Vibrotactile Guidance Cues For Target Identification

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VIBROTACTILE GUIDANCE CUES FOR TARGET IDENTIFICATION

by

JOSHUA LEE DOWNS
M.S. Florida Institute of Technology, 1998

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Psychology in the College of Arts and Sciences at the University of Central Florida Orlando, Florida

Spring Term
2005

Major Professor: Richard D. Gilson
ABSTRACT

The purpose of this dissertation was to establish how vibrotactile guidance cues can be used to improve marksmanship. This work originated in an effort to provide covert communication, navigation, and weapon aiming cues for infantrymen. It is predominantly an application-driven investigation rather than driven a priori by specific theoretical predictions from models of human performance. Three experiments are presented. Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palmer versus dorsal surface of the hand, and targets appearing left versus right of center. Results suggest that tactile cues provided on the left side of the medial line of the hand afford moving the hand to the left, while tactile cues provided on the right side of the medial line afford moving the hand to the right. Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection. Results indicated an interaction between the pulse rate of vibrotactile stimuli and the method used to highlight an “on-target” condition; the suppressed target condition was superior to the enhanced target condition when the pulse rate increased as the cursor moved closer to a target. Experiment 3 established if there are performance differences between discrete and continuous distance information for target selection, and investigated the interaction between the near-target pulse rate and on-target cues. Results indicate that maximizing the difference between near-target guidance cues and on-target cues reduces the target selection time, particularly when the near-target pulse rates are fast (ISI = 10 msec). The results also suggest that, as with vision, the vibrotactile off-target guidance cues are not necessary during the whole
target selection task. Rather, the guidance cues can be provided only during the initial pop-up condition and during the sub-movements closing on the target.
For my wife and best friend, 김 경은.
ACKNOWLEDGMENTS

I would first like to thank Stanley Roscoe for the inspiration of his book “Aviation Psychology”. Without this book I might never have known I could make a living by my passion for interface design. Without his book I might not have been able to put my dad’s fears so quickly to rest when I had phoned home about this hybrid field of study he had never heard of.

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Murphy was an optimist.
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LIST OF ACRONYMS

EHI     Edinburgh Handedness Inventory
GLM     General Linear Model
GraC    Pulse Rate Gradient Continuous
GraCDi  Pulse Rate Gradient Continuous or Discrete
GraD    Pulse Rate Gradient Down
GraDi   Pulse Rate Gradient Discrete
GraDo   Pulse Rate Gradient Down
GraU    Pulse Rate Gradient Up
GraUD   Pulse Rate Gradient Up or Down
GraUDo  Pulse Rate Gradient Up or Down
iMT     Initial Movement Time
iMove   Probability of Correct Initial Movement
ISI     Inter Stimulus Interval
LARS    Laser Aiming Reference System
LSD     Tukey’s Least Significant Difference
msec    Millisecond
nClicks  Number of Mouse Clicks
otCnt   On-Target Count
SME     Subject Matter Expert
ST      Target Selection Time
TacD    Tactors Dorsal
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>TacP</td>
<td>Tactors Palmer</td>
</tr>
<tr>
<td>TacPD</td>
<td>Tactors Palmer or Dorsal</td>
</tr>
<tr>
<td>TAGS</td>
<td>Tactile Aiming Guidance System</td>
</tr>
<tr>
<td>TarE</td>
<td>Target Enhanced</td>
</tr>
<tr>
<td>TarEf</td>
<td>Target Enhanced Fast Pulse Rate</td>
</tr>
<tr>
<td>TarEs</td>
<td>Target Enhanced Slow Pulse Rate</td>
</tr>
<tr>
<td>TarL</td>
<td>Target Left</td>
</tr>
<tr>
<td>TarLR</td>
<td>Target Left or Right</td>
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<tr>
<td>TarR</td>
<td>Target Right</td>
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<tr>
<td>TarS</td>
<td>Target Suppressed</td>
</tr>
<tr>
<td>TarSE</td>
<td>Target Suppressed or Enhanced</td>
</tr>
<tr>
<td>TarSEsf</td>
<td>Target Suppressed or Enhanced Slow or Fast</td>
</tr>
<tr>
<td>TDB</td>
<td>Tactor Discriminability Bias</td>
</tr>
<tr>
<td>WY-Feel-IWYG</td>
<td>What You Feel Is What You Get</td>
</tr>
<tr>
<td>WYSIWYG</td>
<td>What You See Is What You Get</td>
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CHAPTER ONE: BACKGROUND

The purpose of this dissertation was to establish how vibrotactile guidance cues can be used to improve marksmanship. This work originated in an effort to provide covert communication, navigation, and weapon aiming cues for infantrymen. It is predominantly an application-driven investigation rather than driven a priori by specific theoretical predictions from models of human performance.

Though this project was motivated by an application focusing on marksmanship, other applications are readily apparent; any application requiring the tracking or selection of a target condition may benefit from this research. Angioplasty surgery and intravascular coronary ultrasound, way finding in a visually demanding environment such as in a city, and rambunctious object tracking (i.e., keeping track of small children) are examples. In all of these examples it is necessary to have real-time direction and distance information to achieve some desired target condition.

For this project, however, we focus on marksmanship.

Marksmanship

Typically, marksmanship requires a precise alignment of visual cues. When the sight picture is changing due to relative movement between the target and the weapon, the aim-point must be adjusted to account for this movement. This adjustment of the aim-point is a complex task often requiring a great deal of practice to achieve mastery. Once mastery is achieved, however, rapid and accurate aim-point alignment on target becomes routine and likely transferable to other weapons of the same class (e.g., pistols, assault rifles, sniper rifles).
Schmidt’s (1975) schema theory of motor learning and Schmidt, Zelaznik, Hawkins, Frank, and Quinn’s (1979) theory of motor-output variability provide a flexible and relatively complete picture of what may be happening during the target selection task. Through practice, generalized motor programs become available that allow for rapid, adaptable movements. Once triggered, the generalized motor programs allow for the use of feedback to modify the efferent signals in a movement. Since the marksman is normally able see his or her target relative to the aim-point, any deviation in actual aim-point off the desired aim-point provides feedback for moving the actual aim-point onto the desired aim-point.

An enhancement to the traditional iron sights, reflex sights and laser aiming reference systems (LARS) provide rapid and accurate WYSIWYG visual reference for aim-point adjustment. Reflex sites use an optical system that permits the marksman to align a single dot or crosshair with the target. LARS project a beam of coherent light directly onto the weapon’s aim-point, providing visual feedback reflected directly from the aim-point that can be used by the marksman to align the aim-point with the target. By removing the necessity to align a set of iron sights, Reflex sights and LARS reduce the complexity of the aiming task, potentially permitting faster alignment of the aim-point with the target. However, the LARS dot--and often the beam itself--can be detected by enemy combatants and traced back to its source. Relatedly, enhanced visual sights can be degraded by fog, smoke, dust, sand, and other obstructions.

**Tactile Aiming Guidance System**

Vibrotactile stimulation can provide spatially stabilizing cues for feedback of subtle changes in position (Priplata, Niemi, Salen, Harry, Lipsitz, & Collins, 2002; Akamatsu &
Once such a feedback system is engaged, any deviation from the point of origin can result in tactile stimulation indicating the direction and magnitude of the change in position. Likewise, spatial deviations from a desired position displayed tactually can provide robust position guidance and stabilization sufficient to improve the acquisition time and accuracy of fine cursor control (Jagacinski, Flach, & Gilson, 1983; Jagacinski, Miller, & Gilson, 1979).

Tactile aiming guidance systems (TAGS) may provide covert WY-Feel-IWYG aim-point adjustment that is as rapid and accurate as enhanced visual sights for aim-point adjustment. TAGS may also provide tactile feedback that can be used by the marksman to stabilize weapon aiming.

Since TAGS apply their stimuli to the hands or arms directly, and since TAGS are a tactile channel that may be capable of cooperating with the visual channel without interference (Wickens, 2002), their stimuli may have greater affordances for aim-point guidance and stabilization than the iron and enhanced visual sights. These affordances may translate into decreases in time to hit the target and decreases in number of bullets fired relative to visual aiming cues alone.

**Research Questions Addressed Herein**

Given the potential for TAGS to provide guidance cues for target selection, some developmental issues include:

1. Where should the tactors be placed?

2. Do the affordances change with tactor placement?
3. What kinds of stimuli should TAGS employ to give relative distance between aim-point and desired aim-point?

Experiment 1 was designed to address issues 1 and 2. Experiments 2 and 3 were designed to address issue 3. The affect of tactor placement on the affordance of vibrotactile stimuli applied to the hand was investigated in Experiment 1. The affect of continuous relative distance cues and on- versus off-target tactile stimuli on reaction time and accuracy were explored in Experiments 2 and 3. Experiments 1 and 2 revealed a consistent superiority of the visual and visual + tactile conditions over tactile-only. Both of these experiments provided evidence that vision is the dominant source of information for the object selection task employed. As such, only the visual + tactile and tactile-only conditions were employed in Experiment 3.

Experiments 1 and 2 provided evidence suggesting that the perceived left-ness and right-ness of the tactors is independent of which surface the tactors are located when the tactors are located on the same surface (i.e., palmer or dorsal). As such, the tactor placement in Experiment 3 was selected for ease of application, surety of placement, and sensitivity to vibrotactile stimuli.

Experiment 2 also provided evidence suggesting that continuous distance cues may interact with on-target cues when those cues use the same basic stimuli. As such, Experiment 3 further investigated the interaction between gradient of distance cues and the on-target cues examined in Experiment 2. Also, given that research has suggested that the visual display is not necessary for the entire duration of the movement of a fast target-selection task (Jeannerod & Prablanc, 1983; Carlton, 1981), Experiment 3 investigated both continuous and discrete vibrotactile distance cues.
Experiment 3 established the cueing effectiveness of vibrotactile guidance cues on the hand by employing the Fitts movement-time paradigm (Fitts, 1954; Fitts & Peterson, 1964; Fitts & Radford, 1966; Jagacinski, Pepperger, Moran, Ward, & Glass, 1980). Specifically, this study investigated discrete versus continuous vibrotactile relative distance cues, and on- versus off-target vibrotactile stimuli.
CHAPTER TWO: EXPERIMENT 1

Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. It was expected that vibrotactile direction cues applied medially to the same surface of the hand will result in world-centric left-ness and right-ness independent of surface applied.

**Design**

The intent for Experiment 1 was to investigate the affect on affordance of tactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. As such, Experiment 1 employed a two-way repeated measures design (see Table 1).

<table>
<thead>
<tr>
<th>Target Left</th>
<th>Target Right</th>
</tr>
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<tbody>
<tr>
<td>Palmer</td>
<td>Palmer</td>
</tr>
<tr>
<td>Dorsal</td>
<td>Dorsal</td>
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</table>

<table>
<thead>
<tr>
<th>Tactile Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmer</td>
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<tr>
<td>Dorsal</td>
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Table 1: Outline of the design for Experiment 1

The within-subjects variables included Tactors Palmer or Dorsal (TacPD) and Target Left or Right (TarLR). Tactors Palmer refers to the tactors being placed between the mouse and the participant’s hand (see Figure 1). Tactors Dorsal refers to the participant’s hand being place
between the mouse and the tactors (see Figure 2). These positions were chosen because they offered a mirror-image from palmar to dorsal surfaces that minimally interfered with the manipulation of the mouse. Target Left refers to targets to the left of center at the start of a trial. Likewise, Target Right refers to targets to the right of center at the start of a trial.

Figure 1: Palmer location of tactors

Figure 2: Dorsal location of tactors
Participants

24 undergraduate students at the University of Central Florida participated in this first Experiment. There were 12 males and 12 females in the sample. Though 3 males and 1 female stated that they write with their left hand, all participants stated that they use their right hand for mouse operations.

Apparatus

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the tactor driver, which in turn drives the tactors (see Figure 3).
In keeping with the Fitts movement-time paradigm, the software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center, and 2 right of center). The small targets were 14 pixels wide; large targets were 28 pixels wide. The center of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant.

Trials always started with the cursor at the center of the display. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets. The inertial mouse was held unsupported in such a way as to align the forearm parallel to the floor. When the mouse is used in its inertial mouse mode, the user’s hand naturally orients perpendicular with respect to the floor (see Figure 4). Movement of the cursor fully left or right from the center of the screen required a wrist flexion or extension of 60 degrees.
Figure 4: Hand position when holding the inertial mouse

The target left/right guidance cues were provided by the vibrotactile display only. No visual presentation of targets or the cursor was provided. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 5).
The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969).

All participants reported the stimulus from both tactors as being distinct and comfortable. Modulation of the stimuli consisted of a stimulus interval (SI) of 100 msec and an inter stimulus interval (ISI) of 50 msec. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Initial movement time (iMT), probability of correct initial movement direction (iMove), and time-stamped movement profiles were collected for each trial. iMT for this experiment is
defined as the time in msec between target pop-up and the start of movement by the participant. iMove for this experiment is defined as the probability of making a correct initial movement toward the target by the participant. Movement profiles consisted of the time-stamped (in msec) ‘x’ screen coordinate of the center of the cursor recorded once every mouse tick. Mouse ticks only occur when there is movement of the mouse, with a maximum recording rate of about 100 mouse ticks per second for the described system.

**Procedure**

Participants were assigned to one of two orders of presentation of the TacPD condition. The participants were presented 2 blocks of 16 targets, for a total of 32 targets. Each target represented one trial. Upon completion of the first 16 trials, the tactor location was switched. Before each block of trials, the tactor placement was verified by obtaining the participant’s subjective perception of the discriminability and comfort of the tactors. This was accomplished by pulsing first one, then the other tactor, and having the participant point to the tactor they felt was activated. Upon completion of the trials, the participants were asked to fill out a questionnaire about their experience with computers and video games, and their experiences during the experiment.

For all trials the participants sat comfortably in front of the computer monitor in such a way that their hand holding the mouse would not touch the desk supporting the monitor. Participants were asked with which hand they normally used a computer mouse, and the tactors were applied as appropriate for each participant. Tactors were placed in line with the thumb and fourth finger at the base of the palm, either on the palmer or dorsal surface of the hand,
depending on the block of trials. The tactors were held in place by a fabric strap wrapped around the hand. Participants had the tactors in contact with their hand for all trials.

Participants were instructed to depress and hold the inertial mouse mode button under the mouse with their index finger whenever they wanted to move the cursor. The participants then practiced using the inertial mouse to move the cursor fully left, right, up, and down by using only hand motions about the wrist. Though the tactors were in place during this practice, they were not active.

The primary task of the participants during a trial was to depress the inertial mouse mode button under the mouse and quickly move their hand in the direction of the target when they had an idea where the target was located. When a trial began, the tactile stimulus was presented. It continued to be presented until the trial ended. Irrespective of the correctness of the movement, each trial ended when the participant moved the cursor beyond the distance the target was located from the center of the screen. When each trial ended, the participant was to return his or her hand to a neutral, comfortable position and wait for the next trial to begin.

**Results**

The GLM in SPSS 11.5 was employed to analyze the two-way repeated measures design. All tests were run at the $\alpha = .05$ level.

Unambiguous intentional movements did not typically appear within 1 degree of hand movement, suggesting that the tolerance for identifying the initial movement could be widened to 8 pixels (1 degree of hand movement) rather than the 1 pixel tolerance employed by the data collection program. This 1 degree tolerance was applied to the iMT and iMove data.
There was no significant interaction between TacPD and TarLR on iMT ($M_{PL} = 647.771$; $M_{PR} = 643.677; M_{DL} = 708.505; M_{DR} = 679.276$; $F(1,23) = .966, p > .05, \eta_p^2 = .040, 1-\beta = .156$) (see Figure 6).

Figure 6: Interaction between TacPD and TarLR on iMT
The main effect of TacPD on iMT (see Figure 7) was not significant ($M_{Palmer} = 645.724$; $M_{Dorsal} = 693.891$; $F(1,23) = 1.495, p > .05, \eta^2_p = .061, 1-\beta = .216$).

Figure 7: Main effect of TacPD on iMT
The main effect of TarLR on iMT (see Figure 8) was also not significant ($M_{left} = 678.138$; $M_{right} = 661.477$; $F(1,23) = .961, p > .05, \eta^2_p = .040, 1-\beta = .156$).

Figure 8: Main effect of TarLR on iMT
There was no significant interaction between TacPD and TarLR on iMove ($M_{PL} = .776; M_{PR} = .755; M_{DL} = .734; M_{DR} = .682; F(1, 23) = .195, p > .05, \eta^2_p = .008, \beta = .071$) (see Figure 9).

Figure 9: Interaction between TacPD and TarLR on iMove
The main effect of TacPD on iMove (see Figure 10) was not significant ($M_{\text{Palmer}} = .766; M_{\text{Dorsal}} = .708; F(1,23) = 1.031, p > .05, \eta^2_p = .043, 1-\beta = .164)$.

Figure 10: Effect of TacPD on iMove
The main effect of TarLR on iMove (see Figure 11) was also not significant ($M_{\text{left}} = .755$; $M_{\text{right}} = .719$; $F(1,23) = 0.989$, $p > .05$, $\eta_p^2 = .041$, $1-\beta = .159$).

![Figure 11: Effect of TarLR on iMove](image)

**Discussion**

The data suggest that the affordance of vibrotactile guidance cues is independent of the location of the tactors on the hand when both tactors are located on the palmer or dorsal surface. Tactile cues provided on the left side of the hand (palm facing down) afford moving the hand to the left, while tactile cues provided on the right side of the hand afford moving the hand to the right. This affordance holds irrespective of whether the tactile cues are applied to the palmer or the dorsal surface of the hand.

Though effective for establishing the affordance of vibrotactile guidance cues applied to the same surface of the hand oriented with the palmer surface perpendicular to the floor, this
experiment did not fully explore the affordance of these stimuli applied to opposite surfaces (e.g., one tactor palmer and one tactor dorsal) or with more diverse hand orientations. Since the tactors would most likely be applied to only one surface of the hand in TAGS (i.e., palmer or dorsal), our purpose for these studies was to establish, among other things, which surface of the hand should be employed for our given application rather than exploring the more fundamental affordance issues requiring an exhaustive analysis of the possible combinations of tactor placement, hand orientation, acceleration, visual stimuli, cognitive congruency, etc. Such a study would permit a more complete analysis of the possible shift between negative- and positive-feedback that may occur with multi-surface tactor placement spanning a wide range of hand orientations with respect to the floor.
CHAPTER THREE: EXPERIMENT 2

Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection.

For these studies, visual target cues were set against a visual background that must be searched. Tactile target cues were set against a relatively quiet background, and always correctly indicated the direction of the target. As such, it was expected that tactile target cues would facilitate target search, and that visual + vibrotactile direction and distance cues would result in faster time-to-target compared to visual cues only.

Initial pulse on target popup gives direction; increasing pulse rate gradient gives rapid feedback during near-target sub movements. Decreasing pulse rate gradient gives similar initial pulse cue on target popup, but less rapid feedback during near-target sub movements. Unlike the initial, ballistic movement from the origin to a location near the target, near-target sub movements are generally considered to be closed loop; feedback is useful for providing cues for determining relative-position near the target. Rapidly updating feedback close to the target should provide a more accurate indication of relative location as the user continues his or her target-selection task than feedback that is updated slowly. As such, it was expected that fast pulse rates near the target would result in faster time-to-target compared to slow pulse rates.

**Design**

The intent of Experiment 2 was to investigate the affect on affordance of tactile guidance cues of on-target versus off-target tactile guidance, and pulse rate gradient of the tactile stimulus.
sweeping up versus sweeping down as the cursor approaches the target. As such, Experiment 2 employed a 3 x 2 x 2 mixed factorial design (see Table 2).

Table 2: Outline of the design for Experiment 2

<table>
<thead>
<tr>
<th>Target Suppressed</th>
<th>Target Enhanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient UP</td>
<td>Gradient UP</td>
</tr>
<tr>
<td>Gradient DOWN</td>
<td>Gradient DOWN</td>
</tr>
<tr>
<td>Visual</td>
<td>Visual +Tactile</td>
</tr>
<tr>
<td>Tactile</td>
<td></td>
</tr>
<tr>
<td>Visual + Tactile</td>
<td></td>
</tr>
</tbody>
</table>

The within-subjects variable was Display (visual, tactile, and visual + tactile). Between-subjects variables included TarSE (Target Suppressed or Enhanced) and GraUD (pulse rate gradient sweeps Up or Down as the cursor approaches the target). Target Suppressed refers to the tactors being activated only when the cursor is off the target; when the cursor is on the target, the tactile display is turned off. Target Enhanced refers to the tactors being activated when the cursor is both off and on the target; when the cursor is on the target, both tactors are activated at the same time. Pulse rate gradient sweeps Up refers to increasing the pulse rate as the cursor gets closer to the target; the farther the cursor is from the target, the slower the pulse rate. Pulse rate gradient sweeps Down, conversely, refers to decreasing the pulse rate as the cursor gets closer to the target; the farther the cursor is from the target, the faster the pulse rate.
**Participants**

The 24 undergraduate students at the University of Central Florida who participated in Experiment 1 also participated in this experiment. Hence, there were 12 males and 12 females in the sample. Though 3 males and 1 female stated that they write with their left hand, all participants stated that they use their right hand for mouse operations. Each participant performed both experiments on the same day. A short break was offered between the experiments, but all participants declined.

**Apparatus**

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the driver, which in turn drives the tactors (see Figure 12).
In keeping with the Fitts movement-time paradigm, the software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center, and 2 right of center). Targets consisted of a soldier from the Ghost Recon game holding an AK-74 pointed at the participant (actor “m05_eli_ak74_1.atr”) (see Figure 13).

Figure 13: Visual Target
The target was captured in perspective for each target location and size, and included a shadow. Small targets were 14 pixels wide; large targets were 28 pixels wide. The centers of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant.

The cursor was depicted as a white ‘+’ 19 pixels across, and always started a trial in the center of the screen. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets.

The inertial mouse was used in its optical mouse mode on the desk surface in front of the monitor. Tactors were positioned on either side of the mouse such that the thumb and third finger were in direct contact with the tactors’ vibrating elements (see Figure 14). Movement of the mouse required to put the cursor onto the nearest targets required a 2.5-inch movement of the mouse from the point of origin. Movement of the mouse required to put the cursor onto the farthest targets required a 5.0-inch movement of the mouse from the point of origin.
The target left/right guidance cues were provided by the visual display, by the tactile display, or by both the visual and tactile display, depending on the block of trials. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 15).
The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969). The pulse rate was defined by varying the inter stimulus interval (ISI) of the vibrotactile stimulus. The rising and falling of the pulse rate with distance from the target was driven by a 3rd order polynomial function ranging from ISIs of 250 msec to 10 msec (see Figure 16).
The distribution of ISIs by distance from target was obtained by fitting a curve to the average movement profile from Experiment 1. This distribution was applied whenever the cursor was within 60 degrees of the target; beyond 60 degrees the ISI was constant at either 250 msec or 10 msec. A stimulus interval of 100 msec was applied to the tactile stimuli irrespective of the ISI. All participants had a 100% detection rate for the tactile stimuli. All participants reported the stimulus from both tactors as being distinct and comfortable. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Raw initial movement time (iMT), raw probability of correct initial movement (iMove), the number of times on-target (otCnt), time from target pop-up to target drop (ST), and time-stamped movement profiles were collected for each trial. iMT for this experiment is defined as the time in msec between target pop-up and the start of movement by the participant. iMove is the probability of a correct initial movement toward the target by the participant. otCnt is defined as the number of times the cursor went from off-target to on-target. ST is the time in
msec from target pop-up to target drop. Movement profiles consisted of the time-stamped (in msec) horizontal screen coordinate of the center of the cursor recorded once every mouse tick. Mouse ticks only occur when there is movement of the mouse, with a maximum recording rate of about 100 mouse ticks per second for the described system.

**Procedure**

Participants were randomly assigned to one of four groups: target suppressed, gradient UP; target suppressed, gradient DOWN; target enhanced, gradient UP; and target enhanced, gradient DOWN. The participants were presented 3 blocks of 32 targets, for a total of 96 targets. Each presentation of a target represents one trial. The first block of trials was visual only, the second block of trials was tactile only, and the third block of trials was visual and tactile. Order of presentation of the blocks was not varied in this experiment. Before each block of trials, the instructions specific for the next block of trials were briefly reviewed. Upon completion of the experiment, the participants were asked to fill out a questionnaire about their experience with computers and video games, and their experiences during the experiment.

For all trials the participants sat comfortably in front of the computer monitor in such a way that their hand could comfortably move the mouse on the desk. The monitor was positioned approximately 21 inches from the bridge of the participant’s nose. Tactors were positioned on the sides of the mouse such that the thumb and third finger were in direct contact with the vibrating element on the tactors. Participants had the tactors in contact with their fingertips for all trials.
The primary task of the participants during a trial was to quickly move the cursor onto the target when they had an idea where the target was located, and clicking the left mouse button. When a trial began, the target stimuli were presented as appropriate for the block. The stimuli continued to be presented until the trial ended. Each trial ended when the participant clicked on the target. The next trial began after a random delay ranging from 2 to 9 seconds.

**Results**

The GLM in SPSS 11.5 was employed to analyze the 3 x 2 x 2 mixed factorial design. Fisher’s LSD was employed on all post-hoc analyses. All tests were run at the $\alpha = .05$ level.

**Initial Movement Time (iMT)**

The results for iMT are presented in Table 3. Means for the Display x TarSE x GraUD interaction are presented in Table 4. Figure 17 depicts the significant Display x TarSE x GraUD interaction.
### Table 3: Results for raw initial movement time (msec)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-(\beta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>566043.922</td>
<td>71</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TarSE</td>
<td>3346.643</td>
<td>1</td>
<td>3346.643</td>
<td>0.333</td>
<td>ns</td>
<td>0.016</td>
<td>0.085</td>
</tr>
<tr>
<td>GraUD</td>
<td>3087.670</td>
<td>1</td>
<td>3087.670</td>
<td>0.308</td>
<td>ns</td>
<td>0.015</td>
<td>0.083</td>
</tr>
<tr>
<td>TarSE x GraUD</td>
<td>133.049</td>
<td>1</td>
<td>133.049</td>
<td>0.013</td>
<td>ns</td>
<td>0.001</td>
<td>0.051</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
<td>200746.631</td>
<td>20</td>
<td>10037.332</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>186294.635</td>
<td>2</td>
<td>93147.318</td>
<td>33.350</td>
<td>&lt;.05</td>
<td>0.625</td>
<td>1.000</td>
</tr>
<tr>
<td>Display x TarSE</td>
<td>20366.885</td>
<td>2</td>
<td>10183.443</td>
<td>3.646</td>
<td>&lt;.05</td>
<td>0.154</td>
<td>0.639</td>
</tr>
<tr>
<td>Display x GraUD</td>
<td>3771.514</td>
<td>2</td>
<td>1885.757</td>
<td>0.675</td>
<td>ns</td>
<td>0.033</td>
<td>0.156</td>
</tr>
<tr>
<td>Display x TarSE x GraUD</td>
<td>36574.319</td>
<td>2</td>
<td>18287.159</td>
<td>6.547</td>
<td>&lt;.05</td>
<td>0.247</td>
<td>0.887</td>
</tr>
<tr>
<td><strong>Errorw</strong></td>
<td>111722.576</td>
<td>40</td>
<td>2793.064</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

### Table 4: Means for Display x TarSE x TacNF on iMT

<table>
<thead>
<tr>
<th>TarS/GraU</th>
<th>410.948</th>
<th>377.313</th>
<th>293.417</th>
</tr>
</thead>
<tbody>
<tr>
<td>TarS/GraD</td>
<td>344.354</td>
<td>422.656</td>
<td>267.219</td>
</tr>
<tr>
<td>TarE/GraU</td>
<td>427.344</td>
<td>409.542</td>
<td>277.542</td>
</tr>
<tr>
<td>TarE/GraD</td>
<td>435.073</td>
<td>332.969</td>
<td>315.250</td>
</tr>
</tbody>
</table>
For both gradient up (GraU) and gradient down (GraD) at suppressed targets (TarS), the visual-only and tactile-only guidance cues resulted in longer iMT than the combined visual + tactile guidance cues; visual-only was not significantly different from tactile-only. For GraU at enhanced targets (TarE), the visual-only and tactile-only guidance cues resulted in longer iMT...
than the combined visual + tactile guidance cues. For GraD at TarE, the visual-only guidance cues resulted in longer iMT than tactile-only and the combined visual + tactile guidance cues; tactile-only was not significantly different from the combined guidance cues. TarS/GraD resulted in longer iMT than TarE/GraD at tactile-only.

Selection Time (ST)

The results for ST are presented in Table 5. Means for the Display x TarSE interaction are presented in Table 6. Figure 18 depicts the non significant Display x TarSE x GraUD interaction. Figure 19 depicts the significant Display x TarSE interaction.
Table 5: Results for Time from Pop-Up to Drop (msec)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-(\beta)</th>
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</thead>
<tbody>
<tr>
<td>Total</td>
<td>826385362.242</td>
<td>71</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Between Subjects</td>
<td>138783153.596</td>
<td>23</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TarSE</td>
<td>42743969.063</td>
<td>1</td>
<td>42743969.063</td>
<td>11.017</td>
<td>&lt;.05</td>
<td>0.355</td>
<td>0.884</td>
</tr>
<tr>
<td>GraUD</td>
<td>8481922.071</td>
<td>1</td>
<td>8481922.071</td>
<td>2.186</td>
<td>ns</td>
<td>0.099</td>
<td>0.291</td>
</tr>
<tr>
<td>TarSE x GraUD</td>
<td>9959416.949</td>
<td>1</td>
<td>9959416.949</td>
<td>2.567</td>
<td>ns</td>
<td>0.114</td>
<td>0.332</td>
</tr>
<tr>
<td>Errorb</td>
<td>77597845.513</td>
<td>20</td>
<td>3879892.276</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Within Subjects</td>
<td>687602208.646</td>
<td>48</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Display</td>
<td>441362471.881</td>
<td>2</td>
<td>220681235.941</td>
<td>64.920</td>
<td>&lt;.05</td>
<td>0.764</td>
<td>1.000</td>
</tr>
<tr>
<td>Display x TarSE</td>
<td>79018849.743</td>
<td>2</td>
<td>39509424.872</td>
<td>11.623</td>
<td>&lt;.05</td>
<td>0.368</td>
<td>0.990</td>
</tr>
<tr>
<td>Display x GraUD</td>
<td>14132743.636</td>
<td>2</td>
<td>7066371.818</td>
<td>2.079</td>
<td>ns</td>
<td>0.094</td>
<td>0.402</td>
</tr>
<tr>
<td>Display x TarSE x GraUD</td>
<td>17116393.052</td>
<td>2</td>
<td>8558196.526</td>
<td>2.518</td>
<td>ns</td>
<td>0.112</td>
<td>0.475</td>
</tr>
<tr>
<td>Errorw</td>
<td>135971750.334</td>
<td>40</td>
<td>3399293.758</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 6: Means for Display x TarSE on ST

<table>
<thead>
<tr>
<th></th>
<th>Vis</th>
<th>Tac</th>
<th>Vis+Tac</th>
</tr>
</thead>
<tbody>
<tr>
<td>TarS</td>
<td>1390.286</td>
<td>4395.182</td>
<td>1340.813</td>
</tr>
<tr>
<td>TarE</td>
<td>1455.234</td>
<td>8899.255</td>
<td>1394.776</td>
</tr>
</tbody>
</table>
Figure 18: Display x TarSE x GraUD on ST
Figure 19: Display x TarSE on ST

TarE was significantly slower than TarS for tactile-only. TarS and TarE at tactile-only were significantly slower than at visual and visual + tactile.

**On-Target Count (otCnt)**

The results for otCnt are presented in Table 7. Means for the Display x TarSE x GraUD interaction are presented in Table 8. Figure 20 depicts the significant Display x TarSE x GraUD interaction.
Table 7: Results for number of times cursor moves from off- to on-target

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>η²</th>
<th>I-β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>148.456</td>
<td>71</td>
<td>--</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TarSE</td>
<td>6.608</td>
<td>1</td>
<td>6.608</td>
<td>11.309</td>
<td>&lt;.05</td>
<td>0.361</td>
<td>0.892</td>
</tr>
<tr>
<td>GraUD</td>
<td>3.204</td>
<td>1</td>
<td>3.204</td>
<td>5.482</td>
<td>&lt;.05</td>
<td>0.215</td>
<td>0.606</td>
</tr>
<tr>
<td>TarSE x GraUD</td>
<td>3.639</td>
<td>1</td>
<td>3.639</td>
<td>6.228</td>
<td>&lt;.05</td>
<td>0.237</td>
<td>0.661</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
<td>11.687</td>
<td>20</td>
<td>0.584</td>
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<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>83.371</td>
<td>2</td>
<td>41.685</td>
<td>70.895</td>
<td>&lt;.05</td>
<td>0.780</td>
<td>1.000</td>
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<tr>
<td>Display x TarSE</td>
<td>8.087</td>
<td>2</td>
<td>4.043</td>
<td>6.877</td>
<td>&lt;.05</td>
<td>0.256</td>
<td>0.902</td>
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<tr>
<td>Display x GraUD</td>
<td>3.707</td>
<td>2</td>
<td>1.854</td>
<td>3.153</td>
<td>ns</td>
<td>0.136</td>
<td>0.572</td>
</tr>
<tr>
<td>Display x TarSE x GraUD</td>
<td>4.634</td>
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<td>2.317</td>
<td>3.940</td>
<td>&lt;.05</td>
<td>0.165</td>
<td>0.675</td>
</tr>
<tr>
<td><strong>Errorw</strong></td>
<td>23.520</td>
<td>40</td>
<td>0.588</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Means for Display x TarSE x GraUD on otCnt

<table>
<thead>
<tr>
<th>Vis</th>
<th>Tac</th>
<th>Vis+Tac</th>
</tr>
</thead>
<tbody>
<tr>
<td>TarS/GraU</td>
<td>1.198</td>
<td>2.698</td>
</tr>
<tr>
<td>TarS/GraD</td>
<td>1.177</td>
<td>2.802</td>
</tr>
<tr>
<td>TarE/GraU</td>
<td>1.396</td>
<td>5.417</td>
</tr>
<tr>
<td>TarE/GraD</td>
<td>1.146</td>
<td>3.188</td>
</tr>
</tbody>
</table>

37
Figure 20: Display x TarSE x GraUD on otCnt

For both GraU and GraD at TarS, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and combined visual + tactile guidance cues; visual-only was not significantly different from visual + tactile. For GraU at TarE, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and combined visual + tactile guidance cues;
visual-only was not significantly different from visual + tactile. For GraD at TarE, the tactile-only guidance cues resulted in a larger otCnt than the visual-only and visual + tactile. The visual-only guidance cues resulted in a lower otCnt than visual + tactile.

TarS/GraU resulted in a lower otCnt than TarE/GraU at tactile-only and visual + tactile. TarS/GraD resulted in a lower otCnt than TarE/GraU at tactile-only and visual + tactile. TarS/GraD also resulted in a lower otCnt than TarE/GraD at tactile-only. TarE/GraD resulted in a lower otCnt than TarE/GraU at tactile-only.

**Probability of Correct Initial Movement (iMove)**

The results for iMove are presented in Table 9. Figure 21 depicts the Display x TarSE x GraUD interaction.
Table 9: Results for probability of correct initial movement

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-(\beta)</th>
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<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TarSE</td>
<td>0.002</td>
<td>1</td>
<td>0.002</td>
<td>1.111</td>
<td>ns</td>
<td>0.053</td>
<td>0.171</td>
</tr>
<tr>
<td>GraUD</td>
<td>0.005</td>
<td>1</td>
<td>0.005</td>
<td>3.086</td>
<td>ns</td>
<td>0.134</td>
<td>0.387</td>
</tr>
<tr>
<td>TarSE x GraUD</td>
<td>0.003</td>
<td>1</td>
<td>0.003</td>
<td>1.975</td>
<td>ns</td>
<td>0.090</td>
<td>0.268</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
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<td>--</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<td>0.008</td>
<td>2</td>
<td>0.004</td>
<td>2.346</td>
<td>ns</td>
<td>0.105</td>
<td>0.447</td>
</tr>
<tr>
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<td>2</td>
<td>0.001</td>
<td>0.370</td>
<td>ns</td>
<td>0.018</td>
<td>0.105</td>
</tr>
<tr>
<td>Display x GraUD</td>
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<td>2</td>
<td>0.002</td>
<td>0.864</td>
<td>ns</td>
<td>0.041</td>
<td>0.188</td>
</tr>
<tr>
<td>Display x TarSE x GraUD</td>
<td>0.000</td>
<td>2</td>
<td>0.000</td>
<td>0.123</td>
<td>ns</td>
<td>0.006</td>
<td>0.068</td>
</tr>
<tr>
<td><strong>Errorw</strong></td>
<td>0.070</td>
<td>40</td>
<td>0.002</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Figure 21: Display x TarSE x GraUD on iMove
**Discussion**

The data suggest that there may be an interaction between the gradient of vibrotactile stimuli and the method used to highlight an “on-target” condition. The suppressed target condition was superior to the enhanced target condition. This is particularly true when the pulse rate increases as the cursor moves closer to a target.

This experiment employed a target-enhanced condition that pulsed at the same rate as the guidance cues provided immediately to either side of the target. No data are provided by this experiment that suggest how performance changes when the target-enhanced condition pulses at the opposite rate as the guidance cues. Such an extreme variation in near-target versus on-target cues may null any differences between the suppressed and enhanced target conditions. SME comments also suggest that continuous display of distance and direction may not be as useful (or desirable) as discrete distance and direction cues. Likewise, research has suggested that the visual display is not necessary for the entire duration of the movement of a fast target-selection task (Jeannerod & Prablanc, 1983; Carlton, 1981). Rather, feedback providing relative distance information must be provided near the target for any high degree of accuracy in target selection. Providing higher resolution feedback (ISI < 100 msec) should improve target selection accuracy compared to lower resolution feedback (ISI > 100 msec).

As a byproduct of the programming methods used to track timing and changes in mouse position, this experiment and Experiment 1 created movement profiles that, while spatially accurate, were temporally inaccurate. The methods employed permit a time-stamped update of the mouse position roughly once every 10 msec. A large number of mouse movements could have been recorded by the software during this time, but the timing was not updated at rates less
than 10 msec. This lag in update times resulted in sets of records where the mouse position changed but the time stamp did not change. As such, development of velocity and acceleration profiles was problematic at best; only the spatial profiles could be investigated with a high degree of accuracy.
CHAPTER FOUR: EXPERIMENT 3

Experiment 3 established the cueing effectiveness of vibrotactile guidance cues on the hand by employing the Fitts movement-time paradigm (Fitts, 1954; Fitts & Peterson, 1964; Fitts & Radford, 1966; Jagacinski, Pepperger, Moran, Ward, & Glass, 1980). Specifically, this study investigated discrete versus continuous vibrotactile relative distance cues, and on- versus off-target vibrotactile stimuli. Two hypotheses were explored in this experiment.

From the study of JND's in audition, vision, and tactile perception (Friberg & Sundberg, 1995; Drake & Botte, 1993; Orban, Van Calenbergh, de Bruyn, & Maes, 1985; Stevens, 1959; Mowbray & Gebhard, 1955), we know that temporally based perception requires some minimum level of change or difference between stimuli. When you maximize the difference between two stimuli, you maximize the chance of detecting that difference. We achieve this maximum difference for our application by making sure that the on-target stimuli is as different as possible from the near-target guidance cues. This translates into having a fast pulse rate (e.g., ISI = 10 msec) near the target with either an absence of vibrotactile stimuli on-target or a slow pulse rate (e.g., ISI = 250 msec) on-target from both of the tactors. We can also have a slow pulse rate presented near the target with the fast pulse rate on-target. Minimum difference between the on-target and near-target stimuli occurs when the on-target and near-target pulse rates are the same. With this in mind, using the absence of vibrotactile stimuli on-target with the slow pulse rate near the target should result in an intermediate level of difference between the on-target and near-target stimuli. It is thus expected that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate.
Prior research has suggested that visual guidance for target selection is required only at initial movement and at the end of the initial movement during target closure (Jeannerod & Prablanc, 1983; Carlton, 1981). The off-target vibrotactile pulse rates with ISI's in excess of 100 msec used in Experiment 2 may already be providing this discrete form of guidance. When a target was presented, the initial, rapid ballistic movement made by the participants bypassed the slow pulse rates far from the target. At the end of the ballistic movement, the near-target pulse rates were such that several pulses would have been felt during the sub-movements leading to final target selection, providing the needed guidance cues to close on the target. As such, it is expected that discontinuous vibrotactile direction and distance cues will result in identical target selection times to continuous vibrotactile direction and distance cues.

**Design**

The intent of this experiment was to establish if there are performance differences between discrete and continuous distance information for target selection, and investigate the interaction between the near-target pulse rate and on-target cues. This Experiment 1lso was to establish if there are performance differences between tactile and visual + tactile. As such, this experiment employed a 2 x 3 x 2 x 2 mixed factorial design (see Table 10).
The within-subjects variables include Visual + Tactile or Tactile (Display), and Target Suppressed, Target Enhanced Slow, or Target Enhanced Fast (TarSEsf). Target Suppressed refers to the tactors being activated only when the cursor is off the target; when the cursor is on the target, the tactile display is turned off. Target Enhanced Slow refers to the tactors being activated at the slowest pulse rate when the cursor is on the target; when the cursor is on the target, both tactors are activated at the same time with a slow pulse rate. Target Enhanced Fast refers to the tactors being activated at the fastest pulse rate when the cursor is on the target; when the cursor is on the target, both tactors are activated at the same time with a fast pulse rate.

Between-subjects variables include Gradient Continuous or Gradient Discrete (GraCDi), and pulse rate Gradient sweeps UP or pulse rate Gradient sweeps DOWN (GraUDo). Pulse rate Gradient sweeps UP refers to increasing the pulse rate (decreasing ISI) as the cursor gets closer to the target; the farther the cursor is from the target, the slower the pulse rate (increasing ISI). Pulse rate Gradient sweeps DOWN, conversely, refers to decreasing the pulse rate (increasing...
ISI) as the cursor gets closer to the target; the farther the cursor is from the target, the faster the pulse rate (decreasing ISI).

Figure 22 graphically depicts TarSEsf x GraCDi x GraUDo. The height of the curves represents the duration of ISI, where higher points on the curves represent longer ISI. The width of the curves represents the scalar distance from the target, where the target is in the center of convergence of each set of curves. TarSEsf is represented by the blank space or mixed-color bar between the converging curves. GraCDi is represented by the continuity of the curves; the left set of curves is Continuous, while the right set is Discrete. Finally, GraUDo is represented by the height of the curves at the center of convergence of the set of curves. Since both Display conditions contain identical versions of this interaction, the Display conditions are not depicted in Figure 22.

Figure 22: Graphical depiction of design for Experiment 3
Participants

32 undergraduate students at the University of Central Florida participated in this experiment. There were 9 male participants and 23 female participants in this sample. Participants’ handedness was measured using the Edinburgh Handedness Inventory (Oldfield, 1971). A participant questionnaire collected data about their experience with computers and video games. Though no male participants and 3 female participants indicated that they have a left-hand bias, all participants chose to use the mouse with their right hand.

Participants were assigned to an order of presentation of the within-subjects conditions by Latin Square. Each participant was assigned to the next order of presentation of the Display conditions in the Display Latin Square. Each participant was then assigned the next order of presentation of the TarSEs f conditions in the TarSEsf Latin Square.

Apparatus

The software supporting this effort ran on a 3.00 GHz Dell Dimension 8300 with the Windows XP Professional operating system. Screen and color resolution was fixed at 1024 x 768 and 32-bit, respectively. A Dell M992 18 inch monitor was used to project the visual display. A Gyration Ultra inertial mouse was plugged into the high-speed USB port on the computer and functioned like a conventional three-button mouse with a scrolling wheel. The vibrotactile tactor system included two EAI C2 tactors, a tactor driver, and a Velcro strap for positioning the tactors. The computer sends commands and a 250 Hz sinusoid signal to the driver, which in turn drives the tactors (see Figure 23).
The software presented 2 sizes of targets (small and large) at 4 horizontal locations (2 left of center and 2 right of center). Targets consisted of a soldier from the Ghost Recon game holding an AK-74 pointed at the participant (actor “m05_eli_ak74_1.atr”) (see Figure 24).

Figure 24: Visual Target
The target was captured in perspective for each target location and size, and included a shadow. Small targets were 14 pixels wide; large targets were 28 pixels wide. The centers of mass of the target positions were located 423 pixels from the center of the display for the farthest targets, and 169 pixels from the center of the display for the closest targets. The order of presentation of the 8 targets was partially counterbalanced using the Latin Square technique for each participant. A random 2 to 9 second ISI occurred between target drop and target pop-up.

The cursor was depicted as a white ‘+’ 19 pixels across, and always started a trial in the center of the screen. The cursor was constrained by the software to move only in the horizontal plane passing through the center of the screen and the center of mass of all targets.

The inertial mouse was used in its optical mouse mode on the desk surface in front of the monitor. Movement of the mouse required to put the cursor onto the nearest targets required a 2.5-inch movement of the mouse from the point of origin. Movement of the mouse required to put the cursor onto the farthest targets required a 5.0-inch movement of the mouse from the point of origin.

The target left/right guidance cues were provided by the visual + tactile display or tactile-only display, depending on the block of trials. A static background image from Ghost Recon depicting a virtual city scene looking across a street at a brick wall was displayed for the duration of the trials (map “m05_embassy.env”) (see Figure 25).
The vibrotactile stimuli used a modulated 250 Hz sinusoidal signal held at a constant gain for all participants. This frequency was chosen because skin is most sensitive to light vibrations around 200 Hz (Verrillo, 1962), and maximum sensitivity for vibratory touch stimuli occurs from 200 to 400 Hz at stimulus intensities ranging from -20 to +60 dB (Verrillo, Fraioli, & Smith, 1969).

The pulse rate of the vibrotactile signal was defined in real-time by varying the inter stimulus interval (ISI) of the vibrotactile stimulus. The rising and falling of the pulse rate with distance from the target was driven by a 3rd order polynomial function ranging from ISIs of 250 msec to 10 msec (see Figure 26).
The distribution of ISIs by distance from target was obtained by fitting a curve to the average movement profile from Experiment 1. This distribution was applied whenever the cursor was within 60 degrees of the target; beyond 60 degrees the ISI was constant at either 250 msec or 10 msec.

For the Discrete Gradient condition (see Figure 27), movements toward the target within 105 pixels of the nearest edge of the target resulted in a continuous tactile display. Likewise, from target pop-up to 8 pixels of movement toward the target, the tactile display was presented continuously. These distances were estimated from the average movement profile from Experiment 1. They reflect the end of the first ballistic movement, and the tolerance for establishing unambiguous initial movement, respectively. Movement away from the target resulted in a continuous tactile display with ISI following the gradient irrespective of distance from the target.

Figure 26: Continuous Inter Stimulus Interval x Scalar Distance from Target
A stimulus interval of 100 msec was applied to the tactile stimuli irrespective of the ISI. The gain was set such that all participants had a 100% detection rate for the tactile stimuli. White noise was presented via headphones to mask the sound of the mechanical relays used in the tactor driver.

Initial movement time (iMT), probability of correct initial movement (iMove), the number of times on-target (otCnt), time from target pop-up to target selection (ST), final time spent on-target (fTot), workload (WL), and time-stamped movement profiles were collected for each trial.

iMT for this experiment is defined as the time in seconds between target pop-up and the start of movement by the participant. iMT should be faster for the Visual + Tactile Display condition than Tactile-Only. We may use the initial pulse(s) as a simple direction and relative distance cue for planning the initial ballistic movement. When vibrotactile pulses are present, we can reduce the search space by half, reducing the search time by up to half.
iMove is the probability of a correct initial movement toward the target by the participant. iMove should not vary between conditions. The tactile display always indicates the direction to the target irrespective of the condition, so any variation between conditions will be attributable to error in this project.

otCnt is defined as the number of times the cursor went from off-target to on-target. otCnt should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

ST is the time in seconds from target pop-up to target selection. As with otCnt, ST should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

fTot is the time in seconds from the last time the participant moves from off- to on-target until the participant clicks on the target. fTot should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

WL is the workload obtained from the NASA TLX. WL should be at a minimum when the difference between on- and off-target is maximized (e.g., TarS/GraU, TarEf/GraDo).

Movement profiles consisted of the time-stamped (in seconds) horizontal screen coordinate of the center of the cursor recorded every time the mouse position changed. A maximum recording rate of about 100 mouse movements per second was achieved for the described system.

The Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) was used before participant training to collect the degree of handedness of each participant. The NASA-TLX workload assessment tool was used to measure perceived workload after each block of 32 trials.
**Procedure**

Throughout the course of the experiment the participants sat in front of the computer monitor in such a way that their mouse hand could comfortably move the mouse on the desk and the forearm was supported. The monitor was positioned approximately 21 inches from the bridge of the participant’s nose.

The inertial mouse was positioned on the desk between the monitor and the participant on the participant’s medial plane, and a computer-based version of the Edinburgh Handedness Inventory (EHI) was administered. The tactors were then applied to the participant’s preferred hand for manipulating the mouse based on which hand the participant used to perform the EHI. The tactors were placed on the dorsal surface of the hand outside and in the middle of the second and fifth Metacarpals (see Figure 28). A fabric strap wrapped around the hand held the tactors in place.

![Figure 28: Placement of tactors on dorsal surface of hand](image)

A tactor discrimination test was administered before the start of the first block of trials, and again after the last block of trials. Participants were presented a randomized set of left, right,
or both tactor stimuli and asked to select which tactors were activated. Each stimulus pulsed once with an SI of 100 msec. Each of the three tactor stimuli were presented 6 times, for a total of 18 trials. The “left” and “right” buttons for indicating the left and right tactors, respectively, were centered between the nearest and farthest target positions. The “both” button was positioned in the center of the screen. Upon completion of the 18 trials, the participants shifted a continuous scrollbar left or right to indicate the relative intensity of the left and right tactors. The gain of the tactors was kept constant throughout the experiment.

Training before the start of each block of 32 trials included a review of the stimuli that will be presented for the block, 8 training targets, and a post-training opportunity to ask questions about the stimuli. The training targets were presented with a random 2 to 9 second lag between target drop and target pop-up.

The primary task of the participants during a trial was to quickly move the cursor onto the target when they had an idea where the target is located, and clicking the left mouse button. When a trial begins, the target stimuli were presented as appropriate for the block. The stimuli continued to be presented until the trial ended. Each trial ended when the participant clicked on the target. The next trial began after a random delay ranging from 2 to 9 seconds.

**Results**

The GLM in SPSS 11.5 was employed to analyze the $2 \times 3 \times 2 \times 2$ mixed factorial design. Fisher’s LSD was employed on all simple main effects analyses. All tests were run at the $\alpha = .05$ level.
Correlations between participants’ characteristics and the independent variables of interest reveal that Gender was significantly correlated with all of the variables of interest, and Age was significantly correlated with On-Target Count and Workload (see Appendix: Correlation Tables). As such, both characteristics were entered as covariates as appropriate in the GLM. Though the order of presentation of the Visual +Tactile and Tactile-only display modes was fully counterbalanced, the order was also entered as a covariate in the GLM to account for any order effect that may be present.

**Initial Movement Time (iMT)**

The results for iMT are presented in Table 11. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 12. Figure 29 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 13. Figure 30 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Figure 31 depicts the significant main effect of Display.
Table 11: Results for raw initial Movement Time (sec)

<table>
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<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>η²</th>
<th>1-β</th>
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</thead>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
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<td>1</td>
<td>0.010</td>
<td>0.270</td>
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<td>.010</td>
<td>.097</td>
</tr>
<tr>
<td>Visual First</td>
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<td>1</td>
<td>0.012</td>
<td>0.325</td>
<td>ns</td>
<td>.012</td>
<td>.085</td>
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<tr>
<td>GraCDi</td>
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<td>0.013</td>
<td>0.352</td>
<td>ns</td>
<td>.013</td>
<td>.088</td>
</tr>
<tr>
<td>GraUDo</td>
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<td>0.008</td>
<td>0.225</td>
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<td>.009</td>
<td>.074</td>
</tr>
<tr>
<td>GraCDi x GraUDo</td>
<td>0.004</td>
<td>1</td>
<td>0.004</td>
<td>0.123</td>
<td>ns</td>
<td>.005</td>
<td>.063</td>
</tr>
<tr>
<td><strong>Error</strong></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
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<td>.401</td>
<td>.980</td>
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<td>0.000</td>
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<td>.052</td>
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<td>.263</td>
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<td>Display x GraUDo</td>
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<td>0.009</td>
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<td>.019</td>
<td>.105</td>
</tr>
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<td>0.001</td>
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<td>.053</td>
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<td><strong>Error(Display)</strong></td>
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<td>0.001</td>
<td>0.290</td>
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<td>.094</td>
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<tr>
<td>TarSEsf x Gender</td>
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<td>2</td>
<td>0.000</td>
<td>0.094</td>
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<td>.064</td>
</tr>
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<td>TarSEsf x Visual First</td>
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<td>0.000</td>
<td>0.107</td>
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<td>.065</td>
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<tr>
<td>TarSEsf x GraCDi</td>
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<td>0.000</td>
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<td>ns</td>
<td>.005</td>
<td>.068</td>
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<td><strong>Error(TarSEsf)</strong></td>
<td>0.210</td>
<td>52</td>
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<td>0.000</td>
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<td>.005</td>
<td>.069</td>
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<td>ns</td>
<td>.023</td>
<td>.147</td>
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<td>0.001</td>
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<td>.126</td>
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<tr>
<td>Display x TarSEsf x GraCDi</td>
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<td>0.002</td>
<td>0.550</td>
<td>ns</td>
<td>.021</td>
<td>.136</td>
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<tr>
<td>Display x TarSEsf x GraUDo</td>
<td>0.013</td>
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<td>0.007</td>
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<td>ns</td>
<td>.077</td>
<td>.423</td>
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<tr>
<td>Display x TarSEsf x GraCDi x GraUDo</td>
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<td>2</td>
<td>0.006</td>
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<td>.415</td>
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<tr>
<td><strong>Errorw</strong></td>
<td>0.159</td>
<td>52</td>
<td>0.003</td>
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</table>
Table 12: Means for Display x TarSesf x GraCDi x GraUDo on iMT

<table>
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<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>0.3343</td>
<td>0.3319</td>
<td>0.3622</td>
<td>0.4764</td>
<td>0.5110</td>
<td>0.5112</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>0.3366</td>
<td>0.3695</td>
<td>0.3342</td>
<td>0.5182</td>
<td>0.4805</td>
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<tr>
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<td>0.4432</td>
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<td>GraDi/GraDo</td>
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<td>0.3532</td>
<td>0.4931</td>
<td>0.4874</td>
<td>0.4688</td>
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</table>

Figure 29: Display x TarSesf x GraCDi x GraUDo on iMT
Table 13: Means for TarSEsf x GraCDi x GraUDo on iMT

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>0.4054</td>
<td>0.4042</td>
<td>0.4367</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>0.4274</td>
<td>0.4250</td>
<td>0.4331</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>0.3853</td>
<td>0.3934</td>
<td>0.4128</td>
</tr>
<tr>
<td>GraDi/GraDo</td>
<td>0.4221</td>
<td>0.4207</td>
<td>0.4110</td>
</tr>
</tbody>
</table>

Figure 30: TarSEsf x GraCDi x GraUDo on iMT
The Tactile-Only display condition resulted in slower initial movement times than Visual + Tactile. No other main effects were significant. No interactions were significant.

**Selection Time (ST)**

The results for ST are presented in Table 14. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 15. Figure 32 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 16. Figure 33 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GraUDo interaction are presented in Table 17. Figure 34 depicts the significant Display x TarSEsf x GraUDo interaction. Means for the significant TarSEsf x GraUDo interaction.
interaction are presented in Table 18. Figure 35 depicts the significant TarSEsf x GraUDo interaction. Figure 36 depicts the significant main effect of Display.
Table 14: Results for Target Selection Time (sec)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-(\beta)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>25.896</td>
<td>1</td>
<td>25.896</td>
<td>10.626</td>
<td>.003</td>
<td>.290</td>
<td>.880</td>
</tr>
<tr>
<td>Visual First</td>
<td>0.042</td>
<td>1</td>
<td>0.042</td>
<td>0.017</td>
<td>ns</td>
<td>.001</td>
<td>.052</td>
</tr>
<tr>
<td>GraCDi</td>
<td>4.486</td>
<td>1</td>
<td>4.486</td>
<td>1.841</td>
<td>.066</td>
<td>.257</td>
<td></td>
</tr>
<tr>
<td>GraUDo</td>
<td>4.042</td>
<td>1</td>
<td>4.042</td>
<td>1.659</td>
<td>ns</td>
<td>.060</td>
<td>.237</td>
</tr>
<tr>
<td>GraCDi x GraUDo</td>
<td>0.011</td>
<td>1</td>
<td>0.011</td>
<td>0.005</td>
<td>ns</td>
<td>.000</td>
<td>.050</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
<td>63.364</td>
<td>26</td>
<td>2.437</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>416.244</td>
<td>1</td>
<td>416.244</td>
<td>174.830</td>
<td>&lt; .001</td>
<td>.871</td>
<td>1.000</td>
</tr>
<tr>
<td>Display x Gender</td>
<td>14.093</td>
<td>1</td>
<td>14.093</td>
<td>5.919</td>
<td>.022</td>
<td>.185</td>
<td>.649</td>
</tr>
<tr>
<td>Display x Visual First</td>
<td>0.058</td>
<td>1</td>
<td>0.058</td>
<td>0.024</td>
<td>ns</td>
<td>.001</td>
<td>.053</td>
</tr>
<tr>
<td>Display x GraCDi</td>
<td>2.028</td>
<td>1</td>
<td>2.028</td>
<td>0.852</td>
<td>ns</td>
<td>.032</td>
<td>.144</td>
</tr>
<tr>
<td>Display x GraUDo</td>
<td>6.734</td>
<td>1</td>
<td>6.734</td>
<td>2.828</td>
<td>ns</td>
<td>.098</td>
<td>.367</td>
</tr>
<tr>
<td>Display x GraCDi x GraUDo</td>
<td>0.217</td>
<td>1</td>
<td>0.217</td>
<td>0.091</td>
<td>ns</td>
<td>.003</td>
<td>.060</td>
</tr>
<tr>
<td><strong>Error(Display)</strong></td>
<td>61.902</td>
<td>26</td>
<td>2.381</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TarSEsf</td>
<td>1.654</td>
<td>2</td>
<td>0.827</td>
<td>0.718</td>
<td>ns</td>
<td>.027</td>
<td>.165</td>
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<tr>
<td>TarSEsf x Gender</td>
<td>4.513</td>
<td>2</td>
<td>2.257</td>
<td>1.958</td>
<td>ns</td>
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<td>.387</td>
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<tr>
<td>TarSEsf x Visual First</td>
<td>.600</td>
<td>2</td>
<td>0.300</td>
<td>0.260</td>
<td>ns</td>
<td>.010</td>
<td>.089</td>
</tr>
<tr>
<td>TarSEsf x GraCDi</td>
<td>4.893</td>
<td>2</td>
<td>2.446</td>
<td>2.122</td>
<td>ns</td>
<td>.075</td>
<td>.416</td>
</tr>
<tr>
<td>TarSEsf x GraUDo</td>
<td>8.248</td>
<td>2</td>
<td>4.124</td>
<td>3.578</td>
<td>.035</td>
<td>.121</td>
<td>.639</td>
</tr>
<tr>
<td>TarSEsf x GraCDi x GraUDo</td>
<td>1.638</td>
<td>2</td>
<td>0.819</td>
<td>0.710</td>
<td>ns</td>
<td>.027</td>
<td>.164</td>
</tr>
<tr>
<td><strong>Error(TarSEsf)</strong></td>
<td>59.943</td>
<td>52</td>
<td>1.153</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display x TarSEsf</td>
<td>1.727</td>
<td>2</td>
<td>0.864</td>
<td>0.695</td>
<td>ns</td>
<td>.026</td>
<td>.161</td>
</tr>
<tr>
<td>Display x TarSEsf x Gender</td>
<td>3.707</td>
<td>2</td>
<td>1.854</td>
<td>1.492</td>
<td>ns</td>
<td>.054</td>
<td>.304</td>
</tr>
<tr>
<td>Display x TarSEsf x Visual First</td>
<td>0.701</td>
<td>2</td>
<td>0.350</td>
<td>0.282</td>
<td>ns</td>
<td>.011</td>
<td>.092</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi</td>
<td>4.928</td>
<td>2</td>
<td>2.464</td>
<td>1.983</td>
<td>ns</td>
<td>.071</td>
<td>.392</td>
</tr>
<tr>
<td>Display x TarSEsf x GraUDo</td>
<td>8.317</td>
<td>2</td>
<td>4.159</td>
<td>3.347</td>
<td>.043</td>
<td>.114</td>
<td>.608</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi x GraUDo</td>
<td>1.870</td>
<td>2</td>
<td>0.935</td>
<td>0.752</td>
<td>ns</td>
<td>.028</td>
<td>.171</td>
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<tr>
<td><strong>Errorw</strong></td>
<td>64.604</td>
<td>52</td>
<td>1.242</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Table 15: Means for Display x TarSesf x GraCDi x GraUDo on ST

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>1.3675</td>
<td>1.3993</td>
<td>1.4102</td>
<td>4.2978</td>
<td>5.4173</td>
<td>4.0581</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>1.3243</td>
<td>1.2982</td>
<td>1.3105</td>
<td>5.8907</td>
<td>5.4279</td>
<td>5.8280</td>
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<tr>
<td>GraDi/GraU</td>
<td>1.4718</td>
<td>1.4561</td>
<td>1.4756</td>
<td>5.2027</td>
<td>5.4432</td>
<td>5.4790</td>
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<tr>
<td>GraDi/GraDo</td>
<td>1.4091</td>
<td>1.4290</td>
<td>1.3866</td>
<td>6.9126</td>
<td>4.5726</td>
<td>5.8255</td>
</tr>
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</table>

Figure 32: Display x TarSesf x GraCDi x GraUDo on ST
Table 16: Means for TarSEsf x GraCDi x GraUDo on ST

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>2.8326</td>
<td>2.8486</td>
<td>2.7342</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>3.6075</td>
<td>3.3631</td>
<td>3.5692</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>3.3373</td>
<td>3.4496</td>
<td>3.4773</td>
</tr>
<tr>
<td>GraDi/GraDo</td>
<td>4.1608</td>
<td>3.0008</td>
<td>3.6061</td>
</tr>
</tbody>
</table>

Figure 33: TarSEsf x GraCDi x GraUDo on ST
Table 17: Means for Display x TarSEsf x GarUDo on ST

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraU</td>
<td>1.4197</td>
<td>1.4277</td>
<td>1.4429</td>
<td>4.7503</td>
<td>5.4303</td>
<td>4.7685</td>
</tr>
<tr>
<td>GraDo</td>
<td>1.3667</td>
<td>1.3636</td>
<td>1.3485</td>
<td>6.4016</td>
<td>5.0002</td>
<td>5.8268</td>
</tr>
</tbody>
</table>

Figure 34: Display x TarSEsf x GarUDo on ST
Table 18: Means for TarSEsf x GraUDo on ST

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraU</td>
<td>3.0850</td>
<td>3.4290</td>
<td>3.1057</td>
</tr>
<tr>
<td>GraDo</td>
<td>3.8842</td>
<td>3.1819</td>
<td>3.5876</td>
</tr>
</tbody>
</table>

Figure 35: TarSEsf x GraUDo on ST
The Tactile-Only display condition resulted in slower target selection times than Visual + Tactile. No other main effects were significant.

For both the Display x TarSEsf x GarUDo and TarSEsf x GraUDo interactions, the GraDo condition resulted in slower target selection times than GraU at Tac/TarS and Tac/TarEs. The GraDo condition at TarS was slower than GraDo at TarEf.

**On-Target Count (otCnt)**

The results for otCnt are presented in Table 19. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 20. Figure 37 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 21. Figure 38 depicts the non-
significant TarSEsf x GraCDi x GarUDo interaction. Figure 39 depicts TarSEsf. Figure 40 depicts the non-significant main effect of Display.
Table 19: Results for On-Target Count

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>4.829</td>
<td>1</td>
<td>4.829</td>
<td>5.086</td>
<td>.033</td>
<td>.169</td>
<td>.582</td>
</tr>
<tr>
<td>Gender</td>
<td>0.297</td>
<td>1</td>
<td>0.297</td>
<td>0.312</td>
<td>ns</td>
<td>.012</td>
<td>.084</td>
</tr>
<tr>
<td>Visual First</td>
<td>1.915</td>
<td>1</td>
<td>1.915</td>
<td>2.016</td>
<td>ns</td>
<td>.075</td>
<td>.277</td>
</tr>
<tr>
<td>GraCDi</td>
<td>2.840</td>
<td>1</td>
<td>2.840</td>
<td>2.991</td>
<td>ns (.096)</td>
<td>.107</td>
<td>.383</td>
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<tr>
<td>GraUDo</td>
<td>0.714</td>
<td>1</td>
<td>0.714</td>
<td>0.752</td>
<td>ns</td>
<td>.029</td>
<td>.133</td>
</tr>
<tr>
<td>GraCDi x GraUDo</td>
<td>0.025</td>
<td>1</td>
<td>0.025</td>
<td>0.026</td>
<td>ns</td>
<td>.001</td>
<td>.053</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
<td>23.736</td>
<td>25</td>
<td>0.949</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>0.025</td>
<td>1</td>
<td>0.025</td>
<td>0.045</td>
<td>ns</td>
<td>.002</td>
<td>.055</td>
</tr>
<tr>
<td>Display x Age</td>
<td>4.534</td>
<td>1</td>
<td>4.534</td>
<td>8.254</td>
<td>.008</td>
<td>.248</td>
<td>.788</td>
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<tr>
<td>Display x Gender</td>
<td>0.018</td>
<td>1</td>
<td>0.018</td>
<td>0.033</td>
<td>ns</td>
<td>.001</td>
<td>.053</td>
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<tr>
<td>Display x Visual First</td>
<td>0.715</td>
<td>1</td>
<td>0.715</td>
<td>1.302</td>
<td>ns</td>
<td>.050</td>
<td>.195</td>
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<tr>
<td>Display x CraCDi</td>
<td>2.040</td>
<td>1</td>
<td>2.040</td>
<td>3.713</td>
<td>ns (.065)</td>
<td>.129</td>
<td>.457</td>
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<tr>
<td>Display x GraUDo</td>
<td>0.279</td>
<td>1</td>
<td>0.279</td>
<td>0.509</td>
<td>ns</td>
<td>.020</td>
<td>.105</td>
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<tr>
<td>Display x GraCDi x GraUDo</td>
<td>0.089</td>
<td>1</td>
<td>0.089</td>
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<td>ns</td>
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<td>.067</td>
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<tr>
<td><strong>Error(Display)</strong></td>
<td>13.734</td>
<td>25</td>
<td>0.549</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TarSEsf</td>
<td>1.147</td>
<td>2</td>
<td>0.574</td>
<td>3.813</td>
<td>.029</td>
<td>.132</td>
<td>.667</td>
</tr>
<tr>
<td>TarSEsf x Age</td>
<td>2.238</td>
<td>2</td>
<td>1.119</td>
<td>7.436</td>
<td>.001</td>
<td>.229</td>
<td>.928</td>
</tr>
<tr>
<td>TarSEsf x Gender</td>
<td>0.384</td>
<td>2</td>
<td>0.192</td>
<td>1.276</td>
<td>ns</td>
<td>.049</td>
<td>.264</td>
</tr>
<tr>
<td>TarSEsf x Visual First</td>
<td>0.284</td>
<td>2</td>
<td>0.142</td>
<td>0.944</td>
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<td>.204</td>
</tr>
<tr>
<td>TarSEsf x GraCDi</td>
<td>0.318</td>
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<td>0.159</td>
<td>1.057</td>
<td>ns</td>
<td>.041</td>
<td>.225</td>
</tr>
<tr>
<td>TarSEsf x GraUDo</td>
<td>0.440</td>
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<td>0.220</td>
<td>1.462</td>
<td>ns</td>
<td>.055</td>
<td>.298</td>
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<td>0.004</td>
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<td>0.002</td>
<td>0.014</td>
<td>ns</td>
<td>.001</td>
<td>.052</td>
</tr>
<tr>
<td><strong>Error(TarSEsf)</strong></td>
<td>7.523</td>
<td>50</td>
<td>0.150</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Display x TarSEsf</td>
<td>0.730</td>
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<td>0.365</td>
<td>2.272</td>
<td>ns</td>
<td>.083</td>
<td>.441</td>
</tr>
<tr>
<td>Display x TarSEsf x Age</td>
<td>1.464</td>
<td>2</td>
<td>0.732</td>
<td>4.552</td>
<td>.015</td>
<td>.154</td>
<td>.749</td>
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<td>Display x TarSEsf x Gender</td>
<td>0.610</td>
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<td>0.305</td>
<td>1.898</td>
<td>ns</td>
<td>.071</td>
<td>.376</td>
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<tr>
<td>Display x TarSEsf x Visual First</td>
<td>0.526</td>
<td>2</td>
<td>0.263</td>
<td>1.637</td>
<td>ns</td>
<td>.061</td>
<td>.330</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi</td>
<td>0.388</td>
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<td>0.194</td>
<td>1.207</td>
<td>ns</td>
<td>.046</td>
<td>.252</td>
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<tr>
<td>Display x TarSEsf x GraUDo</td>
<td>0.162</td>
<td>2</td>
<td>0.081</td>
<td>0.503</td>
<td>ns</td>
<td>.020</td>
<td>.128</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi x GraUDo</td>
<td>0.040</td>
<td>2</td>
<td>0.020</td>
<td>0.124</td>
<td>ns</td>
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<td>.068</td>
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<tr>
<td><strong>Errorw</strong></td>
<td>8.038</td>
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Table 20: Means for Display x TarSEsf x GraCDi x GraUDo on otCnt

<table>
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<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
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<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
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<tbody>
<tr>
<td>GraC/GraU</td>
<td>1.3672</td>
<td>1.3750</td>
<td>1.2969</td>
<td>2.8672</td>
<td>2.5313</td>
<td>2.1875</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>1.3984</td>
<td>1.2969</td>
<td>1.3516</td>
<td>2.6016</td>
<td>2.4063</td>
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</tr>
<tr>
<td>GraDi/GraU</td>
<td>1.3438</td>
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<td>1.3438</td>
<td>3.0156</td>
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<td>2.6250</td>
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<tr>
<td>GraDi/GraDo</td>
<td>1.4297</td>
<td>1.4141</td>
<td>1.4375</td>
<td>3.2656</td>
<td>2.6406</td>
<td>2.9375</td>
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Figure 37: Display x TarSEsf x GraCDi x GraUDo on otCnt
Table 21: Means for TarSEsf x GraCDi x GraUDo on otCnt

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<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>2.1172</td>
<td>2.1211</td>
<td>1.7422</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>2.0000</td>
<td>1.8516</td>
<td>1.9453</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>2.1797</td>
<td>2.0156</td>
<td>1.9844</td>
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<td>GraDi/GraDo</td>
<td>2.3477</td>
<td>2.0273</td>
<td>2.1875</td>
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</table>

Figure 38: TarSEsf x GraCDi x GarUDo on otCnt
Figure 39: TarSEsf on otCnt

Figure 40: Display on otCnt
Investigating the significant TarSEsf main effect, TarS had more movements from Off- to On-Target than did TarEf or TarEs. TarEf and TarEs were not found to be significantly different. No other main effects were significant. No interaction effects were significant.

**Probability of Correct Initial Movement (iMove)**

The results for iMove are presented in Table 22. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 23. Figure 41 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 24. Figure 42 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Figure 43 depicts the non-significant main effect of Display.
Table 22: Results for Probability of Correct Initial Movement

<table>
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<th>Source</th>
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<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-(\beta)</th>
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<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Gender</td>
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<td>1</td>
<td>0.060</td>
<td>2.642</td>
<td>ns</td>
<td>.092</td>
<td>.347</td>
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<tr>
<td>Visual First</td>
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<td>0.011</td>
<td>0.493</td>
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<tr>
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<td>0.083</td>
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<td>0.014</td>
<td>0.599</td>
<td>ns</td>
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<td>.116</td>
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<td>ns</td>
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<td>.124</td>
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<td><strong>Error</strong></td>
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<td>0.023</td>
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<td><strong>Within Subjects</strong></td>
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<td></td>
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<tr>
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<td>0.002</td>
<td>0.103</td>
<td>ns</td>
<td>.004</td>
<td>.061</td>
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<tr>
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<td>.142</td>
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<tr>
<td>Display x Visual First</td>
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<td>0.022</td>
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<td>ns</td>
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<td>.215</td>
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<td>.072</td>
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<td>0.002</td>
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<td>.066</td>
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<tr>
<td>TarSEsf</td>
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<td>0.000</td>
<td>0.009</td>
<td>ns</td>
<td>.000</td>
<td>.051</td>
</tr>
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<td>TarSEsf x Gender</td>
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<td>0.015</td>
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<td>.063</td>
<td>.350</td>
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<td>0.006</td>
<td>0.635</td>
<td>ns</td>
<td>.024</td>
<td>.151</td>
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<tr>
<td>TarSEsf x GraCDi</td>
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<td>0.012</td>
<td>1.413</td>
<td>ns</td>
<td>.052</td>
<td>.290</td>
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<tr>
<td>TarSEsf x GraUDo</td>
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<td>2</td>
<td>0.005</td>
<td>0.598</td>
<td>ns</td>
<td>.022</td>
<td>.144</td>
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<td>2</td>
<td>0.002</td>
<td>0.221</td>
<td>ns</td>
<td>.008</td>
<td>.083</td>
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<td>52</td>
<td>0.009</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>0.019</td>
<td>2.606</td>
<td>ns</td>
<td>.091</td>
<td>.497</td>
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<td>Display x TarSEsf x Gender</td>
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<td>2</td>
<td>0.001</td>
<td>0.103</td>
<td>ns</td>
<td>.004</td>
<td>.065</td>
</tr>
<tr>
<td>Display x TarSEsf x Visual First</td>
<td>0.018</td>
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<td>0.009</td>
<td>1.236</td>
<td>ns</td>
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<td>Display x TarSEsf x GraCDi</td>
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Table 23: Means for Display x TarSEsf x GraCDi x GraUDo on iMove

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<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
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<td>0.8672</td>
<td>0.9375</td>
<td>0.9219</td>
<td>0.9141</td>
<td>0.9297</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>0.9453</td>
<td>0.9219</td>
<td>0.8984</td>
<td>0.8906</td>
<td>0.8672</td>
<td>0.9141</td>
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<tr>
<td>GraDi/GraU</td>
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<td>0.8672</td>
<td>0.8594</td>
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<tr>
<td>GraDi/GraDo</td>
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<td>0.9063</td>
<td>0.8984</td>
<td>0.8594</td>
<td>0.9219</td>
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</table>

Figure 41: Display x TarSEsf x GraCDi x GraUDo on iMove
Table 24  Means for TarSEsf x GraCDi x GraUDo on iMove

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<th>TarEs</th>
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</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
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<tr>
<td>GraC/GraDo</td>
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<td>0.9063</td>
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<tr>
<td>GraDi/GraU</td>
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<td>GraDi/GraDo</td>
<td>0.8867</td>
<td>0.9141</td>
<td>0.8789</td>
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</table>

Figure 42:  TarSEsf x GraCDi x GraUDo on iMove
No significant main effects were found. No significant interaction effects were found.

**Final Time On-Target (fTot)**

The results for fTot are presented in Table 25. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 26. Figure 44 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 27. Figure 45 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GraUDo interaction are presented in Table 28. Figure 46 depicts the significant Display x TarSEsf x GraUDo interaction. Means for the significant TarSEsf x GraUDo interaction are presented in Table 29. Figure 47 depicts the significant Display x TarSEsf interaction. Means for the significant TarSEsf x GraUDo interaction are presented in Table 30.
Figure 48 depicts the significant TarSEsf x GraUDo interaction. Means for the significant TarSEsf x GraCDi interaction are presented in Table 31. Figure 49 depicts the significant TarSEsf x GraCDi interaction. Figure 50 depicts the significant main effect of TarSEsf. Figure 51 depicts the significant main effect of Display.
Table 25: Results for Final Time On-Target

<table>
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<tr>
<th>Source</th>
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<th>p</th>
<th>$\eta^2$</th>
<th>$1-\beta$</th>
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<td><strong>Between Subjects</strong></td>
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<tr>
<td>Gender</td>
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<td>0.770</td>
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<td>.005</td>
<td>.263</td>
<td>.834</td>
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<td>Visual First</td>
<td>0.012</td>
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<td>0.012</td>
<td>0.141</td>
<td>ns</td>
<td>.005</td>
<td>.065</td>
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<td>GraCDi</td>
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<td>0.117</td>
<td>1.404</td>
<td>ns</td>
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<td>.207</td>
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<tr>
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<td>0.292</td>
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<td>0.292</td>
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<td>ns (.072)</td>
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<tr>
<td><strong>Within Subjects</strong></td>
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</tr>
<tr>
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<td>0.102</td>
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<td>.061</td>
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<td>Display x GraUDo</td>
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<td>1</td>
<td>0.146</td>
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<tr>
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<td>0.541</td>
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<tr>
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<td>1.253</td>
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<tr>
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<td>0.023</td>
<td>2.602</td>
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<td>.091</td>
<td>.496</td>
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<td>TarSEsf x Visual First</td>
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<td>0.025</td>
<td>2.913</td>
<td>ns (.063)</td>
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<td>.545</td>
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<tr>
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<td>0.032</td>
<td>3.684</td>
<td>.032</td>
<td>.124</td>
<td>.652</td>
</tr>
<tr>
<td>TarSEsf x GraUDo</td>
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<td>2</td>
<td>0.111</td>
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<td>.330</td>
<td>.996</td>
</tr>
<tr>
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<td>0.003</td>
<td>0.396</td>
<td>ns</td>
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<td>0.040</td>
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<td>.140</td>
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<td>0.005</td>
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<td>0.029</td>
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<td>ns (.058)</td>
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<td>.273</td>
<td>.977</td>
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<td>0.005</td>
<td>0.571</td>
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<td>0.010</td>
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Table 26: Means for Display x TarSEsf x GraCDi x GraUDo on fTot

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<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
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<td>0.6155</td>
<td>0.9062</td>
<td>0.8629</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>0.3609</td>
<td>0.3449</td>
<td>0.3323</td>
<td>0.8310</td>
<td>0.7331</td>
<td>0.9740</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>0.3863</td>
<td>0.3940</td>
<td>0.3941</td>
<td>0.6976</td>
<td>0.7575</td>
<td>0.9092</td>
</tr>
<tr>
<td>GraDi/GraDo</td>
<td>0.4473</td>
<td>0.4303</td>
<td>0.4108</td>
<td>0.9811</td>
<td>0.8067</td>
<td>1.1267</td>
</tr>
</tbody>
</table>

Figure 44: Display x TarSEsf x GraCDi x GraUDo on fTot
Table 27: Means for TarSEsf x GraCDi x GraUDo on fTot

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>0.4943</td>
<td>0.5020</td>
<td>0.6264</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>0.5960</td>
<td>0.5390</td>
<td>0.6531</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>0.5419</td>
<td>0.5758</td>
<td>0.6516</td>
</tr>
<tr>
<td>GraDi/GraDo</td>
<td>0.7142</td>
<td>0.6185</td>
<td>0.7687</td>
</tr>
</tbody>
</table>

Figure 45: TarSEsf x GraCDi x GraUDo on fTot
Table 28: Means for Display x TarSEsf x GraUDo on fTot

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraU</td>
<td>0.3798</td>
<td>0.3912</td>
<td>0.3920</td>
<td>0.6565</td>
<td>0.8318</td>
<td>0.8860</td>
</tr>
<tr>
<td>GraDo</td>
<td>0.4041</td>
<td>0.3876</td>
<td>0.3715</td>
<td>0.9061</td>
<td>0.7699</td>
<td>1.0503</td>
</tr>
</tbody>
</table>

Figure 46: Display x TarSEsf x GraUDo on fTot
Table 29: Means for Display x TarSEsf on fTot

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vis+Tac</td>
<td>0.3919</td>
<td>0.3894</td>
<td>0.3818</td>
</tr>
<tr>
<td>Tac</td>
<td>0.7813</td>
<td>0.8009</td>
<td>0.9682</td>
</tr>
</tbody>
</table>

Figure 47: Display x TarSEsf on fTot
Table 30: Means for TarSEsf x GraUDo on fTot

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraU</td>
<td>0.5181</td>
<td>0.6115</td>
<td>0.6390</td>
</tr>
<tr>
<td>GraDo</td>
<td>0.6551</td>
<td>0.5787</td>
<td>0.7109</td>
</tr>
</tbody>
</table>

Figure 48: TarSEsf x GraUDo on fTot
Table 31: Means for TarSEsf x GraCDi on fTot

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC</td>
<td>0.5451</td>
<td>0.5931</td>
<td>0.6398</td>
</tr>
<tr>
<td>GraDi</td>
<td>0.6281</td>
<td>0.5971</td>
<td>0.7102</td>
</tr>
</tbody>
</table>

Figure 49: TarSEsf x GraCDi on fTot
Figure 50: TarSEsf on fTot

Figure 51: Display on fTot
The Tac display condition resulted in longer time on-target than Vis+Tac. The TarEs condition resulted in longer time on-target than TarS or TarEf. No other main effects were found.

GraU at Tac/TarS had shorter time on-target than all other Tac conditions. GraU at Tac/TarEs had shorter time on-target than GraDo at Tac/TarEs. GraDo at Tac/TarEf had shorter time on-target than at Tac/TarS and Tac/TarEs, and shorter time on-target than GraU at Tac/TarEs. GraDo at Tac/TarS had shorter time on-target than GraDo at Tac/TarEs.

GraDi at TarEs had longer times on-target than all other TarSEsf conditions. GraDi at TarS had longer times on-target than GraC at TarS. GraC at TarS had shorter times on-target than GraC at TarEs

**Workload (WL)**

The results for WL are presented in Table 32. Means for the non-significant Display x TarSEsf x GraCDi x GarUDo interaction are presented in Table 33. Figure 52 depicts the non-significant Display x TarSEsf x GraCDi x GarUDo interaction. Means for the non-significant TarSEsf x GraCDi x GarUDo interaction are presented in Table 34. Figure 53 depicts the non-significant TarSEsf x GraCDi x GarUDo interaction. Means for the significant Display x TarSEsf x GraUDo interaction are presented in Table 35. Figure 54 depicts the significant Display x TarSEsf x GraUDo interaction. Figure 55 depicts the significant main effect of Display.
Table 32: Results for Workload

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
<th>1-β</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>3188.481</td>
<td>1</td>
<td>3188.481</td>
<td>2.016</td>
<td>ns</td>
<td>.075</td>
<td>.277</td>
</tr>
<tr>
<td>Gender</td>
<td>134.080</td>
<td>1</td>
<td>134.080</td>
<td>0.085</td>
<td>ns</td>
<td>.003</td>
<td>.059</td>
</tr>
<tr>
<td>Visual First</td>
<td>4645.440</td>
<td>1</td>
<td>4645.440</td>
<td>2.938</td>
<td>ns (.099)</td>
<td>.105</td>
<td>.378</td>
</tr>
<tr>
<td>GraCDi</td>
<td>207.415</td>
<td>1</td>
<td>207.415</td>
<td>0.131</td>
<td>ns</td>
<td>.005</td>
<td>.064</td>
</tr>
<tr>
<td>GraUDo</td>
<td>3021.520</td>
<td>1</td>
<td>3021.520</td>
<td>1.911</td>
<td>ns</td>
<td>.071</td>
<td>.265</td>
</tr>
<tr>
<td>GraCDi x GraUDo</td>
<td>5523.705</td>
<td>1</td>
<td>5523.705</td>
<td>3.493</td>
<td>ns (.073)</td>
<td>.123</td>
<td>.435</td>
</tr>
<tr>
<td><strong>Errorb</strong></td>
<td>39534.500</td>
<td>25</td>
<td>1581.380</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>1151.375</td>
<td>1</td>
<td>1151.375</td>
<td>5.491</td>
<td>.027</td>
<td>.180</td>
<td>.615</td>
</tr>
<tr>
<td>Display x Age</td>
<td>216.961</td>
<td>1</td>
<td>216.961</td>
<td>1.035</td>
<td>ns</td>
<td>.040</td>
<td>.165</td>
</tr>
<tr>
<td>Display x Gender</td>
<td>35.433</td>
<td>1</td>
<td>35.433</td>
<td>0.169</td>
<td>ns</td>
<td>.007</td>
<td>.068</td>
</tr>
<tr>
<td>Display x Visual First</td>
<td>58.052</td>
<td>1</td>
<td>58.052</td>
<td>0.277</td>
<td>ns</td>
<td>.011</td>
<td>.080</td>
</tr>
<tr>
<td>Display x CraCDi</td>
<td>189.175</td>
<td>1</td>
<td>189.175</td>
<td>0.902</td>
<td>ns</td>
<td>.035</td>
<td>.150</td>
</tr>
<tr>
<td>Display x GraUDo</td>
<td>110.489</td>
<td>1</td>
<td>110.489</td>
<td>0.527</td>
<td>ns</td>
<td>.021</td>
<td>.107</td>
</tr>
<tr>
<td>Display x GraCDi x GraUDo</td>
<td>286.154</td>
<td>1</td>
<td>286.154</td>
<td>1.365</td>
<td>ns</td>
<td>.052</td>
<td>.203</td>
</tr>
<tr>
<td><strong>Error(Display)</strong></td>
<td>5242.119</td>
<td>25</td>
<td>209.685</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TarSEsf</td>
<td>95.434</td>
<td>2</td>
<td>47.717</td>
<td>0.841</td>
<td>ns</td>
<td>.033</td>
<td>.186</td>
</tr>
<tr>
<td>TarSEsf x Age</td>
<td>109.334</td>
<td>2</td>
<td>54.667</td>
<td>0.963</td>
<td>ns</td>
<td>.037</td>
<td>.208</td>
</tr>
<tr>
<td>TarSEsf x Gender</td>
<td>27.885</td>
<td>2</td>
<td>13.942</td>
<td>0.246</td>
<td>ns</td>
<td>.010</td>
<td>.087</td>
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<tr>
<td>TarSEsf x Visual First</td>
<td>29.940</td>
<td>2</td>
<td>14.970</td>
<td>0.264</td>
<td>ns</td>
<td>.010</td>
<td>.089</td>
</tr>
<tr>
<td>TarSEsf x GraCDi</td>
<td>132.655</td>
<td>2</td>
<td>66.327</td>
<td>1.169</td>
<td>ns</td>
<td>.045</td>
<td>.245</td>
</tr>
<tr>
<td>TarSEsf x GraUDo</td>
<td>231.375</td>
<td>2</td>
<td>115.687</td>
<td>2.039</td>
<td>ns</td>
<td>.075</td>
<td>.401</td>
</tr>
<tr>
<td>TarSEsf x GraCDi x GraUDo</td>
<td>15.585</td>
<td>2</td>
<td>7.793</td>
<td>0.137</td>
<td>ns</td>
<td>.005</td>
<td>.070</td>
</tr>
<tr>
<td><strong>Error(TarSEsf)</strong></td>
<td>2837.232</td>
<td>50</td>
<td>56.745</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display x TarSEsf</td>
<td>178.319</td>
<td>2</td>
<td>89.159</td>
<td>1.790</td>
<td>ns</td>
<td>.067</td>
<td>.357</td>
</tr>
<tr>
<td>Display x TarSEsf x Age</td>
<td>234.506</td>
<td>2</td>
<td>117.253</td>
<td>2.354</td>
<td>ns</td>
<td>.086</td>
<td>.455</td>
</tr>
<tr>
<td>Display x TarSEsf x Gender</td>
<td>30.369</td>
<td>2</td>
<td>15.184</td>
<td>0.305</td>
<td>ns</td>
<td>.012</td>
<td>.096</td>
</tr>
<tr>
<td>Display x TarSEsf x Visual First</td>
<td>23.630</td>
<td>2</td>
<td>11.815</td>
<td>0.237</td>
<td>ns</td>
<td>.009</td>
<td>.085</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi</td>
<td>138.828</td>
<td>2</td>
<td>69.414</td>
<td>1.394</td>
<td>ns</td>
<td>.053</td>
<td>.286</td>
</tr>
<tr>
<td>Display x TarSEsf x GraUDo</td>
<td>403.431</td>
<td>2</td>
<td>201.715</td>
<td>4.050</td>
<td>.023</td>
<td>.139</td>
<td>.695</td>
</tr>
<tr>
<td>Display x TarSEsf x GraCDi x GraUDo</td>
<td>3.593</td>
<td>2</td>
<td>1.797</td>
<td>0.036</td>
<td>ns</td>
<td>.001</td>
<td>.055</td>
</tr>
<tr>
<td><strong>Errorw</strong></td>
<td>2490.204</td>
<td>50</td>
<td>49.804</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 33: Means for Display x TarSEsf x GraCDi x GarUDo on WL

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>24.1667</td>
<td>24.1667</td>
<td>25.5833</td>
<td>31.1667</td>
<td>37.7917</td>
<td>32.0000</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>16.6667</td>
<td>20.1667</td>
<td>19.6250</td>
<td>37.1667</td>
<td>35.2083</td>
<td>42.9583</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>33.0833</td>
<td>32.2083</td>
<td>33.0833</td>
<td>47.3750</td>
<td>48.4167</td>
<td>39.5000</td>
</tr>
</tbody>
</table>

Figure 52: Display x TarSEsf x GraCDi x GarUDo on WL
Table 34: Means for TarSEsf x GraCDi x GarUDo on WL

<table>
<thead>
<tr>
<th></th>
<th>TarS</th>
<th>TarEf</th>
<th>TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraC/GraU</td>
<td>27.6667</td>
<td>27.6667</td>
<td>28.7917</td>
</tr>
<tr>
<td>GraC/GraDo</td>
<td>26.9167</td>
<td>27.6875</td>
<td>31.2917</td>
</tr>
<tr>
<td>GraDi/GraU</td>
<td>40.2292</td>
<td>40.3125</td>
<td>36.2917</td>
</tr>
</tbody>
</table>

Figure 53: TarSEsf x GraCDi x GarUDo on WL
Table 35: Means for Display x TarSEsf x GraUDo on WL

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac/TarS</th>
<th>Vis+Tac/TarEf</th>
<th>Vis+Tac/TarEs</th>
<th>Tac/TarS</th>
<th>Tac/TarEf</th>
<th>Tac/TarEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GraU</td>
<td>28.6250</td>
<td>28.1875</td>
<td>29.3333</td>
<td>39.2708</td>
<td>43.1042</td>
<td>35.7500</td>
</tr>
<tr>
<td>GraDo</td>
<td>14.3125</td>
<td>18.7292</td>
<td>17.8750</td>
<td>31.9583</td>
<td>28.5000</td>
<td>34.4792</td>
</tr>
</tbody>
</table>

Figure 54: Display x TarSEsf x GraUDo on WL
The Tactile-Only display condition resulted in more perceived workload than Visual + Tactile. No other main effects were significant.

For the Tac display condition, GraU at Tac/TarEf had higher WL than GraU at Tac/TarEs. All other pairwise comparisons involving only the Tac display condition were not significant.

For the Vis+Tac display condition, GraU had higher WL than GraDo for all comparisons. GraDo at Vis+Tac/TarS had lower WL than GraDo at Vis+Tac/TarEf and Vis+Tac/TarEs. GraDo at Vis+Tac/TarEf and GraDo at Vis+Tac/TarEs were not significantly different.

With the exception of GraU at TarEs, GraU at Vis+Tac had lower WL than GraU at Tac for all pairwise comparisons. GraDo at Vis+Tac had lower WL for all pairwise comparisons with Tac.
**Discussion**

The data suggest that the larger the difference between off- and on-target cues (e.g., TarS/GraU, TarEs/GraU, TarEf/GraDo), the less time the participant spends on the target before selecting the target, and the less time it takes from target pop-up for the participant to select the target (see Table 36). This appears to be particularly true when the approach to the target is with an increasing pulse rate (GraU). These results support the hypothesis that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate.

Table 36: Rank-Order of Distance and On-Target Cues

<table>
<thead>
<tr>
<th>Rank Order</th>
<th>Final Time On-Target (sec)</th>
<th>Selection Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TarS x GraU</td>
<td>0.4943</td>
<td>2.8326</td>
</tr>
<tr>
<td>TarEs x GraU</td>
<td>0.6264</td>
<td>2.7342</td>
</tr>
<tr>
<td>TarEf x GraDo</td>
<td>0.5390</td>
<td>3.3631</td>
</tr>
<tr>
<td>TarS x GraDo</td>
<td>0.5960</td>
<td>3.6075</td>
</tr>
<tr>
<td>TarEf x GraU</td>
<td>0.5020</td>
<td>2.8486</td>
</tr>
<tr>
<td>TarEs x GraDo</td>
<td>0.6531</td>
<td>3.5692</td>
</tr>
</tbody>
</table>
Given that there was no difference in target selection time across the continuous and discrete conditions, the data also suggest that gradient continuity is not necessary on this measure of marksmanship. There was, however, a significant interaction of GraCDi with TarSEsf on fTot. This interaction provides support for the hypothesis that variation in pulse rate when moving On/Off the target will result in shorter time-on-target than no variation in pulse rate, since the largest differences between off- and on-target cues resulted in shorter times on target. Generally, however, the results support the hypothesis that discontinuous vibrotactile direction and distance cues will result in identical target selection times to continuous vibrotactile direction and distance cues.

Data necessary for determining velocity and acceleration profiles relative to the combinations of target size and distance from origin were collected in Experiments 1 & 2; we will be presenting these velocity and acceleration profiles in a later paper. By investigating these profiles, we can more fully understand how the interaction between GraCDi and TarSEsf affects target selection.

We did not explore the plethora of possible gradients. Instead, we chose to use the prototypical movement profile from Experiment 1 as the curve driving the vibrotactile relative distance gradient. Likewise, during the discrete gradient conditions, continuous guidance cues were provided when the participant moved away from the target irrespective of target distance.

We did not investigate the fully discrete gradient option since we were interested only in the approach phase of the target selection task, and since SME comments on the matter suggested that full-time location and relative distance cues were annoying and possibly counterproductive. Future investigations may more fully explore the ramifications of this partial-feedback approach.
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this project was to establish if vibrotactile guidance cues can improve marksmanship. To that end, this project has been successful.

Experiment 1 established the affect on initial response to vibrotactile guidance cues of tactor placements on the palm (palmer) versus on the back of the hand (dorsal), and targets appearing left versus right of center. Results suggest that tactile cues provided on the left side of the medial line of the hand afford moving the hand to the left, while tactile cues provided on the right side of the medial line afford moving the hand to the right.

Experiment 2 established the affect of continuous relative distance cues and on- versus off-target vibrotactile stimuli on reaction time and accuracy for target selection. Results suggest that there may be an interaction between the pulse rate of vibrotactile stimuli and the method used to highlight an “on-target” condition. Generally, the suppressed target condition was superior to the enhanced target condition. This was particularly true when the pulse rate increased as the cursor moved closer to a target.

Experiment 3 established if there are performance differences between discrete and continuous distance information for target selection, and investigated the interaction between the near-target pulse rate and on-target cues. Results suggest that maximizing the difference between near-target guidance cues and on-target cues reduces the target selection time, particularly when the near-target pulse rates are fast (ISI = 10 msec). The results also suggest that, as with vision, the vibrotactile off-target guidance cues are not necessary during the whole
target selection task. Rather, the guidance cues can be provided only during the initial pop-up condition and during the sub-movements closing on the target with little or no change in performance.

Practical Implications

The results obtained from the studies described herein offer several practical implications for the design of vibrotactile guidance cues for target identification:

1. It is possible to reduce the visual search time by almost half.
2. Some form of relative distance cue should be provided in addition to the direction cue to reduce uncertainty regarding position relative to the target.
3. Generally, when varying the pulse rate with distance off-target, and when providing for on-target cues, the larger the difference between near- and on-target the better.

The worst combination of cues is to have the same on-target pulse rate as the near-target pulse rate. For our project, we found the best combination of cues is to have a fast pulse rate (e.g., ISI = 10 msec) near the target, with vibrotactile cues absent on-target. The next best combination of cues is to have a fast pulse rate near the target, with slow pulse rates (e.g., ISI = 250 msec) from both tactors on-target.

Recommendations for Future Research

For these studies, visual target cues were set against a visual background that must be searched. Tactile target cues were set against a relatively quiet background. Future research
needs to vary the background noise to fully explore the affect background has on tactile vs. visual perception of guidance cues.

These experiments do not exhaust the possible combinations of gradient continuity. Rather, the designs focus on establishing the affect of subtle versus extreme variations in on-versus off-target guidance cues, and whether or not a continuously presented gradient is necessary for providing guidance cues to the target. Subtle variations in this series of experiments were presented by simply adding or removing a tactor from a stimulus. For example, when moving from off- to on-target, a subtle variation in guidance cues would be adding a second tactor to the first at the same pulse rate and in sync with the first tactor’s pulse rate, where the on-target pulse rate is the same as the near-target pulse rate. An extreme variation in guidance cues would be a fast pulse rate (ISI = 10 msec) near the target, with an absence of any vibrotactile stimulation on-target. Future research needs to explore various pulse rate gradients off-target.

Experience with the tactors seems to affect participants’ ability to perform the target selection task irrespective of the type of tactile guidance cues provided. This appears to be particularly true when prior experience included both visual and tactile displays. It also appears to be true when participants take the time to explore the full range of the tactile display during training rather than simply seeking the target. For future iterations of this methodology, emphasizing the exploration of the tactile display for a target or two during training may help to reduce the number of targets required to generate a stable movement profile with little variability.

Though effective for establishing the affordance of vibrotactile guidance cues applied to the same surface of the hand oriented with the palmer surface parallel and perpendicular to the
floor, this series of experiments did not fully explore the affordance of these stimuli applied to opposite surfaces (e.g., one tactor palmer and one tactor dorsal) or with more diverse hand orientations. Since the tactors would most likely be applied to only one surface of the hand in TAGS (i.e., palmer or dorsal), our purpose for these studies was to establish, among other things, which surface of the hand should be employed for our given application rather than exploring the more fundamental affordance issues requiring an exhaustive analysis of the possible combinations of tactor placement and hand orientation. Such a study would permit a more complete analysis of the possible shift between negative- and positive-feedback that may occur with multi-surface tactor placement spanning a wide range of hand orientations with respect to the floor.
APPENDIX: EHI
Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities.

The stronger your hand preference on an activity, the farther the scroll bar should be moved to the preferred hand. For example, if you would NEVER use scissors with your Left hand, the scroll bar should be moved all the way to the Right.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throwing</td>
<td></td>
<td></td>
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<tr>
<td>Scissors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toothbrush</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knife (without fork)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spoon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broom (upper hand)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Striking a match (match)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening a box (lid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which foot do you prefer to kick with?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which eye do you use when using only one?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Subject ID: 1  Laterality Quotient: 0.00
APPENDIX: TDB
Figure 56: TDB Pulse selection task

Figure 57: TDB Tactor Bias
APPENDIX: WORKLOAD DATA
Figure 58: Workload Data, Vis+Tac First vs. Tac First

<table>
<thead>
<tr>
<th></th>
<th>Vis+Tac</th>
<th>Tac</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GraC</td>
<td>GraDi</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>2.33</td>
<td>6.54</td>
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<tr>
<td>Physical Demand</td>
<td>3.67</td>
<td>1.00</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>6.67</td>
<td>3.50</td>
</tr>
<tr>
<td>Effort</td>
<td>4.64</td>
<td>2.92</td>
</tr>
<tr>
<td>Performance</td>
<td>3.50</td>
<td>4.75</td>
</tr>
<tr>
<td>Frustration</td>
<td>2.71</td>
<td>2.75</td>
</tr>
<tr>
<td>Mental Demand Weight</td>
<td>2.50</td>
<td>3.13</td>
</tr>
<tr>
<td>Physical Demand Weight</td>
<td>2.50</td>
<td>0.63</td>
</tr>
<tr>
<td>Temporal Demand Weight</td>
<td>3.13</td>
<td>2.50</td>
</tr>
<tr>
<td>Effort Weight</td>
<td>3.13</td>
<td>3.00</td>
</tr>
<tr>
<td>Performance Weight</td>
<td>2.75</td>
<td>2.00</td>
</tr>
<tr>
<td>Frustration Weight</td>
<td>1.00</td>
<td>1.63</td>
</tr>
<tr>
<td>WL</td>
<td>24.64</td>
<td>32.79</td>
</tr>
</tbody>
</table>

Figure 59: Workload Data, Vis+Tac vs. Tac
APPENDIX: SURVEY DATA
Participant Survey

Age: 

Gender:

Male  Female

With which hand do you write?

Left  Both  Right

With which hand do you use a mouse?

Left  Both  Right
Participant Survey

On average, how many hours a \( \text{Day} \) \( \text{Week} \) do you use software applications involving mouse operations (e.g., mouse clicks, drag-n-drop, etc.)?

Less than 1  1  2  3  4  5  More than 5

On average, how many hours a \( \text{Day} \) \( \text{Week} \) do you play computer/video games involving the use of a hand-held controller?

Less than 1  1  2  3  4  5  More than 5

On average, how many hours a \( \text{Day} \) \( \text{Week} \) do you play computer/video games involving the use of first-person perspectives?

Less than 1  1  2  3  4  5  More than 5
How good at tasks involving fine motor skills do you consider yourself to be?

Very Poor  Poor  Fair  Good  Very Good

Have you ever participated in a tactile displays study?

Yes  No

If "Yes":

Did the study use tactile displays applied to your hands?

Yes  No

Did the study use tactile displays for spatial guidance?

Yes  No

How well do you feel you did on the tasks today?

Very Poor  Poor  Fair  Good  Very Good
Participant Survey

In the combined visual and tactile condition, how easily were you able to position the cursor over the targets?

Not Easily  Somewhat Easily  Easily  Very Easily

In the tactile-only condition, how easily were you able to position the cursor over the targets?

Not Easily  Somewhat Easily  Easily  Very Easily

In the combined visual and tactile condition, how useful was the VISUAL display in helping you to position the cursor over the targets?

Not Useful  Somewhat Useful  Useful  Very Useful

In the combined visual and tactile condition, how useful was the TACTILE display in helping you to position the cursor over the targets?

Not Useful  Somewhat Useful  Useful  Very Useful
Participant Survey

When there was NO tactile display on-target, how easily were you able to determine that you were on-target?

Not Easily  Somewhat Easily  Easily  Very Easily

When the on-target tactile display consisted of a FAST pulse rate, how easily were you able to determine you were on-target?

Not Easily  Somewhat Easily  Easily  Very Easily

When the on-target tactile display consisted of a SLOW pulse rate, how easily were you able to determine you were on-target?

Not Easily  Somewhat Easily  Easily  Very Easily
Participant Survey

Rank the on-target cues in order of preference, with '1' being your MOST preferred, and '3' being your LEAST preferred:

- NO tactile display
- FAST tactile pulse rate
- SLOW tactile pulse rate

Assume that you have a TOTAL of 10 extra-credit points that you can assign to the set of on-target cues. You can distribute the points among each of the cues as you wish, keeping in mind that you have a total of 10 points to distribute. For example, if you give 5 points to one of the cues, you have only 5 points left to distribute between the remaining cues.

Indicate how many of the extra-credit points you would give to each of the cues:

- NO tactile display
- FAST tactile pulse rate
- SLOW tactile pulse rate

Comments:
<table>
<thead>
<tr>
<th></th>
<th>VisFirst</th>
<th>TacFirst</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GraC</td>
<td>GraDi</td>
</tr>
<tr>
<td></td>
<td>GraU</td>
<td>GraDe</td>
</tr>
<tr>
<td>Age</td>
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<td>24.25</td>
</tr>
<tr>
<td>Gender (0 Female, 1 Male)</td>
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<td>0.25</td>
</tr>
<tr>
<td>Hand Write (0 Left, 1 Right)</td>
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<td>1.00</td>
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<tr>
<td>Hand Mouse (0 Left, 1 Right)</td>
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<td>1.00</td>
</tr>
<tr>
<td>Span Mouse (0 Day, 1 Week)</td>
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<td>0.00</td>
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<td>Hours Mouse</td>
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<td>2.75</td>
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<tr>
<td>Span Game (0 Day, 1 Week)</td>
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<td>0.75</td>
</tr>
<tr>
<td>Hours Game</td>
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<td>0.75</td>
</tr>
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<td>Span Perspective (0 Day, 1 Week)</td>
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<tr>
<td>Hours Perspective</td>
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<td>Motor Skill</td>
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<td>2.50</td>
</tr>
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<td>Tac Study Before</td>
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<td>Tac Study Hands</td>
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<td>Tac Study Spatial</td>
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<td>No Tac On-Target</td>
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<tr>
<td>Tac On-Target Slow</td>
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<td>1.00</td>
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<td>Pref Fast Tac On-Target</td>
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<tr>
<td>Credit Slow Tac On-Target</td>
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Note: All selections range from ‘0’ to \( n \)

Figure 60: Survey Data, VisFirst vs. TacFirst
APPENDIX: CORRELATION TABLES
Table 37: Survey Correlations, Vis+Tac Suppressed

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Gender</th>
<th>EHI Lateral Quotient</th>
<th>Mouse Use (hrs/day)</th>
<th>General Game Use (hrs/day)</th>
<th>First Person Games (hrs/day)</th>
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</thead>
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<td>-.111</td>
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<td>.596</td>
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<td>.673</td>
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<td><strong>Sig. (2-tailed)</strong></td>
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<td><strong>First Person Games</strong></td>
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<td>.201</td>
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<td>(Vis+Tac, On-Target Suppressed)</td>
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<td><strong>First Time Move from Off-to On-Target (Vis+Tac, On-Target Suppressed)</strong></td>
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<td>-.145</td>
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<td>32</td>
<td>32</td>
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</tr>
<tr>
<td><strong>Final Time Move from Off-to On-Target (Vis+Tac, On-Target Suppressed)</strong></td>
<td>.143</td>
<td>.337</td>
<td>-.198</td>
<td>.098</td>
<td>-.286</td>
<td>-.167</td>
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<td><strong>Final Time Move from Off-to On-Target (Vis+Tac, On-Target Suppressed)</strong></td>
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<td>-.040</td>
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<td><strong>Sig. (2-tailed)</strong></td>
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* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).
Table 38: Survey Correlations, Vis+Tac Enhanced Fast

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* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
Table 39: Survey Correlations, Vis+Tac Enhanced Slow

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** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Table 40: Survey Correlations, Tac Suppressed

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* Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).
Table 41: Survey Correlations, Tac Enhanced Fast

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<tr>
<th></th>
<th>Age</th>
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<th>Mouse Use (hrs/day)</th>
<th>General Game Use (hrs/day)</th>
<th>First Person Games (hrs/day)</th>
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* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
Table 42: Survey Correlations, Tac Enhanced Slow

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<th>General Game Use (hrs/day)</th>
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* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
Table 43: Dependent Variable Inter Item Correlations, Vis+Tac Suppressed

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<th>Final Time Move from Off to On-Target (Vis+Tac Suppressed)</th>
<th>N Movements from Off to On-Target (Vis+Tac, On-Target Suppressed)</th>
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<th>n Clicks (Vis+Tac, On-Target Suppressed)</th>
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** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
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** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).
Table 45: Dependent Variable Inter Item Correlations, Vis+Tac Enhanced Slow

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** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).
Table 46: Dependent Variable Inter Item Correlations, Tac Suppressed

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** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).
Table 47: Dependent Variable Inter Item Correlations, Tac Enhanced Fast

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** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Table 48: Dependent Variable Inter Item Correlations, Tac Enhanced Slow

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<th>Initial Movement Time (Tac, On-Target)</th>
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<th>Target Selection Time (Tac, On-Target Before Click)</th>
<th>n Clicks (Tac, On-Target Enhanced Slow)</th>
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* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
April 9, 2004

Richard Gilson, Ph.D.
Department of Psychology
University of Central Florida
PH, Room 302F
4000 Central Florida Boulevard
Orlando, Florida 32816-1390

Dear Dr. Gilson:

With reference to your protocol entitled, “Covert Multi-sensory Feedback for the Dismounted Soldier,” I am enclosing for your records the approved, executed document of the UCFIRB Form you had submitted to our office.

Please be advised that this approval is given for one year. Should there be any addendums or administrative changes to the already approved protocol, they must also be submitted to the Board. Changes should not be initiated until written IRB approval is received. Adverse events should be reported to the IRB as they occur. Further, should there be a need to extend this protocol, a renewal form must be submitted for approval at least one month prior to the anniversary date of the most recent approval and is the responsibility of the investigator (UCF).

Should you have any questions, please do not hesitate to call me at 823-2901.

Please accept our best wishes for the success of your endeavors.

Cordially,

Chris Grayson
Institutional Review Board (IRB)

Copies: IRB File
LIST OF REFERENCES


