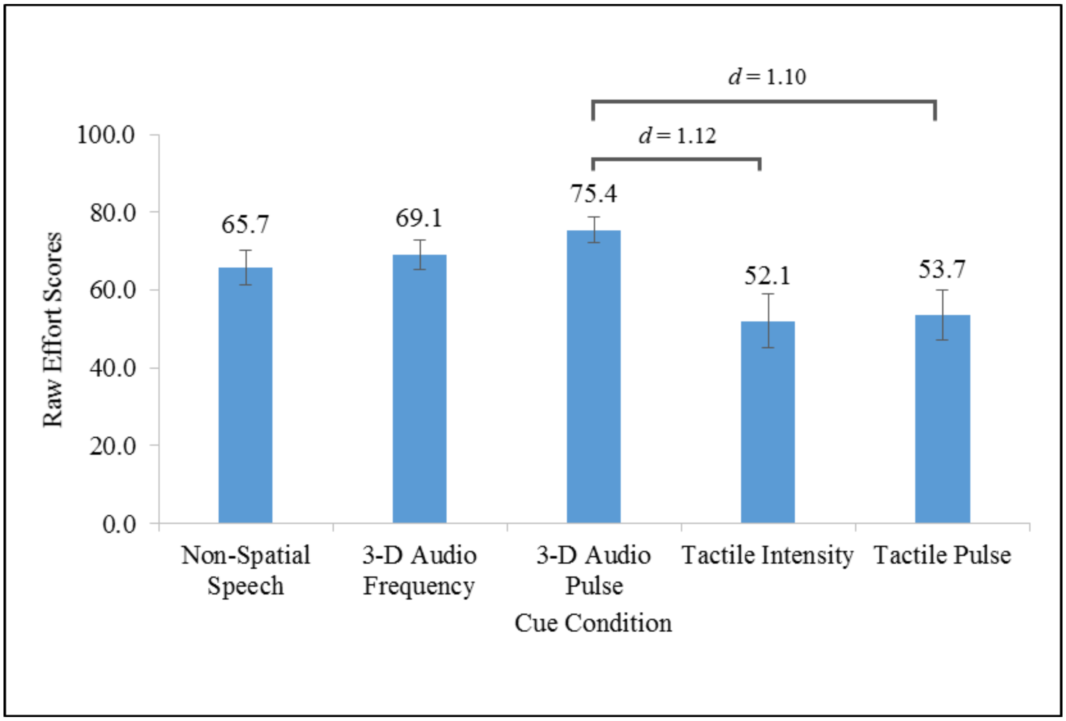


Figure 22. Experiment 1 Main effect of cue condition on raw effort scores.

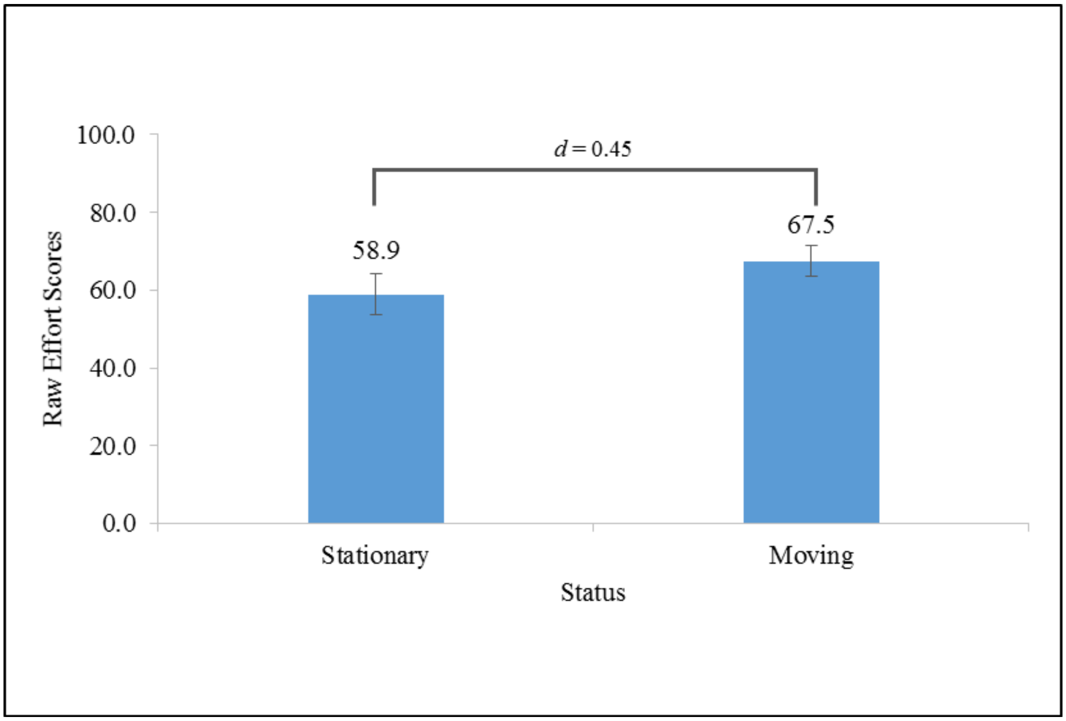


Figure 23. Experiment 1 Main effect of status on raw effort scores.

A repeated measures ANOVA revealed a significant interaction between cue condition and status on frustration, Wilks' Lambda = .417, F (4, 13) = 4.547, p = .016, n_p^2 = .583 (see Figure 24). An analysis of simple effects revealed that in the stationary condition, frustration was significantly lower with the tactile intensity cue than with the non-spatial speech (p < .001, d = 1.16), the 3-D audio frequency (p < .001, d = 2.09), and the 3-D audio pulse cues (p < .001, d = 2.23). Frustration was significantly lower with the tactile pulse cue than with the non-spatial speech (p = .001, d = 1.25), the 3-D audio frequency (p < .001, d = 2.21), and the 3-D audio pulse cues (p < .001, d = 2.47). For the moving condition, frustration was significantly lower with the tactile intensity than with the non-spatial speech (p = .005, d = 0.98) and the 3-D audio frequency cues (p = .020, d = 0.92). Frustration was significantly lower with the tactile pulse cue than with the non-spatial speech (p = .004, d = 0.85) and the 3-D audio frequency cues (p = .034, *d* = 0.78). The analysis of simple effects also indicated that frustration was significantly higher in the moving condition than in the stationary condition with the tactile pulse cue (*p* = .009, *d* = 0.96).

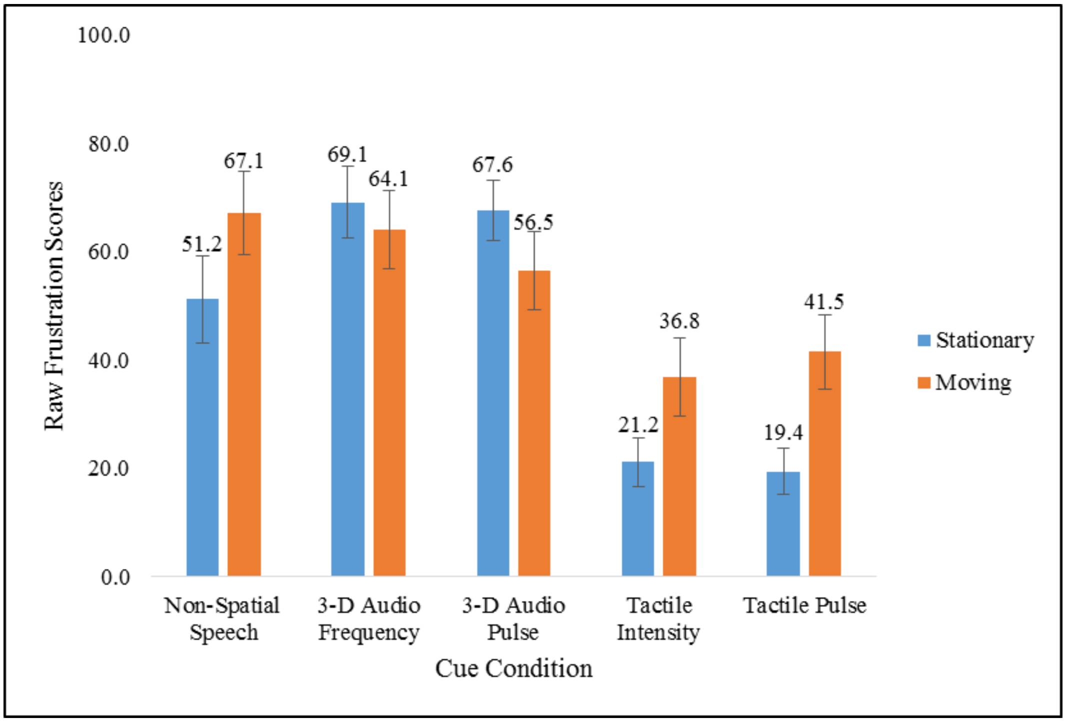


Figure 24. Experiment 1 Cue condition X status interaction on raw frustration scores.

Cue Preference

With regard to the auditory cues, a higher percentage of participants preferred the non-spatial speech cue over the 3-D audio frequency and the 3-D audio pulse cues and with the tactile cues, a higher percentage of participants preferred the tactile pulse cue over the tactile intensity cues (see Table 3).

Table 3

Experiment 1 Cue Preference

Cue Type	
Auditory	
Non-Spatial Speech	58.8%
3-D Audio Frequency	5.9%
3-D Audio Pulse	35.3%
Tactile	
Tactile Intensity	29.4%
Tactile Pulse	70.6%

Discussion

In Experiment 1, findings indicate that the tactile modality improved performance. There was a higher percentage of hits with the tactile intensity and tactile pulse cues than with the non-spatial speech, 3-D audio frequency, and the 3-D audio pulse cues in both the stationary and moving conditions. This finding can be attributed in part to the background noise provided during the stationary conditions and the noise generated by the treadmill during the moving conditions. Perhaps the noise made auditory perception more difficult than tactile perception. For all of the cue conditions, the percentage of hits was lower when moving than when stationary. This finding supports the hypothesis that the percentage of hits would be lower in the moving condition than in the stationary condition for the tactile intensity and tactile pulse cues. With regard to misses in this investigation, more misses due to inaccurate engagement occurred while participants were moving than when stationary. Because the targets missed due to inaccurate engagement was less than 1% in the stationary conditions and around 3% in the moving conditions, this indicates that participants had good aiming skills. Targets were more difficult to engage in the moving scenarios because participants were walking and because targets appeared in less conspicuous locations (e.g., between buildings, on top of buildings, in balconies) in the urban environment. During the stationary trials, targets were more conspicuous because the environment was less cluttered. The majority of misses occurred because targets were not detected. Of those misses due to targets not being detected, the tactile intensity and the tactile pulse cues resulted in a lower percentage than the non-spatial speech, 3-D audio frequency, and the 3-D audio pulse cues in both the moving and stationary conditions. Again, this finding is likely due to the noise associated with the stationary and moving conditions. Due to the conspicuity of targets in the stationary conditions, a lower percentage of targets were not detected as opposed to the moving condition for each of the cue types. The findings of this investigation yielded no false alarms. This seems to indicate that participants relied on the cues.

For response time, the tactile intensity and the tactile pulse cues yielded the fastest target engagement than with the non-spatial speech, the 3-D audio frequency, and the 3-D audio pulse cues. Contrary to the proposed hypothesis, there was no significant difference in response time between the non-spatial speech, the 3-D audio frequency, and the 3-D audio pulse cues. The lack of significant differences in the auditory cues may be due to the combination of the time needed to translate the linguistics of non-spatial speech (Loomis et al., 2002) and the HRTF used to create the 3-D audio cues. A number of participants reported difficulty localizing the 3-D audio cues. In order for 3-D audio cues to be localized best, the cues must be created based on the individual user's HRTF. Since it was not feasible to create custom 3-D audio cues for each individual, the 3-D cues were created using a standard headform which resulted in some participants having difficulty localizing those cues. Begault (1991) reported that there are three components that make up the source of a 3-D audio sound: the recording engineer, the 3-D audio system used for playback, and the listener. Consequentially, a standard HRTF works better in some individuals than others (Begault, 1991). Therefore the difficulty in localizing the 3-D audio cues may have reduced their associated response times. The HRTF issue may also provide insight on the percentage of targets hit and the percentage of targets not detected with the two 3-D audio cue types. Overall, response time slower when participants were moving than when they were stationary.

Analysis of the global mental workload scores indicated that participants had lower overall workload with the tactile intensity and tactile pulse cues than with the non-spatial speech, 3-D audio frequency, and the 3-D audio pulse cues in both the stationary and the moving conditions. This finding is likely due to the noisy task environment as well as the aforementioned HRTF issue. Because global mental workload for the non-spatial speech cue was lower than the 3-D audio frequency and the 3-D audio pulse cues in the stationary condition, this further confirms the HRTF issue. The hypothesis that mental workload would be higher in the moving condition than for the stationary condition was partially supported. This proved to be the case only with the non-spatial speech, the tactile intensity, and the tactile pulse cues. However, both the 3-D audio cue types increased global mental workload despite whether participants were moving or stationary. The global mental workload scores of this investigation revealed a dissociation between subjective workload and performance. The theory of dissociation states that manipulating parameters of a single task will generally influence performance to a greater degree than subjective workload (Wickens & Yeh, 1983). The 3-D audio frequency and 3-D audio pulse cues had significantly higher performance in the stationary conditions than in the moving conditions. However, there were no significant differences in global mental workload between the stationary and moving conditions for those cues. The increased difficulty of engaging targets due to the addition of mobility resulted in a more drastic effect on performance than on subjective workload.

A closer examination of the raw mental workload subscales also revealed the advantages of the tactile intensity and tactile pulse cues. The tactile intensity and tactile pulse cues reduced mental demand over three auditory cue types. With regard to the temporal demand, the tactile pulse cue yielded lower scores than the three auditory cue types. The tactile intensity cue reduced temporal demand lower than the 3-D audio frequency and the 3-D audio pulse cues. These findings are mostly consistent with performance. Subjective ratings of raw performance scores revealed that when stationary, participants felt they performed better with the tactile intensity cue than with the 3-D audio frequency and the 3-D audio pulse cues. They felt that they performed better with the tactile pulse cue than all of the audio cue types. Furthermore, participants felt that they performed better with then non-spatial speech cue than with the 3-D audio frequency and 3-D audio pulse cues. This finding sheds light on participant preference. Although there were no differences actual performance among the auditory cues, because participants felt they performed better with the non-spatial speech cue, this is likely the reason that it was preferred over the 3-D audio frequency and 3-D audio pulse cues. For the moving condition, as expected, the tactile intensity cue yielded better subjective performance scores than the non-spatial speech, 3-D audio frequency, and 3-D audio pulse cues. However, it is unclear why participants felt they performed better with the tactile intensity cue than with the tactile pulse cue. Subjective performance was better for the 3-D audio pulse and tactile pulse cues when stationary than when moving. It would seem that this would be the case for each of the cue types. With regard to effort, participants felt that less effort was required for the tactile intensity and tactile pulse cues than for the 3-D audio pulse cue. Based the localization difficulty associated with the 3-D audio cues, it would seem that more effort would be required for the 3-D audio frequency cue than the tactile intensity and tactile pulse cues as well. When stationary, consistent with performance scores, the tactile intensity and tactile pulse cues yielded lower frustration than the three auditory cue types. When moving, the tactile intensity and tactile pulse cues resulted in lower frustration than the non-spatial speech and 3-D audio frequency cues. Again, it would seem that the 3-D audio pulse cue would have equivalent frustration levels with the 3-D audio frequency cue based on the difficulty participant had with localization. Only the tactile pulse cue had lower frustration while moving than while stationary. Generally, the tactile intensity and tactile pulse cues reduced workload with each of the respective raw subscales. The stationary status also reduced workload with each of the respective raw subscales.

There were no significant findings with regard to navigation errors in this experiment. So the secondary navigation task was not an indication of situation awareness. However, if the primary performance of the target engagement task is considered, situation awareness was higher with the two tactile cue types because more targets were detected and engaged more quickly than with the three auditory cue types. Because the performance of the two tactile cue types and the three auditory cue types was mostly consistent, respectively, participant preference was used to determine that the tactile pulse and the non-spatial speech cues would be utilized in Experiment 2.

For the subsidiary hypotheses of Experiment 2, it was hypothesized that the cued conditions would have more hits, less misses, and shorter response time than the no cueing condition. A decrease in hits and an increase in false alarms, and response time with the tactile cues was expected during the moving condition versus the stationary condition because cues are more likely to be missed while in motion. A decrease in hits and an increase in response time with the visual cues was expected in the moving condition versus the stationary condition because users will have to attend to navigating the environment. An increase in the number of navigation errors was expected in the visual cueing condition because participants will have to attend to the visual display for cues to locate targets when cues are provided. Mental workload was expected to be highest in the moving condition with no cues, and it was expected to be the lowest in the stationary condition, with cues provided. Because it is not known if the tactile cue without distance information will provide any advantages over the tactile cue with the distance information, no hypothesis was made about differences in performance and the mental workload between the tactile cue with azimuth information only and the tactile pulse cue. These hypotheses are formally given in Table 4.

Table 4

Experiment 2 Subsidiary Hypotheses

Measure	Hypotheses
Hit Rate (%)	No Cueing < Cueing Stationary > Moving (Tactile) Stationary > Moving (Visual)
False Alarm Rate (%)	Stationary < Moving (Tactile)
Response Time (ms)	No Cueing > Cueing Auditory, Tactile < Visual Stationary < Moving (Tactile)
Navigation Errors	Auditory, Tactile < Visual
Mental Workload	No Cueing > Cueing Stationary < Moving

CHAPTER FOUR
EXPERIMENT 2

The objective of this laboratory experiment was to investigate the effects of auditory, tactile and visual cueing on the perceived distance and azimuth location of enemy targets in a simulated environment. This investigation examined these cues in both stationary and moving conditions. Cues provided information about the location and distance of an enemy target firing a weapon in a 360-degree field. Participants were asked to locate and engage targets with the aid of the cues. The findings of this investigation will indicate how performance with the various cueing modalities compare.

Experimental Methods

Experimental Participants

A power analysis was conducted using GPower 3.1 software was used to determine that seventeen participants were needed for this study. Sixteen male infantry Soldiers from the 3rd Infantry Division of Ft. Stewart, GA, the 82nd Airborne Division of Ft. Bragg, NC, and the 1st Infantry Division of Ft. Riley, KS volunteered participate in this investigation. The age of participants ranged from 19 – 29 years of age (*M* = 22.1 years, *SD* = 3.0). One of the participants had combat experience.

Experimental Apparatus

The apparatus used in this study were the same as in Experiment 1.

Experimental Design

The present investigation was a 5 x 2 within participant design in which cue condition and status represented the within-participants factors. The cue conditions include a no cueing control, a non-spatial speech condition, a visual condition, a tactile direction only condition (i.e., no encoded distance information), and a tactile pulse cue condition. The auditory and tactile cue types were determined by experiment 1. The tactile direction only cue was included to determine if the distance information encoded in the tactile pulse cue provides any advantage over a tactile cue that only provides azimuth information. The status levels are represented by stationary and moving. In the stationary condition participants completed the target acquisition task while standing, and in the moving condition participants completed the target acquisition task while navigating a virtual environment. Each participant completed a block in each of the five conditions twice, once while stationary and once while navigating the virtual environment. The conditions were counterbalanced across participants using the latin square design. Eight dependent variables were measured: hits, misses due to inaccurate target engagement, misses due to targets not being detected, false alarms, response time to accurate target engagement, navigation errors, and mental workload.

Experimental Procedures

When participants arrived, they received a brief overview of the study and administered the informed consent form (see Appendix F). They were then asked to complete a demographics survey to obtain pertinent information about them. The participants then received a vision screening and a hearing screening. Before the experimental runs begin, participants were trained on each of the cue modalities to ensure that they comprehend the localization and distance information that they provide. They were also shown an example of the enemy target. Since there were no significant differences in the three auditory cue types and the two tactile cue types in Experiment 1, the non-spatial speech and the tactile pulse conditions were selected for this investigation because they were preferred by participants. The tactile cue with only azimuth information was a single 900 ms vibration with a frequency of 250 Hz and a gain of 255 (113.96 dB). The visual cue condition will be an icon that has twelve clock positions to indicate the azimuth location and distance in meters. Participants will then be trained on the omni-directional treadmill to ensure that they can maneuver safely. The will be required to walk for a minimum of five minutes. Extra time will be provided if needed. Participants were then asked to engage targets while navigating a path using a map while received each of the cue types to familiarize them with the task.

During each experimental run, forty eight enemy targets would appear on the screen at random intervals and fire a weapon. Participants were asked to engage those enemy targets as quickly as possible by firing a mock weapon. Enemy targets appeared for 5 seconds in the stationary scenarios and 6 seconds in the moving scenarios. The additional second provided for target exposures in the moving scenarios was due to the difficulty associated with engaging targets located in between buildings in the scenarios. A slight reduction in the speed of the omni-directional treadmill’s responsiveness when a user side steps or walk backwards made it more difficult to engage targets within 5 seconds. In the stationary condition, participants were be allowed to stand at the centermost point of the omni-directional treadmill and allowed to turn their bodies 360 degrees from the specified 12 o’clock position to engage targets. In the moving condition, participants were asked to engage targets while navigating a map of a Middle Eastern urban environment. Each of the moving blocks of the study employed a unique path. Each path was approximately 890 meters (.553 miles). If participants got off the navigation path, the error was counted as a navigation error and the experimenter directed them back to the specified path. Background noise was provided during all stationary conditions of the study. This background noise was a recording of the noise generated by the omni-directional treadmill for consistency with the moving conditions. Background noise was play at approximately 80 dB. Participants completed the NASA-TLX workload assessment after each block. Upon completion of the study, participants were asked to identify their preferred cue modality and were allowed to make open-ended comments about their experience with the various cue modalities.

Results

Separate repeated measures analyses of variance (ANOVA) were conducted on each of the dependent variables ($\alpha = 0.05$). Post hoc tests were performed using the Bonferroni method. Effect sizes are reported as Cohen's D.

Hits

A repeated measures ANOVA revealed a significant interaction between cue condition and status on the percentage of targets hit, Wilks' Lambda = .251, F (4, 11) = 8.167, $p = .003$, $n_p^2 = .748$ (see Figure 25). An analysis of simple effects revealed that in the stationary condition, the percentage of targets hit was significantly higher with the tactile direction only cue than with the no cueing control ($p < .001$, $d = 2.60$) and the non-spatial speech cue ($p < .001$, $d = 1.53$). The percentage of targets hit was significantly higher with the tactile pulse than with the no cueing control ($p < .001$, $d = 2.01$) and the non-spatial speech cue ($p = .006$, $d = 1.00$). The visual cue also resulted in a higher percentage of hits than the no cueing control ($p < .001$, $d =$

2.33) and the non-spatial speech cue (*p* = .001, *d* = 1.24). The percentage of targets hit was also significantly higher with the non-spatial speech cue than with no cueing control (*p* < .001, *d* = 1.21). For the moving condition, the percentage of targets hit was significantly higher with the tactile direction only cue than with the no cueing control (*p* < .001, *d* = 1.17), non-spatial speech (*p* = .001, *d* = 0.99), and the visual cues (*p* = .003, *d* = 1.21). The percentage of targets hit was significantly higher with the tactile pulse cue than with the no cueing control (*p* < .001, *d* = 1.83), non-spatial speech (*p* < .001, *d* = 1.59), and the visual cues (*p* < .001, *d* = 2.24). The analysis of simple effects also indicated that the percentage of targets hit was significantly higher in the stationary condition than in the moving condition, with the tactile direction only (*p* < .001, *d* = 1.57), the tactile pulse (*p* = .014, *d* = 1.04), the non-spatial-speech (*p* < .001, *d* = 1.44), and the visual cues (*p* < .001, *d* = 3.65).

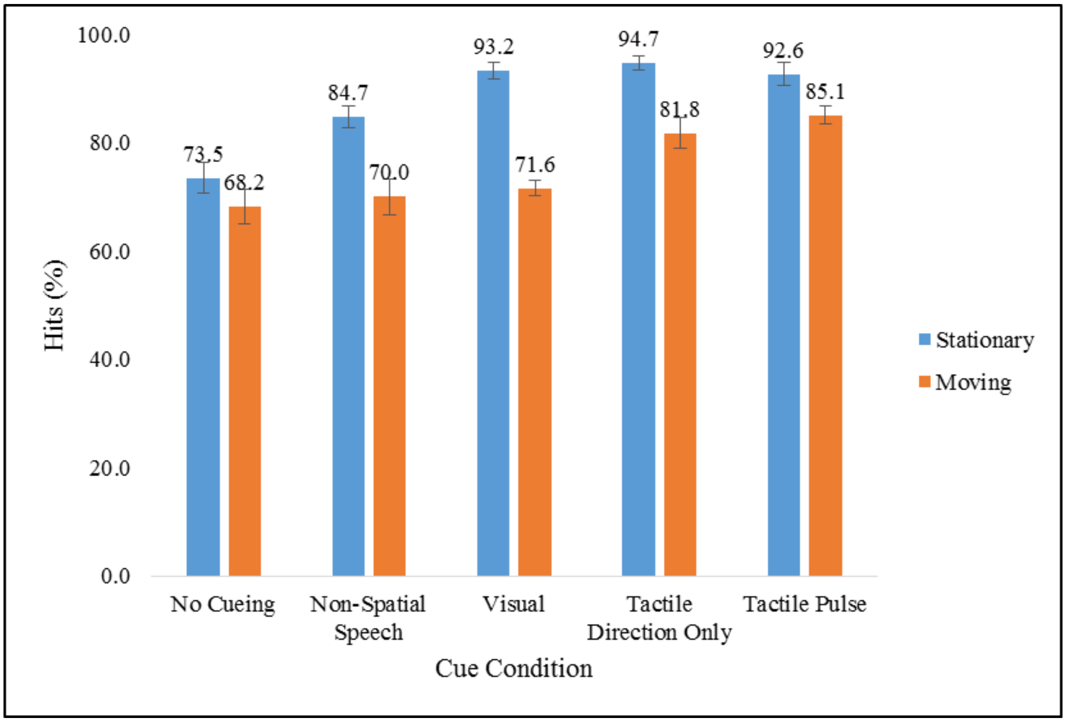


Figure 25. Experiment 2 Cue condition X status interaction on the percentage of targets hit.

Misses

Inaccurate Engagement

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .523, F (1, 14) = 12.745, p = .003, n_p^2 = .477, on the percentage of targets missed because they were not accurately engaged. A greater percentage of targets were missed in the moving condition than in the stationary condition (see Figure 26).

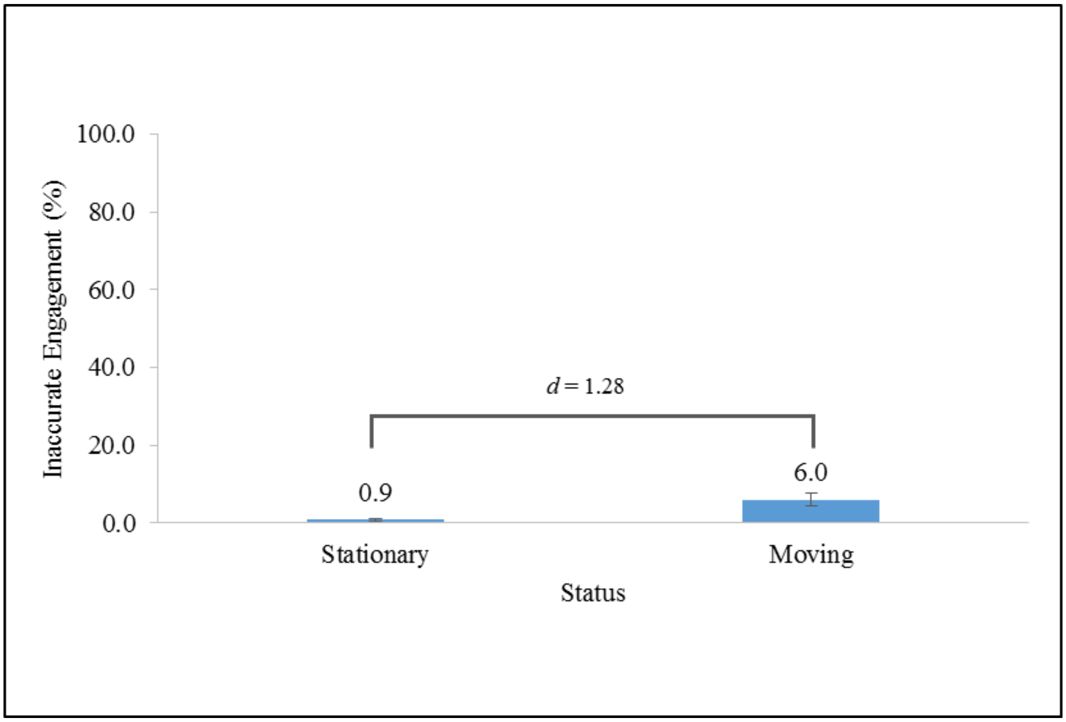


Figure 26. Experiment 2 Main effects of status on the percentage of inaccurate engagement.

Targets Not Detected

A repeated measures ANOVA revealed a significant interaction between cue condition and status on the percentage of targets missed because they were not detected, Wilks' Lambda = .305, F (4, 11) = 6.268, p = .007, n_p^2 = .695 (see Figure 27). An analysis of simple effects revealed that in the stationary condition, the percentage of targets not detected was significantly lower with the tactile direction only cue than with the no cueing control ($p < .001$, $d = 2.43$) and the non-spatial speech cue ($p < .001$, $d = 1.37$). The percentage of targets not detected was significantly lower with the tactile pulse cue than with the no cueing control ($p < .001$, $d = 1.86$) and the non-spatial speech cue ($p < .001$, $d = 0.87$). The percentage of targets not detected was significantly lower with the visual cue than with the no cueing control ($p < .001$, $d = 2.13$) and the non-spatial speech cue ($p = .002$, $d = 1.06$). The percentage of targets not detected was also significantly lower with the non-spatial speech cue than with no cueing control ($p < .001$, $d = 1.13$). In the moving condition, the percentage of targets not detected was significantly lower with the tactile direction only cue than with the no cueing control ($p < .001$, $d = 1.35$), non-spatial speech ($p < .001$, $d = 1.17$), and the visual cues ($p = .002$, $d = 1.20$). The percentage of targets not detected was significantly lower with the tactile pulse cue than with the no cueing control ($p < .001$, $d = 1.99$), non-spatial speech ($p < .001$, $d = 1.78$), and the visual cues ($p < .001$, $d = 1.98$). The analysis of simple effects also indicated that the percentage of targets not detected was significantly higher in the moving condition than in the stationary condition, with the tactile direction only ($p = .005$, $d = 0.98$), the non-spatial-speech ($p < .001$, $d = 1.01$), and the visual cues ($p < .001$, $d = 2.21$).

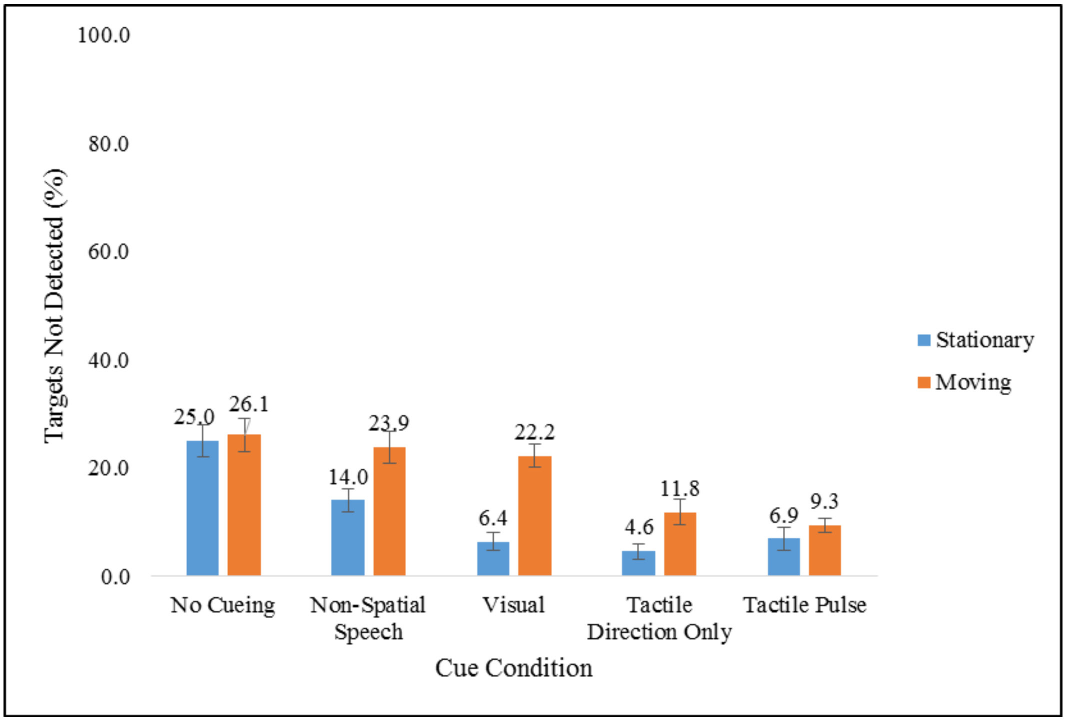


Figure 27. Experiment 2 Cue condition X status interaction on the percentage of targets not detected.

False Alarms

There were no false alarms in this experiment.

Response Time

A repeated measures ANOVA revealed a significant main effect of cue condition Wilks' Lambda = .114, F (4, 11) = 21.385, $p < .001$, $n_p^2 = .886$, on response time (see Figure 28). Post hoc comparisons indicated that the tactile direction only cue yielded a significantly shorter response time than the no cueing control, the non-spatial speech, and the visual cues (all $p < .001$). The tactile pulse cue yielded a significantly shorter response time than the no cueing control ($p = .001$), the non-spatial speech ($p < .001$), and the visual cues ($p < .001$). The analysis also revealed a significant main effect of status, Wilks' Lambda = .115, F (1, 14) = 107.784, $p <$ .001, $n_p^2 = .885$, on response time. Response time was significantly longer in the moving conditions than in the stationary conditions (see Figure 29).

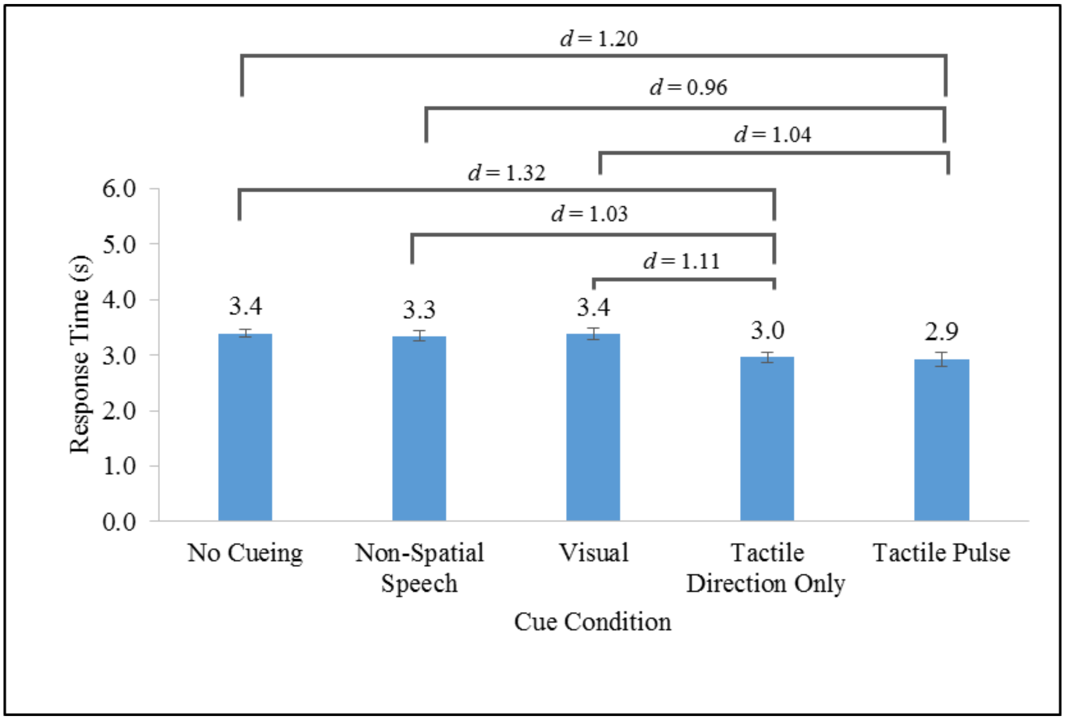


Figure 28. Experiment 2 Main effect of cue condition on response time.

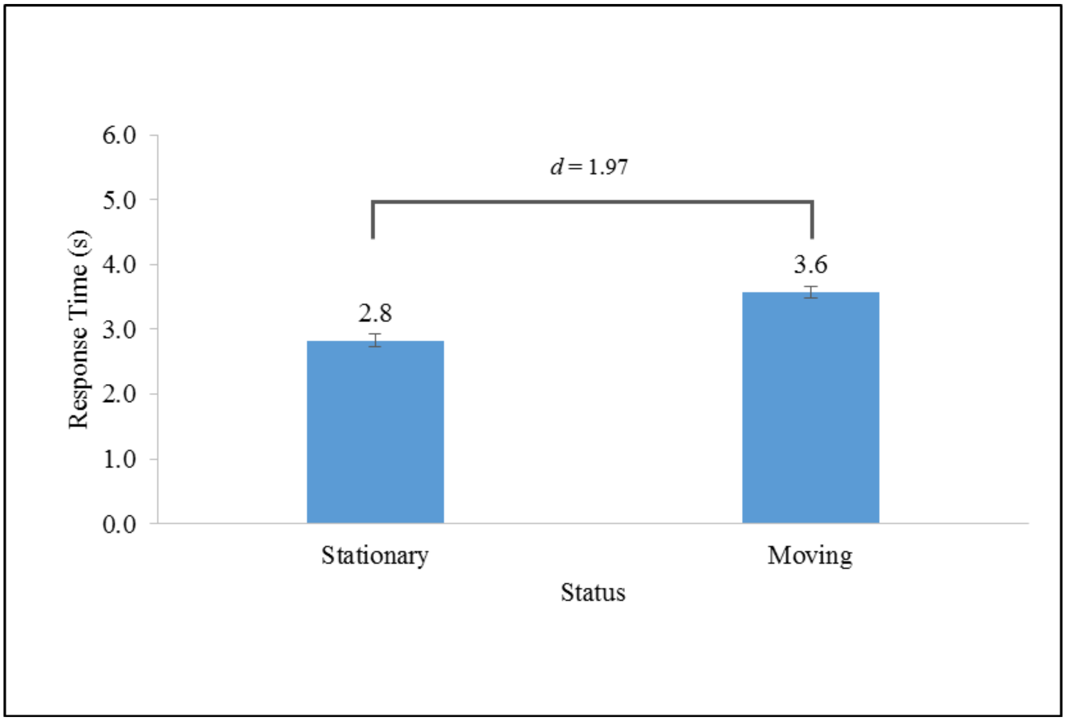


Figure 29. Experiment 2 Main effect of status on response time.

Navigation Errors

A repeated measures ANOVA did not reveal any significant effects of cue condition on the number of navigation errors.

Mental Workload

In addition to global mental workload scores, raw workload scores for each of the six subscales were analyzed.

Global Workload

A repeated measures ANOVA revealed a significant interaction between cue condition and status on global mental workload, Wilks' Lambda = .301, *F* (4, 11) = 6.398, *p* = .007, n_p^2 =

.699 (see Figure 30). An analysis of simple effects revealed that in the stationary condition, global mental workload was significantly lower with the tactile direction only cue than with the no cueing control (*p* = .003, *d* = 1.23) and the non-spatial speech cue (*p* = .026, *d* = 0.79). Global mental workload was significantly lower with the tactile pulse cue than with the no cueing control (*p* = .002, *d* = 1.23) and the non-spatial speech cue (*p* = .013, *d* = 0.84). The visual cue yielded significantly lower workload than the no cueing control (*p* = .002, *d* = 0.87). In the moving condition, global mental workload was significantly lower with the tactile direction only cue than with the non-spatial speech cue (*p* = .047, *d* = 0.66). Mental workload was significantly lower with the tactile pulse cue than with the non-spatial speech (*p* = .030, *d* = 0.72) and visual cues (*p* = .020, *d* = 0.72). The analysis of simple effects also indicated that global mental workload was significantly higher in the moving condition than in the stationary condition, with the tactile direction only (*p* = .007, *d* = 0.63), the tactile pulse (*p* = .001, *d* = 0.69), the non-spatial speech (*p* = .005, *d* = 0.66), and the visual cues (*p* < .001, *d* = 1.20).

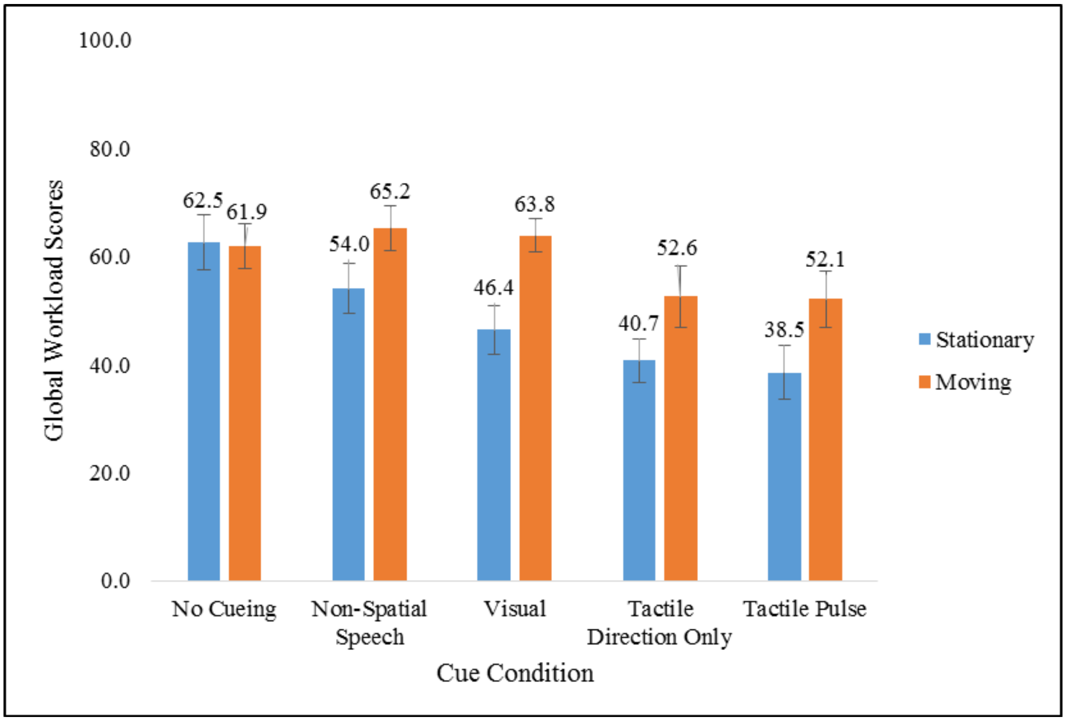


Figure 30. Experiment 2 Cue condition X status interaction on global mental workload scores.

Raw Subscale Workload

A repeated measures ANOVA revealed a significant main effect of cue condition, Wilks' Lambda = .441, *F* (4, 11) = 3.481, *p* = .045, n_p^2 = .673, on mental demand (see Figure 31). Post hoc comparisons indicated that the no cueing control yielded significantly higher mental demand scores than the visual (*p* = .021), the tactile direction only (*p* = .045), and the tactile pulse cues (*p* = .033). The analysis also revealed a significant main effect of status, Wilks' Lambda = .584, *F* (1, 14) = 9.980, *p* = .007, n_p^2 = .416, on mental demand. Mental demand scores were significantly lower in the stationary conditions than in the moving conditions (see Figure 32).

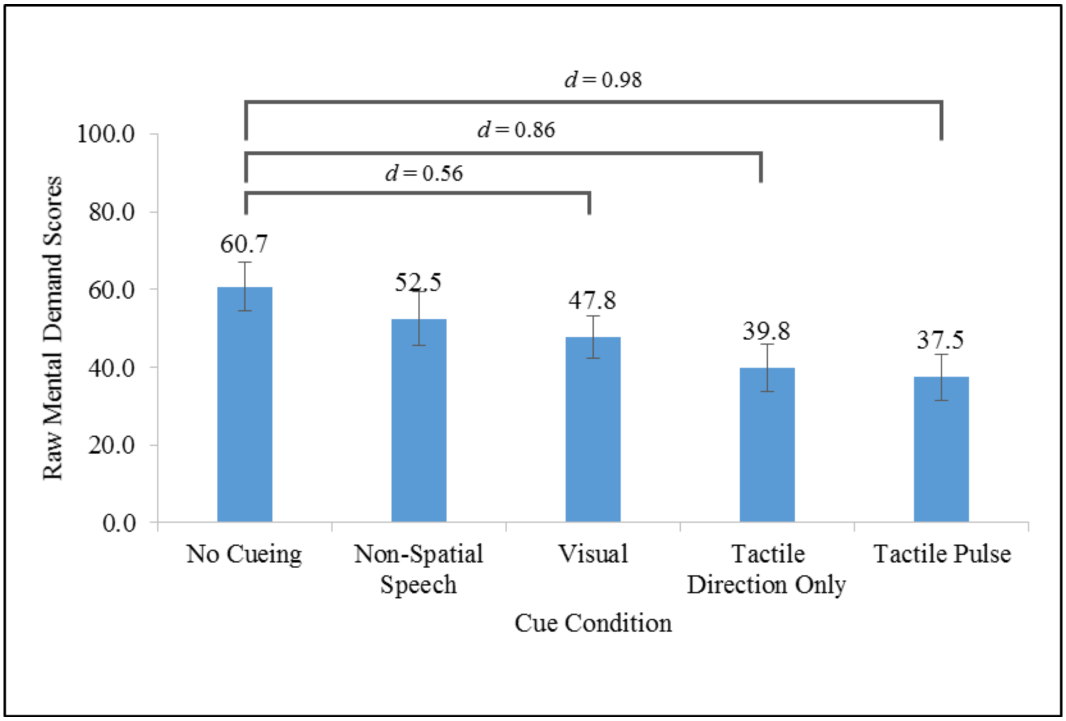


Figure 31. Experiment 2 Main effect of cue condition on raw mental demand scores.

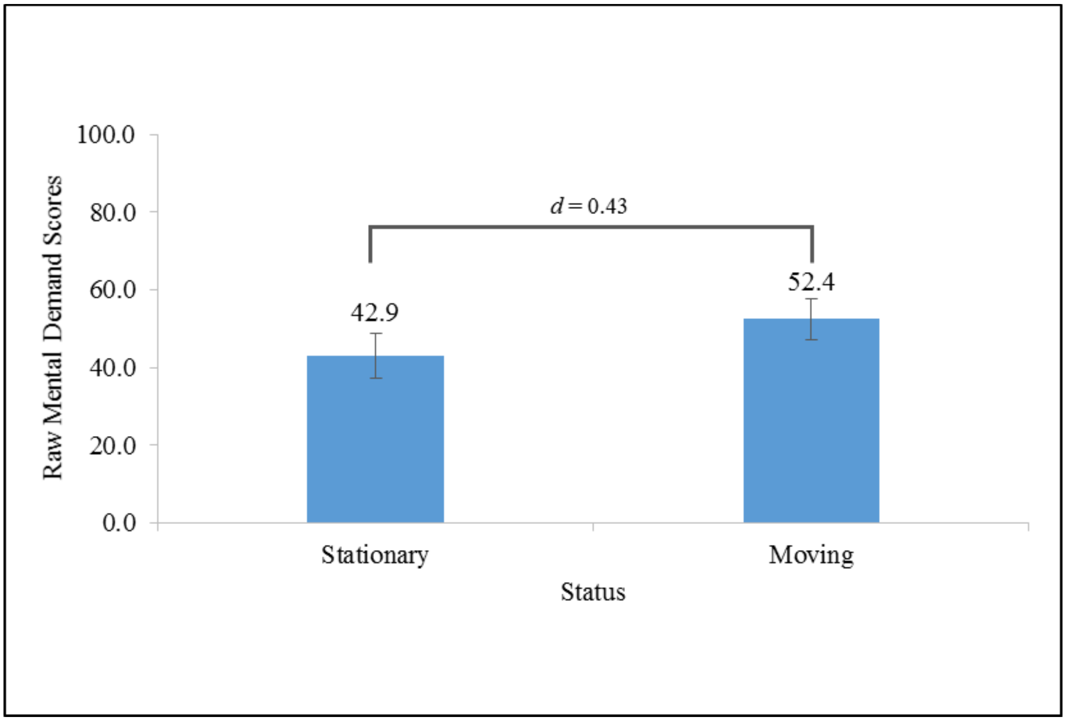


Figure 32. Experiment 2 Main effect of status on raw mental demand scores.

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .321, *F* (1, 14) = 29.657, $p < .001$, $n_p^2 = .679$, on physical demand (see Figure 33). Physical demand scores were significantly lower in the stationary conditions than in the moving conditions.

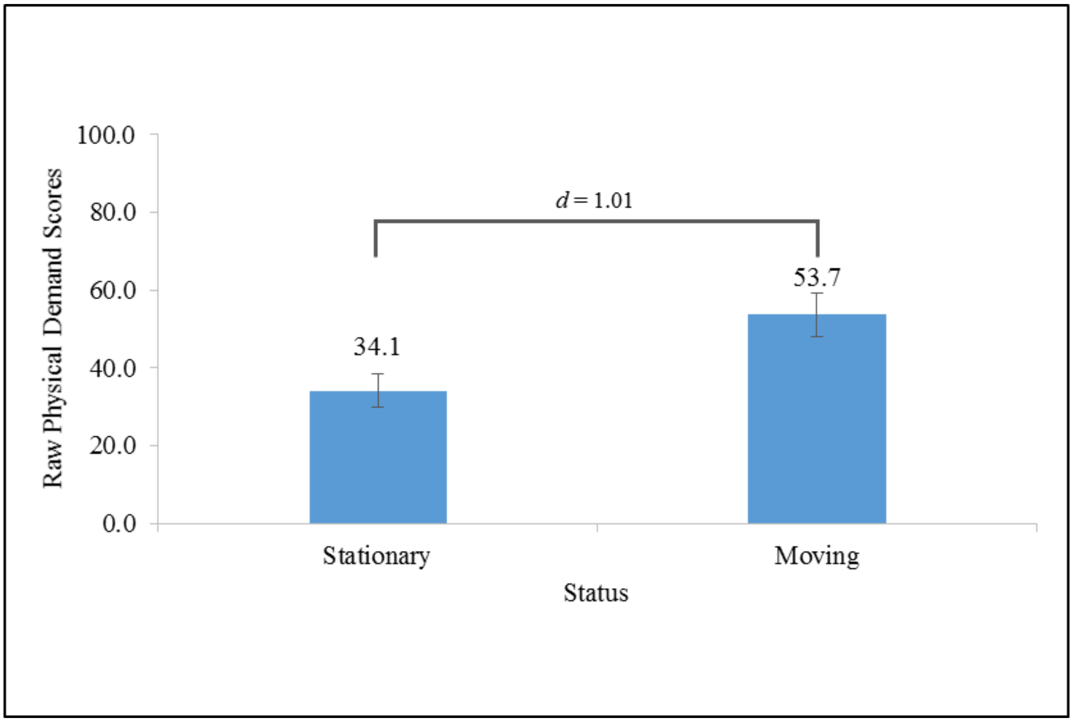


Figure 33. Experiment 2 Main effect of status on raw physical demand scores.

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .659, *F* (1, 14) = 7.248, $p = .018$, $n_p^2 = .341$, on temporal demand (see Figure 34). Temporal demand scores were significantly lower in the stationary conditions than in the moving conditions.

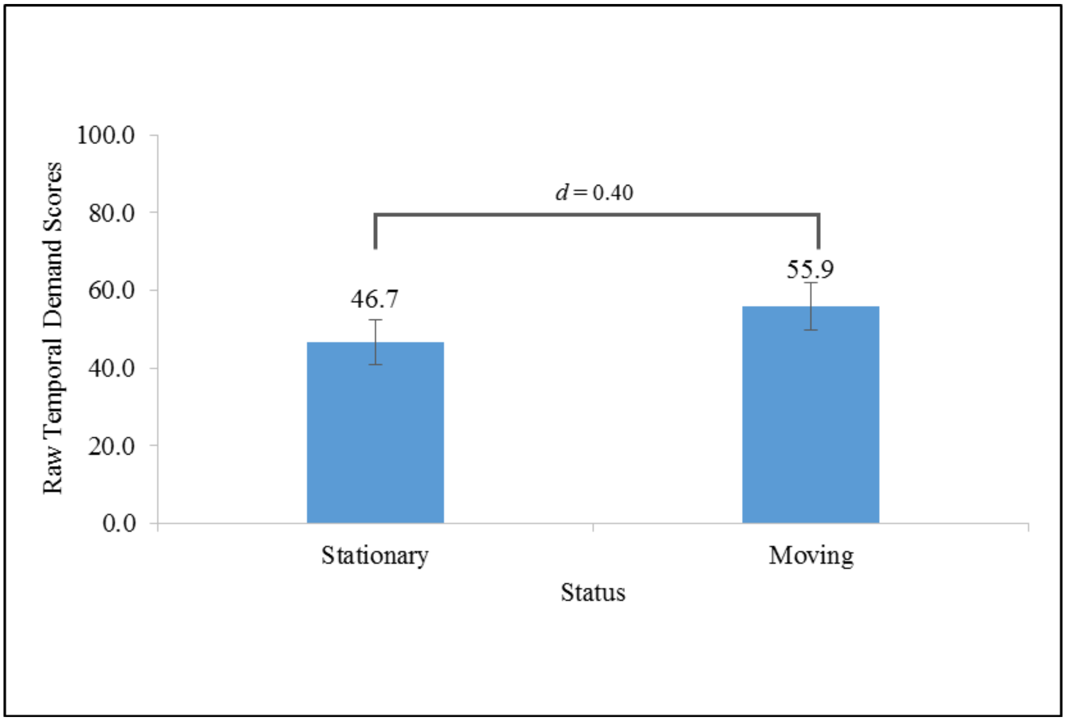


Figure 34. Experiment 2 Main effect of status on raw temporal demand scores.

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .532, F (1, 14) = 12.325, p = .003, n_p^2 = .468, on effort (see Figure 35). Effort scores were significantly lower in the stationary conditions than in the moving conditions.

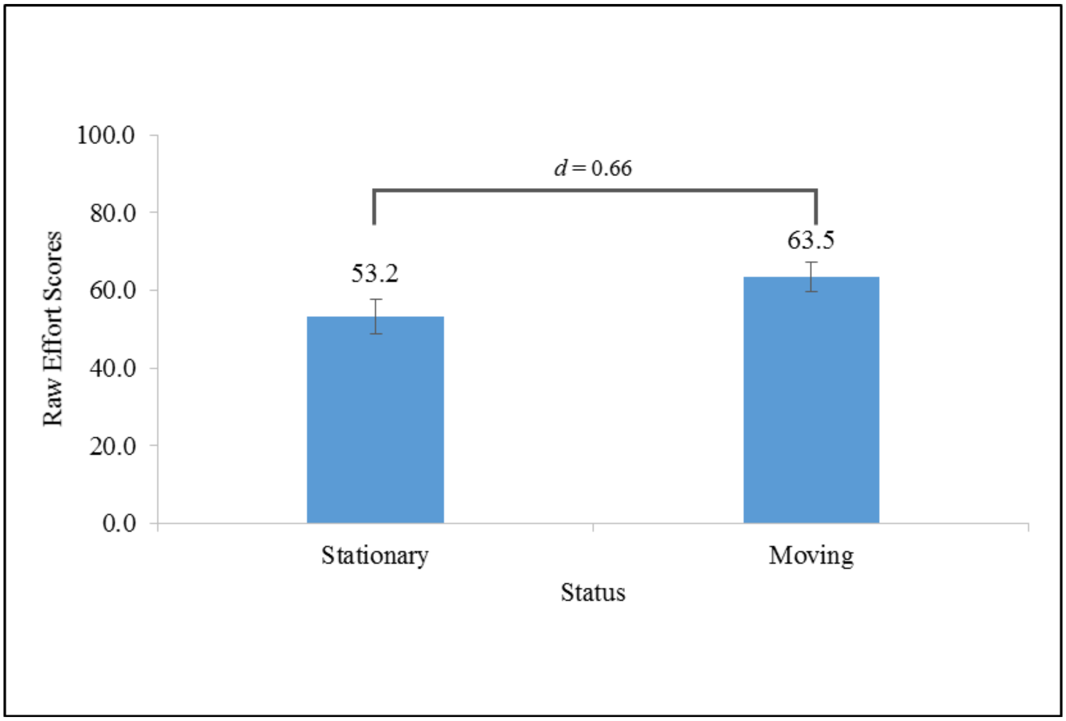


Figure 35. Experiment 2 Main effect of status on raw effort scores.

A repeated measures ANOVA revealed a significant interaction between cue condition and status on frustration, Wilks' Lambda = .389, F (4, 11) = 4.327, p = .024, n_p^2 = .611 (see Figure 36). An analysis of simple effects revealed that in the stationary condition, frustration was significantly higher with the no cueing control than with the non-spatial speech (p = .008, d = 0.42), the visual (p < .001, d = 1.18), the tactile direction only (p < .001, d = 1.38), and the tactile pulse cues (p < .001, d = 1.28). Frustration was significantly higher with the non-spatial speech cue than with the visual (p = .002, d = 0.82), the tactile direction only (p = .003, d = 1.02), and the tactile pulse cues (p = .005, d = 0.93). For the moving condition, frustration was significantly lower with the tactile direction only cue than with the non-spatial speech cue (p = .013, d = 0.70). Frustration was significantly lower with the tactile pulse cues than with the non-spatial speech (p = .020, d = 0.75) and the visual cues (p = .042, d = 0.55). The analysis of simple effects also indicated that performance was significantly higher in the moving condition than in the stationary condition with the visual (*p* = .005, *d* = 1.01), tactile direction only (*p* = .021, *d* = 0.58), and the tactile pulse cues (*p* = .046, *d* = 0.48). There were no other findings among the raw mental workload subscales.

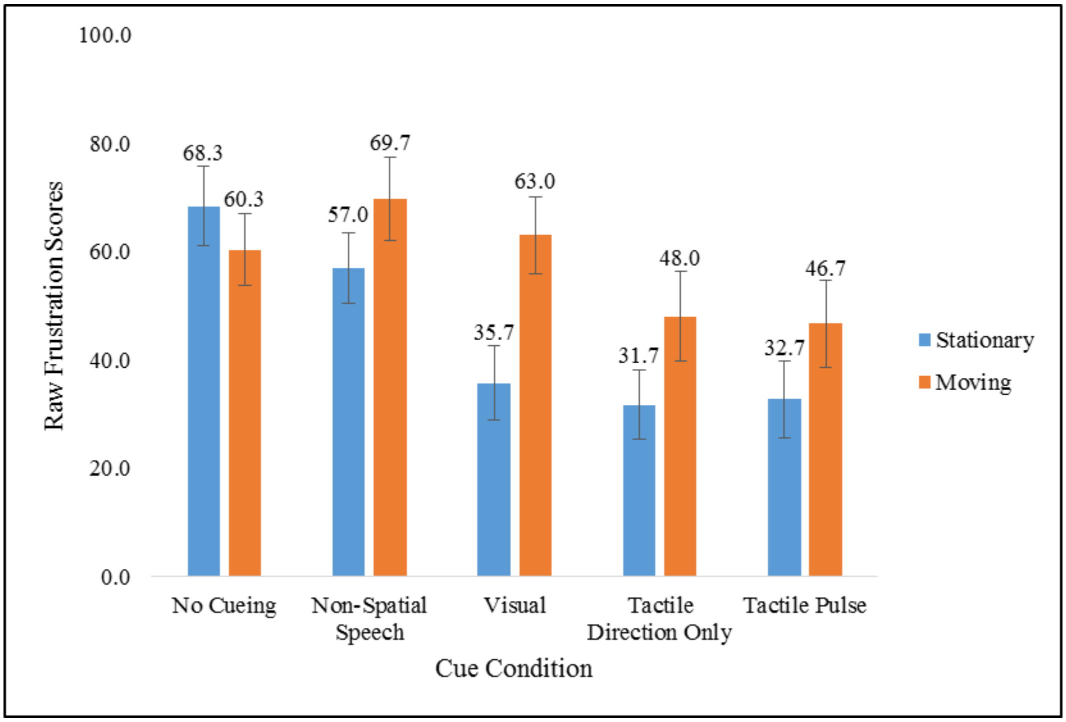


Figure 36. Experiment 2 Cue condition X status interaction on raw frustration scores.

Cue Preference

With regard to cue preference, 100% of the participants preferred the tactile modality.

Discussion

In Experiment 2, there was a higher percentage of hits with the tactile direction only, tactile pulse, and visual cues than with the no cueing control and the non-spatial speech in the stationary condition. The non-spatial speech cue also yielded more hits than the no cueing control in the stationary condition. The cues clearly aided participants in engaging targets in the stationary conditions. However, in the moving condition, the percentage of hits with the tactile direction only and the tactile pulse cues was higher than the no cueing control, the non-spatial speech cues, and the visual cues. In other words the hit performance of the non-spatial speech and visual cues dropped to levels equivalent to not having a cueing aid at all when moving. These findings partially support the hypothesis that the no cueing control would have less hits than the cueing conditions. The analysis revealed that the percentage of hits were higher in the stationary condition than in the moving condition with the tactile direction only, the tactile pulse, the non-spatial speech, and the visual cues. This supports the hypotheses that states that percentage of targets hit would be higher in the stationary condition than in the moving condition for the tactile and the visual cues. With regard to misses in this investigation, more misses due to inaccuracy occurred in the moving condition than in the stationary condition due to the conspicuity of the targets. Targets missed due to inaccurate engagement was less than 1% in the stationary conditions and around 6% in the moving conditions, this again indicates that participants had good aiming skills. As in Experiment 1, the majority of misses occurred because targets were not detected. Of those misses due to targets not being detected, the tactile direction only, the tactile pulse, the non-spatial speech, and the visual cues resulted in a lower percentage than the no cueing control in the stationary condition. In the moving condition, the tactile direction only and the tactile pulse cues had a lower percentage of targets not detected than the no cueing control, the non-spatial speech, and the visual cues.   Therefore when participants were moving, the percentage of targets missed due to targets not being detected with the non-spatial speech and visual cues increased to levels statistically equivalent to the no cueing control. A lower percentage of targets were not detected in the stationary condition than in the moving condition with the tactile direction only, the non-spatial speech, and the visual cues. The lack of a significant increase in targets not detected in the moving conditions as opposed to the stationary conditions is an indication that the encoded distance information may have aided participants in engaging targets. The tactile direction only cue did not have encoded distance information, and this resulted in a significant increase in targets not detected in the moving conditions as opposed to the stationary conditions. Because participants relied on the cues, the findings of this investigation yielded no false alarms.

For response time, the tactile direction only and the tactile pulse cues yielded faster target engagement than with the no cueing control, the non-spatial speech, and the visual cues. It was hypothesized that the no cueing control would have a longer response time than with cues. This hypothesis is partially supported in that only the tactile direction only and the tactile pulse cues yielded significantly lower response times. The lack of findings with the non-spatial speech cue is likely related to the competing noisy environment and the time needed to translate the linguistics of the cue (Loomis et al., 2002). The hypothesis stating that the non-spatial speech and the tactile cues would have shorter response times than the visual cue was only partially supported. There was no statistical significance between the non-spatial speech and visual cues. Since the stationary condition had a significantly lower response time than the moving condition, this supports the hypothesis that response time would be shorter in the stationary condition than the moving condition with the tactile cues. The reduced conspicuity of targets in the moving conditions is the reason for this finding.

Analysis of the global mental workload scores indicate that participants had lower scores with the tactile direction only and tactile pulse cues than with the no cueing control and the non-spatial speech cues in both the stationary and moving conditions. Consistent with the findings of Experiment 1, it was expected that the two tactile cue types would result in less workload. The no cueing control resulted in statistically equivalent workload to the non-spatial speech cue because of the linguistic translation issue and the competing noisy environment. The visual cue yielded lower global mental workload scores than the no cueing control in the stationary conditions only. The tactile pulse cue yielded lower global mental workload than the visual cue in the moving conditions. Therefore, the hypothesis that states that mental workload would be lower when cues were provided than with no cueing is partially supported. For the cued conditions, global mental workload was higher when moving than when stationary. The hypothesis that mental workload would be higher in the moving condition than in the stationary condition was supported.

A closer examination of the raw mental workload subscales revealed that the no cueing control resulted in higher mental demand than the visual, tactile direction only, and the tactile pulse cues. Cues were expected to reduce mental demand. With regard to the non-spatial speech cue, the translation of linguistics may be the reason that the no cueing control did not have higher mental demand. In the stationary condition, frustration was higher with the no cueing control that than the cued conditions. Frustration was higher with the non-spatial speech cue than with the visual, tactile direction only, and the tactile pulse cues which provided a more direct indication of target locations. In the moving condition, frustration was lower with the tactile direction only cue than with the non-spatial speech cue. The tactile pulse cue yielded lower frustration levels than that visual and non-spatial speech cues. Again the translation of linguistics may be the reason for higher frustration levels with the non-spatial speech cue. The frustration associated with the visual cue may be due to participants also having to utilize the visual channel to also navigate a map and to look for targets. Frustration with the visual, tactile direction only, and the tactile pulse cues was lower when stationary than when moving because these cues provided a more direct indication of target locations. The no cueing control did not provide any target location information and the non-spatial speech required the translation of linguistics. The mental demand, physical demand, temporal demand, and effort subscales resulted in lower scores while stationary than while moving.

There were no significant findings with regard to navigation errors in this experiment. The participants unanimously preferred the tactile modality (i.e., tactile direction only and tactile pulse) over the non-spatial speech and visual cues.

For the subsidiary hypotheses of Experiment 3, it was hypothesized that the multimodal cues would have more hits and shorter response time than the unimodal cues in Experiment 2. Because of redundancy, it was expected that there would be a lower number of false alarms with the multimodal cues than with the unimodal cues in this experiment. No hypothesis was made about which specific cue pairings would yield the best performance. Performance was expected to be degraded in conditions in which participants were moving. The Auditory+Tactile and the Auditory+Tactile+Visual conditions were expected to have less than or an equivalent number of navigation errors as the Auditory+Visual and the Tactile+Visual because the cues would reduce the time needed to view the visual cues. Mental workload was expected to be highest in the moving condition than in the stationary condition. These hypotheses are formally given in Table 5.

Table 5

Experiment 3 Subsidiary Hypotheses

Measure	Hypotheses
Hit Rate (%)	Multimodal >= Unimodal
False Alarms (%)	Multimodal < Unimodal
Response Time (ms)	Multimodal < Visual
Navigation Errors	Auditory+Tactile, Auditory+Tactile+Visual <= Auditory+Visual, Tactile + Visual
Mental Workload	Stationary < Moving

CHAPTER FIVE
EXPERIMENT 3

The objective of this laboratory experiment was to investigate the effects of auditory + tactile, auditory + visual, tactile + visual, and auditory + tactile + visual cueing on the perceived distance and azimuth location of enemy targets in a simulated environment. This investigation examined the cue pairings in both stationary and moving conditions. Cues provided information about the location and distance of an enemy target firing a weapon in a 360-degree field. Participants were asked to locate and engage targets with the aid of the cues. The findings of this investigation will indicate how performance with the various cueing modalities compare. It will also indicate the effects of walking on performance.

Experimental Methods

Experimental Participants

A power analysis was conducted using GPower 3.1 software was used to determine that fifteen participants were needed for this study. Ten Soldiers from the 1st Infantry Division of Ft. Riley, KS and the 1st Calvary Division of Ft. Hood, TX volunteered to participate in this investigation. The lack of needed participants to meet the findings of the power analysis was due to an equipment failure. The age of participants ranged from 20 - 26 years of age (*M* = 21.7 years, *SD* = 1.9). One of the participants had combat experience.

Experimental Apparatus

The apparatus used in this study was the same as in Experiment 1 and 2.

Experimental Design

The present investigation was a 4 x 2 within participant design in which cue condition and status represented the within-participant factors. The cue conditions included an auditory + tactile cue condition, an auditory + visual condition, a tactile + visual condition, and an auditory + tactile + visual cue condition. The status levels were represented by stationary and moving. Each participant completed a block in each of the four conditions twice, once while stationary and once while moving. The conditions were counterbalanced across participants using the latin square design. Eight dependent variables were measured: hits, misses due to inaccurate target engagement, misses due to targets not being detected, false alarms, response time to accurate target engagement, navigation errors, and mental workload.

Experimental Procedures

The procedures for this experiment were the same as for experiment 2. A copy of the informed consent has been provided in Appendix G. Combinations of the non-spatial speech, visual, and tactile pulse cues were employed.

Results

Separate repeated measures analyses of variance (ANOVA) were conducted on each of the dependent variables ($\alpha = 0.05$). Post hoc tests were performed using the Bonferroni method. Independent samples t-test were performed on the multimodal cues and the relevant unimodal cues of Experiment 2. Equal variance was not assumed. Effect sizes are reported as Cohen's D.

Hits

A repeated measures ANOVA revealed a significant interaction between cue condition and status on the percentage of targets hit, Wilks' Lambda = .291, F (3, 7) = 5.691, p = .027, n_p^2 = .709 (see Figure 37). An analysis of simple effects revealed that in the stationary condition, the percentage of targets hit was significantly higher with the non-spatial speech + tactile pulse + visual cue than with the non-spatial speech + visual cue (p = .024, d = 0.77). For the moving condition, the percentage of targets hit was significantly lower with the non-spatial speech + visual cue than with the tactile pulse + visual (p = .002, d = 1.28) and the non-spatial speech + tactile pulse + visual cues (p = .006, d = 1.20). The analysis of simple effects also indicated that the percentage of targets hit was significantly higher in the stationary condition than in the moving condition, with the non-spatial speech + tactile pulse (p = .004, d = 1.58), the non-spatial speech + visual (p < .001, d = 2.15), the tactile pulse + visual (p < .001, d = 1.88), and the non-spatial speech + tactile pulse + visual cues (p < .001, d = 2.09).

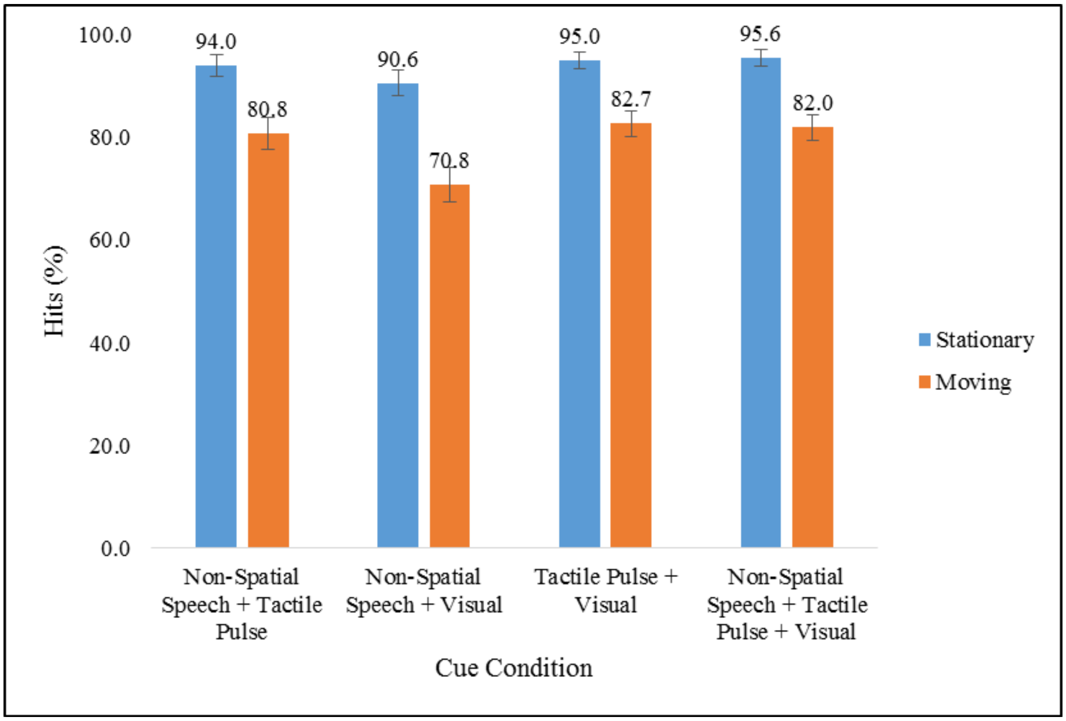


Figure 37. Experiment 3 Cue condition X status interaction on the percentage of targets hit.

Independent samples t-test were conducted to compare the percentage of targets hit for the multimodal cues in this experiment and the unimodal cues in Experiment 2. The analysis revealed that the percentage of targets hit was significantly higher for the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than for the unimodal non-spatial speech cue in the stationary conditions (see Table 6). The percentage of targets hits with the non-spatial speech + visual cue and the unimodal non-spatial speech cue was at the threshold of significance ($p = .05$). In the moving conditions, the percentage of targets hit was significantly higher for the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than for the unimodal non-spatial speech cue. Also, the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues resulted in a significantly higher percentage of hits than the unimodal visual cue (see Table 7).

Table 6

Experiment 3 Hits T-Tests for Unimodal versus Multimodal (Stationary)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	84.0	8.0	2.0	21.5	-3.39	.003*	1.35
NSS + TP	10	94.0	6.8	2.2				
NSS	16	84.0	8.0	2.0	19.6	-2.09	.050	0.84
NSS + V	10	90.6	7.8	2.5				
NSS	16	84.0	8.0	2.0	23.9	-4.53	.000*	1.78
NSS + TP + V	10	95.6	5.2	1.6				
TP	16	93.1	8.1	2.0	21.7	-1.02	.775	0.11
NSS + TP	10	94.0	6.8	2.2				
TP	16	93.1	8.1	2.0	23.9	-0.73	.474	0.29
TP + V	10	95.0	5.2	1.7				
TP	16	93.1	8.1	2.0	24.0	-0.97	.341	0.38
NSS + TP + V	10	95.6	5.2	1.6				
V	16	93.5	5.9	1.5	15.5	0.99	.337	0.42
NSS + V	10	90.6	7.8	2.5				
V	16	93.5	5.9	1.5	21.2	-0.69	.501	0.27
TP + V	10	95.0	5.2	1.7				
V	16	93.5	5.9	1.5	15.6	-0.97	.341	0.39
NSS + TP + V	10	95.6	5.2	1.6				

* Denotes ($p < .05$)

Table 7

Experiment 3 Hits T-Tests for Unimodal versus Multimodal (Moving)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	69.1	12.9	3.2	22.8	-2.60	.016*	1.03
NSS + TP	10	80.8	9.9	3.1				
NSS	16	69.1	12.9	3.2	22.0	-0.37	.713	0.15
NSS + V	10	70.8	10.6	3.4				
NSS	16	69.1	12.9	3.2	24.0	-3.16	.004*	1.24
NSS + TP + V	10	82.0	7.9	2.5				
TP	16	84.5	6.6	1.7	14.1	1.06	.309	0.45
NSS + TP	10	80.8	9.9	3.1				
TP	16	84.5	6.6	1.7	16.7	0.60	.555	0.25
TP + V	10	82.7	7.9	2.5				
TP	16	84.5	6.6	1.7	16.6	0.84	.412	0.35
NSS + TP + V	10	82.0	7.9	2.5				
V	16	71.8	5.7	1.4	12.3	0.27	.795	0.12
NSS + V	10	70.8	10.6	3.4				
V	16	71.8	5.7	1.4	14.9	-3.81	.002*	1.61
TP + V	10	82.7	7.9	2.5				
V	16	71.8	5.7	1.4	14.8	-3.54	.003*	1.50
NSS + TP + V	10	82.0	7.9	2.5				

* Denotes ($p < .05$)

Misses

Inaccurate Engagement

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .311, *F* (1, 9) = 19.940, *p* = .002, n_p^2 = .689, on the percentage of targets missed because they were not accurately engaged. A greater percentage of targets were missed in the moving condition than in the stationary condition (see Figure 38). Independent samples t-test were conducted to compare the percentage of targets missed due to inaccurate engagement for the multimodal cues in this experiment and the unimodal cues in Experiment 2. There were no significant findings.

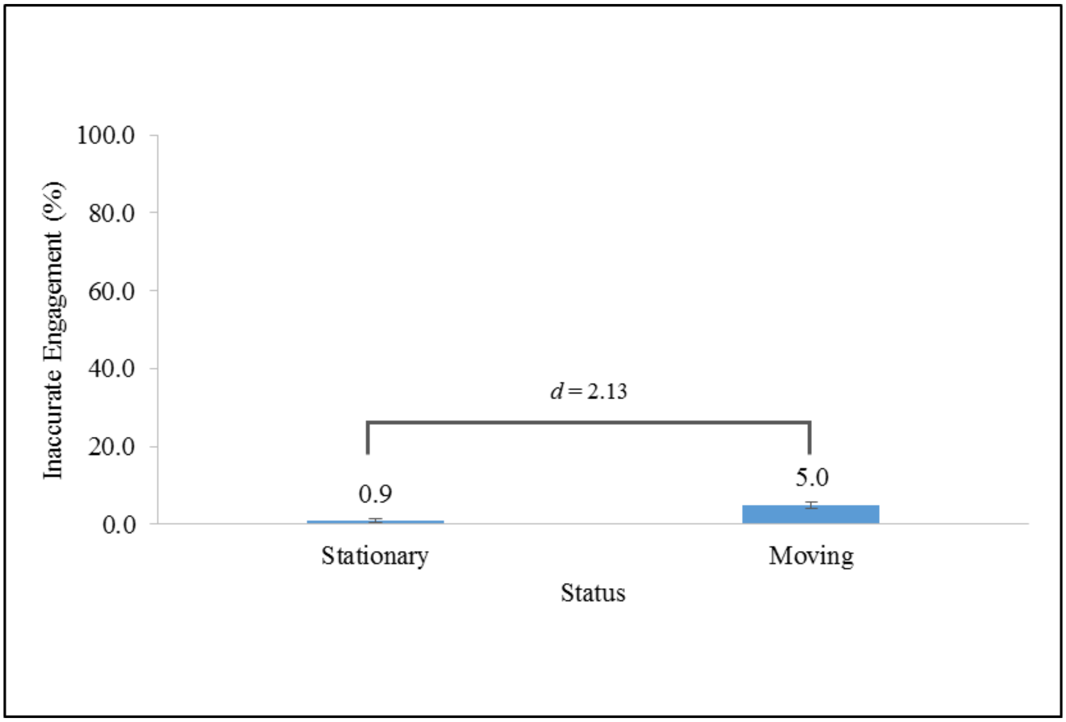


Figure 38. Experiment 3 Main effect of status on the percentage of inaccurate engagement.

Targets Not Detected

A repeated measures ANOVA revealed a significant interaction between cue condition and status on the percentage of targets missed because they were not detected, Wilks' Lambda = .246, F (3, 7) = 7.143, p = .015, n_p^2 = .754 (see Figure 39). An analysis of simple effects revealed that in the stationary condition, the percentage of targets not detected was significantly higher with the non-spatial speech + visual cue than with the non-spatial speech + tactile pulse (p = .013, d = 0.79) and the non-spatial speech + tactile pulse + visual cue (p = .013, d = 0.95). For the moving condition, the percentage of targets not detected was significantly higher with the non-spatial speech + visual cue than with the tactile pulse + visual (p = .001, d = 1.49) and the non-spatial speech + tactile pulse + visual cues (p = .001, d = 1.44). The analysis of simple effects also indicated that the percentage of targets not detected was significantly higher in the moving condition than in the stationary condition, with the non-spatial speech + tactile pulse (p = .004, d = 1.66), the non-spatial speech + visual ($p < .001$, d = 1.70), the tactile pulse + visual (p = .007, d = 1.07), and the non-spatial speech + tactile pulse + visual cues (p = .003, d = 1.50).

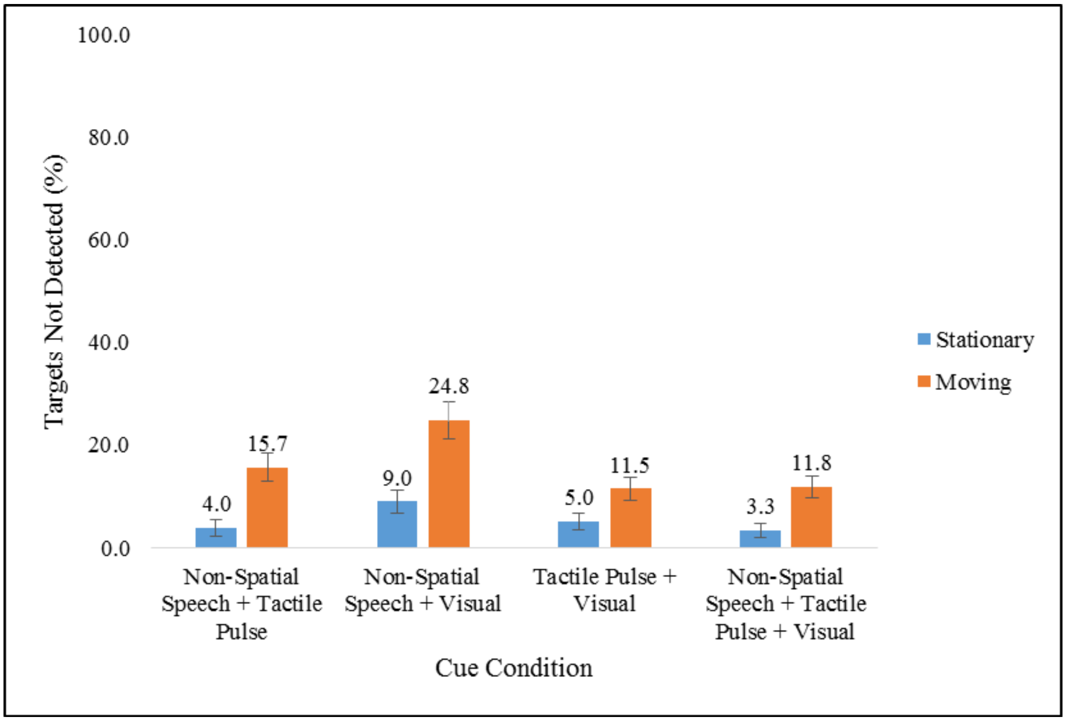


Figure 39. Experiment 3 Cue condition X status interaction on the percentage of targets not detected.

Independent samples t-test were conducted to compare the percentage of targets not detected for the multimodal cues in this experiment and the unimodal cues in Experiment 2. The analysis revealed that the percentage of targets not detected was significantly lower for the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than for the unimodal non-spatial speech cue in the stationary conditions (see Table 8). In the moving conditions, the percentage of targets not detected was significantly lower for the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than for the unimodal non-spatial speech cue. Also, the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues resulted in a significantly lower percentage of targets not detected than the unimodal visual cue (see Table 9).

Table 8

Experiment 3 Targets Not Detected T-Tests for Unimodal versus Multimodal (Stationary)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	14.7	8.4	2.1	24.0	4.06	.000*	1.59
NSS + TP	10	4.0	5.2	1.6				
NSS	16	14.7	8.4	2.1	20.9	1.82	.083	0.73
NSS + V	10	9.0	7.5	2.4				
NSS	16	14.7	8.4	2.1	23.6	4.53	.000*	1.78
NSS + TP + V	10	3.3	4.4	1.4				
TP	16	6.5	8.1	2.0	24.0	0.98	.335	0.39
NSS + TP	10	4.0	5.2	1.6				
TP	16	6.5	8.1	2.0	23.9	0.58	.568	0.23
TP + V	10	5.0	5.2	1.7				
TP	16	6.5	8.1	2.0	23.7	1.29	.208	0.51
NSS + TP + V	10	3.3	4.4	1.4				
V	16	6.1	6.1	1.5	16.3	-1.01	.329	0.42
NSS + V	10	9.0	7.5	2.4				
V	16	6.1	6.1	1.5	21.4	0.50	.620	0.20
TP + V	10	5.0	5.2	1.7				
V	16	6.1	6.1	1.5	23.3	1.36	.188	0.53
NSS + TP + V	10	3.3	4.4	1.4				

* Denotes ($p < .05$)

Table 9

Experiment 3 Targets Not Detected T-Tests for Unimodal versus Multimodal (Moving)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	25.2	12.2	3.1	23.2	2.28	.032*	0.90
NSS + TP	10	15.7	9.0	2.8				
NSS	16	25.2	12.2	3.1	20.6	0.08	.936	0.03
NSS + V	10	24.8	11.1	3.5				
NSS	16	25.2	12.2	3.1	23.9	3.56	.002*	1.40
NSS + TP + V	10	11.8	6.9	2.2				
TP	16	10.0	5.6	1.4	13.3	-1.79	.097	0.78
NSS + TP	10	15.7	9.0	2.8				
TP	16	10.0	5.6	1.4	16.3	-0.56	.584	0.23
TP + V	10	11.5	6.8	2.2				
TP	16	10.0	5.6	1.4	16.2	-0.69	.497	0.29
NSS + TP + V	10	11.8	6.9	2.2				
V	16	22.4	7.9	2.0	14.7	-0.59	.563	0.25
NSS + V	10	24.8	11.1	3.5				
V	16	22.4	7.9	2.0	21.4	3.74	.001*	1.49
TP + V	10	11.5	6.8	2.2				
V	16	22.4	7.9	2.0	21.3	3.60	.002*	1.43
NSS + TP + V	10	11.8	6.9	2.2				

* Denotes ($p < .05$)

False Alarms

There were no false alarms in this experiment.

Response Time

A repeated measures ANOVA revealed a significant main effect of cue condition Wilks' Lambda = .096, F (3, 7) = 22.077, p = .001, n_p^2 = .904, on response time (see Figure 40). Post hoc comparisons indicated that the non-spatial speech + visual cue yielded a significantly longer response time than the non-spatial speech + tactile pulse (p = .003), the tactile pulse + visual (p < .001), and the non-spatial speech + tactile pulse + visual cues (p = .007). The analysis also revealed a significant main effect of status, Wilks' Lambda = .134, F (1, 9) = 58.014, p < .001, n_p^2 = .866, on response time. Response time was significantly longer in the moving conditions than in the stationary conditions (see Figure 41).

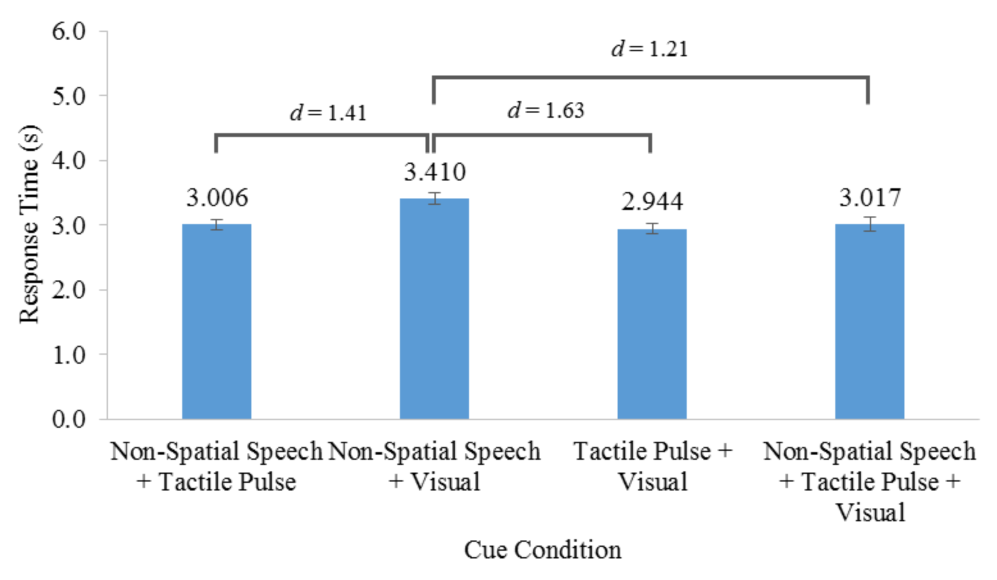


Figure 40. Experiment 3 main effect of cue condition on response time.

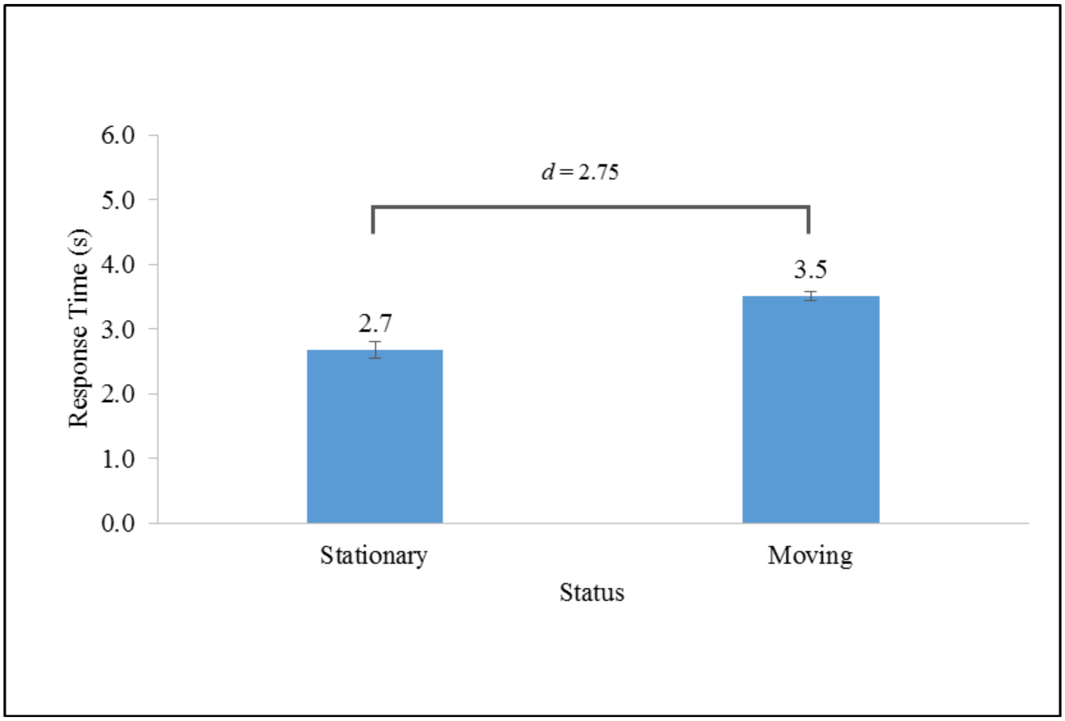


Figure 41. Experiment 3 main effect of status on response time.

Independent samples t-test were conducted to compare response time for the multimodal cues in this experiment and the unimodal cues in Experiment 2. The analysis revealed that the response time was significantly shorter for the non-spatial speech + tactile pulse cue than for the unimodal non-spatial speech cue in the stationary conditions (see Table 10). Also, the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues resulted in shorter response time than the unimodal visual cue. In the moving conditions, response time was significantly shorter for the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues than for the unimodal visual cue (see Table 11).

Table 10

Experiment 3 Response Time T-Tests Unimodal versus Multimodal (Stationary)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	3.0	0.4	0.1	16.9	2.62	.018*	1.08
NSS + TP	10	2.5	0.5	0.1				
NSS	16	3.0	0.4	0.1	19.8	-0.28	.782	0.11
NSS + V	10	3.0	0.4	0.1				
NSS	16	3.0	0.4	0.1	15.8	2.01	.062	0.84
NSS + TP + V	10	2.6	0.5	0.2				
TP	16	2.6	0.6	0.2	23.4	0.28	.779	0.11
NSS + TP	10	2.5	0.5	0.1				
TP	16	2.6	0.6	0.2	23.9	0.42	.676	0.17
TP + V	10	2.5	0.4	0.1				
TP	16	2.6	0.6	0.2	22.6	-0.10	.922	0.04
NSS + TP + V	10	2.6	0.5	0.2				
V	16	3.0	0.4	0.1	20.4	-0.01	.949	0.03
NSS + V	10	3.0	0.4	0.1				
V	16	3.0	0.4	0.1	20.6	3.32	.003*	1.32
TP + V	10	2.5	0.4	0.1				
V	16	3.0	0.4	0.1	16.2	2.17	.045*	0.90
NSS + TP + V	10	2.6	0.5	0.2				

* Denotes ($p < .05$)

Table 11

Experiment 3 Response Time T-Tests Unimodal versus Multimodal (Moving)

	N	Mean	SD	SE	*df*	*t*	*p*	Cohen's *d*
NSS	16	3.7	0.4	0.1	23.2	1.66	.110	0.66
NSS + TP	10	3.5	0.2	0.1				
NSS	16	3.7	0.4	0.1	22.8	-0.77	.447	0.31
NSS + V	10	3.8	0.3	0.1				
NSS	16	3.7	0.4	0.1	24.0	2.01	.056	0.79
NSS + TP + V	10	3.4	0.3	0.1				
TP	16	3.2	0.5	0.1	22.2	-1.87	.075	0.74
NSS + TP	10	3.5	0.2	0.1				
TP	16	3.2	0.5	0.1	24.0	-0.97	.341	0.38
TP + V	10	3.4	0.3	0.1				
TP	16	3.2	0.5	0.1	23.8	-1.31	.203	0.51
NSS + TP + V	10	3.4	0.3	0.1				
V	16	3.8	0.5	0.1	23.8	-0.16	.876	0.06
NSS + V	10	3.8	0.3	0.1				
V	16	3.8	0.5	0.1	24.0	2.58	.016*	1.01
TP + V	10	3.4	0.3	0.1				
V	16	3.8	0.5	0.1	23.7	2.43	.023*	0.95
NSS + TP + V	10	3.4	0.3	0.1				

* Denotes ($p < .05$)

Navigation Errors

A repeated measures ANOVA did not reveal any significant effects of cue condition on the number of navigation errors.

Mental Workload

In addition to global mental workload scores, raw workload scores for each of the six subscales were analyzed.

Global Workload

A repeated measures ANOVA did not reveal any significant effects of cue condition or moving condition on global mental workload.

Raw Subscale Workload

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .611, F (1, 9) = 5.725, p = .040, n_p^2 = .389, on physical demand (see Figure 42). Physical demand scores were significantly lower in the stationary conditions than in the moving conditions.

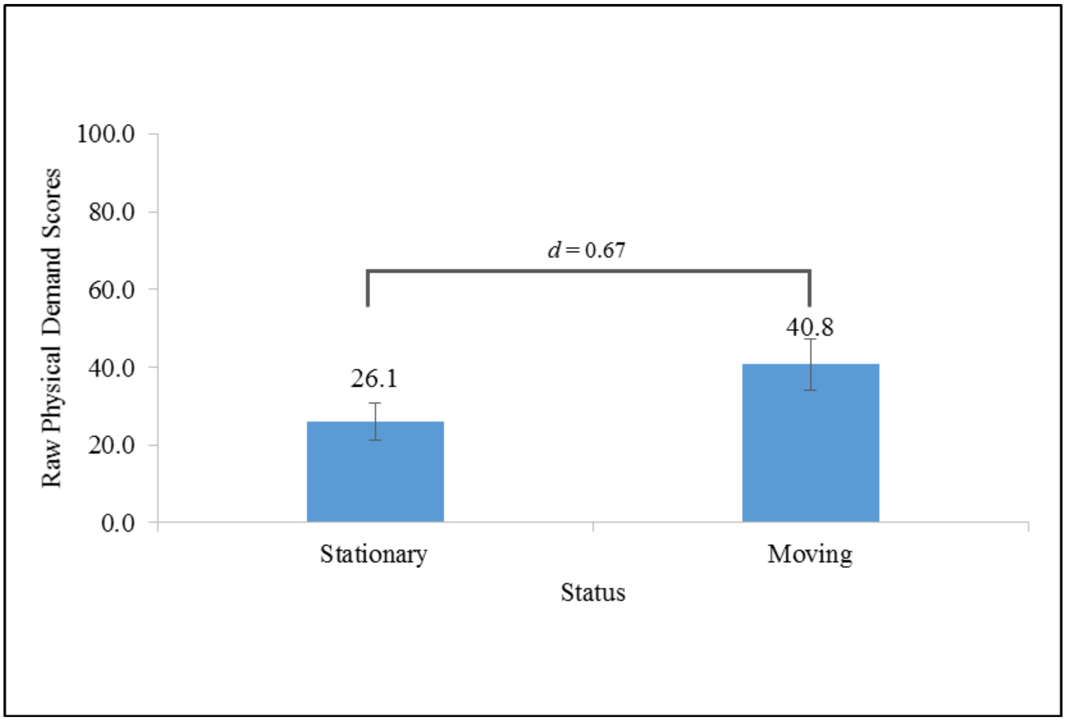


Figure 42. Experiment 3 Main effect of status on raw physical demand scores.

A repeated measures ANOVA revealed a significant main effect of status, Wilks' Lambda = .595, F (1, 9) = 6.121, p = .035, n_p^2 = .405, on performance (see Figure 43). Performance scores were significantly better in the stationary conditions than in the moving conditions. There were no other findings among the raw mental workload subscales.

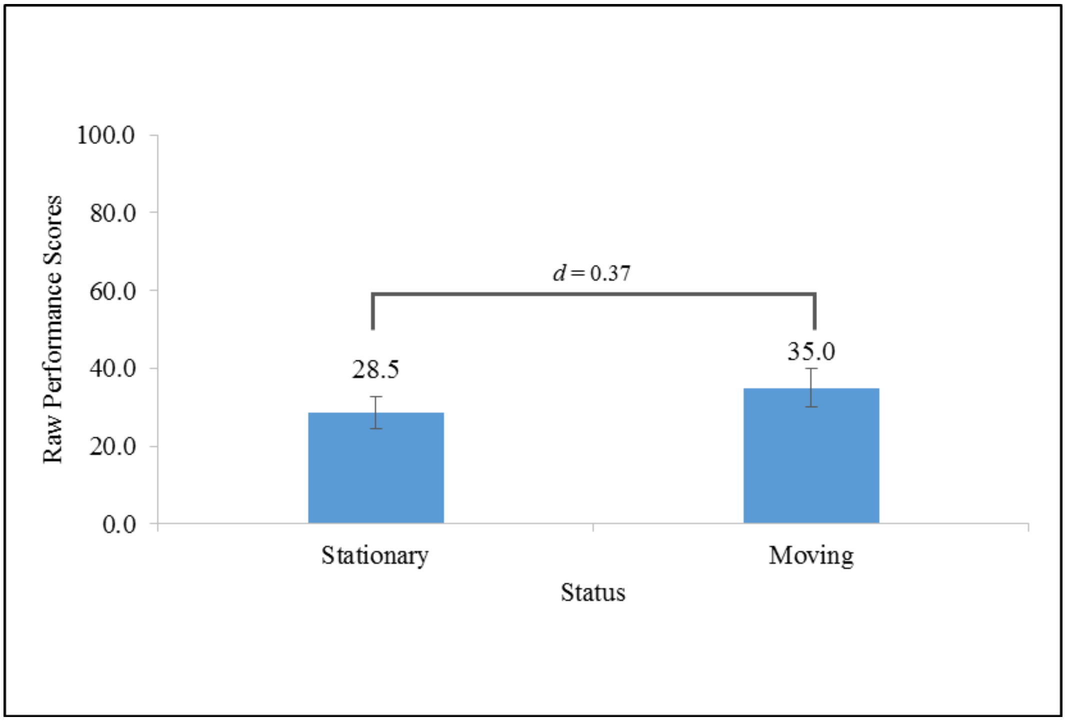


Figure 43. Experiment 3 Main effect of status on raw performance scores.

Cue Preference

With regard to cue preference, a higher percentage of participants preferred the Non-Spatial Speech + Tactile Pulse cue over the Non-Spatial Speech + Visual, the Tactile Pulse + Visual, and the Non-Spatial Speech + Tactile Pulse + Visual cues (see Table 12).

Table 12

Experiment 3 Cue Preference

Cue Preference	
Non-Spatial Speech + Tactile Pulse	90.0%
Non-Spatial Speech + Visual	0.0%
Tactile Pulse + Visual	10.0%
Non-Spatial Speech + Tactile Pulse + Visual	0.0%

Discussion

The power analysis for this experiment indicated that fifteen participants were necessary for this research. However, due to an equipment failure, data was only collected on ten participants. There are three factors that can effect power: sample size, the population effect size, and alpha level. Despite lack of a sufficient number of participants, the significant findings consistent with experiments 1 and 2 indicate that the power for this investigation was sufficient. Because non-significant findings are associated with low power, O'Keefe (2007) do not deem post hoc or after the fact power analysis as useful or of any interest. However, effect sizes, confidence intervals, and *p* values should be used to interpret results. In general, analyses of this experiment yielded large effect sizes.

In Experiment 3, there was a higher percentage of hits with the non-spatial speech + tactile pulse + visual cue than with the non-spatial speech + visual cue in the stationary condition. However, for each of the multimodal cues that included tactile pulsing, the percentage of hits was 94% and above. The percentage of hits for the non-spatial speech + visual was about 91%. So despite the significance, hit rate was good in all conditions, particularly those that included the tactile pulsing. In the moving condition, the percentage of hits with the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues was higher than with the non-spatial speech + visual cue. The moving condition seemed to have driven down performance on hits with the non-spatial speech + visual cue more drastically than the other multimodal cues. The percentage of targets was higher in the stationary conditions than in the moving conditions for all of the multimodal cues as expected.

When the percentage of targets hit for the multimodal cues was compared to the unimodal cues of Experiment 2, findings revealed that there was a higher percentage of targets hit with the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than the non-spatial speech cue in both the stationary and moving conditions. Combining the tactile pulse cue with the non-spatial speech cue improves the percentage of targets hit. In the moving condition only, the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues resulted in more hits than the unimodal visual cue. In this case, combining the tactile pulse cue with the visual cue improves the percentage of targets hit when moving. These findings support the hypothesis that the multimodal cues would have a percentage of hits greater than or equal to the unimodal cues. The multimodal cues that included tactile pulse cues in particular yielded better hit performance than the unimodal non-spatial speech cue. With regard to misses in this investigation, there were more misses due to inaccurate engagement occurred in the moving condition than in the stationary condition due to the conspicuity of the targets. Targets missed due to inaccurate engagement was less than 1% in the stationary conditions and around 5% in the moving conditions, this again indicates that participants had good aiming skills. Again the majority of misses were due to targets not being detected. Of those misses due to targets not being detected, the non-spatial speech+ tactile pulse and the non-spatial speech + tactile pulse + visual cues resulted in a lower percentage than the non-spatial speech + visual cue in the stationary condition. In the moving condition, the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues had a lower percentage of targets not detected than the non-spatial speech + visual cue. A lower percentage of targets were not detected in the stationary condition than in the moving condition with all of the multimodal cues.

When the percentage of targets not detected for the multimodal cues was compared to the unimodal cues of Experiment 2, findings revealed that there was a lower percentage of targets not detected with the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than with the unimodal non-spatial speech cue in both the stationary and moving conditions. Combining the tactile pulse cue with the non-spatial speech cue reduced the number of undetected targets. In the moving conditions, the percentage of targets not detected with the tactile pulse + visual and the non-spatial speech + tactile pulse + visual cues was lower than with the unimodal visual cue. Combining the tactile pulse cue with the visual cue reduced the number of undetected targets. Because participants relied on the cues, the findings of this investigation yielded no false alarms.

For response time, the non-spatial speech + tactile pulse, the tactile pulse + visual, and the non-spatial speech + tactile pulse + visual cues yielded faster target engagement than with the non-spatial speech + visual cue. Without the inclusion of the tactile pulse cue, response time was significantly longer. Response time was also significantly longer in the moving conditions than in the stationary conditions.

When response time for the multimodal cues was compared to the unimodal cues of Experiment 2, findings revealed that for the stationary conditions, response time was shorter with then non-spatial speech + tactile pulse cue than for the unimodal non-spatial speech cue. Response time was shorter for the tactile pulse + visual and non-spatial speech + tactile pulse + visual cues than for the unimodal visual cue in both the stationary and moving conditions. Combining the tactile pulse cue with the visual cue reduced response time. It was hypothesized that multimodal cues would have a shorter response time than the unimodal visual cue. This hypothesis was not supported.

Analysis of the global mental workload scores among the multimodal cues did not yield any significant findings. A closer examinatreion of the raw mental workload subscales revealed that subjective physical demand and performance was better when stationary than when moving. Therefore the hypothesis that states that mental workload would be significantly lower in the stationary conditions than in the moving conditions was only partially supported. Because the differences in actual performance are not reflected in mental workload scores, there was a dissociation of performance and subjective workload (Wickens & Yeh, 1983). Due to the lack of significant findings, the hypothesis that navigation errors would be significantly less with the non-spatial speech + tactile pulse and the non-spatial speech + tactile pulse + visual cues than with the non-spatial speech + visual and the tactile + visual cues was not supported. The majority (90%) of participants preferred the non-spatial speech + tactile pulse cue. The remaining 10% preferred the tactile pulse + visual cue.

CHAPTER SIX
GENERAL DISCUSSION

The present dissertation research investigated the use of tactile display in providing both azimuth and distance information about the location of enemy threats. This research was designed based on the currently fielded SWATS system, which can detect enemy gunfire and provide azimuth and distance information either auditorily or visually. The auditory cues were provided as non-spatial speech through earbuds, and the visual cues were provided using a visual display. For this research, three studies were conducted. Experiment 1 sought to determine whether 3-D audio frequency cue or 3-D audio pulse cues would provide any performance advantages over the already existent non-spatial speech cue in providing azimuth and distance information about enemy threats. This experiment also sought to investigate how a tactile intensity cue compared to a tactile pulse cue in providing distance and azimuth information about enemy threats. There were no performance differences in the three auditory cue types and in the two tactile cue types, respectively. However, the non-speech cue and the tactile pulse cue were found to be preferred by participants. Experiment 2 sought to determine how the preferred auditory and tactile from Experiment 1 compared to a no cueing control, a tactile cue that only provided azimuth information, and a visual cue. Experiment 3 was a multimodal study which sought to determine how combinations of the cues used in experiment 2 compared to each other. It also compared the multimodal cues to the unimodal cues in experiment 2.

Three general hypotheses were offered for this research. The first hypothesis stated that the tactile modality would be an effective indicator of target distance as a single modality or as part of a pairing with other sensory modalities. The tactile modality yielded the best performance in experiments 1 and 2. When the tactile modality was employed the number of hits were increased, the number of misses due to targets not being detected were decreased, and response time decreased. In experiment 2, a tactile direction only cue condition was included to determine if the encoded distance information in the tactile pulse cue provided any advantage. Although the majority of participants reported that they mainly used distance information with the non-spatial speech cue only, findings seem to indicate that participant perhaps did use the encoded distance information in the tactile pulse cue to some degree because, unlike the tactile direction only cue, there was a lack of significant findings between the moving and stationary conditions with the tactile pulse cue. Also, some participants indicated that they would likely not use the auditory cues because it would interfere with other auditory equipment used to provide communication among their team in a combat environment. Some participants suggested that they would more than likely to use the tactile distance information in the real world as opposed to a virtual world. Whether distance information was utilized or not, the findings still indicate that the tactile modality outperformed the auditory and visual modalities. In experiment 3, the cue combinations that included the tactile pulse cue resulted in increased hits, decreased misses due to targets not being detected, and decreased response time. Most participant reported that they prefer to have the tactile modality, but with regard to multimodal cues, they would use the auditory or visual cue as confirmation of the information received. Misses due to inaccurate engagement were minimal across all three experiments, with the only significant findings between the moving and stationary conditions. This finding confirms that participants were highly accurate when they engaged detected enemy targets. There were no false alarms in any of the experiments. So the participants must have relied on the cues heavily.

With regard to navigation errors, there were no significant findings. Therefore, the participants were able to navigate a path while concurrently engaging targets with minimal mistakes. Neither the type of cue nor the lack of cues have an impact on navigation. In a real combat situation, map navigation may have been more problematic because the nature of the environment. For this research, there were enemy targets with which participants were asked to engage. However, there was no real world threat, no threat of being shot. If there a real enemy in a real combat situation, there may be more navigation errors. Furthermore, instead of traditional maps many Soldiers currently utilize Global Positioning Systems.

The tactile cues were also found to be effective in reducing subjective global mental workload in experiments 1 and 2. These findings are likely due to the ear free, eye free nature of the tactile utility. With the auditory cues, participants had to compete with the background noise provided in the stationary conditions and the noise generated by the treadmill in the moving conditions. There were also issues related to participants having difficulty localizing 3-D audio cues and the translation of linguistics with the non-spatial speech cue. In experiments 1 and 2, global mental workload was significantly higher in moving conditions than in the stationary conditions. Targets were more difficult to engage due to their conspicuity, and participants had the additional task of navigating a specific path. In Experiment 3, there were no significant findings with regard to mental workload. This can be attributed to the redundancy of the multimodal cues. The issues related to individual cue types seem to have been mitigated by the addition another cue, especially a tactile cue. The findings related to global mental workload revealed a dissociation between performance and subjective workload. In some cases, the differences in performance were not reflected in subjective workload scores.

Based on the overall findings of this research, I would recommend that a tactile pulse cue be integrated either unimodally or multimodally into the SWATS to improve performance. Based on performance, the tactile pulse cue will improve Soldiers' situation awareness by increasing hit rates, reducing miss rates, and reducing response time. It will also aid in maintaining situation awareness by not interfering with other information that is already being provided to Soldiers via the auditory and visual channels. The tactile pulse cue will keep mental workload levels to minimum because the tactile modality does not interfere with the already highly taxed auditory and visual processes.

Current findings of this research may be useful in and generalizable to domains beyond military operations. With the ongoing threat of violence, hostage taking, and terrorist attacks, police officers may well be subjected to equally dangerous situations. Being able to provide law enforcement with distance information about malefactors via the tactile modality, can yield similar benefits to those in the military context. Police officers are also required to operate in dynamic environments in which the tactile modality may be the best suited cueing aid. Similar advantages are anticipated for firefighters who often work in conditions which are noisy and prevent clear visual display of information that can save lives. Providing tactile distance information will also be beneficial to those who are visually impaired (Gustafson-Pearce, Billett, & Cecelja). Many injuries, some of which are fatal, occur as a result of falls and collisions when walking with poor vision or no vision at all (Manduchi & Kurniawan, 2011). If the tactile modality can be used to alert visually impaired individuals of the distance of a potentially hazard such injuries can be reduced. Cholewiak and Collins (2000) also identified that tactile information can also be useful for pilots, astronauts, and scuba divers. Thus, while the experiments of this dissertation were set in a military context, the results may be generally helpful in a variety of application domains.

With regard to future research, care must be taken to determine how to best integrate the tactile equipment into current Soldier systems. The equipment must not impede Soldier maneuvers or add excessive weight. One participant mentioned that Soldiers have so much equipment to carry and that although he thinks the tactile utility is useful, the way in which it is integrated with already fielded equipment is an imperative issue to consider. In this series of experiments, the participants were always standing or walking, future research should examine other postures. Particularly, the effects of lying down (i.e., torso in contact with the ground) on the perception of tactile cues with encoded distance and azimuth information. Because equipment may sometimes fail, future research should also examine how reduced reliability levels of the cue information impacts performance and trust. Finally, this research should be expanded from its current simulation environment to a more realistic field environment where participants are able to engage pop up targets either on a shooting range or within an urban environment designed specifically for dismounted research.

APPENDIX A: NASA-TLX

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

Pairwise Comparisons of Factors

Physical Demand / Mental Demand

Temporal Demand / Mental Demand

Performance / Mental Demand

Frustration / Mental Demand

Effort / Mental Demand

Temporal Demand / Physical Demand

Performance / Physical Demand

Frustration / Physical Demand

Effort / Physical Demand

Temporal Demand / Performance

Temporal Demand / Frustration

Temporal Demand / Effort

Performance / Frustration

Performance / Effort

Effort / Frustration

APPENDIX B: DEMOGRAPHICS QUESTIONNAIRE

Demographics Form

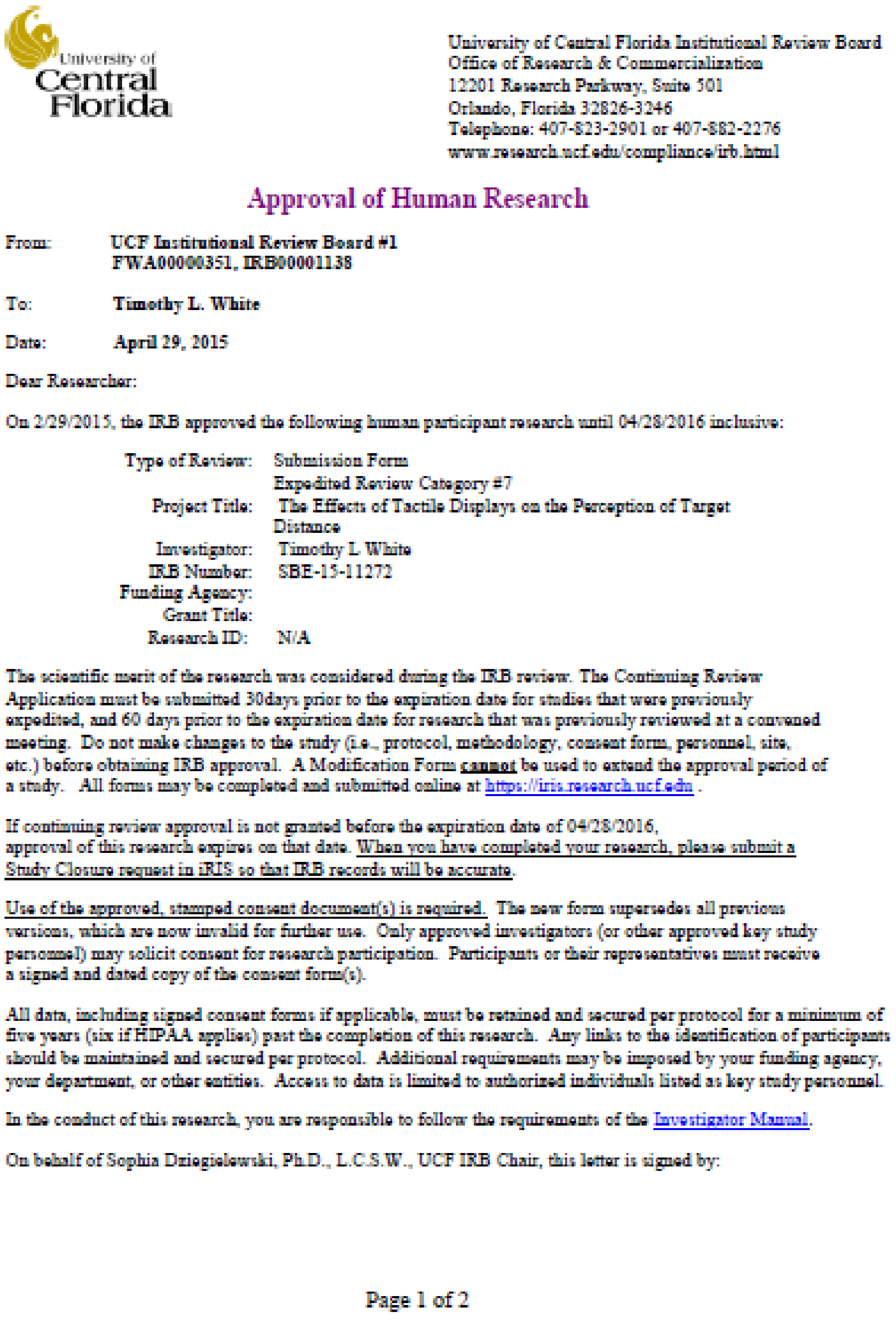
1. Participant #: _____ **2. Date: ________________**

3. Age: ______ **4. Gender: M F** **5.Contacts/Glasses: Y N**

6. Military Data
Do you have combat experience? Y N
If yes, identify location, time frame and your duty position:
____

____

APPENDIX C: IRB PERMISSION LETTERS



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

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Timothy L. White**

Date: **April 29, 2015**

Dear Researcher:

On 2/29/2015, the IRB approved the following human participant research until 04/28/2016 inclusive:

Type of Review: Submission Form
Expedited Review Category #7
Project Title: The Effects of Tactile Displays on the Perception of Target Distance
Investigator: Timothy L White
IRB Number: SBE-15-11272
Funding Agency:
Grant Title:
Research ID: N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 04/28/2016, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a signed and dated copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. 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.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

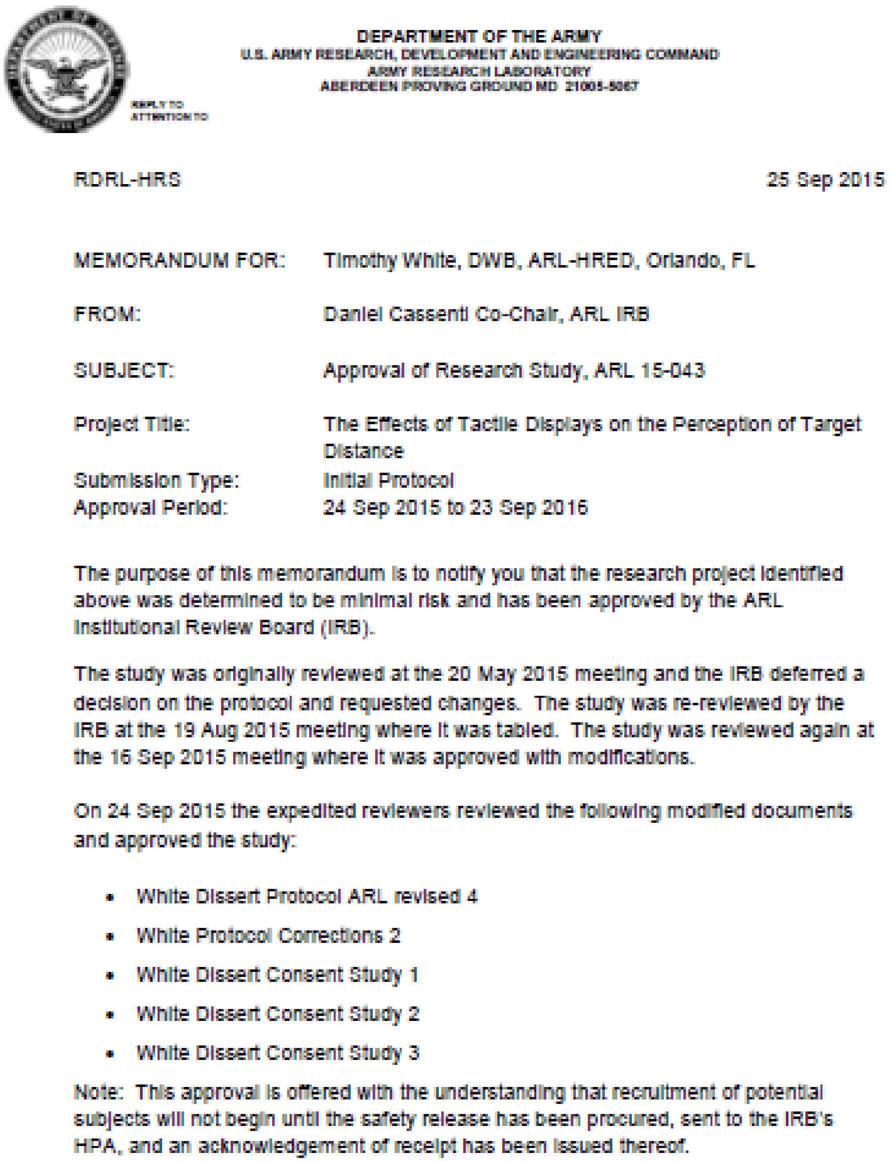
On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Page 1 of 2

Joanne Muratori

Signature applied by Joanne Muratori on 04/29/2015 02:57:30 PM EDT

IRB manager



DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
ARMY RESEARCH LABORATORY
ABERDEEN PROVING GROUND MD 21005-5067

REPLY TO
ATTENTION TO

RDRL-HRS 25 Sep 2015

MEMORANDUM FOR: Timothy White, DWB, ARL-HRED, Orlando, FL

FROM: Daniel Cassenti Co-Chair, ARL IRB

SUBJECT: Approval of Research Study, ARL 15-043

Project Title: The Effects of Tactile Displays on the Perception of Target Distance
Submission Type: Initial Protocol
Approval Period: 24 Sep 2015 to 23 Sep 2016

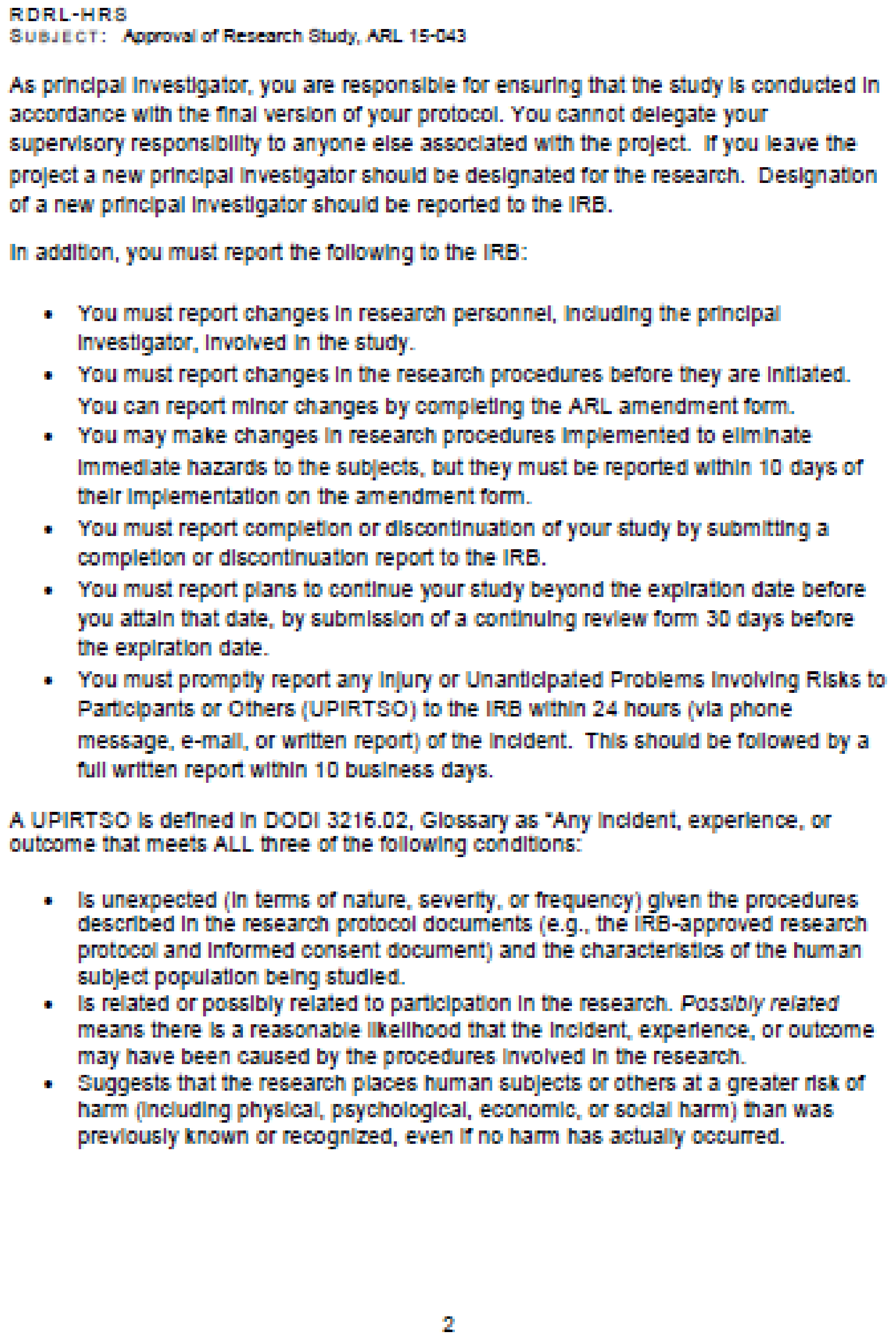
The purpose of this memorandum is to notify you that the research project identified above was determined to be minimal risk and has been approved by the ARL Institutional Review Board (IRB).

The study was originally reviewed at the 20 May 2015 meeting and the IRB deferred a decision on the protocol and requested changes. The study was re-reviewed by the IRB at the 19 Aug 2015 meeting where it was tabled. The study was reviewed again at the 16 Sep 2015 meeting where it was approved with modifications.

On 24 Sep 2015 the expedited reviewers reviewed the following modified documents and approved the study:

- White Dissert Protocol ARL revised 4
- White Protocol Corrections 2
- White Dissert Consent Study 1
- White Dissert Consent Study 2
- White Dissert Consent Study 3

Note: This approval is offered with the understanding that recruitment of potential subjects will not begin until the safety release has been procured, sent to the IRB's HPA, and an acknowledgement of receipt has been issued thereof.



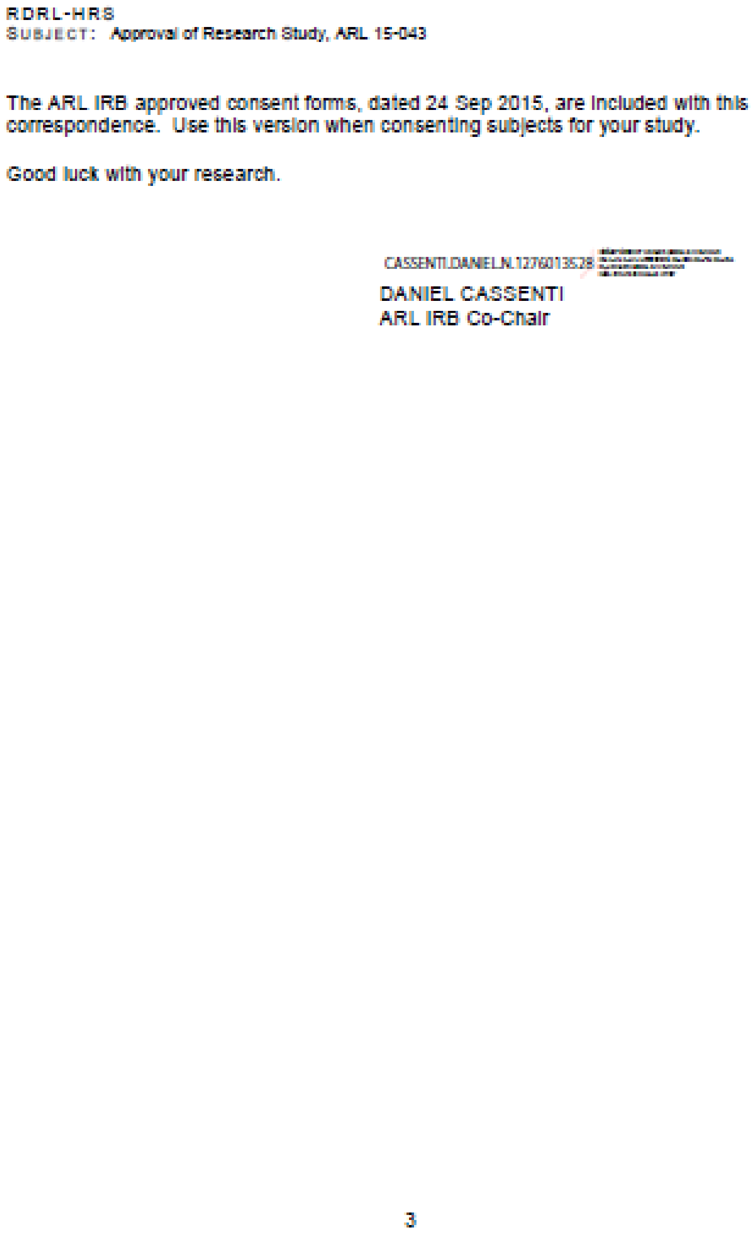
As principal investigator, you are responsible for ensuring that the study is conducted in accordance with the final version of your protocol. You cannot delegate your supervisory responsibility to anyone else associated with the project. If you leave the project a new principal investigator should be designated for the research. Designation of a new principal investigator should be reported to the IRB.

In addition, you must report the following to the IRB:

- You must report changes in research personnel, including the principal investigator, involved in the study.
- You must report changes in the research procedures before they are initiated. You can report minor changes by completing the ARL amendment form.
- You may make changes in research procedures implemented to eliminate immediate hazards to the subjects, but they must be reported within 10 days of their implementation on the amendment form.
- You must report completion or discontinuation of your study by submitting a completion or discontinuation report to the IRB.
- You must report plans to continue your study beyond the expiration date before you attain that date, by submission of a continuing review form 30 days before the expiration date.
- You must promptly report any injury or Unanticipated Problems Involving Risks to Participants or Others (UPIRTSO) to the IRB within 24 hours (via phone message, e-mail, or written report) of the incident. This should be followed by a full written report within 10 business days.

A UPIRTSO is defined in DODI 3216.02, Glossary as "Any incident, experience, or outcome that meets ALL three of the following conditions:

- Is unexpected (in terms of nature, severity, or frequency) given the procedures described in the research protocol documents (e.g., the IRB-approved research protocol and informed consent document) and the characteristics of the human subject population being studied.
- Is related or possibly related to participation in the research. *Possibly related* means there is a reasonable likelihood that the incident, experience, or outcome may have been caused by the procedures involved in the research.
- Suggests that the research places human subjects or others at a greater risk of harm (including physical, psychological, economic, or social harm) than was previously known or recognized, even if no harm has actually occurred.



RDRL-HRS
SUBJECT: Approval of Research Study, ARL 15-043

The ARL IRB approved consent forms, dated 24 Sep 2015, are included with this correspondence. Use this version when consenting subjects for your study.

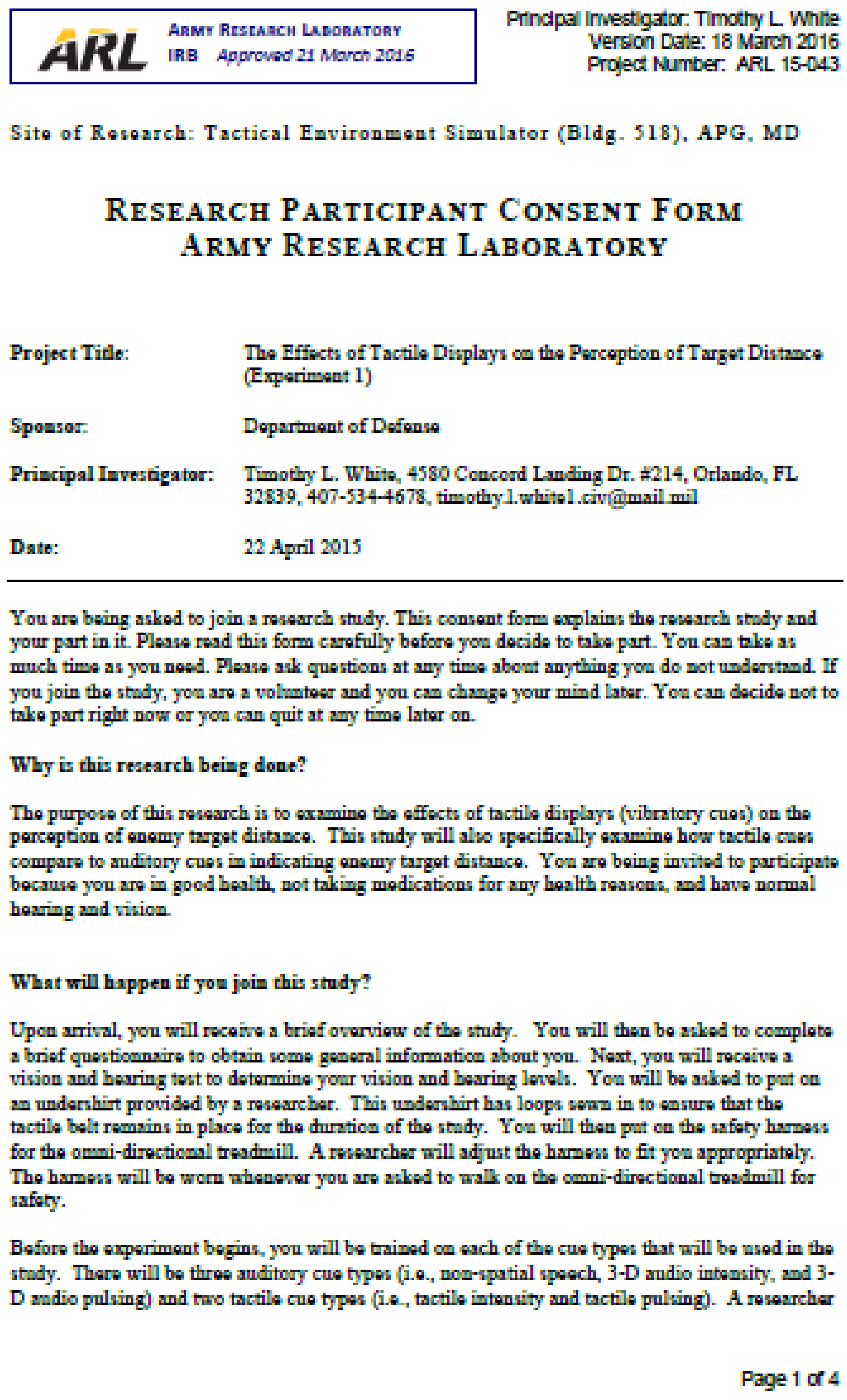
Good luck with your research.

CASSENTI.DANIEL.N.1276013528

DANIEL CASSENTI
ARL IRB Co-Chair

3

APPENDIX D: INFORMED CONSENT EXPERIMENT 1



ARL ARMY RESEARCH LABORATORY
IRB *Approved 21 March 2016*

Principal Investigator: Timothy L. White
Version Date: 18 March 2016
Project Number: ARL 15-043

Site of Research: Tactical Environment Simulator (Bldg. 518), APG, MD

RESEARCH PARTICIPANT CONSENT FORM
ARMY RESEARCH LABORATORY

Project Title:	The Effects of Tactile Displays on the Perception of Target Distance (Experiment 1)
Sponsor:	Department of Defense
Principal Investigator:	Timothy L. White, 4580 Concord Landing Dr. #214, Orlando, FL 32839, 407-534-4678, timothy.l.white1.civ@mail.mil
Date:	22 April 2015

You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask questions at any time about anything you do not understand. If you join the study, you are a volunteer and you can change your mind later. You can decide not to take part right now or you can quit at any time later on.

Why is this research being done?

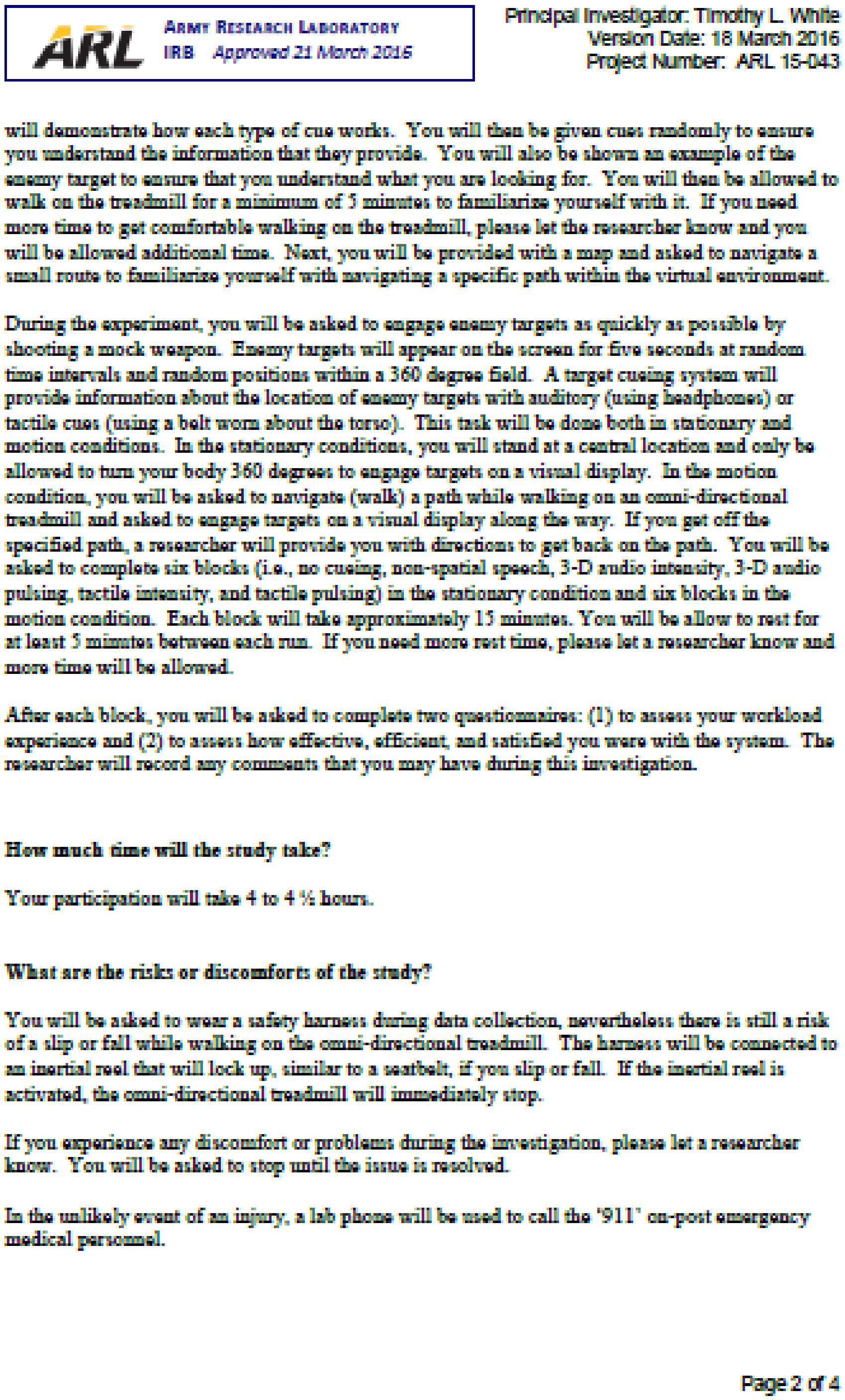
The purpose of this research is to examine the effects of tactile displays (vibratory cues) on the perception of enemy target distance. This study will also specifically examine how tactile cues compare to auditory cues in indicating enemy target distance. You are being invited to participate because you are in good health, not taking medications for any health reasons, and have normal hearing and vision.

What will happen if you join this study?

Upon arrival, you will receive a brief overview of the study. You will then be asked to complete a brief questionnaire to obtain some general information about you. Next, you will receive a vision and hearing test to determine your vision and hearing levels. You will be asked to put on an undershirt provided by a researcher. This undershirt has loops sewn in to ensure that the tactile belt remains in place for the duration of the study. You will then put on the safety harness for the omni-directional treadmill. A researcher will adjust the harness to fit you appropriately. The harness will be worn whenever you are asked to walk on the omni-directional treadmill for safety.

Before the experiment begins, you will be trained on each of the cue types that will be used in the study. There will be three auditory cue types (i.e., non-spatial speech, 3-D audio intensity, and 3-D audio pulsing) and two tactile cue types (i.e., tactile intensity and tactile pulsing). A researcher

Page 1 of 4



will demonstrate how each type of cue works. You will then be given cues randomly to ensure you understand the information that they provide. You will also be shown an example of the enemy target to ensure that you understand what you are looking for. You will then be allowed to walk on the treadmill for a minimum of 5 minutes to familiarize yourself with it. If you need more time to get comfortable walking on the treadmill, please let the researcher know and you will be allowed additional time. Next, you will be provided with a map and asked to navigate a small route to familiarize yourself with navigating a specific path within the virtual environment.

During the experiment, you will be asked to engage enemy targets as quickly as possible by shooting a mock weapon. Enemy targets will appear on the screen for five seconds at random time intervals and random positions within a 360 degree field. A target cueing system will provide information about the location of enemy targets with auditory (using headphones) or tactile cues (using a belt worn about the torso). This task will be done both in stationary and motion conditions. In the stationary conditions, you will stand at a central location and only be allowed to turn your body 360 degrees to engage targets on a visual display. In the motion condition, you will be asked to navigate (walk) a path while walking on an omni-directional treadmill and asked to engage targets on a visual display along the way. If you get off the specified path, a researcher will provide you with directions to get back on the path. You will be asked to complete six blocks (i.e., no cueing, non-spatial speech, 3-D audio intensity, 3-D audio pulsing, tactile intensity, and tactile pulsing) in the stationary condition and six blocks in the motion condition. Each block will take approximately 15 minutes. You will be allow to rest for at least 5 minutes between each run. If you need more rest time, please let a researcher know and more time will be allowed.

After each block, you will be asked to complete two questionnaires: (1) to assess your workload experience and (2) to assess how effective, efficient, and satisfied you were with the system. The researcher will record any comments that you may have during this investigation.

How much time will the study take?

Your participation will take 4 to 4 ½ hours.

What are the risks or discomforts of the study?

You will be asked to wear a safety harness during data collection, nevertheless there is still a risk of a slip or fall while walking on the omni-directional treadmill. The harness will be connected to an inertial reel that will lock up, similar to a seatbelt, if you slip or fall. If the inertial reel is activated, the omni-directional treadmill will immediately stop.

If you experience any discomfort or problems during the investigation, please let a researcher know. You will be asked to stop until the issue is resolved.

In the unlikely event of an injury, a lab phone will be used to call the '911' on-post emergency medical personnel.

Are there benefits to being in the study?

You will receive a free vision and hearing test.

Will you be paid if you join this study?

You will receive no payment for taking part in this study.

Can you leave the study early?

If you decide not to participate, or wish to withdraw during the study, you can convey your choice privately to one of the researchers. Your reasons for withdrawing will not be passed on to anyone outside the research staff, including anyone in your chain of command and the researcher will say that you did not meet experimental criteria. However, since you are taking part in this study as part of a group, it might not be possible to hide the details of your withdrawal from the other participants, and because of this your confidentiality cannot be completely protected.

How will your privacy be protected?

Your participation in this research is confidential. You will be assigned a participant number to ensure anonymity. Data sheets will be stored in a locked filing cabinet. Once the data from the data sheets are transferred to a computer, the data sheets will be shredded. The data will be stored and secured at on a password protected computer. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared, unless you give permission below in the section requesting consent for us to photograph you. This consent form will be retained by the principal investigator for a minimum of three years.

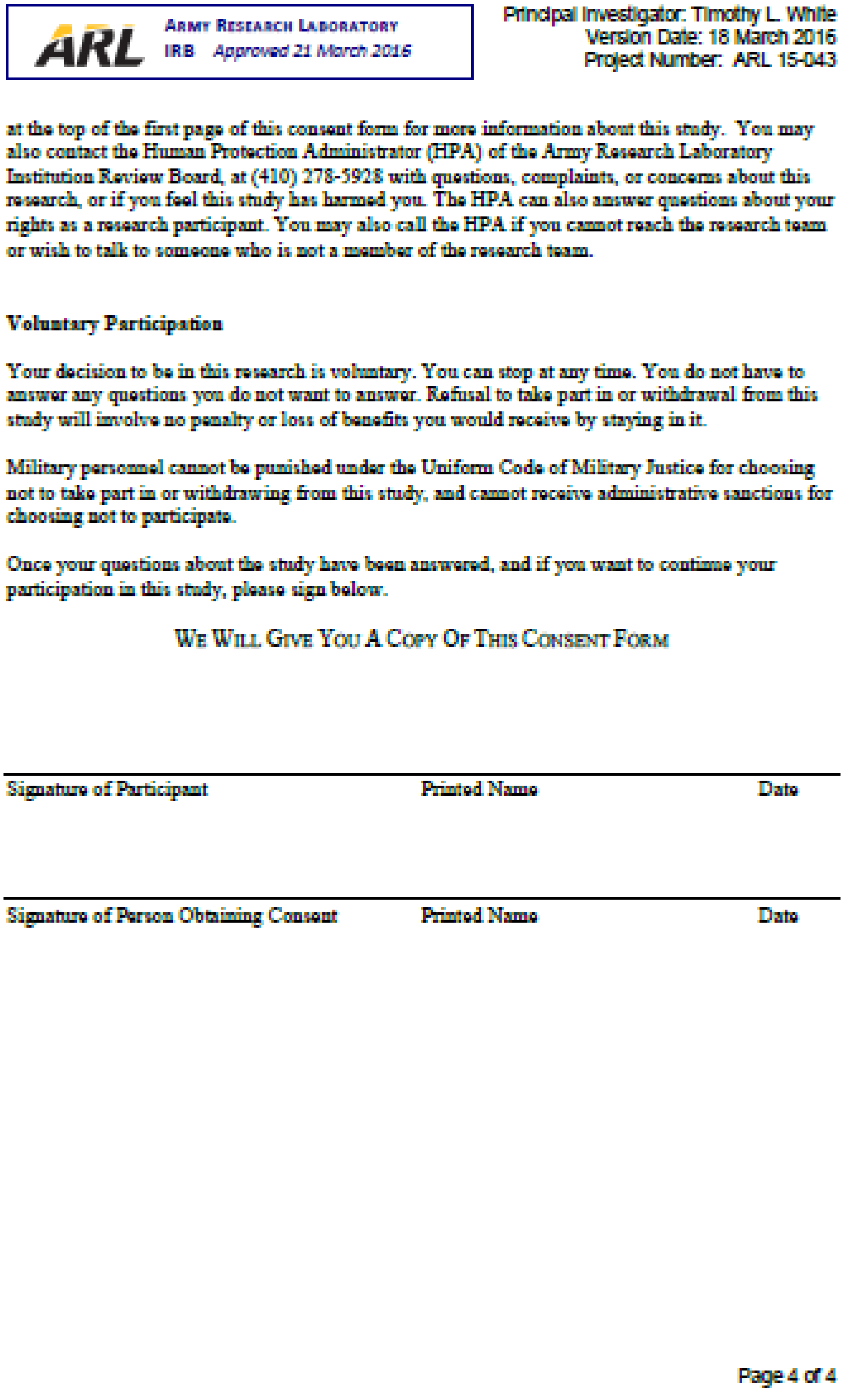
The research staff will protect your data from disclosure to people not connected with the study. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army Human Research Protections Office and the Army Research Laboratory's Institutional Review Board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects.

We would like your permission to take pictures during the experimental session. The pictures will be used in publications and presentations. Although we may photograph your activities during the experiment, we will pixelate your face and any other identifying information to protect your identity. Please indicate below if you will agree to allow us to photograph you. You can still be in the study if you prefer not to be recorded.

I give consent to be photographed during this study: ___Yes ___No please initial:____

Where can I get more information?

You have the right to obtain answers to any questions you might have about this research both while you take part in the study and after you leave the research site. Please contact anyone listed



ARL Army Research Laboratory
IRB Approved 21 March 2016

Principal Investigator: Timothy L. White
Version Date: 18 March 2016
Project Number: ARL 15-043

at the top of the first page of this consent form for more information about this study. You may also contact the Human Protection Administrator (HPA) of the Army Research Laboratory Institution Review Board, at (410) 278-5928 with questions, complaints, or concerns about this research, or if you feel this study has harmed you. The HPA can also answer questions about your rights as a research participant. You may also call the HPA if you cannot reach the research team or wish to talk to someone who is not a member of the research team.

Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawal from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform Code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate.

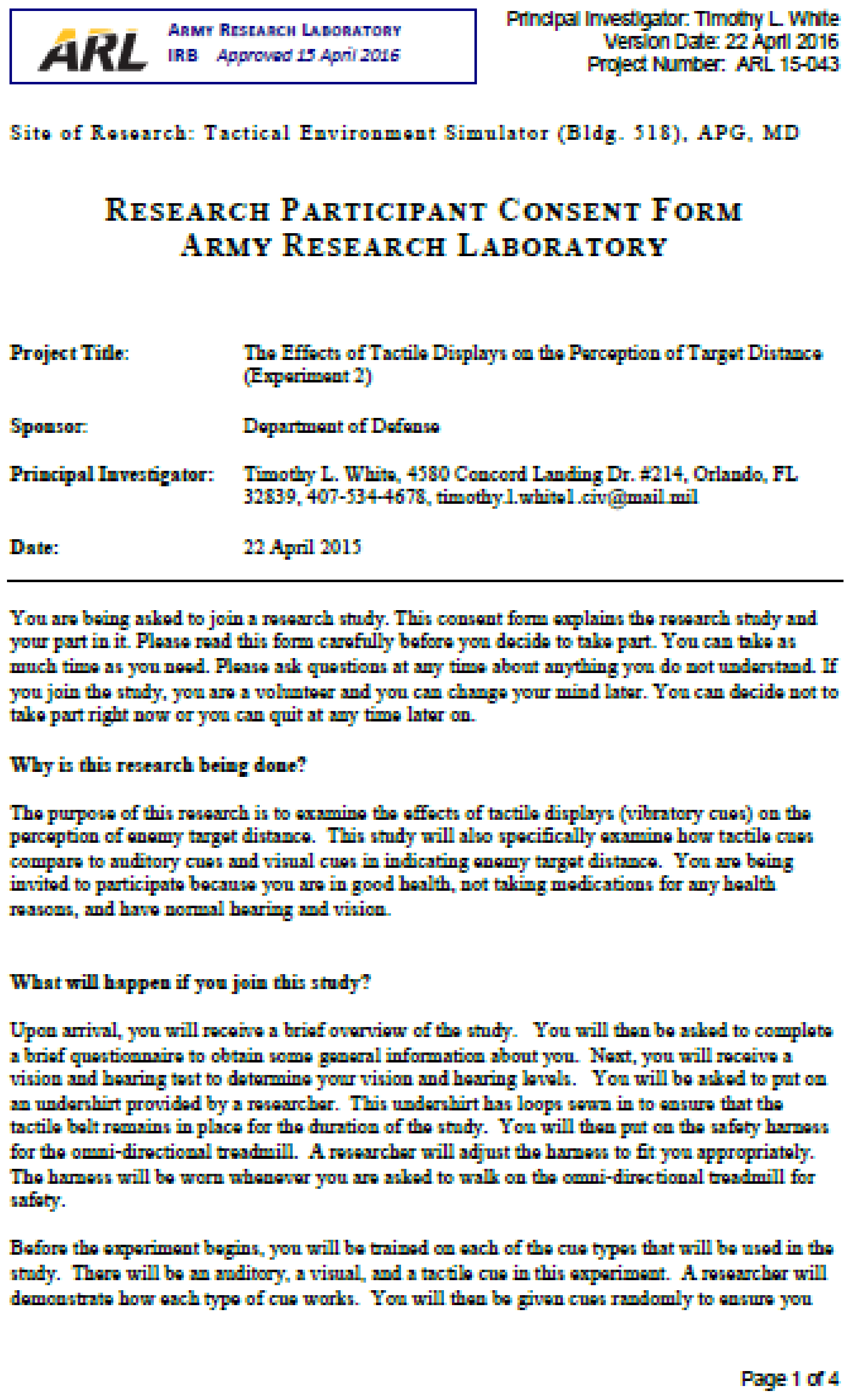
Once your questions about the study have been answered, and if you want to continue your participation in this study, please sign below.

WE WILL GIVE YOU A COPY OF THIS CONSENT FORM

Signature of Participant	Printed Name	Date
Signature of Person Obtaining Consent	Printed Name	Date

Page 4 of 4

APPENDIX E: INFORMED CONSENT EXPERIMENT 2



Site of Research: Tactical Environment Simulator (Bldg. 518), APG, MD

RESEARCH PARTICIPANT CONSENT FORM
ARMY RESEARCH LABORATORY

Project Title:	The Effects of Tactile Displays on the Perception of Target Distance (Experiment 2)
Sponsor:	Department of Defense
Principal Investigator:	Timothy L. White, 4580 Concord Landing Dr. #214, Orlando, FL 32839, 407-534-4678, timothy.l.white1.civ@mail.mil
Date:	22 April 2015

You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask questions at any time about anything you do not understand. If you join the study, you are a volunteer and you can change your mind later. You can decide not to take part right now or you can quit at any time later on.

Why is this research being done?

The purpose of this research is to examine the effects of tactile displays (vibratory cues) on the perception of enemy target distance. This study will also specifically examine how tactile cues compare to auditory cues and visual cues in indicating enemy target distance. You are being invited to participate because you are in good health, not taking medications for any health reasons, and have normal hearing and vision.

What will happen if you join this study?

Upon arrival, you will receive a brief overview of the study. You will then be asked to complete a brief questionnaire to obtain some general information about you. Next, you will receive a vision and hearing test to determine your vision and hearing levels. You will be asked to put on an undershirt provided by a researcher. This undershirt has loops sewn in to ensure that the tactile belt remains in place for the duration of the study. You will then put on the safety harness for the omni-directional treadmill. A researcher will adjust the harness to fit you appropriately. The harness will be worn whenever you are asked to walk on the omni-directional treadmill for safety.

Before the experiment begins, you will be trained on each of the cue types that will be used in the study. There will be an auditory, a visual, and a tactile cue in this experiment. A researcher will demonstrate how each type of cue works. You will then be given cues randomly to ensure you understand the information that they provide. You will also be shown an example of the enemy target to ensure that you understand what you are looking for. You will then be allowed to walk on the treadmill for a minimum of 5 minutes to familiarize yourself with it. If you need more time to get comfortable walking on the treadmill, please let the researcher know and you will be allowed additional time. Next, you will be provided with a map and asked to navigate a small route to familiarize yourself with navigating a specific path within the virtual environment.

During the experiment, you will be asked to engage enemy targets as quickly as possible by shooting a mock weapon. Enemy targets will appear on the screen for five seconds at random time intervals and random positions within a 360 degree field. A target cueing system will provide information about the location of enemy targets with auditory (using headphones), visual (using a small display attached to your arm), or tactile cues (using a belt worn about the torso). This task will be done both in stationary and motion conditions. In the stationary conditions, you will stand at a central location and only be allowed to turn your body 360 degrees to engage targets on a visual display. In the motion condition, you will be asked to navigate (walk) a path while walking on an omni-directional treadmill and asked to engage targets on a visual display along the way. If you get off the specified path, a researcher will provide you with directions to get back on the path. You will be asked to complete five blocks (i.e., no cueing, auditory, visual, and two tactile) in the stationary condition and five blocks in the motion condition. Each block will take approximately 15 minutes. You will be allow to rest for at least 5 minutes between each run. If you need more rest time, please let a researcher know and more time will be allowed.

After each block, you will be asked to complete a questionnaireto assess your workload experience. After all blocks have been completed, you will be asked to complete a questionnaire to assess how effective, efficient, and satisfied you were with the system. The researcher will record any comments that you may have during this investigation.

How much time will the study take?

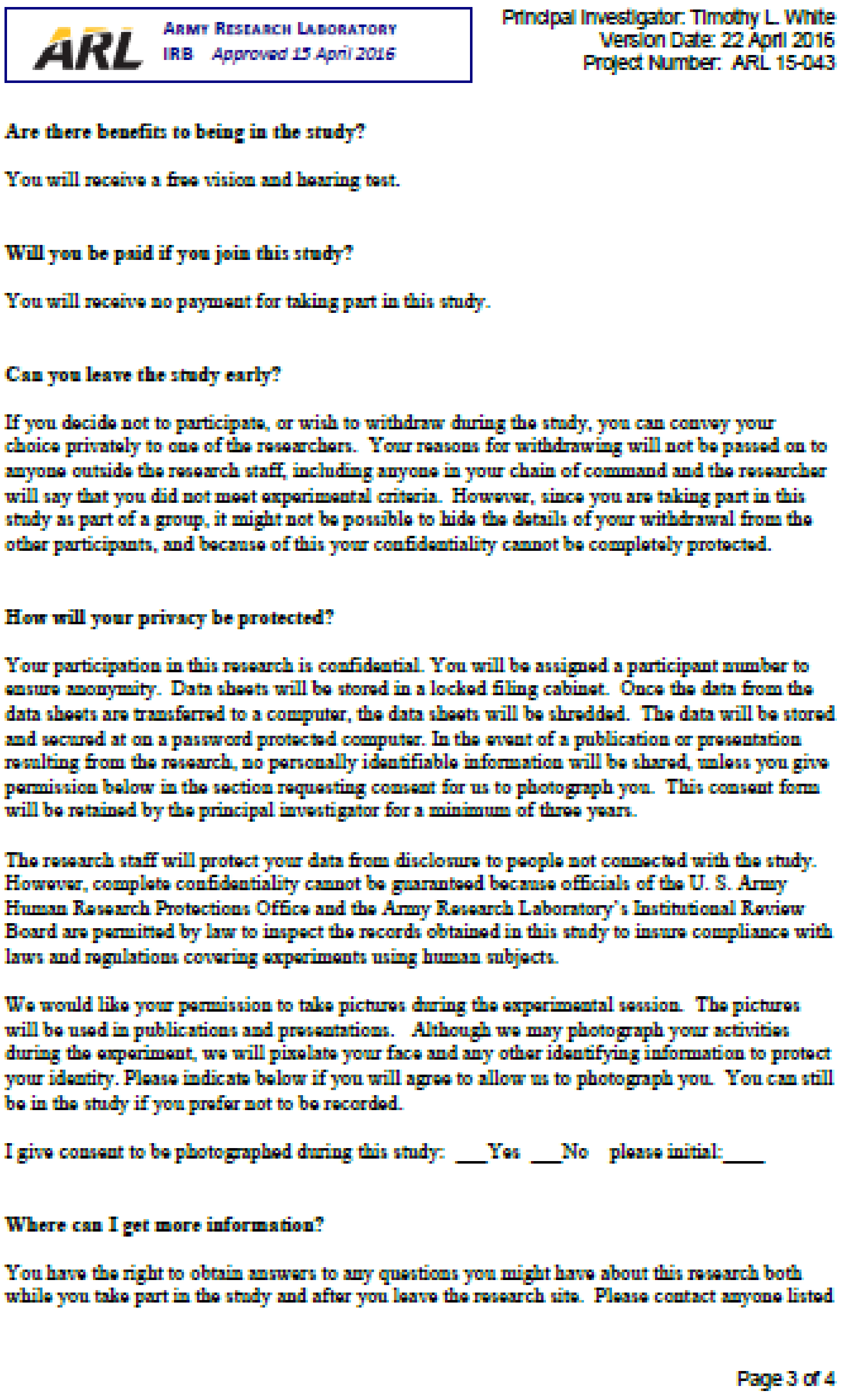
Your participation will take 4 to 4 ½ hours.

What are the risks or discomforts of the study?

You will be asked to wear a safety harness during data collection, nevertheless there is still a risk of a slip or fall while walking on the omni-directional treadmill. The harness will be connected to an inertial reel that will lock up, similar to a seatbelt, if you slip or fall. If the inertial reel is activated, the omni-directional treadmill will immediately stop.

If you experience any discomfort or problems during the investigation, please let a researcher know. You will be asked to stop until the issue is resolved.

In the unlikely event of an injury, a lab phone will be used to call the '911' on-post emergency medical personnel.



Are there benefits to being in the study?

You will receive a free vision and hearing test.

Will you be paid if you join this study?

You will receive no payment for taking part in this study.

Can you leave the study early?

If you decide not to participate, or wish to withdraw during the study, you can convey your choice privately to one of the researchers. Your reasons for withdrawing will not be passed on to anyone outside the research staff, including anyone in your chain of command and the researcher will say that you did not meet experimental criteria. However, since you are taking part in this study as part of a group, it might not be possible to hide the details of your withdrawal from the other participants, and because of this your confidentiality cannot be completely protected.

How will your privacy be protected?

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The research staff will protect your data from disclosure to people not connected with the study. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army Human Research Protections Office and the Army Research Laboratory's Institutional Review Board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects.

We would like your permission to take pictures during the experimental session. The pictures will be used in publications and presentations. Although we may photograph your activities during the experiment, we will pixelate your face and any other identifying information to protect your identity. Please indicate below if you will agree to allow us to photograph you. You can still be in the study if you prefer not to be recorded.

I give consent to be photographed during this study: ___Yes ___No please initial:____

Where can I get more information?

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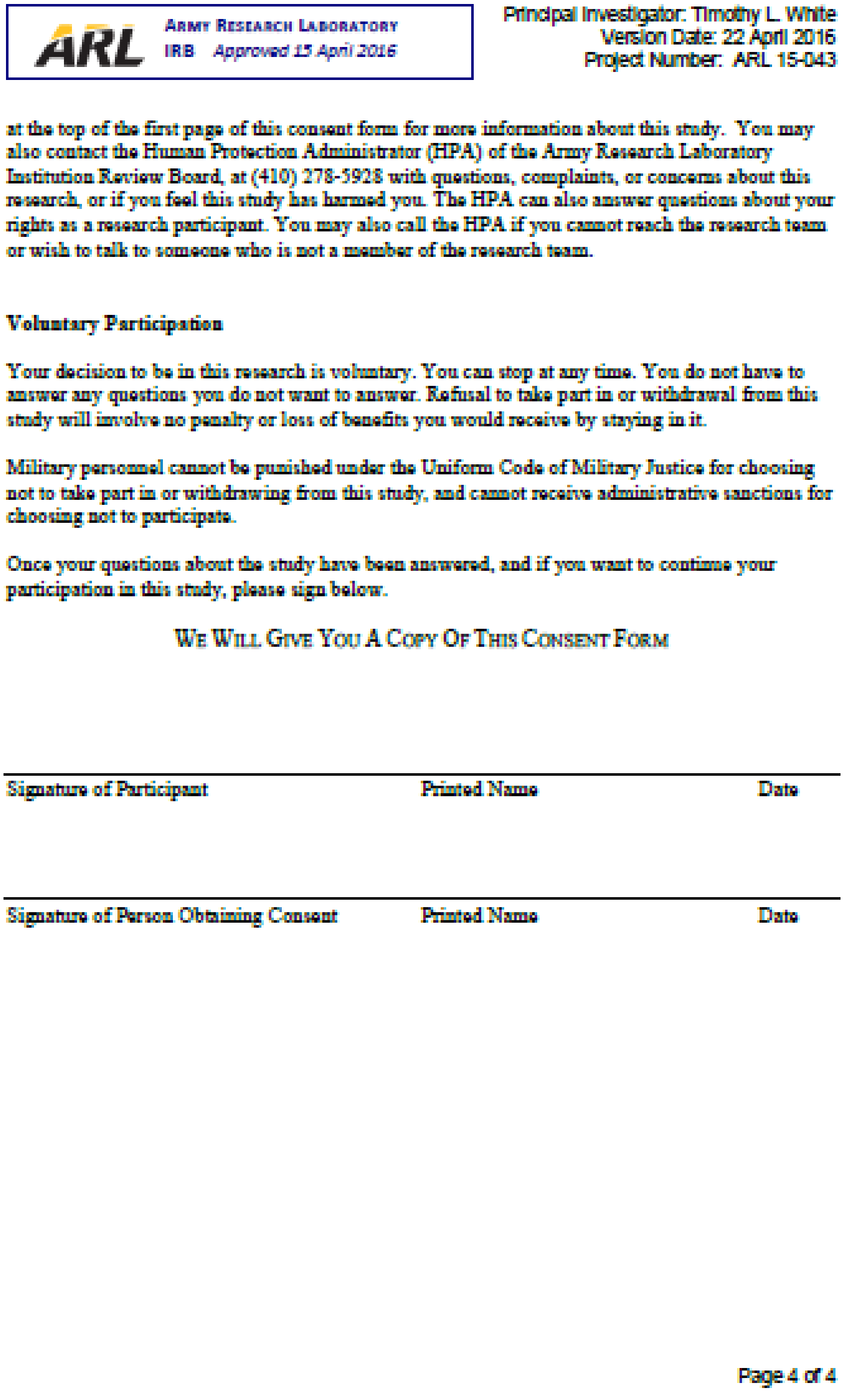

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Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawal from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform Code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate.

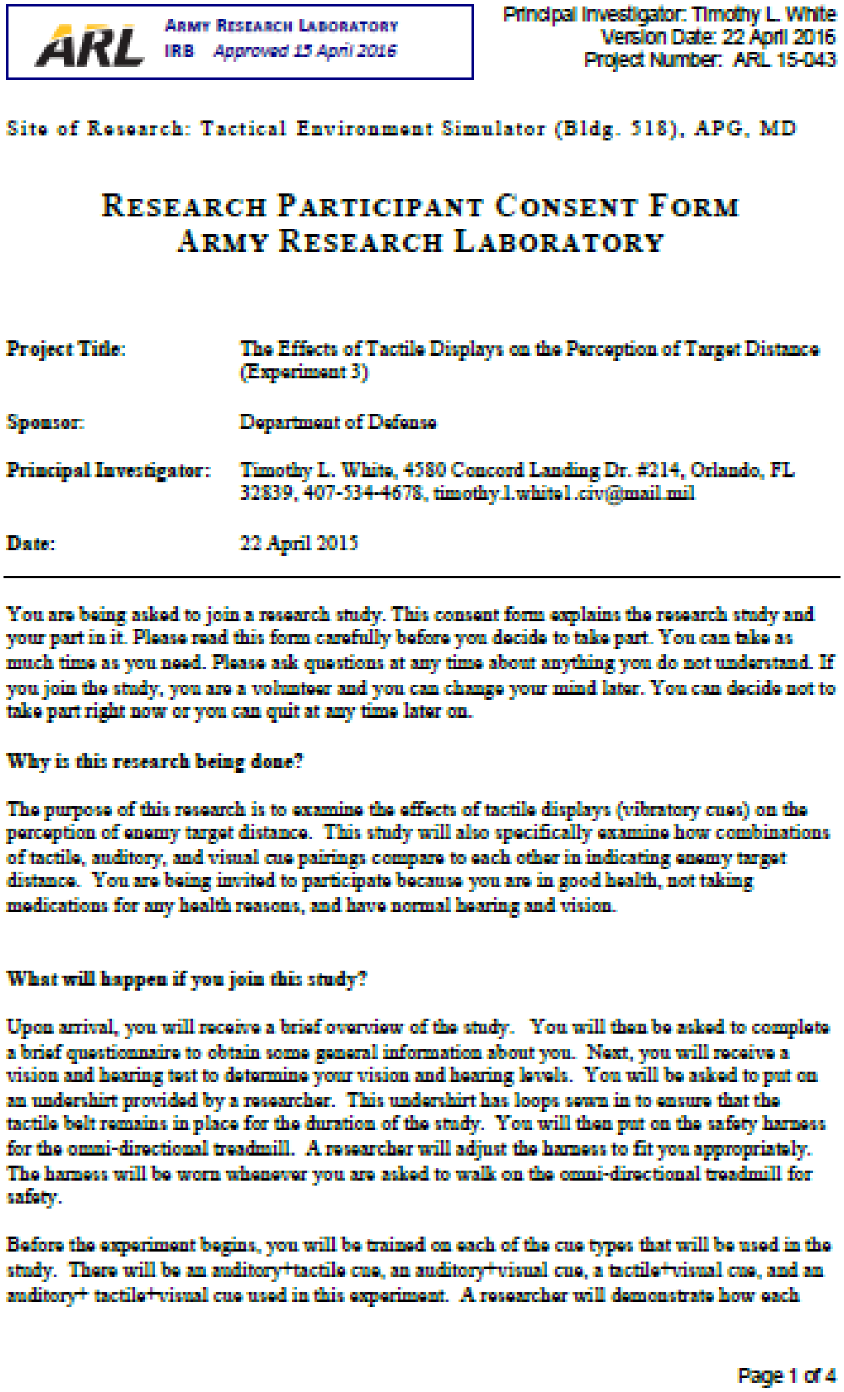
Once your questions about the study have been answered, and if you want to continue your participation in this study, please sign below.

WE WILL GIVE YOU A COPY OF THIS CONSENT FORM

Signature of Participant   Printed Name   Date

Signature of Person Obtaining Consent   Printed Name   Date

APPENDIX F: INFORMED CONSENT EXPERIMENT 3



ARMY RESEARCH LABORATORY
IRB *Approved 15 April 2016*

Principal Investigator: Timothy L White
Version Date: 22 April 2016
Project Number: ARL 15-043

Site of Research: Tactical Environment Simulator (Bldg. 518), APG, MD

RESEARCH PARTICIPANT CONSENT FORM
ARMY RESEARCH LABORATORY

Project Title:	The Effects of Tactile Displays on the Perception of Target Distance (Experiment 3)
Sponsor:	Department of Defense
Principal Investigator:	Timothy L. White, 4580 Concord Landing Dr. #214, Orlando, FL 32839, 407-534-4678, timothy.l.white1.civ@mail.mil
Date:	22 April 2015

You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask questions at any time about anything you do not understand. If you join the study, you are a volunteer and you can change your mind later. You can decide not to take part right now or you can quit at any time later on.

Why is this research being done?

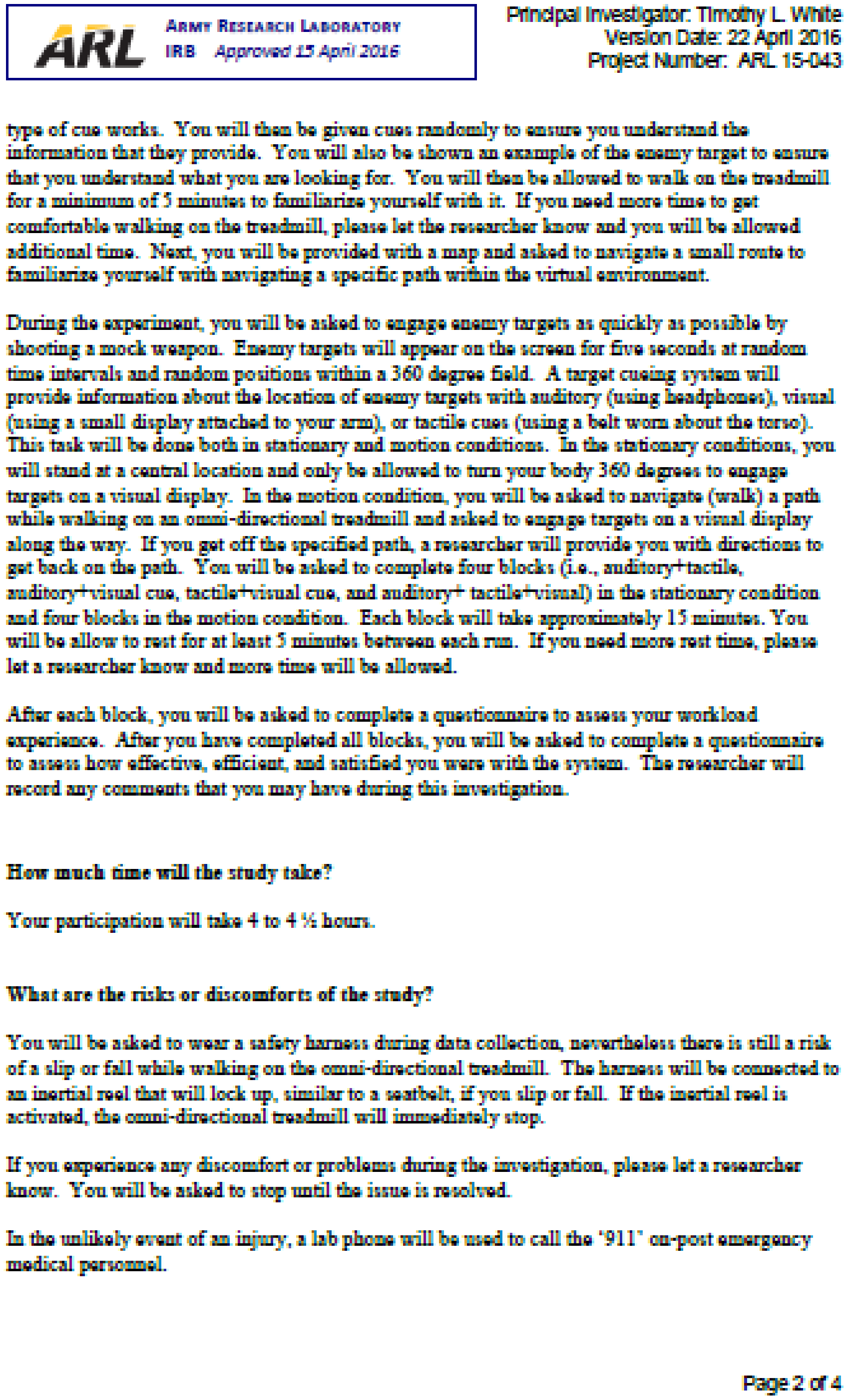
The purpose of this research is to examine the effects of tactile displays (vibratory cues) on the perception of enemy target distance. This study will also specifically examine how combinations of tactile, auditory, and visual cue pairings compare to each other in indicating enemy target distance. You are being invited to participate because you are in good health, not taking medications for any health reasons, and have normal hearing and vision.

What will happen if you join this study?

Upon arrival, you will receive a brief overview of the study. You will then be asked to complete a brief questionnaire to obtain some general information about you. Next, you will receive a vision and hearing test to determine your vision and hearing levels. You will be asked to put on an undershirt provided by a researcher. This undershirt has loops sewn in to ensure that the tactile belt remains in place for the duration of the study. You will then put on the safety harness for the omni-directional treadmill. A researcher will adjust the harness to fit you appropriately. The harness will be worn whenever you are asked to walk on the omni-directional treadmill for safety.

Before the experiment begins, you will be trained on each of the cue types that will be used in the study. There will be an auditory+tactile cue, an auditory+visual cue, a tactile+visual cue, and an auditory+ tactile+visual cue used in this experiment. A researcher will demonstrate how each

Page 1 of 4



type of cue works. You will then be given cues randomly to ensure you understand the information that they provide. You will also be shown an example of the enemy target to ensure that you understand what you are looking for. You will then be allowed to walk on the treadmill for a minimum of 5 minutes to familiarize yourself with it. If you need more time to get comfortable walking on the treadmill, please let the researcher know and you will be allowed additional time. Next, you will be provided with a map and asked to navigate a small route to familiarize yourself with navigating a specific path within the virtual environment.

During the experiment, you will be asked to engage enemy targets as quickly as possible by shooting a mock weapon. Enemy targets will appear on the screen for five seconds at random time intervals and random positions within a 360 degree field. A target cueing system will provide information about the location of enemy targets with auditory (using headphones), visual (using a small display attached to your arm), or tactile cues (using a belt worn about the torso). This task will be done both in stationary and motion conditions. In the stationary conditions, you will stand at a central location and only be allowed to turn your body 360 degrees to engage targets on a visual display. In the motion condition, you will be asked to navigate (walk) a path while walking on an omni-directional treadmill and asked to engage targets on a visual display along the way. If you get off the specified path, a researcher will provide you with directions to get back on the path. You will be asked to complete four blocks (i.e., auditory+tactile, auditory+visual cue, tactile+visual cue, and auditory+ tactile+visual) in the stationary condition and four blocks in the motion condition. Each block will take approximately 15 minutes. You will be allow to rest for at least 5 minutes between each run. If you need more rest time, please let a researcher know and more time will be allowed.

After each block, you will be asked to complete a questionnaire to assess your workload experience. After you have completed all blocks, you will be asked to complete a questionnaire to assess how effective, efficient, and satisfied you were with the system. The researcher will record any comments that you may have during this investigation.

How much time will the study take?

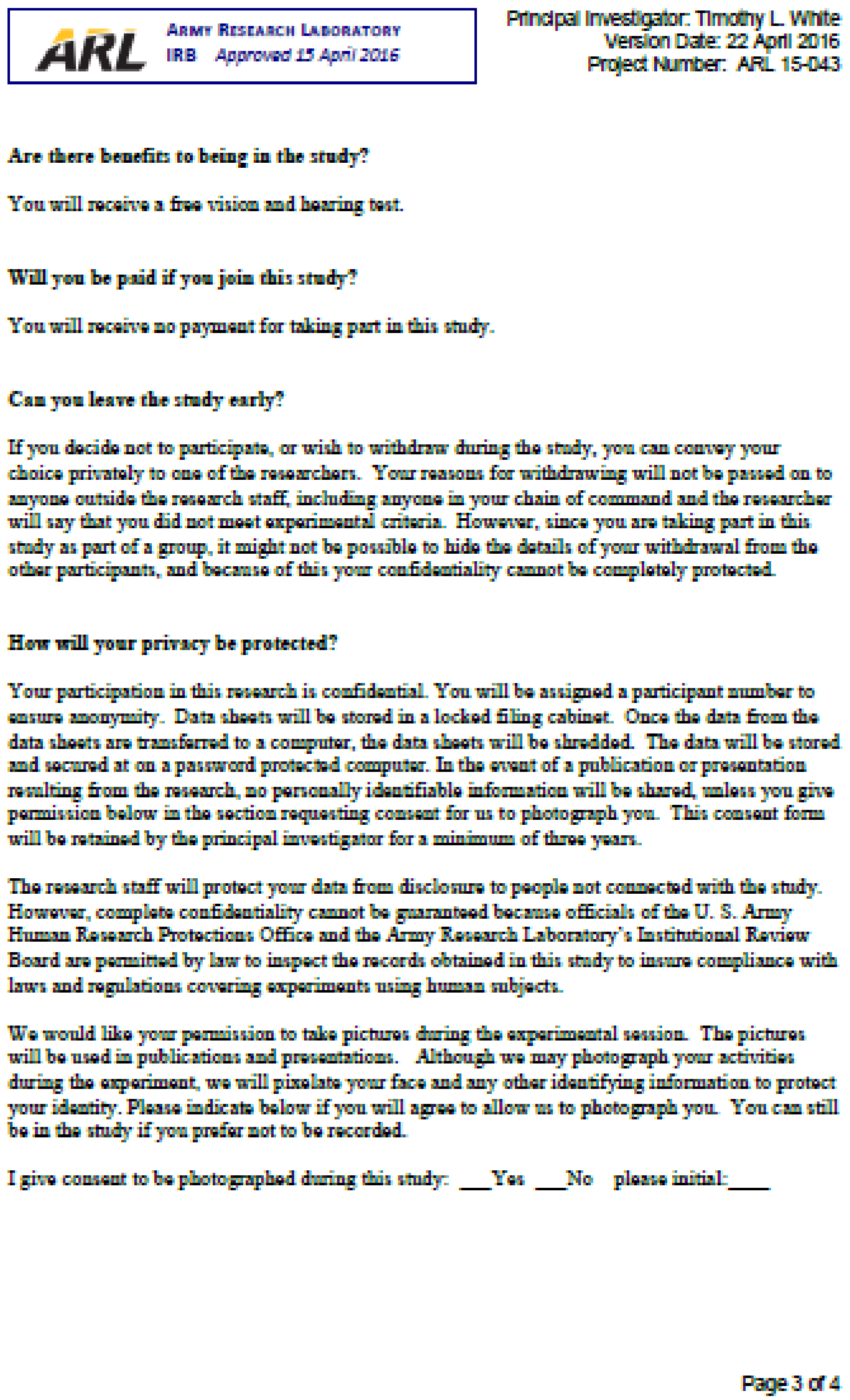
Your participation will take 4 to 4 ½ hours.

What are the risks or discomforts of the study?

You will be asked to wear a safety harness during data collection, nevertheless there is still a risk of a slip or fall while walking on the omni-directional treadmill. The harness will be connected to an inertial reel that will lock up, similar to a seatbelt, if you slip or fall. If the inertial reel is activated, the omni-directional treadmill will immediately stop.

If you experience any discomfort or problems during the investigation, please let a researcher know. You will be asked to stop until the issue is resolved.

In the unlikely event of an injury, a lab phone will be used to call the "911" on-post emergency medical personnel.



ARMY RESEARCH LABORATORY
IRB Approved 15 April 2016

Principal Investigator: Timothy L. White
Version Date: 22 April 2016
Project Number: ARL 15-043

Are there benefits to being in the study?

You will receive a free vision and hearing test.

Will you be paid if you join this study?

You will receive no payment for taking part in this study.

Can you leave the study early?

If you decide not to participate, or wish to withdraw during the study, you can convey your choice privately to one of the researchers. Your reasons for withdrawing will not be passed on to anyone outside the research staff, including anyone in your chain of command and the researcher will say that you did not meet experimental criteria. However, since you are taking part in this study as part of a group, it might not be possible to hide the details of your withdrawal from the other participants, and because of this your confidentiality cannot be completely protected.

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I give consent to be photographed during this study: ___Yes ___No please initial:____

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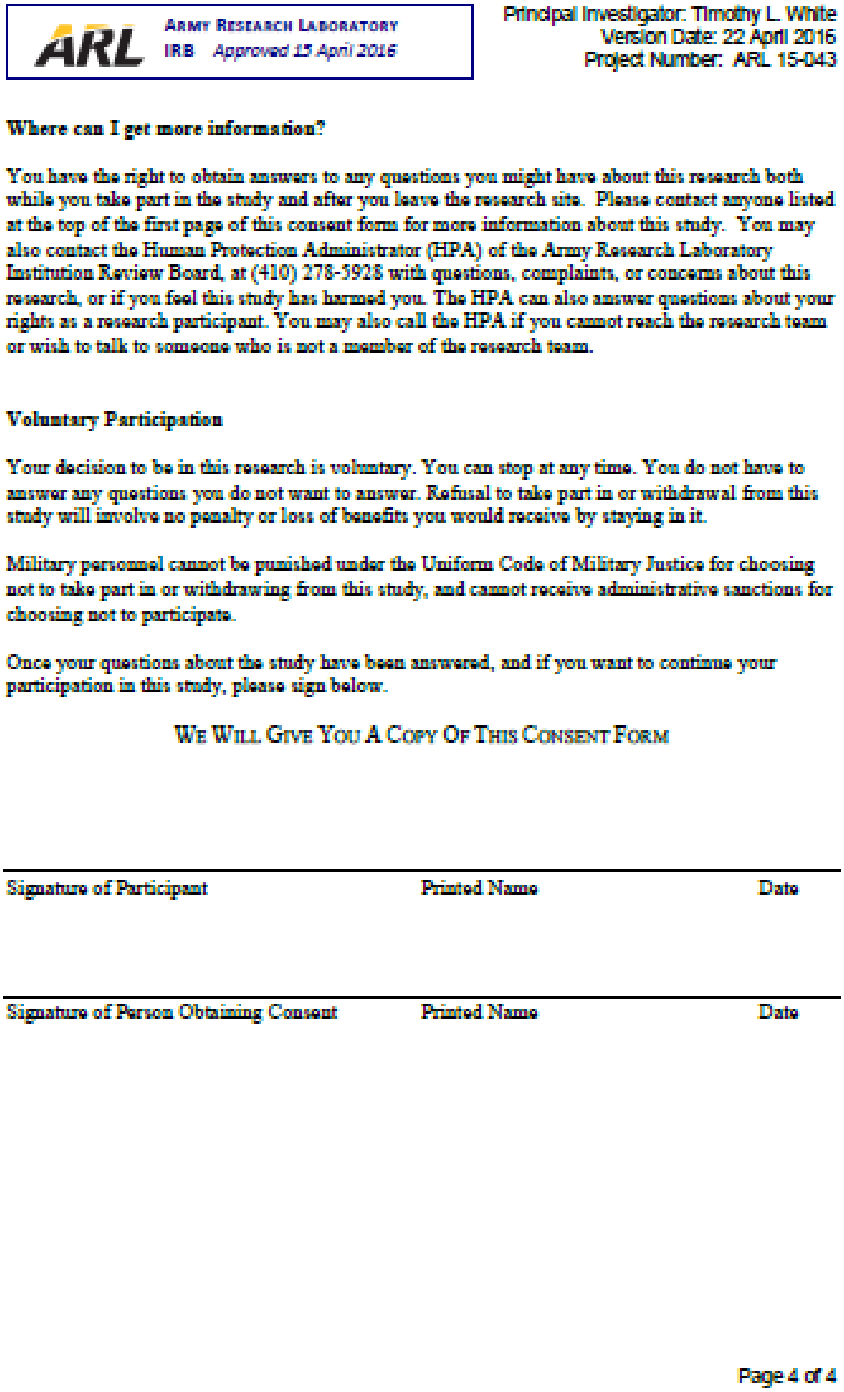

ARL Army Research Laboratory
IRB Approved 15 April 2016

Principal Investigator: Timothy L. White
Version Date: 22 April 2016
Project Number: ARL 15-043

Where can I get more information?

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Signature of Participant	Printed Name	Date
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Page 4 of 4

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