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by Linda R Elliott, Bruce JP Mortimer, Regina A Pomranky-Hartnett, Felicia Rapozo, Rodger A Pettitt, Robert E Wooldridge, Amaurys Rapozomeran, and Greg R Mort

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13. SUPPLEMENTARY NOTES *ORCID ID: Linda R Elliott, 0000-0002-4000-9929			
14. ABSTRACT Previous research investigated the conceptualization of tactile salience and core variables mediating effects on human perception and learning. This definition provides an integrated and systematic approach to assess effectiveness of tactile displays. We report an initial series of comparative tests of various multitactor cues, or tactions, using independent scaled ratings. Tactions were developed to vary along two dimensions: 1) complexity of tactor cue stimulus and 2) sequencing (simultaneous and repetitive versus sequential cuing across multiple tactors). Results from the first experiment served to refine methodology and measures in the second experiment. Results suggest that standard repetitive tactions were perceived as more salient and more easily learned. Comparison of morning versus afternoon performance showed significant decline in performance for more dynamic tactions and an interaction effect, such that standard/dynamic tactions were most negatively affected by time. Comparison of stationary and balance beam conditions also showed that standard/dynamic tactions were significantly lower in the movement condition. Further study will investigate these concepts with additional tasks and recall over a longer period of time.			
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Contents

List of Figures

List of Tables

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1. Introduction

1.1 Tactile Displays

The somatosensory system enables a wide-ranging capacity for touch-based perception, through cutaneous sensory neurons (Verrillo et al. 1969; Abraira and Ginty 2013; Lederman and Klatzky 2009; Loomis and Lederman 1986). The development of vibrating tactors has focused on these physiological characteristics when optimizing tactile systems for human perception (Cholewiak et al. 1991, 1992, 2004, 2006; van Erp and Werkhoven 1999; Cheung et al. 2008; Jones and Sarter 2008; Jones et al. 2006; Mortimer et al. 2007, 2011). At the same time, neuropsychological research has focused on cognitive and neural correlates of tactile perception and memory (Gallace and Spence 2009). An understanding of both physiological and neuropsychological requirements is needed to develop advanced human-in-the-loop, tactile-based systems.

Vibrotactile cues can provide user information ranging from simple alerts for attention management (e.g., cell phone vibrations) to direction, spatial orientation, and more complex communications (Elliott et al. 2009a, 2015; Rupert 2000a, 2000b; van Erp 2005a, 2005b, 2007). Studies have also found that more complex vibrotactile cues driven from simultaneously or dynamically activating multiple tactors can be developed to be intuitively understood, with little or no training (Brill et al. 2006; Elliott and Redden 2012; Lylykangas et al. 2013).

Quantitative meta-analyses of over 40 empirical studies meeting well-specified inclusion criteria compared visual, tactile, and mixed (i.e., both visual and tactile) displays (Elliott et al. 2009a, 2009b; Burke et al. 2006; Prewett et al. 2012). These meta-analyses showed significant positive impacts of tactile cueing on operational workload and performance, and significant interactions with levels of workload and nature of communications (Coovert et al. 2006). Specifically, tactile cues were particularly likely to enhance performance when workload and attentional demands were high and when tactile cues were added to augment any visual cues. Tactile cues were particularly effective for direction and spatial orientation. When developed properly (i.e., consistent with expectations), the intuitive nature of tactile cues for direction and spatial orientation is more easily understood, due to concepts of automatic processing (Shiffrin and Schneider 1984) and precognitive attention (van Erp 2007). In other situations, where tactile cues were used to manage attention, convey information, and/or augment visual or audio cues, the reduced workload is consistent with Wickens's theory of multiple resources and mental workload, in that the tactile communication channel was augmenting, not competing with, other sensory information (Wickens 1992, 2002, 2008).

Consistent with the meta-analytic results, many individual studies have demonstrated effectiveness of tactile displays across a variety of military situations involving direction and spatial orientation (Raj et al. 2000; Benson 2003; Chiasson et al. 2002; van Erp et al. 2003, 2004a, 2004b, 2006, 2007; van Erp and Self 2008; Aretz et al. 2006; Calhoun et al. 2002, 2004, 2005; Moorhead et al. 2004; McGrath et al. 2004; Carlander and Eriksson 2006; Dorneich et al. 2006; Eriksson et al. 2006; McKinley and Tripp 2007; Self et al. 2007; Chen and Terrence 2008; Redden et al. 2008; Brill et al. 2014; McGrath et al. 2014; Rupert et al. 2016). Tactile direction and spatial orientation cues have also proven effective in additional civilian applications (Dobbins and Samways 2003; van Erp et al. 2003; Bloomfield and Badler 2007; Scott and Gray 2008) and in attention management and interface design (Ho et al. 2001, 2007; Spence and Driver 1997; Spence and Ho 2008; Hameed et al. 2006, 2007; Hopp et al. 2005; Krausman et al. 2005, 2007, 2008). For dismount Soldiers, tactile direction cues resulted in faster waypoint navigation time, lower workload, and/or higher user satisfaction (Eriksson et al. 2008; van Erp 2007; Elliott et al. 2006a, 2006b, 2010, 2011a, 2011b, 2013, 2015; Pomranky-Hartnett et al. 2015; Aaltonen and Laarni 2017).

While single tactor cues can provide intuitive direction cues for spatial orientation, navigation, and movement, Soldiers were also able to detect and correctly interpret previously associated meanings for spatio–temporal patterns presented across multiple tactors. These patterns represent meaning, which usually results in action, and thus have been referred to as "tactions" (tactile actions) by Mortimer et al. (2011), who also introduced software for creating tactions. Tactions are similar to the "tactons" discussed by Brewster and Brown (2004) and Brewster and King (2005); however, in this context, tactons refer to the aspect of the characteristics (such as "melody") associated with vibrotactile cueing and can be instantiated with a single tactor. In contrast, "tactions" are instantiated using a multitactor array and can vary with respect to characteristics such as location, amplitude, and tempo. Several tactions may have the same tempo, yet be easily distinguished through other aspects.

A set of tactions was developed to emulate Soldier arm and hand signals. These tactions were quickly learned (Gilson et al. 2007) and recognized accurately, even while performing strenuous movements (Pettitt et al. 2006) and simultaneously navigating with tactile direction cues (Mortimer and Elliott 2016; Pomranky-Hartnett et al. 2015). Tactions have also been integrated with instrumented glove technology, allowing hand and arm signals to be covertly communicated to the wearer of the tactile display, while maintaining accuracy of interpretation and also reducing times and allowing hand signal recognition when out of line of sight (Elliott et al. 2014a, 2014b; Baraniecki et al. 2017). Other experiments have also been reported that suggest the feasibility of multitactor cues for communication (Barber et al. 2014).

These results demonstrate several key advantages to adding a tactile aspect to dismount Soldier navigation and communication displays (e.g., communications from other Soldiers and robotic sensors). This report describes efforts to further investigate taction attributes as cues to communicate a variety of alerting messages, with regard to ease of learning and recall. Previous investigations have found differences in response time and accuracy based on taction characteristics such as static, dynamic, and salutatory dimensions (Roady and Ferris 2012). Our work further explores taction differences, relating them to measures of salience, ease of learning, and recall.

Previous studies showed the effectiveness of tactile cueing during strenuous movement but have not addressed interference during balance tasks. It has been shown that attentional demands during balance control can interfere with other cognitive tasks (Woollacott and Shumway-Cook 2002). Thus, we also investigate the effects of additional physical and cognitive task demands when users must accomplish balanced movement on a 2- by 4-inch beam placed on the floor in a slightly raised square pattern. In Experiment 1, we collected the balance data outdoors (Fig. 1); in Experiment 2, we replicated the balance task indoors.

Fig. 1 Balance beam task

1.2 Tactile Salience

Tactile salience has frequently been defined as the probability that the tactile cue will be detected (Mortimer et al. 2011). It is often measured as a percentage of cues that were correctly perceived within a forced-choice signal detection paradigm that demands the comparison of each different cue with every other cue. This measurement approach can work well in controlled laboratory settings, where salience is often modeled as a function of tactor engineering and the vibratory stimuli characteristics (i.e., engineering characteristics of the signal itself) when context (or "noise") is very low and where a large number of comparisons can be accomplished. Many investigations and reviews of tactile characteristics have been performed that focus on characteristics such as amplitude, intensity, frequency, duration, and rhythm (Geldard 1957; Cholewiak and Wollowitz 1992; Jones and Sarter 2008).

However, laboratory-based measures of tactile salience do not necessarily generalize to field settings—tactors engineered to be felt easily under stationary laboratory conditions may not be noticed under more naturalistic conditions with various, uncontrolled, and interacting contextual factors. Designers must consider these factors as part of any cognitive task assessment prior to development (Hollnagel 2003; Crandall et al. 2006). We systematically organized the contextual factors that must be considered when designing tactile systems for use "in the wild" in a previous report (Mortimer et al. 2007), as shown in Fig. 2. Predicting operator performance in naturalistic settings requires the consideration of these characteristics as they interact in a particular setting.

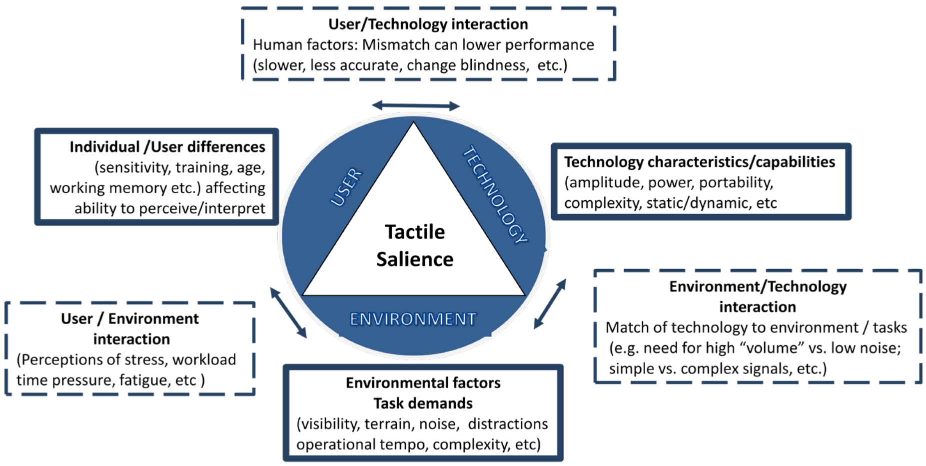

Fig. 2 Core factors and interactions affecting tactile salience

In our initial tactile salience investigation, we compared traditional laboratory forced-choice measures of salience with independent direct ratings ranging from 1 (very low) to 7 (very high) salience, and found direct ratings to be a reliable and valid method (Elliott et al. 2015). For this study, we used the direct salience ratings to investigate effects due to technology (tactile cue characteristics) and task demands (stationary versus movement and balance). We also relate aspects of technology and salience to ease of learning and recall.

1.3 Study Goals

In this study, we report the tactile salience of several multitactor cues (i.e., tactions) that vary in characteristics such as temporal sequencing, location, and amplitude. The tactions are conveyed through a torso-mounted belt having 16 tactile actuators (i.e., tactors) in 2 rows of 8, with each row comprising a particular type of tactor. An initial set of eight tactions was developed to systematically vary in taction characteristics. We examined differences in tactile salience, ease of learning, and accuracy of recall after a three-hour break. Measures were taken under two participant movement conditions: 1) when they stood stationary and 2) when they walked on a balance beam placed on the floor.

We operationally defined and measured tactile salience based on self-reports, which participants used to record their perceptions of various tactions. Tactile salience was explained as the degree to which a taction was perceived to be "noticeable, distinct, strong" through independent scale ratings. This technique was investigated previously and found to be particularly suited (as compared to force choice pairings) when the number of signals exceeds three or four (Elliott et al. 2015).

Two data collection sessions were accomplished. The first, described in Experiment 1 (Section 2), was based on eight tactions. The second, described in Experiment 2 (Section 3), used refined and additional tactions and procedures and was based on 12 tactions.

2. Experiment 1

2.1 Method

In Experiment 1, we examined the effect on salience of eight different tactions with varying engineering characteristics. Ratings of salience were collected for each taction prior to any explanations of meaning. After participants provided ratings of salience, they were taught the meaning of each taction through controlled training sessions. They were asked to recall the meaning of each taction as it was presented. Presentation was counterbalanced between the following performance sessions:

1) AM (morning) stationary
2) AM (morning) balance beam
3) PM (afternoon) stationary
4) PM (afternoon) balance beam

2.1.1 Tactors

For Experiment 1, we utilized two types of tactors developed to optimize human tactile perception—the Engineering Acoustics, Inc (EAI) C-2/C-3 and the EAI eccentric-mass rubber (EMR) (Fig. 3).

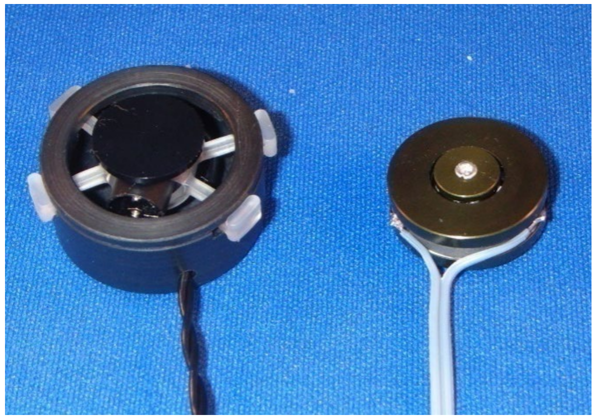

Fig. 3 EAI EMR (left) and EAI C-3 (right) tactor transducers

The characteristics of the C-3 and EMR tactors are listed in Table 1.

Table 1 Characteristics of C-3 and EMR tactors

Characteristic	C-3	EMR
Mechanism	Moving magnet linear actuator	Motor-based actuator
Diameter	0.74-inch	1-inch
Thickness	0.24-inch	0.4-inch
Main frequency	200–300 Hz (but can operate at lower frequencies	50–140 Hz (but can operate at lower frequencies)
Peak displacement	0.04-inch	0.047-inch
Material	Anodized aluminum, polyurethane	Polycarbonate and ABS plastic

Note: ABS = acrylonitrile butadiene styrene

2.1.1.1 EAI C-3

The C-3 tactor used in this study is small (20.3 mm in diameter and 6.4 mm in height), lightweight (8 g), and performs similarly to the C-2. The C-series tactors use a unique engineering approach (Fig. 4) proven to be particularly salient under strenuous movement (Redden et al. 2006). Skin contact occurs through the predominant moving mass, driving the skin with perpendicular sinusoidal movement that is independent of the loading effects (Mortimer et al. 2007). In this study, the C-3 tactors were programmed at 250 Hz, which is optimal for human perception on the torso. The sensation is particularly "sharp" with this type of tactor due to its structure and designed resonance. The linear actuator design of these tactors provides a strong, point-like sensation that is easily felt and localized. The C-3 tactors have a rise time of less than 2 ms.

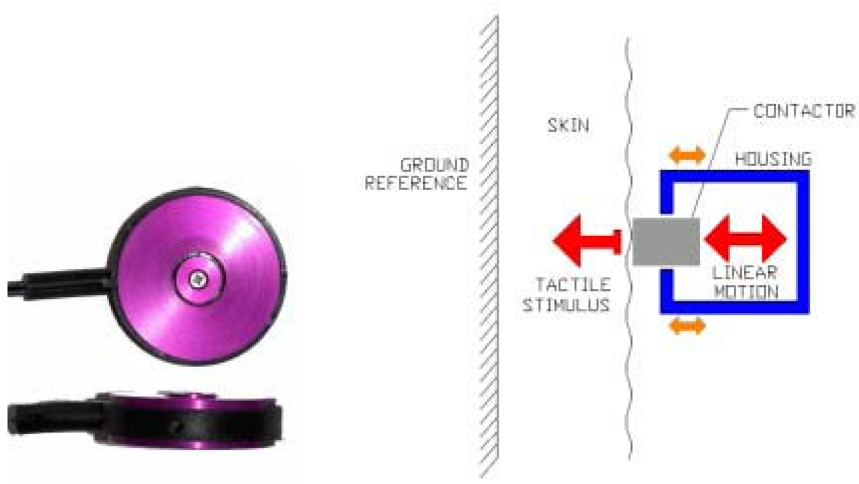

Fig. 4 C-series linear actuator design approach: photograph (left) and operational schematic (right)

2.1.1.2 EAI EMR

The EMR tactor used in this study produces the highest displacement amplitudes reported thus far, with an operating frequency of around 80–100 Hz. The EMR has a rise time of about 12 ms. The C-3 tactors are considered as moving magnet linear motors, while the EMR uses rotational motors that are suspended in a unique linear actuator configuration. The rotational motor is mounted on the moving “contactor,” which is lightly preloaded against the skin. When an electrical signal is applied, the contactor vibrates approximately perpendicular to the skin.

2.1.1.3 Prototype Dual Row Tactile Belt

Tactors are the individual vibrating actuators (e.g., EMR and C-3) used to create the tactions. Tactors were embedded in a prototype dual row tactile belt, which participants affixed around their waists. The belt is lightweight (< 1 lb), somewhat stretchy, and comes in small (30–32 inches), medium (34–36 inches), large (36–38 inches), and extra large (40–42 inches) sizes. Each belt has two rows of eight tactors that are positioned so that they are spaced approximately equally when worn on the torso (Fig. 5). Tactors 1–8 corresponded to a lower row of EMR tactors, and tactors 9–16 corresponded to a higher row of C-3 tactors. Each tactor was separated by approximately three inches horizontally and one inch vertically. Figure 6 shows the EMR and C-3 tactors on the inside of the belt as they are embedded within the prototype dual row belt used in this study.

Fig. 5 Prototype dual row tactile belt. Each belt contained a row of eight C-3 tactors (top) and a row of eight EMR tactors (bottom). Tactors 9 and 1 correspond to the front of the abdomen.

Fig. 6 Prototype dual row tactile belt (inside part touching the skin)

2.1.2 Tactions

Tactions are the tactile patterns created by multiple tactors, felt as a single pattern, and designed to be associated with meaning. In this study, eight tactions were generated using software (TAction Creator) that enables systematic specification of tactor activation characteristics, timing, and sequencing. TAction Creator uses visual graphics with drag-and-drop features to systematically create and modify taction characteristics.

We used a total of eight tactions to represent operation definitions that corresponded with critical communications to Soldiers. Some of the tactions were developed and used in previous studies with Soldier subjects, where they represented communications commonly conveyed with Army hand and arm signals (e.g., “halt”, “rally”, “NBC” [nuclear, biological, chemical threat], or “move up”). These tactions were found in previous investigations to be easily perceived and interpreted (Gilson et al. 2007; Stafford et al. 2007; Brill et al. 2006). As an example, the “Rally” taction used a sequenced activation of tactors around the torso, felt as a discrete circling sensation, to associate with the Rally hand and arm signal, where the hand is upraised and moves in a circular motion. All tactions were developed to help the participant associate the taction with its meaning. Tactions were chosen or developed to vary systematically in two characteristics: 1) locational sequencing (whether they were static or dynamic in presentation) and 2) complexity (whether their tactor cue stimulation characteristics were standard or complex). We based our definition of static and dynamic tactile patterns and introduction of complexity on the work of Barber et al. (2014) as follows:

1) Locational Sequencing. *Static tactions* represent a constant pattern using the same tactors. This is perceived as a stimulus at the same locations together with an associated temporal sequence. *Dynamic tactions* present a changing sequence of tactors usually experienced as motion by the user, similar to how sequential activation of lights can be perceived as motion.

2) Complexity. *Standard tactions* include tone burst pulsating vibrotactile patterns, as described by Jones and Sarter (2008). These patterns are typically single-frequency and can be pulse-length modulated, as described by Brewster and Brown (2004). *Complex tactions* use amplitude and/or frequency sweeps and/or short pulsatile to create somatosensory illusion experiences (usually associated with movement perception). Examples include various illusions such as the cutaneous rabbit (Geldard and Sherrick 1972), paint brush illusion (Israr and Poupyrev 2011), and phi (motion; Burtt 1917). These illusionary characteristics were utilized to develop tactions with complex characteristics.

Table 2 lists the eight tactions used in Experiment 1 and some of their characteristics.

Table 2 Characteristics of tactions used in Experiment 1

Taction	Locational sequencing[a]	Complexity[b]	Pattern length (ms)	C-3	EMR	Max tactors/ spatial sites
NBC	S	st	2000	X	. . .	2/4
PointRight	D	st	990	X	. . .	3/5
Rally-2x	D	st	1930	X	. . .	2/8
WheelSpin	D	st	2310	X	. . .	2/7
Looming	S	cp	3150	X	. . .	8/8
IED	S	cp	1500	X	X	9/9
MoveUp	D	cp	1840	X	X	4/5
Disperse	D	cp	9700	. . .	X	2/8

[a] S = static; D = dynamic.
[b] st = standard; cp = complex.

2.1.2.1 Standard Tactions

Screenshots of the taction creator display are used in the following subsections to describe the eight tactions used for Experiment 1. Tactors 1–8 and 9–16 of the display represent the EMR tactors (bottom row) and C-3 tactors (top row) on the tactile belt, respectively. Tactors 1 and 9 are located at the left edge of the tactile belt, and when worn, correspond to the front of the torso. The tactor numbering continues clockwise sequentially such that tactors 5 and 13 are positioned along the spine. The blue boxes represent which tactors were activated, when, and for how long.

NBC (Standard/Static). The NBC threat taction comprises a repetitive sequence of pulses that alternate between the back left and front right. It was implemented on C-3, tactors 9–16, as portrayed in Fig. 7. Each tactor pulse in the sequence comprises a 250-Hz tone-burst at the maximum displacement. The NBC taction was designed to be felt on the sides in a repetitive manner to evoke the Army hand signal for NBC. The Army has since changed the terminology of the hand signal from NBC to chemical, biological, radioactive, nuclear threat. The terminology will be updated in subsequent use of this taction.

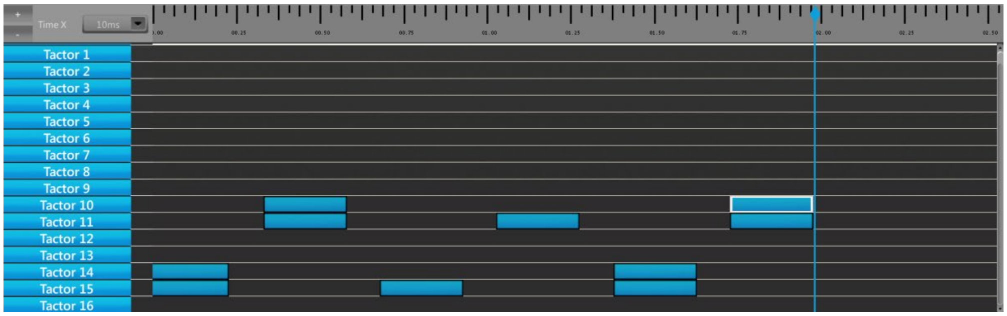

Fig. 7 NBC taction using the C-3 (tactors 9–16)

PointRight (Standard/Dynamic). The PointRight (direction attention cue) taction comprises a dynamic sequence of pulses that start simultaneously on the back and front and then move toward the right side. The overlap of tactor sites and active locations gives a strong sense of movement. The PointRight taction was implemented on C-3 (tactors 9–16), as portrayed in Fig. 8.

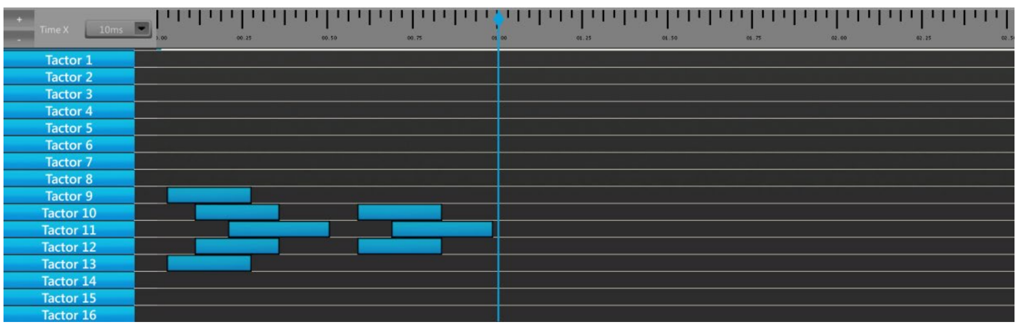

Fig. 8 PointRight taction using the C-3 (tactors 9–16)

Rally-2x (Standard/Dynamic). The Rally-2x taction comprises a dynamic sequence of pulses that start in the center (belly) and move clockwise around the body. Note that this Rally-2x implementation is slightly different from previous experiments; specifically, the pattern composition of a rotating dynamic sequence of tactors that partially overlap in duration. The Rally-2x taction was implemented on C-3 (tactors 9–16), as portrayed in Fig. 9.

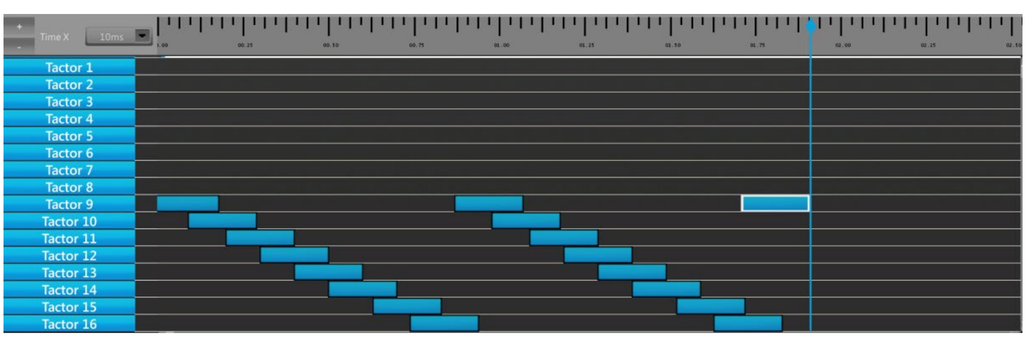

Fig. 9 Rally-2x taction using a pulse sequence on the C-3 (tactors 9–16)

WheelSpin (Standard/Dynamic). The WheelSpin taction comprises a dynamic sequence of alternating pulses (between the back and sides, ending at front left). It was implemented on C-3 (tactors 9–16), as portrayed in Fig. 10. The WheelSpin sequencing was perceived as a “stuttering” to evoke the association of a wheel that is stuck and spinning to move out. The WheelSpin taction was developed as a status update that could be sent from a semiautonomous robot to the Soldier operator, to indicate that it is stuck and cannot move.

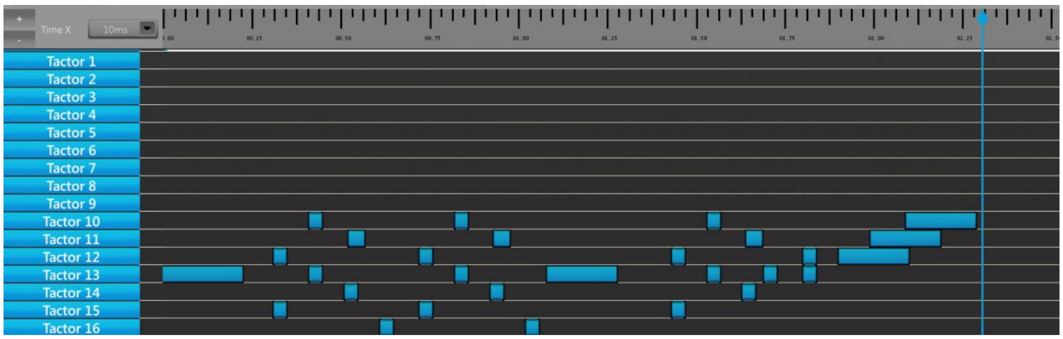

Fig. 10 WheelSpin taction using the C-3 (tactors 9–16)

2.1.2.2 Complex Tactions

Looming (Complex/Static). The Looming taction comprises a complex static pulsatile pattern on simultaneous tactors. It was implemented on C-3 (tactors 9–16), as portrayed in Fig. 11. The Looming taction was developed to convey the idea of “approaching”. Increasing (or ramping) the frequency of vibration over the period of stimulation was determined as most effective way to communicate this construct (Lawson et al. 2015).

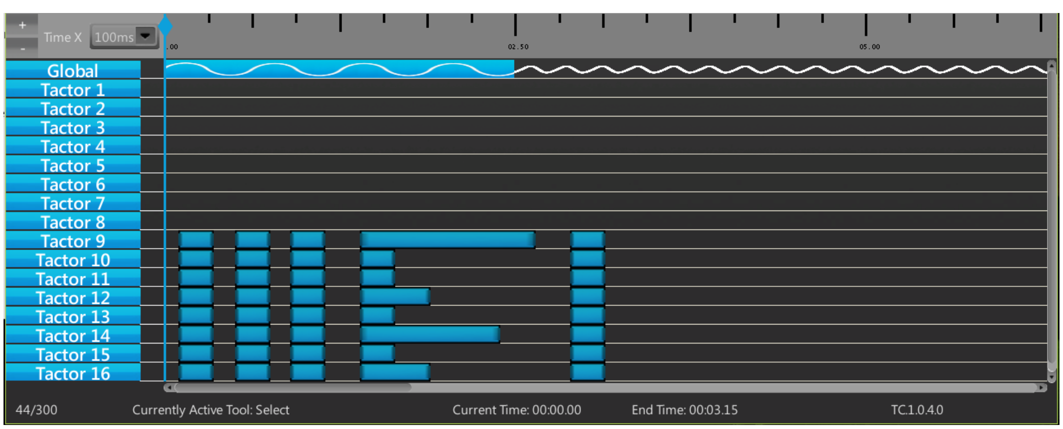

Fig. 11 Looming taction using the C-3 (tactors 9–16)

IED (Complex/Static). The IED taction comprises nine simultaneous pulses and uses both the EMR (tactors 1–8) and C-3 (tactors 9–16). This taction was “static” in the sense that the pulse stimuli were presented on fixed tactors in the tactile belt array. However, each tactor pulse was "complex" in that the amplitude or gain was ramped linearly. Specifically, each tactor was pulsed on for a 1,500-ms tone-burst duration, while the gain was linearly varied from maximum to 0 (254-1 gain) (Fig. 12). The IED taction was perceived in the torso front as vibrations that immediately ramp high, then lower, to emulate an IED explosion.

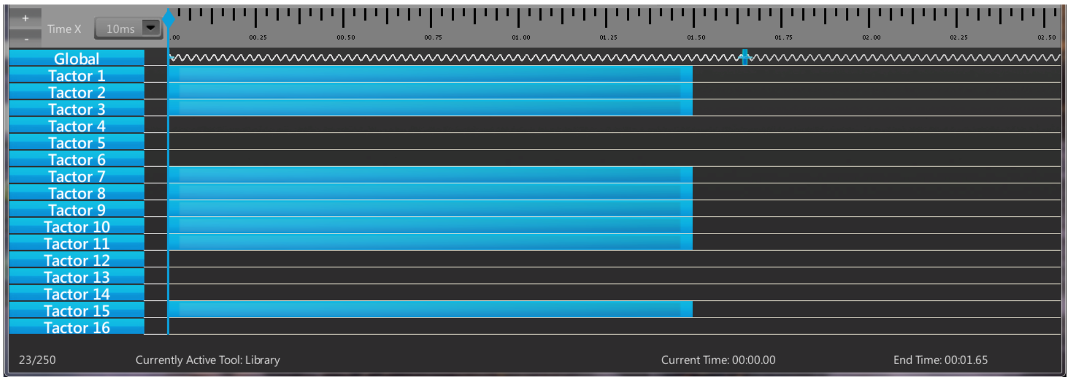

Fig. 12 IED taction using the EMR (tactors 1–8) and C-3 (tactors 9–16)

MoveUp (Complex/Dynamic). The MoveUp taction comprises simultaneous ramps on two (or four) tactors in adjacent rows. Thus, the EMR (tactors 1–8) and C-3 (tactors 9–16) are used and ramped simultaneously, as shown in Fig. 13. The pattern follows the tactile "paintbrush" (Israr and Poupyrev 2011) and provides a sensation of movement toward the front, with a final vibration at the front.

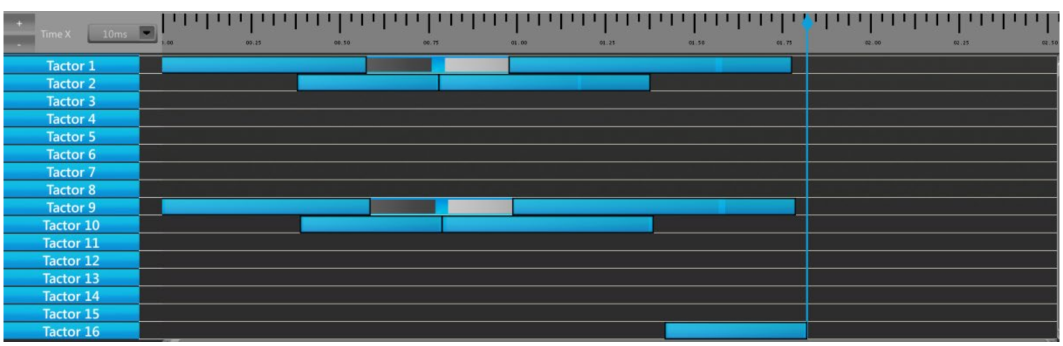

Fig. 13 MoveUp taction using both the EMR (tactors 1–8) and C-3 (tactors 9–16)

Disperse (Complex/Dynamic). The Disperse taction comprises a series of overlapping ramps on EMR (tactors 1–8) that wrap around the torso, as shown in Fig. 14. This pattern utilizes the tactile "paintbrush" (Israr and Poupyrev 2011) illusion and provides a sensation of movement that starts at the belly and moves clockwise around the torso, with distinct vibrations at different locations. Participants were told to think of how a squad disperses in different directions on command.

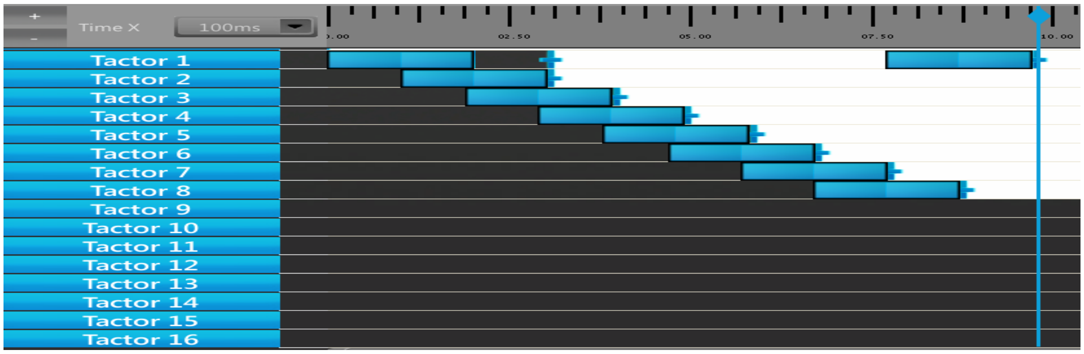

Fig. 14 Disperse taction using the EMR (tactors 1–8)

2.2 Participants

Twenty Soldiers attending Officer Candidate School were recruited from active-duty units located at Fort Benning, Georgia (14 males and 6 females). The Soldiers ranged in age from 23 to 33 (the mean age was 27.2). They averaged 15 months of military service, and ranged in rank from Private to Sergeant. Their occupational specialties were in infantry/armor and support operations.

2.3 Procedures

2.3.1 Orientation

Upon arrival, each Soldier was briefed on the purpose of the investigation, the procedures to be followed, and any risks involved in their participation. Though Soldiers volunteered to be part of this study, they were given a formal opportunity to reconsider. The informed consent form was provided to all Soldiers, and the investigator explained its contents, reciting text approved by the US Army Research Laboratory* Institutional Review Board. Soldiers were informed that the nature of the experiment focused on their perceptions and rankings with regard to tactile cues. They understood that they would wear the tactile belt and headphones delivering pink noise to mask audio cues. Soldiers were given an opportunity to review the experiment objectives, ask investigators any questions, and sign the consent form indicating their informed voluntary consent to participate if they were still willing. Soldiers were informed that if they chose not to participate, they could convey that choice privately to the investigator. They were also informed that, even if they chose to participate, they could stop their participation at any time during the experiment. All Soldiers agreed to participate. A demographic questionnaire was

* As of February 2019, the US Army Research Laboratory (ARL) has been renamed the US Army Combat Capabilities Development Command – Army Research Laboratory (CCDC-ARL).

then administered to obtain pertinent information on their backgrounds (Appendix A).

2.3.2 Training

As each Soldier donned the belt, investigators ensured that it was situated and fitted correctly, then ensured that the tactile belt system was functioning properly by using the handheld tablet to activate each tactor. The Soldier responded to each discrete activation by indicating whether each vibratory sensation was felt. No problems with belt functionality were noted during the course of the study.

Training was conducted in two parts. In the first part, Soldiers provided ratings of salience prior to being trained on assigned meanings to attain a rating of salience per se, as opposed to interpretability. This consisted of familiarizing them with the rating scale used to assess salience. Soldiers were given the following instructions:

"We will be presenting you with eight different patterns of tactile signals. We will let you feel each of them first, to give you an idea of what each one feels like. Then, we will give you the signals one at a time, and ask you to give each one a rating from one to five that indicates how strongly, or easily, you think each one can be felt."

A poster was then presented that described the five-point scale for salience, ranging from 1 (weak, blurred, faint, vague) to 5 (noticeable, distinct, strong, salient). Each Soldier provided ratings of salience for each taction. Each taction was presented twice. Ratings of salience were collected.

In the second part, each Soldier was trained on the meaning of each signal (i.e., taction). First, the tactions were trained in pairs—two tactions were presented, with meanings. The instructor repeated each taction of this pair, in random order, until the Soldier labeled each taction correctly, three times in a row. After eight tactions were presented to the Soldier in this way, the instructor repeated each of the eight tactions, in counterbalanced order, until the Soldier was able to correctly identify each signal, three times in a row. The instructor documented the number of times each taction was repeated to achieve requisite performance.

2.3.3 Experiment Design

The eight tactions used in this experiment varied in characteristics of complexity (standard or complex) and locational sequencing (static or dynamic), and were categorized into one of four resulting taction categories—standard/static, standard/dynamic, complex/static, or complex/dynamic—as shown in Table 3. The intention was to have two tactions in each category; however, the PointRight taction had a dynamic characteristic that caused it to be reclassified from standard/static to standard/dynamic. These tactions were presented in a counterbalanced manner throughout the experiment, from initial presentations for ratings of salience, training, and recall conditions. Each taction was presented twice in each condition.

Table 3 Tactions associated with each category, Experiment 1

	Static	Dynamic
Standard	NBC	Rally-2x, PointRight, WheelSpin
Complex	Looming, IED	Disperse, MoveUp

Table 4 describes the counterbalanced assignment of categories to Soldiers by roster number. Assignment was based on William's Square design, a variant of Latin Square design that controls for order effects (Williams 1949).

Table 4 Assignment of Soldiers to movement conditions

Soldier roster no.	Morning		Afternoon	
1, 5, 9, 13, 17	Stationary[a]/A[b]	Balance beam/B	Balance beam/C	Stationary/D
2, 6, 10, 14, 18	Stationary/B	Balance beam/A	Stationary/D	Balance beam/C
3, 7, 11, 15, 19	Balance beam/C	Stationary/D	Balance beam/A	Stationary/B
4, 8, 12, 16, 20	Balance beam/D	Stationary/C	Stationary/B	Balance beam/A

[a] Stationary and balance beam refer to the movement conditions under which measurements were taken.
[b] A, B, C, and D refer to the four different taction presentation sequences used to counterbalance the order.

2.4 Results

Results are presented in accordance with the extent to which various taction characteristics affect the following:

1) Salience (during the ratings of salience segment of training)
2) Learning (during the taction meanings segment of training)
3) Recall (during the performance sessions)

Results from the final questionnaire Soldiers completed at the end of the experiment are summarized and presented as well.

2.4.1 Salience

Table 5 provides the mean ratings of salience for the first and second presentation of each taction and for the total of the two presentations. These values, along with 95% confidence intervals, are presented in Fig. 15.

Table 5 Mean ratings of salience by taction presentation, Experiment 1

Taction category	Taction	First presentation		Second presentation		Total	
		Mean	SD[a]	Mean	SD	Mean	SD
Standard/Static	NBC	3.8	1.1	3.7	1.1	3.7	1.10
Standard/Dynamic	PointRight	3.1	1.0	2.7	1.2	2.9	1.10
	Rally-2x	3.4	1.0	3.6	0.8	3.5	0.93
	WheelSpin	2.9	1.2	2.9	1.1	2.9	1.15
Complex/Dynamic	MoveUp	2.4	1.3	2.4	0.9	2.4	1.11
	Disperse	2.6	1.2	2.7	1.1	2.7	1.14
Complex/Static	Looming	3.6	1.3	4.2	0.7	3.9	1.06
	IED	3.9	1.2	4.2	1.1	4.0	1.15

[a] SD = standard deviation.

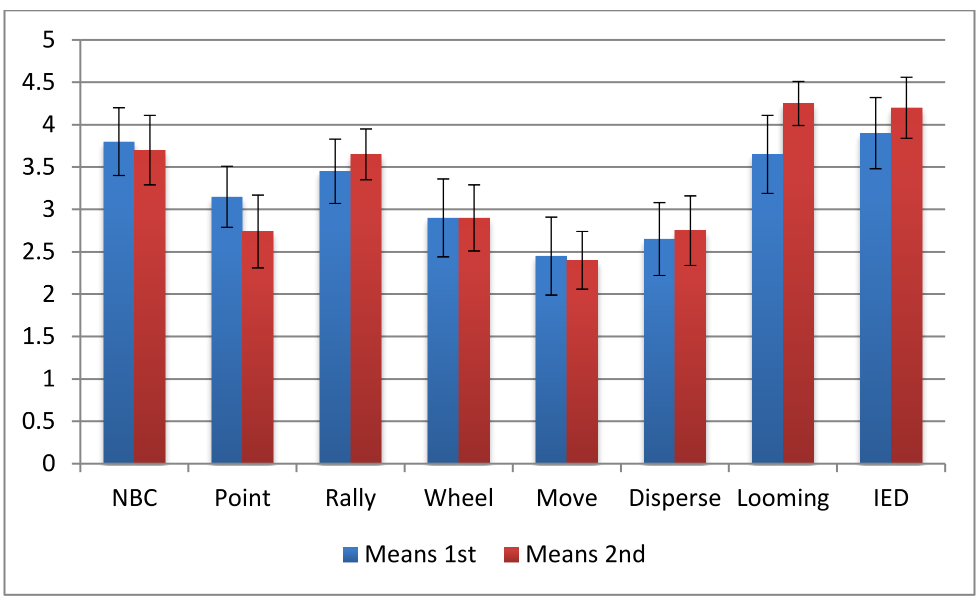

Fig. 15 Mean ratings of taction salience, first vs. second presentation. Bars represent 95% confidence intervals.

Table 6 provides mean ratings of salience for each of the four taction categories according to first and second presentation and for the total of the two presentations. There was little difference between the first and second presentations, indicating high test–retest reliability. The breakdown of overall mean ratings by taction characteristic is also presented in Table 6. Overall means ranged from 2.6 for dynamic/complex to 3.8 for static/complex.

Table 6 Mean ratings of salience by taction category, Experiment 1

Taction category	First presentation		Second presentation		Total	
	Mean	SD[a]	Mean	SD[a]	Mean	SD[a]
Standard/Static	3.7	1.1	3.8	0.96	3.8	0.9
Complex/Static	3.2	0.8	3.1	0.84	3.1	0.8
Standard/Dynamic	3.2	1.0	3.2	0.84	3.2	0.8
Complex/Dynamic	2.6	1.1	2.7	0.80	2.6	0.9

[a] SD = standard deviation.

As shown in Fig. 16, both variables (complexity and locational sequencing) had main effects on ratings of salience. Repeated measures analysis of variance (ANOVA) shows a significant main effect for the locational sequencing variable, as indicated by the overall F statistic, that indicates whether differences among a set of variable means are statistically significant, within a set probability ($p \leq 0.05$ indicates the probability of the difference occurring by chance is equal to or less than 0.05). (F [1, 18] = 17.09, $p < 0.01$, $\eta\rho^2 = 0.49$) and for the complexity variable (F [1, 18] = 24.21, $p < 0.01$, $\eta\rho^2$ 0.57). Effect sizes were calculated by partial eta squared ($\eta\rho^2$), which represents the degree to which the two conditions differed, while accounting for variance around each mean. In this case, $\eta\rho^2$ was relatively high. Interaction effects were not significant.

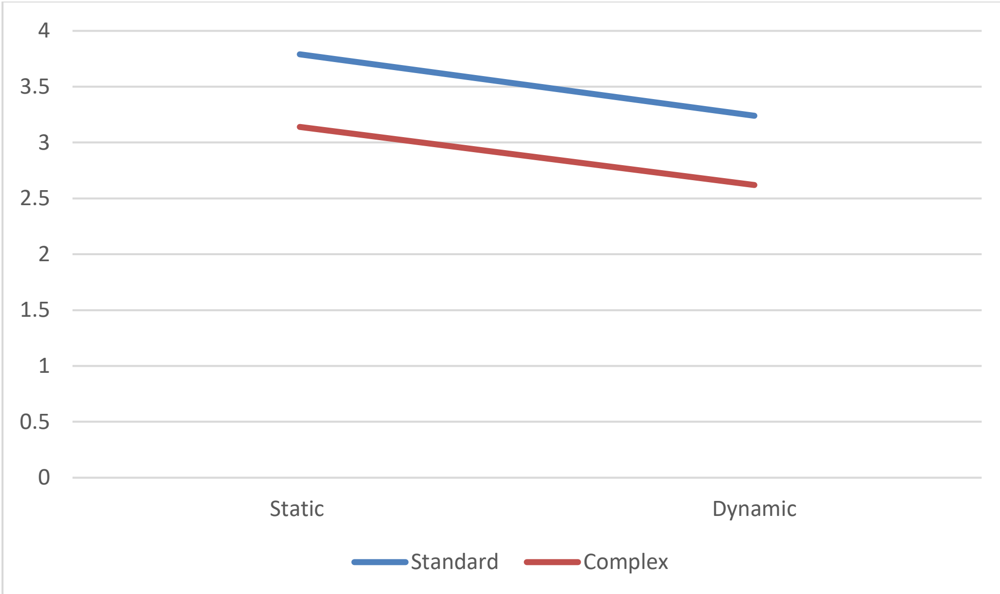

Fig. 16 Overall mean ratings of salience by taction category, Experiment 1

2.4.2 Ease of Learning

Soldiers were trained on the meaning of the tactions (which were presented in sets of two), and had no problem distinguishing and learning the meaning of the tactions. Pairs were presented to the Soldiers until they correctly identified the tactions in each pair three consecutive times. They were then asked to define all eight tactions, one at a time. Each time they made an error, the instructor noted the error and the taction for which it was mistaken, and communicated the correct taction meaning. This process was repeated, going through each of the eight tactions until the Soldiers correctly identified each one three consecutive times. Table 7 provides various measurements that indicate the ease with which each taction was learned, including the mean number of repetitions for each taction, along with the taction for which it was mistaken.

Table 7 Indices representing ease in training by taction, Experiment 1

Taction category	Taction	Mean repetition	Total errors	Tactions reported in error
Standard/Static	NBC	3.1	1	IED
Standard/Dynamic	PointRight	3.0	0	. . .
	Rally-2x	3.5	10	WheelSpin (7) MoveUp (1) Disperse (1) Looming (1)
	WheelSpin	3.2	4	Rally-2x (4)
Complex/Dynamic	MoveUp	3.2	4	Rally-2x (1) PointRight (3)
	Disperse	3.1	2	Rally-2x (1) Looming (1)
Complex/Static	Looming	3.2	4	MoveUp (1) Rally-2x (1) IED (1) WheelSpin (1)
	IED	3.1	3	MoveUp (1) NBC (1) WheelSpin (1)

It should be noted that while errors did occur with particular tactions, individual Soldiers differed with respect to the number of errors and repetitions needed to learn each taction. Nine Soldiers learned all eight tactions without error from the initial paired taction training. Four Soldiers had more difficulty than the others. Results indicate that individual variables may account for these differences. Consequently, the decision was made to include measures of working memory as a covariate in subsequent data collections.

Of the errors reported, the highest number was associated with Rally-2x—Soldiers tended to mistake Rally-2x for other dynamic tactions (WheelSpin, MoveUp, Disperse, and Looming). Rally-2x is a relatively simple dynamic taction, designed for two sequential "passes" around the torso to associate it with the hand and arm signal for Rally, which is a circular movement made with the hand. We expected Rally-2x to be the most easily recognized of the dynamic tactions; however, including other dynamic tactions greatly reduced its overall ease of recognition. Wheelspin especially shares some Rally-2x similarities in pattern dynamics and rotation. This interaction illustrates the importance of designing taction patterns (and even portions of tactions) that are unique and distinct.

2.4.3 Recall

Soldiers participated in four recall performance sessions—two in the morning (stationary and balance beam) and two more in the afternoon (2–3 h later). The presentation order of each taction was counterbalanced (see Table 4) to minimize order effects of primacy (a higher recall of the first items in a list) and recency (a higher recall of the latest items in a list).

2.4.3.1 Effect of Individual Tactions on Recall

Table 8 provides mean overall recall accuracy averaged over time and movement condition. It can be seen that Soldiers had the most difficulty with the Rally-2x taction.

Table 8 Mean overall recall accuracy by taction, Experiment 1

Taction	Mean accuracy (% correct)
NBC	0.95
PointRight	0.96
Rally-2x	0.78
WheelSpin	0.94
MoveUp	0.95
Disperse	0.97
Looming	0.92
IED	0.99

2.4.3.2 Reliability of Taction Ratings within Condition

Tactions were presented twice during each performance session. A breakdown of mean performance by the first versus the second eight-taction set is provided in Table 9. It can be seen that mean accuracies were similar for first versus second presentations, and that this Rally-2x implementation was just as likely to be mistaken on the second presentation as the first. Results indicate participant responses were both accurate and consistent.

Table 9 Mean recall accuracy by taction: first vs. second set within a performance session, Experiment 1

Taction	Mean recall accuracy	
	First set	**Second set**
NBC	0.94	0.96
PointRight	0.94	0.97
Rally-2x	0.78	0.78
WheelSpin	0.92	0.95
MoveUp	0.93	0.96
Disperse	0.97	0.97
Looming	0.91	0.92
IED	0.98	0.99

2.4.3.3 Effect of Elapsed Time on Recall

Each Soldier performed tactions under stationary and balance beam movement conditions twice: once immediately after training (morning) and again about 3 h later (afternoon). We expected that the passage of time (greater than 2 to 3 h), along with the lunch break, would degrade recall accuracy during the afternoon sessions. We averaged across the movement conditions to assess any effect of time on recall accuracy. Table 10 shows performance of each taction as a function of time of day, showing the mean accuracy for tactions in the morning and in the afternoon. It can be seen that accurate recall of Rally-2x declined over time, while other tactions were relatively unaffected.

Table 10 Mean recall accuracy by taction: morning vs. afternoon, Experiment 1

Taction	Mean recall accuracy	
	Morning	**Afternoon**
NBC	0.93	0.98
PointRight	0.96	0.96
Rally-2x	0.84	0.72
WheelSpin	0.93	0.94
MoveUp	0.96	0.93
Disperse	0.97	0.92
Looming	0.92	0.91
IED	0.99	0.98

Table 11 and Fig. 17 show the mean recall accuracy for each taction category for morning and afternoon. It can be seen that the standard/static tactions were remembered most accurately over the three-hour time period, while the recall accuracy for other categories of tactions declined over time.

Table 11 Mean recall accuracy by taction category: morning vs. afternoon, Experiment 1

Taction category	Mean recall accuracy	
	Morning	Afternoon
Standard/Static	0.93	0.98
Complex/Static	0.91	0.87
Standard/Dynamic	0.96	0.95
Complex/Dynamic	0.96	0.94

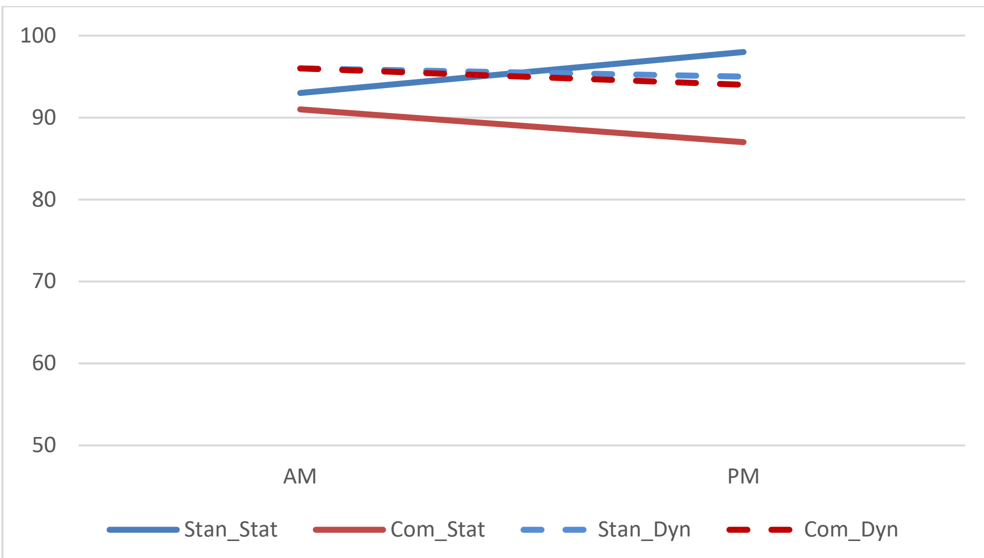

Fig. 17 Mean recall accuracy by taction category over time, Experiment 1

2.4.3.4 Effect of Complexity and Locational Sequencing on Recall

Table 12 and Fig. 18 show overall mean accuracy by taction category. While the graph suggests an interaction effect (i.e., when effects of one characteristic can be affected by another characteristic), repeated measures ANOVA analyses found significant effects only for the main effects. Results showed significant main effects due to the locational sequencing variable ($F [1, 71] = 6.003$, $p < 0.02$, $\eta\rho^2 = 0.08$) and the complexity variable ($F [1, 71] = 5.56$, $p < 0.03$, $\eta\rho^2 = 0.07$), while the interaction did not reach $p = 0.05$ significance criterion ($F [1, 71] = 3.50$, $p = 0.06$, $\eta\rho^2 = 0.05$).

Table 12 Overall mean recall accuracy by taction category, Experiment 1

Taction category	Mean recall accuracy	SD[a]
Standard/Static	0.95	0.14
Standard/Dynamic	0.89	0.13
Complex/Static	0.96	0.12
Complex/Dynamic	0.95	0.13

[a] SD = standard deviation.

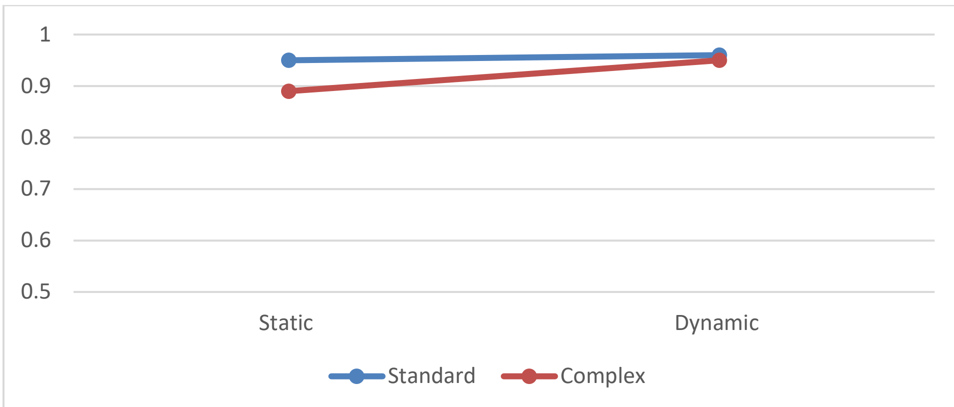

Fig. 18 Overall mean recall accuracy by taction category, Experiment 1

2.4.3.6 Effect of Movement Condition on Recall

Each Soldier performed tactions under stationary and balance beam movement conditions twice: once in the morning and once in the afternoon. Table 13 shows the mean recall accuracy of each taction by movement condition. Most of the tactions were unaffected, but the recall accuracy of WheelSpin, Looming, and MoveUp decreased on the balance beam.

Table 13 Mean recall accuracy by taction: stationary vs. balance beam, Experiment 1

Taction	Mean recall accuracy	
	Stationary	Balance beam
NBC	0.95	0.95
PointRight	0.96	0.96
Rally-2x	0.78	0.79
WheelSpin	0.97	0.90
MoveUp	0.96	0.93
Disperse	0.97	0.96
Looming	0.94	0.89
IED	0.99	0.98

Table 14 and Fig. 19 show the mean recall accuracy of each taction category by movement condition, along with paired sample t-test results. There were no significant differences between the stationary and balance beam movement conditions.

Table 14 Mean recall accuracy of each taction category by movement condition, Experiment 1

Taction category	Mean recall accuracy		Paired sample t-test
	Stationary	Balance beam	
Standard/Static	0.95	0.95	0.002 ns
Complex/Static	0.90	0.88	0.736 ns
Standard/Dynamic	0.88	0.84	0.611 ns
Complex/Dynamic	0.97	0.95	0.791 ns

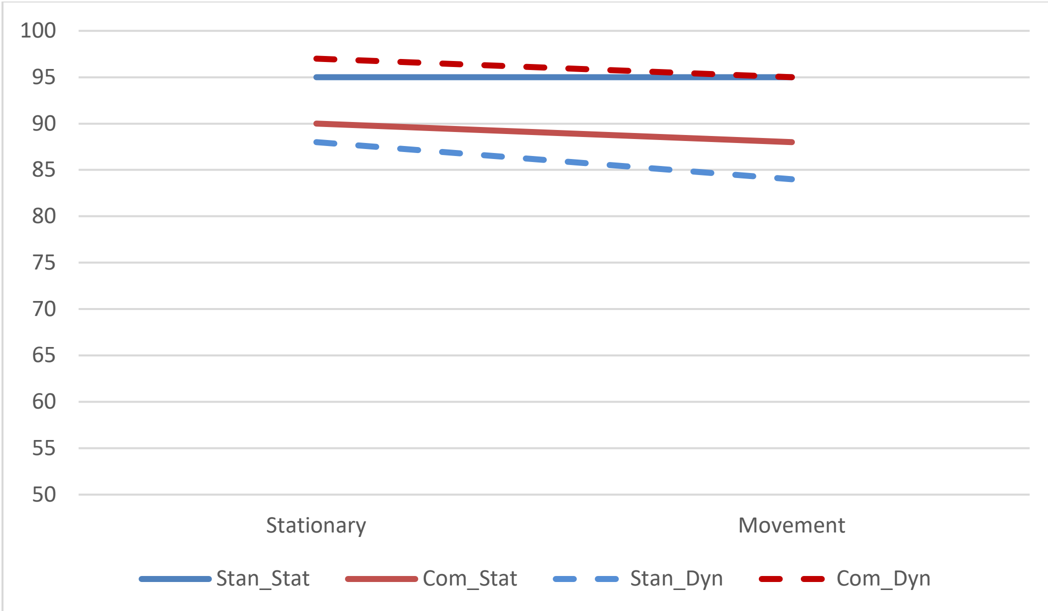

Fig. 19 Mean recall accuracy of each taction category by movement condition, Experiment 1

Appendix B provides a breakdown of mean recall accuracy data for each taction category in a two-way breakdown using the Time of Day and Movement Condition categories.

2.4.3.7 Mean Time to Interpret as a Dependent Variable

Experiment data observers recorded the total mean time for each Soldier to interpret all of the tactions presented during each performance session. As shown in Table 15, the amount of time did not vary significantly according to time of day or movement condition.

Table 15 Mean time to interpret by performance session, Experiment 1

Performance session	Movement condition	Time of day	Mean time to interpret (s)	SD[a]	N[b]
1	Balance beam	Morning	40.10	6.387	19
3	Balance beam	Afternoon	41.21	14.399	16
	Total		40.61	10.648	35
2	Stationary	Morning	37.25	6.554	20
4	Stationary	Afternoon	39.38	7.276	17
	Total		38.22	6.882	37

[a] SD = standard deviation.
[b] N= number of observations.

2.4.3.8 Analysis of Taction Execution Time

Some of the tactions took longer to execute than others, as seen in Table 16. (In particular, Disperse was a much longer taction.) We investigated whether taction length had any effect on ratings of salience. Taction execution times varied, from 990 ms for PointRight to 9700 ms for Disperse. However, reaction time did not correlate significantly with mean ratings of salience ($r = 0.34$, $p = 0.41$). In addition, there was no effect on accuracy. Analysis of covariance did not result in significant effects in performance for any of the fixed categorical variables (i.e., movement condition or time of day).

Table 16 Total execution time by taction, Experiment 1

Taction	Execution time (ms)
NBC	2000.00
PointRight	990.00
Rally-2x	1930.00
WheelSpin	2310.00
MoveUp	1840.00
Disperse	9700.00
Looming	3150.00
IED	1500.00

2.4.4 Final Questionnaire

After all performance trials were concluded, each Soldier completed the end-of-experiment questionnaire and offered verbal and written comments. An experimenter was present at these sessions to answer questions, discuss issues, and encourage written documentation.

2.4.4.1 Training Effectiveness

The first section of the final questionnaire asked respondents to rate, using a scale from 1 (extremely ineffective) to 7 (extremely effective), specific aspects of training. Table 17 indicates high levels of satisfaction with training and perceptions of preparedness.

Table 17 Training effectiveness, Experiment 1

Training aspect	Mean[a]	SD[b]
Overall effectiveness of training for use	6.30	0.86
Hands-on training	6.45	0.69
How prepared did you feel for using the tactile display?	5.95	0.99
How well do you think you used the tactile display?	6.10	0.85

[a] 1 = extremely ineffective/unprepared to 7 = extremely effective/prepared.
[b] SD = standard deviation.

Comments provided after training were generally positive. Soldiers indicated that the training was effective. They also gave preliminary feedback on the tactions. Some stated that the tactions were easy to distinguish. Others said some of the tactions were too long (e.g., Disperse). Several stated that it was difficult to distinguish between WheelSpin and Rally-2x.

2.4.4.2 Tactile Belt Comfort and Fit

Soldiers reported relatively high ratings for comfort and fit of the dual row tactile belt (Table 18). Comments suggested more sizes for better fit. The smaller belt was not small enough for some of the Soldiers, particularly female Soldiers.

Table 18 Dual row tactile belt, comfort and fit, Experiment 1

Belt feature	Mean[a]	SD[b]
Comfort	5.70	1.21
Adjustability	5.21	1.23
Fit	5.25	1.29

[a] 1 = extremely negative to 7 = extremely positive.
[b] SD = standard deviation.

Soldier comments were generally positive, particularly with regard to weight. However, several Soldiers found that the belt was too loose. This was addressed by adding a cinch-type belt on top of the tactile belt, to ensure closer tactor-to-body contact. Soldiers indicated that the snug fit would ultimately cause perspiration, so the belt needs further modification to be better suited for combat operations.

2.4.4.3 Ease of Feeling Tactions

Table 19 provides mean ratings for ease of feeling tactions.

Table 19 Ease of feeling tactions, Experiment 1

Feature	Mean[a]	SD[b]
Ease of feeling taction patterns in general	5.60	0.88

[a] 1 = extremely difficult to 7 = extremely easy.
[b] SD = standard deviation.

Soldiers were asked to indicate which three tactions were easiest and most difficult to learn/remember. These results are summarized in Table 20.

Table 20 Summary of tactions chosen as easiest vs. most difficult, Experiment 1

Taction	Easiest	Most difficult
NBC	15	3
PointRight	9	7
Rally-2x	9	19
WheelSpin	4	14
MoveUp	9	5
Disperse	14	4
Looming	12	4
IED	14	4

The tactions most frequently listed as easiest were NBC, Disperse, and IED. Those most frequently listed as most difficult were Rally-2x and WheelSpin. Comments indicated that Rally-2x and WheelSpin were easily confused.

2.4.4.4 Ease of Perception and Recall

Tactions identified by Soldiers as more easily confused included Rally-2x, WheelSpin, Disperse, and MoveUp, which are all dynamic. The Disperse taction was described as too long. The MoveUp taction was most commonly mentioned as one needing refinement to distinguish it from other tactions.

Soldiers were then asked to indicate the degree to which they agreed or disagreed with the statements listed in Table 21 (1 = strongly disagree; 7 = strongly agree). Responses from 19 participants indicate that Soldiers were able to perceive each taction with ease and that the tactions were easy to learn and remember. Recall was more difficult while focused on the movement task. Soldiers also indicated high levels of operational relevance of the concept, and provided suggestions for additional mission concept of operations and commands.

Table 21 Mean taction perception ratings, Experiment 1

Perception statement	Mean[a]	SD[b]
"It was easy to feel each tactile signal in general"	6.00	0.82
"It was easy to feel each tactile signal while walking"	5.61	1.04
"The tactile signal should be stronger"	4.26	1.82
"The tactile signal was annoying"	2.11	1.33
"The tactile signal felt ticklish"	3.00	2.08
"It was easy to understand what each signal meant"	5.32	0.95
"I was very certain what each signal meant"	5.42	1.22
"I recognized each signal immediately"	4.79	1.18

[a] 1 = strongly disagree to 7 = strongly agree.
[b] SD = standard deviation.

2.5 Results Summary and Implications for Experiment 2

2.5.1 Salience

Ratings of salience ranged from 2.42 (MoveUp) to 4.05 (IED) for individual tactions. When averaged across each taction category, mean ratings were higher for standard than for complex tactions and higher for static than for dynamic tactions. Comparing the four taction categories, ratings ranged from 2.62 for Dynamic/Complex to 3.97 for Static/Complex. Differences were significant for each factor comparison, with no significant interaction effect.

In response, for Experiment 2, additional tactions were developed to further explore differences in salience due to taction characteristics, for a total of 12 tactions.

2.5.2 Ease of Learning

Soldiers learned the tactile signals quickly, taking an average of three repetitions to learn each. Of the errors reported, the highest number of errors was associated with Rally-2x. The specific identification errors occurring with Rally-2x involved dynamic tactions: WheelSpin, MoveUp, Disperse, and Looming. Rally-2x was more likely to be confused with the other dynamic tactions, but they were less likely to be confused than Rally-2x. This suggests that Rally-2x may, in comparison, be a less distinctive dynamic taction. As a result, the Rally-2x taction was refined to be more distinct in tempo by reducing the temporal overlap between pulses.

For Experiment 2, these results support the investigation of a larger taction set, and so four tactions were added (one for each taction category). The Disperse taction was shortened to be comparable in execution time to other tactions. In addition, the Rally-2x taction was refined to be more distinct in tempo by reducing the temporal overlap between pulses.

2.5.3 Recall

Overall mean recall accuracy, averaged over time and movement condition, showed that Soldiers learn 7 of 8 tactions with over 90% accuracy (92–99%). Soldiers had most difficulty with Rally-2x (78%).

For Experiment 2, the Rally-2x taction was revised to be more distinct from other tactions, while preserving the category characteristics.

Soldiers were able to recall tactions in the afternoon to the same high degree of accuracy, without any refresher training. This also supported using additional tactions for Experiment 2, to increase variance in performance and minimize ceiling effects.

There was no significant difference in accuracy between the stationary and balance beam movement conditions. Though some Soldiers provided their responses when moving slower, overall times were not significantly different. It may be that response times were slower but Soldiers compensated with quicker movement when not responding. Further research regarding compensatory mechanisms between mobility and attentional demands is recommended. It is also likely that the balance beam movement condition was not sufficiently demanding, as it would be in realistic operations. In a standard "obstacle course," the balance beam would be at least a foot off the ground, and somewhat uneven (i.e., not parallel to the ground). The balance beam movement condition was limited for this experiment in order to minimize risk of injury to the Soldiers.

2.5.4 Final Questionnaire

Soldier-based feedback was positive overall, indicating that the tactions were easy to learn and recognize. In addition, comments yielded issues to consider with regard to comfort, fit, and operational use.

Given the promising results from Experiment 1 and the overall high performance results, it was decided to conduct a follow-on experiment to further explore issues of perception, learning, and recall, expanding the number of tactions from 8 to 12.

3. Experiment 2

Experiment 2 was conducted in the same way as Experiment 1. The following changes were implemented for Experiment 2 based on Experiment 1 results:

- Additional tactor belt sizes were used to include smaller and larger sizes.
- Three of the tactions used in Experiment 1 were modified.
- Four tactions were added, for a total of 12.

3.1 Method

In Experiment 2, we examined the effect on salience of 12 different tactions with varying engineering characteristics, using the methods described in Section 2.1.

3.1.1 Tactors

We utilized the EAI C-2/C-3 and EAI EMR tactors described in Section 2.1.1 for Experiment 2. Small, medium, large, and extra-large tactor belt sizes were added to accommodate Experiment 2 participants.

3.1.2 Tactions

The tactions for Experiment 2 were generated as described in Section 2.1.2. The following revisions were made, based on Experiment 1 results:

- Four tactions were added (Freeze, TargetDetected, Stop, and RogerThat), one in each category (standard/static, standard/dynamic, complex/static, and complex/dynamic).
- PointRight was refined as standard/static to achieve the same number of tactions in each category.
- The Disperse execution time was shortened so its duration was more like that of the other tactions.
- Rally-2x was edited into Rally-A to be more distinct.

Table 22 lists the 12 tactions used in Experiment 2 and some of their characteristics.

Table 22 Characteristics of tactions used in Experiment 2

Taction	Locational sequencing[a]	Complexity[b]	Pattern length (ms)	C-3	EMR	Max tactors/ spatial sites
NBC	S	st	2000	X	. . .	2/4
Freeze [c]	S	st	2170	X	. . .	4/4
PointRight-A[d]	S	st	960	X	. . .	3/3
Looming	S	cp	3150	X	. . .	8/8
IED	S	cp	1500	X	X	9/9
Stop[c]	S	cp	760	X	X	3/7
Rally-A[d]	D	st	2430	X	. . .	1/8
WheelSpin	D	st	2310	X	. . .	2/7
TargetDetected[c]	D	st	1480	X	X	3/7
MoveUp	D	cp	1840	X	X	4/5
Disperse-A[d]	D	cp	1800	. . .	X	2/8
RogerThat[c]	D	cp	1690	X	X	4/4

[a] S = static; D = dynamic.
[b] st = standard; cp = complex.
[c] = additional tactions.
[d] = modified tactions.

3.1.2.1 Additional Tactions

Freeze (Standard/Static). The Freeze taction comprises a sequence of simultaneous pulses felt on the front, left, right, and back quadrants and was implemented on C-3 (tactors 9–16), as portrayed in Fig. 20. Each tactor pulse in the sequence comprises a 250-Hz tone burst at the maximum displacement. The strong, repetitive signals were developed to convey importance and urgency. Participants were asked to associate the taction with the urgency conveyed by the Army "freeze" command, which means to immediately stop all movement and not move in any way—a command usually given because of high threat. "Freeze" differs from "halt" in that all body movements (not just forward movements) must stop.

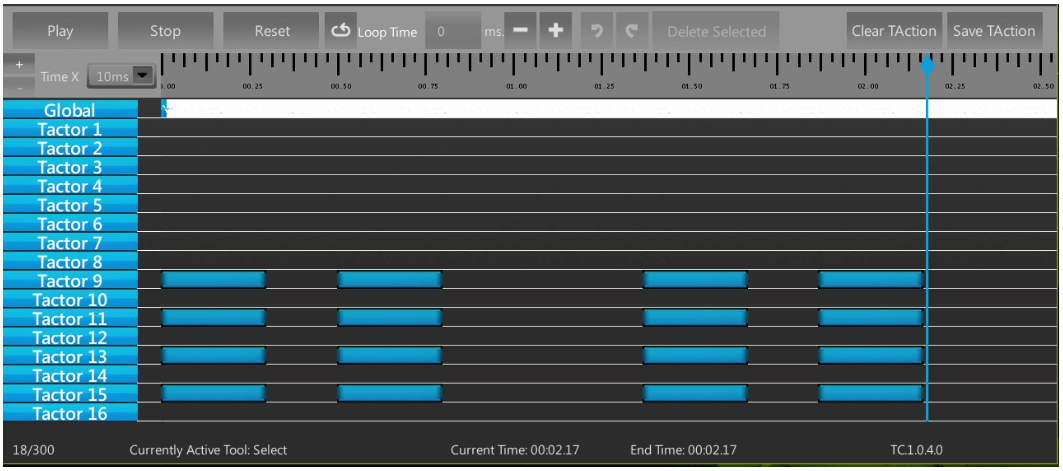

Fig. 20 Freeze taction using the C-3 (tactors 9–16)

TargetDetected (Dynamic/Standard). The TargetDetected taction comprises a dynamic sequence of pulses that originate on the back, move simultaneously up the sides to the front, followed by a pause, then a rapid pulse on the front and a final simultaneous pulse on three tactors on the belly. It was primarily implemented on C-3 (tactors 9–16) as portrayed in Fig. 21. One EMR tactor (at the front) was used (together with the C-3 tactors) in the final pulse. Each C-3 tactor pulse in the sequence comprises a 250-Hz tone burst at the maximum displacement. Participants were asked to associate the command with the message that the threat is in front of them.

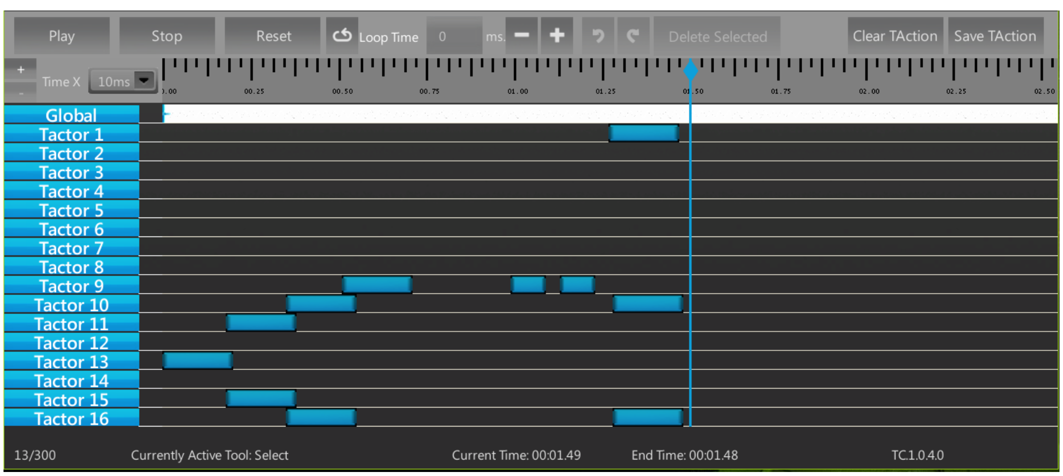

Fig. 21 TargetDetected taction using the C-3 (tactors 9–16)

Stop (Static/Complex). The Stop taction comprises a complex static pulsatile pattern on simultaneous tactors felt repetitively on the side and front. The Stop taction was implemented on C-3 (tactors 9–16), and EMR (tactors 1-8), as portrayed in Fig. 22. Participants were asked to associate this command with the Army "stop" command, which means to stop moving forward.

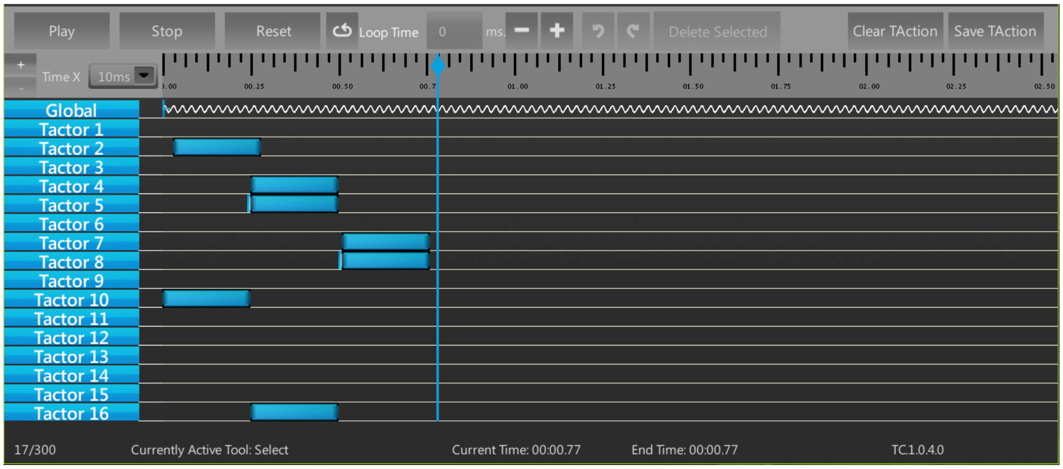

Fig. 22 Stop taction using C-3 (tactors 9–16) and EMR (tactors 1–8)

RogerThat (Dynamic/Complex). The RogerThat taction comprises a complex dynamic pulsatile pattern. It uses a series of staggered pulses, each of which ramps up and down in gain (or displacement), resulting in a circular sensation on the front of the torso at low amplitude. The RogerThat taction was implemented on simultaneous C-3 and EMR tactors, as portrayed in Fig. 23.

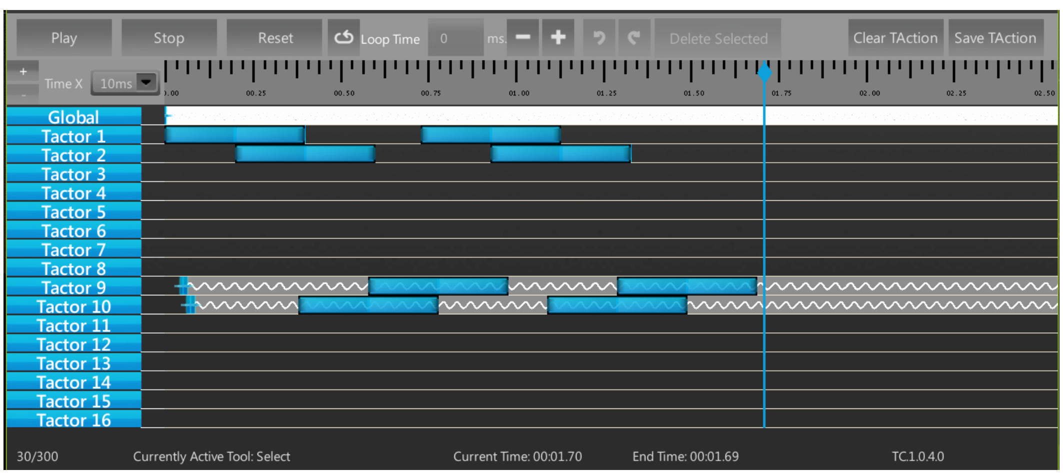

Fig. 23 RogerThat taction using simultaneous C-3 and EMR tactors

3.1.2.2 Modified Tactions

PointRight-A (Standard/Static). The PointRight-A (direction attention cue) taction was modified to comprise a standard static sequence of pulses on three adjacent tactor locations felt on the right side of the torso. The multiple active adjacent tactor sites give a strong stimulus. The PointRight-A taction was implemented on C-3 (tactors 9–16), as portrayed in Fig. 24.

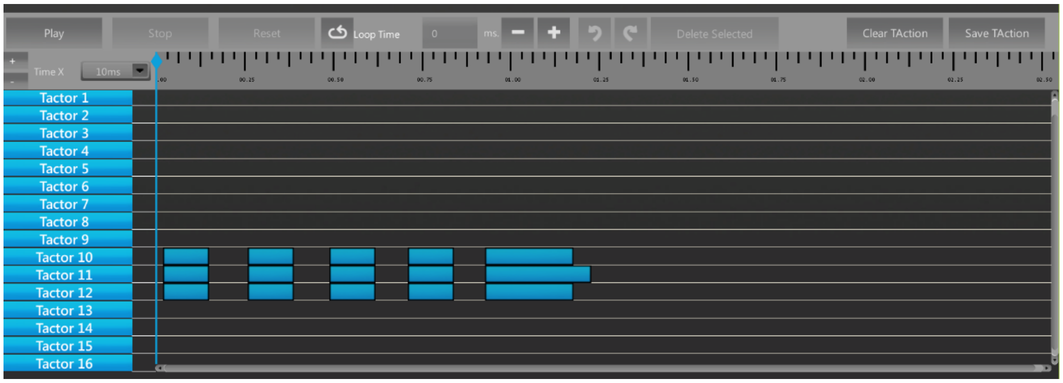

Fig. 24 PointRight-A taction (modified) using the C-3 (tactors 9–16)

*Disperse-A (Dynamic/Static).*The Disperse-A taction comprises a series of overlapping ramps on EMR (tactors 1–8) that wrap around the torso, as shown in Fig. 25. This taction utilizes the tactile "paintbrush" (Israr and Poupyrev 2011) illusion, but was significantly shorter than the Disperse taction tested in Experiment 1.

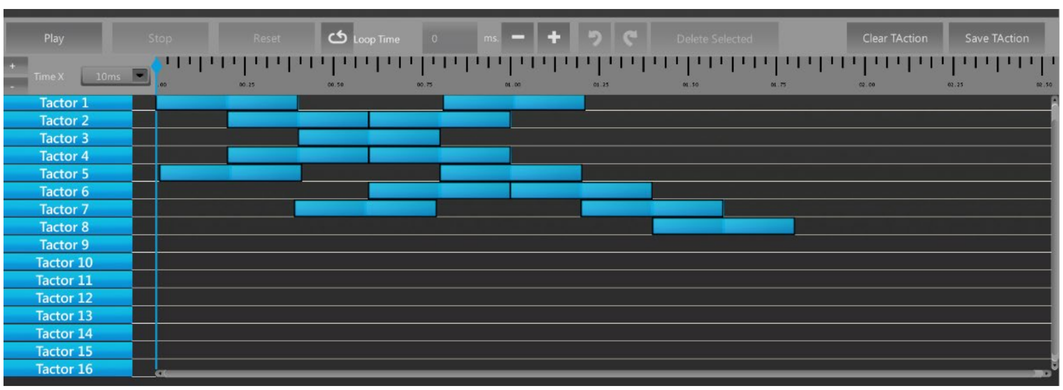

Fig. 25 Disperse-A taction (modified) using the EMR (tactors 1–8)

Rally-A (Dynamic/Static). The Rally-A taction comprises a dynamic sequence of distinct pulses starting in the center (belly) and moving clockwise around the body twice. It was implemented on C-3 (tactors 9–16), as portrayed in Fig. 26. Rally-A was modified to be slightly longer than Rally-2x (used in Experiment 1) to remove any overlapping tactor stimuli. Rally-A is also similar to the original implementation for the hand signal studies (Gilson et al. 2007).

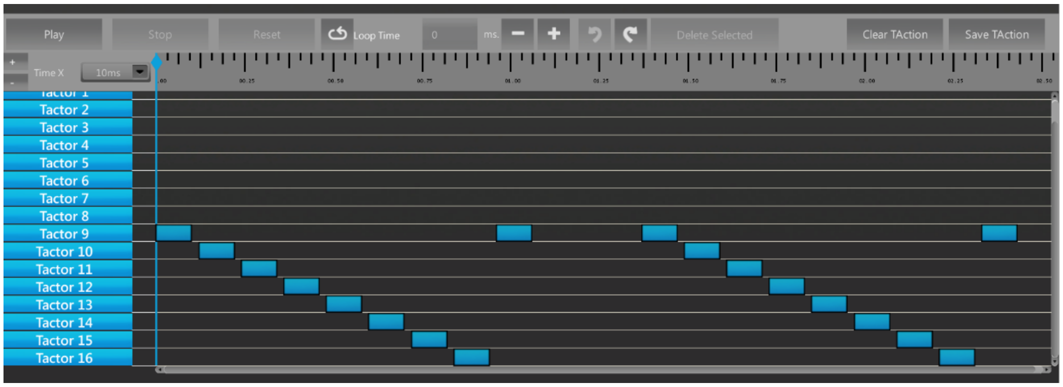

Fig. 26 Rally-A taction (modified) using C-3 (tactors 9–16)

3.2 Participants

Twenty Soldiers attending Officer Candidate School were recruited from active-duty units located at Fort Benning (6 females and 14 males).The average of age of the Soldiers was 27.25 years. Soldiers ranged in rank from E-4 to E-5, with 70% of them being E-4. An average of 3.38 years for time in service was reported by 40% of the Soldiers, while 55% reported less than one year of time in service (5% did not report). Ten percent of Soldiers had recent deployments with an average length of 8.67 months. In addition, 90% of Soldiers reported that they would be able to obtain a passing score on the Army Physical Fitness Test. Lastly, 90% of Soldiers reported no current skin sensitivities (10% did not report). Detailed responses to the demographic questionnaire are available in Appendix A.

3.3 Procedures

Soldier orientation and training were conducted as described in section 2.3, but included the additional tactions. The design for Experiment 2 was as described for Experiment 1 (Section 2.3.3), but included the additional and modified tactions shown in Table 23. Soldiers were assigned to counterbalanced conditions (Williams 1949) in the same way as described for Experiment 1 (see Table 4).

Table 23 Tactions associated with each category, Experiment 2

	Static	Dynamic
Standard	PointRight-A, NBC, Freeze	Rally-A, WheelSpin, TargetDetected
Complex	Looming, IED, Stop	Disperse-A, MoveUp, RogerThat

3.4 Results

Experiment 1 results provided the foundation for Experiment 2. As with Experiment 1, results are presented in accordance with the extent to which various taction characteristics affect salience, learning, and recall. The format for Experiment 2 results is somewhat different from Experiment 1 because, since Experiment 2 lends greater statistical power, it focused primarily on inferential hypothesis testing of overall taction characteristics. Results from the final questionnaire Soldiers completed at the end of the experiment are also summarized and presented.

3.4.1 Salience

Table 24 provides the mean ratings of salience for the first and second presentation of each taction and for the total of the two presentations. As seen in Fig. 27, ratings of salience were stable from the first to second presentation. The correlation of mean scores between the first and second ratings was 0.989 ($p < 0.001$).

Table 24 Mean ratings of salience by taction presentation, Experiment 2

Taction category	Taction	First presentation		Second presentation		Total	
		Mean	SD[a]	Mean	SD	Mean	SD
Standard/Static	NBC	3.9	0.99	3.8	1.04	3.9	0.92
	PointRight-A	4.3	0.87	4.4	0.82	4.3	0.70
	Freeze	4.4	0.82	4.5	0.60	4.4	0.58
Standard/ Dynamic	Rally-A	3.8	1.19	3.6	1.08	3.7	1.09
	WheelSpin	3.6	1.08	3.6	0.99	3.6	0.88
	TargetDetected	3.7	1.17	3.5	0.94	3.6	0.97
Complex/ Dynamic	MoveUp	3.2	1.01	2.9	0.82	3.1	0.77
	Disperse-A	2.7	0.92	2.5	0.94	2.6	0.80
	RogerThat	2.3	1.15	1.9	1.16	2.0	1.11
Complex/Static	Looming	3.9	0.96	4.0	0.97	3.9	0.88
	IED	3.8	1.04	3.8	0.95	3.8	0.87
	Stop	3.6	0.94	3.7	1.01	3.6	0.86

[a] SD = standard deviation.

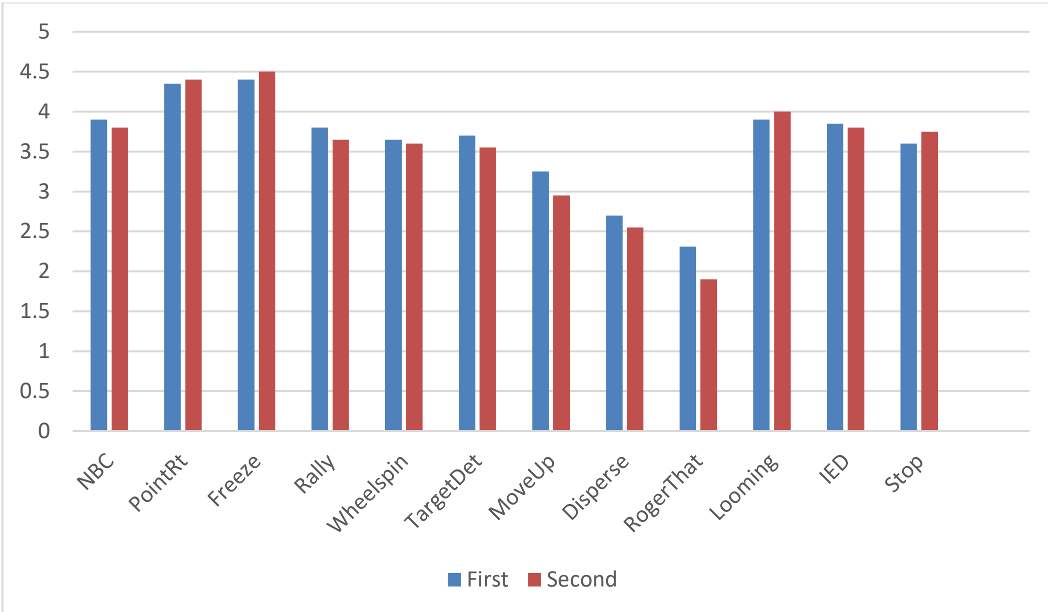

Fig. 27 Mean ratings of taction salience, first vs. second presentation, Experiment 2

Table 25 provides mean ratings of salience for each of the four taction categories.

Table 25 Total mean ratings of salience by taction category, Experiment 2

	Level of sequencing					
Level of complexity	**Static**		**Dynamic**		**Total (rows)**	
	Mean	**SD**[a]	**Mean**	**SD**	**Mean**	**SD**
Standard	4.2	0.66	3.6	0.90	3.9	0.71
Complex	3.8	0.75	2.6	0.75	3.2	0.67
Total (columns)	4.0	0.63	3.1	0.74	. . .	. . .

[a] SD = standard deviation.

As Fig. 28 shows, both the locational sequencing (static versus dynamic) and complexity (standard versus complex) variables and the interaction term had main effects on ratings of salience. Repeated measures ANOVA show a significant main effect for the locational sequencing variable ($F [1, 19] = 6.67$, $p < 0.02$, $\eta\rho^2 = 0.26$), the complexity variable ($F [1, 19] = 56.18$, $p < 0.001$, $\eta\rho^2 = 0.75$), and the interaction term ($F [1, 19] = 97.37$, $p < .001$, $\eta\rho^2 = 0.83l$). Effect sizes as calculated by $\eta\rho^2$ were high. Results mirrored those for Experiment 1 in main effects—static tactions were higher in salience compared to dynamic tactions. However, Experiment 2 had a significant interaction effect, in that the difference in main effect was significantly larger for complex tactions. This is likely due to the higher precision gained from the additional tactions.

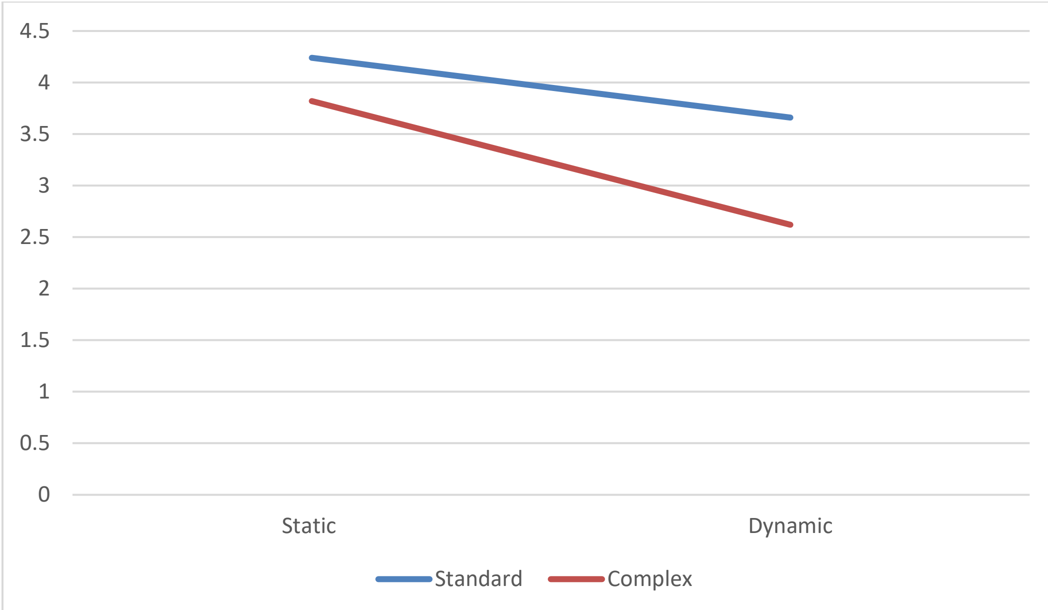

Fig. 28 Overall mean ratings of salience by taction category, Experiment 2

3.4.2 Ease of Learning

Soldiers were trained on the meaning of the tactions, which were presented in sets of three according to the categories and tactions shown in Table 24. Soldiers had no problem distinguishing each taction presented in this way. Experiment trainers trained three tactions at a time, repeating any tactions until the participant correctly identified the tactions in a given set of three. They then trained on another set of three and so on, until all four sets were trained. Trainers then proceeded to train all 12 tactions, going through the entire set of 12, one taction at a time. Each time the Soldier participant made an error, the instructor noted the error and the taction for which it was mistaken, and communicated the correct taction meaning. This process was repeated, going through each of the 12 tactions, until the Soldiers correctly identified each one three consecutive times. Table 29 provides various measurements that indicate the ease with which each taction was learned, including the mean number of repetitions for each taction, along with the taction for which it was mistaken.

Table 29 **Indices representing ease in training by taction, Experiment 2**

Taction category	Taction	Mean repetition	Total errors	Taction reported in error
Standard/Static	NBC	2.15	2	WheelSpin (2)
	PointRight-A	2.00	0	. . .
	Freeze	2.35	5	MoveUp (1), NBC (2), RogerThat (1), Looming (1)
Standard/Dynamic	Rally-A	2.05	1	Looming (1)
	WheelSpin	2.35	5	Stop (1), Disperse-A (3), NoGuess[a] (1)
	TargetDetected	2.70	13	MoveUp (10), RogerThat (2), NoGuess (1)
Complex/Static	Looming	2.10	2	IED (1), MoveUp (1)
	IED	2.15	4	Stop (1), Freeze (3)
	Stop	2.30	4	Freeze (1), IED (3)
Complex/Dynamic	RogerThat	2.90	3	MoveUp (2), PointRight-A (1)
	MoveUp	2.30	12	TargetDetected (3), Rally-A (1), Disperse (5), WheelSpin (1), Freeze (1), MoveUp (1)
	Disperse-A	2.20	5	Rally-A (1), WheelSpin (1), TargetDetected (2), Freeze (1)

[a] Participant could not identify and did not provide any response.

It should be noted that while errors did occur with particular tactions, individual Soldiers differed with respect to the number of errors and repetitions needed to learn each taction. Some learned the tactions quickly, easily, and accurately: Three Soldiers learned all 12 tactions without error and three others missed only one. Four Soldiers had more difficulty than the rest, requiring four to five repetitions to learn each taction. However, all Soldiers were able to learn the 12 tactions by the end of training.

The tactions associated with highest total number of errors during training are TargetDetected (13 errors), MoveUp (12 errors), WheelSpin (5 errors), Disperse-A (5 errors), and Freeze (5 errors). All but the Freeze tactions are dynamic. The mean number of repetitions to learn the tactions to criterion performance ranged from 2.00 to 2.90. A small number of Soldiers had particular problems discriminating a subset of the tactions.

3.4.3 Recall

As in Experiment 1, Soldiers participated in four performance sessions, two in the morning (stationary and balance beam) and two more in the afternoon (2–3 h later). The presentation order of each taction was counterbalanced, as previously shown in Table 4.

3.4.3.1 Effect of Individual Tactions on Recall

Table 30 provides mean overall recall accuracy for each taction, averaged over time and movement condition. It can be seen that Soldiers had the most difficulty with MoveUp, TargetDetected, and WheelSpin, which are all dynamic tactions. The Rally-2x taction used in Experiment 1 was modified because it was difficult to remember. This resulted in Rally-A, which achieved much higher recall accuracy during Experiment 2.

Table 30 Mean overall recall accuracy by taction, Experiment 2

Taction category	Taction	Mean (%)	SD[a]
Standard/Static	Freeze	93.75	0.10
	NBC	96.25	0.14
	PointRight-A	100.00	0.00
Standard/Dynamic	TargetDetected	80.63	0.17
	Rally-A	94.38	0.12
	WheelSpin	79.38	0.25
Complex/Static	Stop	91.88	0.13
	Looming	94.38	0.10
	IED	95.62	0.10
Complex/Dynamic	RogerThat	95.63	0.09
	MoveUp	71.88	0.20
	Disperse-A	97.50	0.05

[a] SD = standard deviation.

3.4.3.2 Effect of Elapsed Time on Recall

Table 31 provides mean performance scores for each taction as a function of time of day, as illustrated in Fig. 29. There were a few differences in recall accuracy due to time of day. Mean accuracy remained high for tactions associated with high accuracy in the morning. There was some decline for standard/dynamic tactions (TargetDetected, Rally-A, and WheelSpin). Repeated measures ANOVA examining three variables and interactions showed a significant effect due to the locational sequencing variable ($F [1, 19] = 30.16$, $p < 0.00$, $\eta\rho^2 = 0.61$), and a significant interaction between the complexity variable and and time of day ($F [1, 19] = 4.13$, $p = 0.05$, $\eta\rho^2 = 0.13$).

Table 31 Mean recall accuracy by taction and taction category: morning vs. afternoon, Experiment 2

Taction category	Taction	Mean recall accuracy (%)	
		Morning	Afternoon
Standard/Static	Freeze	95.00	92.50
	NBC	95.00	95.00
	PointRight-A	100.00	100.00
	Subtotal	96.67	95.83
Standard/Dynamic	TargetDetected	85.00	76.25
	Rally-A	96.25	92.50
	WheelSpin	82.50	76.25
	Subtotal	87.92	81.67
Complex/Static	Stop	92.50	91.25
	Looming	91.25	97.50
	IED	97.50	93.75
	Subtotal	93.75	94.17
Complex/Dynamic	RogerThat	93.75	97.50
	MoveUp	72.50	71.25
	Disperse-A	97.50	97.50
	Subtotal	87.92	88.75

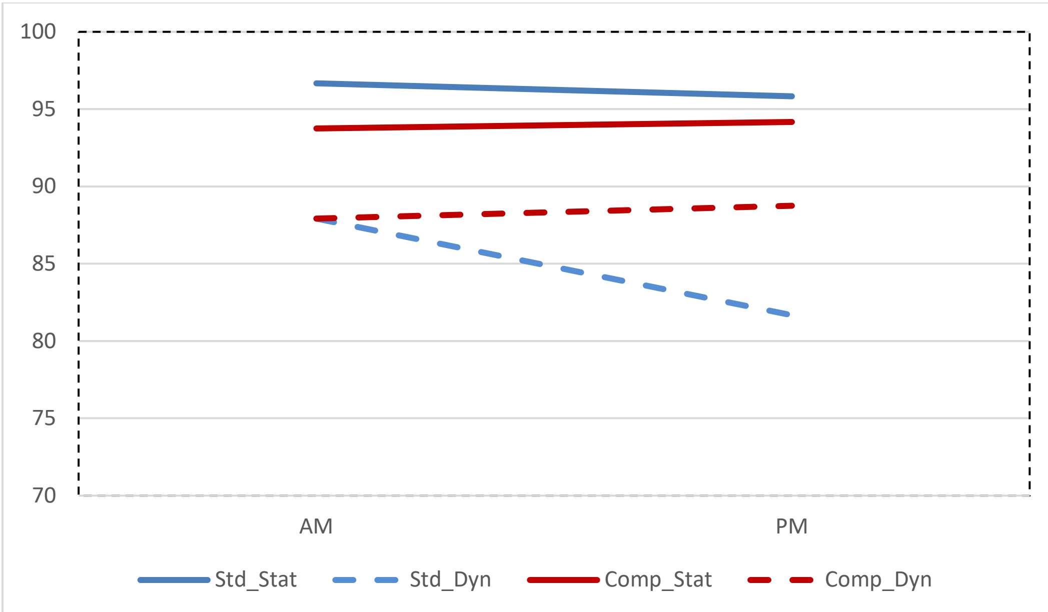

Fig. 29 Mean accuracy by taction category over time, Experiment 2

3.4.3.3 Effect of Complexity and Locational Sequencing on Recall

Figure 30 shows overall mean accuracy by taction category. Repeated measures ANOVA described a significant effect due to the locational sequencing variable ($F [1, 19] = 30.16$, $p < 0.0001$, $\eta\rho^2 = 0.61$). The interaction factor approached significance ($p = 0.11$), and the effect size was relatively high, suggesting an effect that may be consistent over larger samples having higher statistical power.

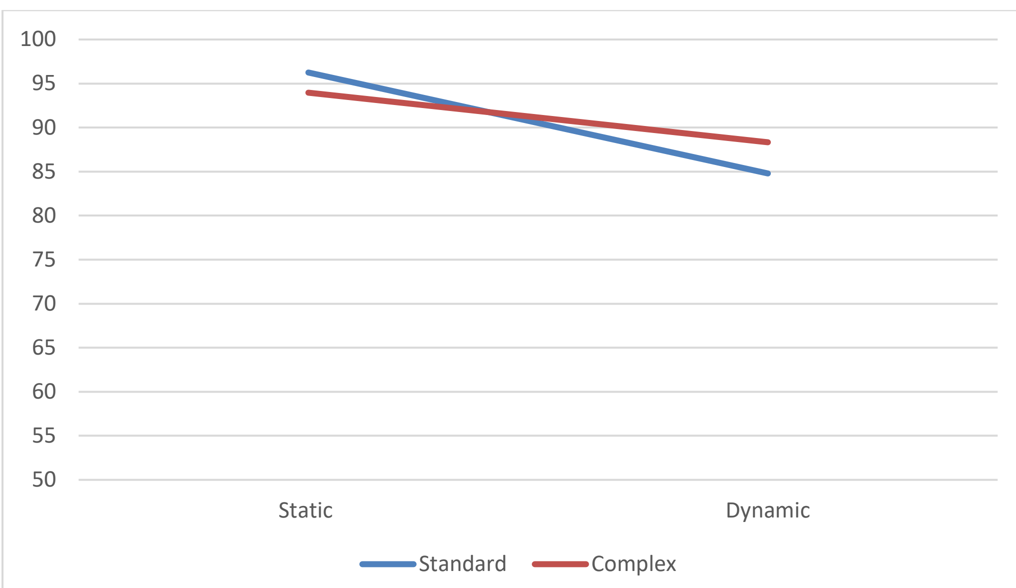

Fig. 30 Overall mean recall accuracy by taction category, Experiment 2

3.4.3.4 Effect of Movement Condition on Recall

Table 32 and Fig. 31 provide mean recall accuracy scores for each taction and taction category, by movement condition. The movement conditions were counterbalanced against order. Values were quite similar across movement conditions, with the exception of WheelSpin, which differed from 87.5% (stationary) to 71.3% (balance beam). Repeated measures ANOVA showed a significant effect for the locational sequencing variable ($F [1, 19] = 37.74$, $p < 0.0001$, $\eta\rho^2 = 0.66$), but not for the complexity variable ($F [1, 19] = 0.33$, $p = 0.57$, $\eta\rho^2 = 0.02$) or the movement condition ($F [1, 19] = 2.41$, $p = 0.14$, $\eta\rho^2 = 0.11$). There was a significant interaction for static versus dynamic and stationary versus balance beam, showing that the difference in movement condition had an effect depending on whether the taction was static or dynamic ($F [1, 19] = 6.65$, $P < 0.02$, $\eta\rho^2 = 0.26$). Other interactions were not significant.

Table 32 Mean recall accuracy by taction category and taction: stationary vs. balance beam, Experiment 2

Taction category	Taction	Mean recall accuracy	
		Stationary (%)	Balance beam (%)
Standard/Static	Freeze	93.75	93.75
	NBC	97.50	95.00
	PointRight-A	100.00	100.00
	Subtotal	97.08	96.25
Standard/Dynamic	TargetDetected	82.50	78.75
	Rally-A	96.25	92.50
	WheelSpin	87.50	71.25
	Subtotal	88.75	80.83
Complex/Static	Stop	90.00	93.75
	Looming	98.75	93.75
	IED	96.25	95.00
	Subtotal	95.00	94.17
Complex/Dynamic	RogerThat	97.50	93.75
	MoveUp	73.75	70.00
	Disperse-A	97.50	97.50
	Subtotal	89.58	87.08

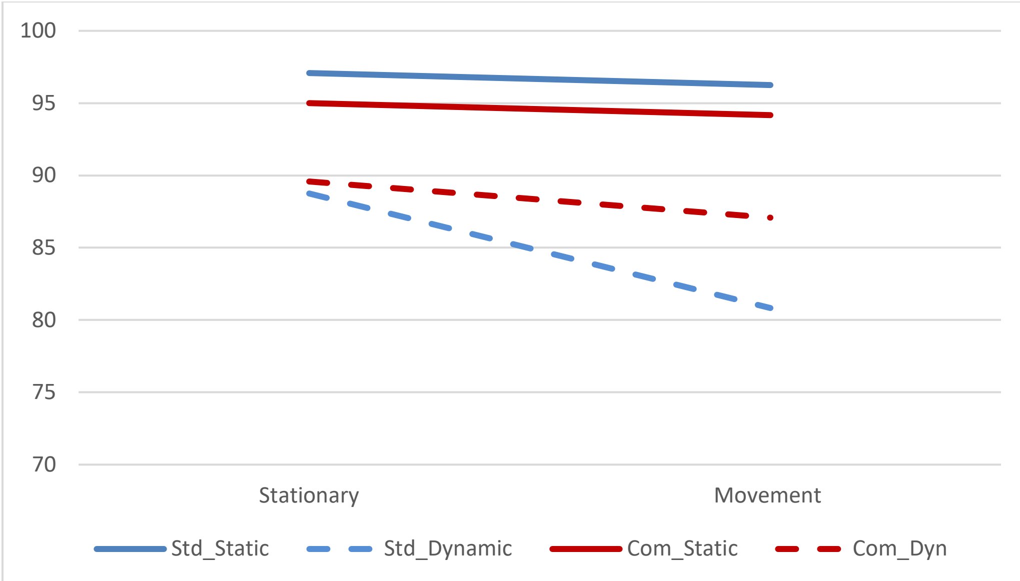

Fig. 31 Mean recall accuracy of each taction category by movement condition, Experiment 2

3.4.4 Final Questionnaire

After all performance trials were concluded, each Soldier completed the end-of-experiment questionnaire and offered verbal and written comments. An experimenter was present to answer questions, discuss issues, and encourage written documentation.

3.4.4.1 Training Effectiveness

Table 32 indicates high levels of satisfaction with training and perceptions of preparedness.

Table 32 Training effectiveness, Experiment 2

Training aspect[a]	Mean[b]	SD[c]
Overall effectiveness of training for use	5.70	0.92
Hands-on training	5.80	0.83
How prepared did you feel for using the tactile display?	5.20	0.95
How well do you think you used the tactile display?	5.20	0.89
How easy was it to learn meanings of each tactile signal in groups of 3?	5.80	0.83
How easy was it to learn meanings of each tactile signal for all 12, after each group of 3 was learned?	5.25	0.97

[a] Number of participant questionnaires = 20.
[b] 1 = extremely ineffective/unprepared/difficult to 7 = extremely effective/prepared/easy.
[c] SD = standard deviation.

3.4.4.2 Tactile Belt Comfort and Fit

Soldiers reported very high ratings for system comfort and fit (see Table 33). Most agreed the belt fit was comfortable, but many comments were made concerning how comfortable the belt would be once a soldier was in full battle gear or in a more physically demanding environment.

Table 33 Dual row tactile belt, comfort and fit, Experiment 2

Belt feature[a]	Mean[b]	SD[c]
Comfort	6.10	0.97
Adjustability	5.35	1.46
Fit	5.70	1.53
Weight	6.15	0.99

[a] Number of participant questionnaires = 20.
[b] 1 = extremely negative to 7 = extremely positive.
[c] SD = standard deviation.

3.4.4.3 Tactile Belt Comfort and Fit

Soldiers rated the ease of feeling tactions as relatively high (Table 34).

Table 34 Ease of feeling tactions, Experiment 2

Feature	Mean[a]	SD[b]
Ease of feeling tactor patterns in general	5.85	0.88
Ease of feeling tactor patterns while standing still	6.15	0.99
Ease of feeling tactor patterns while moving	5.10	1.21

[a] 1 = extremely difficult to 7 = extremely easy.
[b] SD = standard deviation.

Soldiers were asked to specify which three tactions were easiest and most difficult to learn/remember by checking the “easiest” and “most difficult” boxes. Results are summarized in Table 35.

Table 35 Summary of tactions chosen as easiest vs. most difficult, Experiment 2

Taction	Easiest	Most difficult
NBC	9	2
PointRight-A	13	0
Rally-A	16	0
WheelSpin	1	10
MoveUp	0	12
Disperse-A	1	6
Looming	5	3
IED	4	3
Freeze	4	1
Roger that	8	3
Stop	1	3
Target Detected	1	14

The tactions that were most repeatedly listed as easiest were Rally-A, PointRight-A, and NBC. The tactions more often listed as most difficult were TargetDetected, MoveUp, and WheelSpin. Comments indicated that that tactions listed as the "easiest" all had distinct and different patterns, while the tactions listed as "most difficult" had patterns that were too similar to other patterns.

3.4.4.3 Ease of Perception and Recall

Soldiers were asked to indicate the ease with which they recognized each taction. Results are summarized in Table 36.

Table 36 Ease of recognizing each taction, Experiment 2

Taction	Mean[a]	SD[b]
NBC	6.05	1.22
PointRight-A	7.00	0.00
Rally-A	6.68	0.67
WheelSpin	4.37	1.26
MoveUp	3.79	0.71
Disperse-A	4.78	1.56
Looming	6.17	1.34
IED	5.63	1.38
Freeze	6.05	1.27
Roger that	6.21	0.92
Stop	5.53	1.39
TargetDetected	4.00	1.25

[a] 1 = Extremely difficult to 7 = Extremely easy.
[b] SD = standard deviation.

Soldiers were then asked to indicate the degree to which they agreed or disagreed the statements listed in Table 37 (1 = strongly disagree; 7 = strongly agree). Comments are provided in Appendix C.

Table 37 Mean taction perception ratings, Experiment 2

Perception statement	Mean[a]	SD[b]
"It was easy to feel each tactile signal in general"	6.11	0.88
"It was easy to feel each tactile signal while walking"	5.63	1.30
"The tactile signal should be stronger"	4.53	1.61
"The tactile signal was annoying"	2.37	1.21
"The tactile signal felt ticklish"	2.84	1.74
"It was easy to understand what each signal meant"	4.95	0.97
"I was very certain what each signal meant"	4.21	1.44
"I recognized each signal immediately"	4.37	1.46

[a] 1 = strongly disagree to 7 = strongly agree.
[b] SD = standard deviation.

3.4.4.3 Additional Comments

Additional comments provided by Soldiers on their questionnaires are provided in Appendix C.

4. Discussion

4.1 Overview

This report summarizes published research regarding the effectiveness of tactile displays in tactical operational environments. These findings show that this technology, when implemented effectively, can increase performance (e.g., speed and accuracy) and lower cognitive workload in general across a diverse domain of operational settings.

While many research results show a positive effect, they also indicate multiple moderating variables (e.g., operator training, tactor characteristics, workload level, and operational context) that affect whether and to what degree a tactile display would impact performance. These variables were organized into the following core areas that mediate the salience of a tactile cue or taction:

- User characteristics, including training, sensitivity, stress tolerance, and ability.
- Operational context, including task demands, environmental factors, noise, visibility, and threat.
- Technology characteristics, including tactor characteristics such as amplitude and power and system characteristics such as wearability, portability, and weight loading.

It is particularly important to consider the interactions among these core areas when evaluating the effectiveness of tactile displays. The main effect of one factor, such as tactor technology, can be reduced or enhanced, depending on the nature of other factors, such as workload or environmental context.

4.2 Summary of Results

The experiments described in this report addressed some baseline issues with regard to relative salience of a small set of tactions varying in taction characteristics. One dimension investigated is type of tactor sequencing: whether tactions are static (simultaneous presentation of multiple tactors) or dynamic (sequential activation of tactors). The second dimension of interest is degree of complexity: whether they use standard consistent activation (standard) or activation of multiple tactors using ramp modulations in vibrational amplitude (complex). Tactions also varied with regard to the type of tactor used in the presentation.

Eight tactions were developed for Experiment 1. Results from Experiment 1 led to a follow-up experiment, incorporating revisions suggested from Experiment 1. Three of the original eight tactions were refined and four tactions were added. Also, additional belt sizes were used.

4.2.1 Salience

In Experiment 1, mean ratings of salience were found to have high test-retest reliability. Ratings of salience were significantly higher for standard tactions than for complex tactions and higher for static tactions than for dynamic tactions. The highest and lowest mean salience was for the Standard/Static and Complex/Dynamic taction categories, respectively. Differences were significant for each factor comparison, with no significant interaction effect. This trend was supported in Experiment 2, where ratings of salience were again significantly higher for standard tactions than for complex tactions and for static tactions than for dynamic tactions. In addition, an interaction effect was noted—both complex and dynamic tactions were perceived as the least salient (i.e., dynamic tactions were more negatively affected by complex features).

4.2.2 Ease of Learning

In Experiment 1, Soldiers learned the tactile signals quickly, with an average of three repetitions to learn each cue. Of the errors reported, the highest number was associated with Rally-2x. Errors associated with Rally-2x were all dynamic tactions: WheelSpin, MoveUp, Disperse, and Looming. Rally-2x was more likely confused with the other dynamic tactions, but they were less likely to be confused as Rally-2x, suggesting that Rally-2x may be less distinctive as a dynamic taction.

For Experiment 2, the Disperse taction was shortened to be comparable in time to other tactions (Disperse-A), the Rally taction was refined to be more distinct in tempo (Rally-A), PointRight was modified to be a standard static taction (PointRight-A), and four more tactions were added, for a total of 12. Again, results were consistent with Experiment 1. Training was rated as very effective and Soldiers were able to learn the 12 tactions with relative ease, with mean repetitions for each taction of 2.90 or less and total training time less than 20 minutes.

4.2.3 Recall

In Experiment 1, overall mean accuracy, averaged over time and movement condition, showed that Soldiers learned seven of eight tactions with over 90% accuracy (92% to 99%). Soldiers had the most difficulty with Rally-2x (78%). Performance was high and not significantly affected by movement or elapsed time (i.e., 3 h between sessions).

Results were similar in Experiment 2. Refinement to the Rally taction resulted in higher performance with the Rally-A taction (94% accuracy); however, three other dynamic tactions were associated with lower accuracy: MoveUp (72%), WheelSpin (79%), and TargetDetected (80%). Overall, there was a significant decline in accuracy for tactions that were dynamic, as opposed to static. Standard/Dynamic tactions were also significantly and negatively affected by elapsed time and by movement.

4.2.4 Final Questionnaire

In Experiment 1, Soldier ratings were positive overall, indicating that the tactions were easy to learn and recognize. In addition, comments yielded issues to consider with regard to comfort, fit, and operational use. Additional belts were used in Experiment 2, to accommodate smaller and larger sizes. Feedback was also consistently positive with regard to comfort, fit, and operational relevance.

5. Conclusions

Soldiers were able to learn up to 12 tactions in a relatively short time (between 10 and 20 minutes). Overall results for the two experiments show a consistent trend with regard to taction characteristics.

Tactions that were composed of standard and static repetitive cuing were more salient and more accurately recalled. The more problematic tactions (i.e., those that were less easily distinguished) had dynamic, sequentially activated tactors. Developers of tactile displays are cautioned to use dynamic tactions sparingly, since the dynamic characteristics can be easily confused. Even portions of tactions that are similar in temporal and spatial structure can be easily misidentified. Our experiments used a construct where the tactions were presented without prior notification and only once. Recognition may be improved if there is a notification alert prior to the taction and/or repetition of the taction. Dynamic and complex tactions typically introduce movement sensations that may require more focus than static/standard patterns.

While dynamic tactions can be confused, the emulations of movement offer possibilities for intuitive design. The Rally taction, with a sequential activation around the waist, emulates the hand and arm signal of Rally, during which the hand gestures in a circular motion. When the Rally taction was revised to be more distinct from the other dynamic tactions, accuracy in recall was significantly improved.

Tactor placement can also facilitate intuitive design. A simple example is that of PointRight, where tactors on the right side of the torso were activated. Another example, more specific to Army context, is that of NBC (nuclear biologic chemical threat). The hand signal for NBC uses both hands in an alternating left-right manner. Similarly, the NBC taction uses tactors on the left and right sides, activated in alternating fashion.

Taction recognition is facilitated by building or reinforcing associations with prior knowledge. For example, while the PointRight taction requires little effort to map the association between "go to the right" and activation of tactors on the right side, some of the other tactions had associations that required more explanation. Trainers explained each taction using examples that offered associations that linked to taction characteristics (e.g., tactor placement, tempo, etc.). For example, the Wheelspin taction had an erratic tempo that was associated with the noise of wheels spinning back and forth, while the underlying meaning of the taction, is that a robotic asset is "stuck" and requires attention. The Looming taction starts with a low activation that increases steadily to a somewhat explosive end, and is explained with the metaphor of looming threat. In contrast, the IED taction starts with a very high activation that dissipates, and was likened to an explosion, that is sudden and intense, followed by fallout (low activation). These associations are key to rapid and accurate learning.

While all Soldiers were able to learn up to 12 tactions during a short training time, some were particularly adept at learning and recall, learning the cues with very little training repetition and recall error. A small number of others had more difficulty in learning and recall. These results augment previous investigations of individual differences in tactile perception. Cholewiak (2014) discusses variations in sensation, perception, and cognition, with regard to individual difference within an age group and over time, as a function of age. Further investigations of individual differences such as working memory are underway for subsequent investigation.

6. References

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Appendix A. Demographic Data

Experiment 1.

1. Do you have any physical injury at the present time?

YES	NO
2	18

If yes, please describe.

- STRESS FACTURE HIP
- HAMSTRING INJURY

2. Are you presently on a profile of any type?

YES	NO
2	18

If yes, please describe your current limitations.

- TEMPORARY, NO RUNNING LONG DISTANCE
- NO WALK MORE THAN 30 MINS; WALK AT OWN PACE

3. If the APFT (Army Physical Fitness Test) were held today, could you obtain a passing score on it?

YES	NO
17	3

4. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by wearing a haptic belt (for example, poison ivy, insect bites, rash, etc.)?

YES	NO
0	20

5. On a scale from 1 to 5, how ticklish are you? (chest/waist area)
1 = Not at all______2_________3______4_____5 = Very ticklish

Rating	1	2	3	4	5
N	6	9	4	0	1

MEAN	2.05
SD	.999

6. Age

MEAN	27.2 years
MIN	23 years
MAX	33 years

Gender

MALE	FEMALE
14	6

Military Experience

a. How many years have you been in the military? (mean, s.d. min, max)

MEAN	1.34 years
SD	1.20 years
MIN	.25 years
MAX	4 years

b. Current rank list/frequency

Rank	E-4	E-5	OC
N	10	6	4

c. What is your MOS? List/freq

MOS	09S	25U	31B	68E	92Y	68T	09S/35D	OC
N	12	1	1	1	1	1	1	1

d. Please list most recent combat deployments

Deployment	Sudan	Rwanda	Ft. Jackson	BCT
N	1	1	1	1

MEAN	6.33 months
SD	4.93 months
MIN	3 months
MAX	12 months

Experiment 2.

1. Do you have any physical injury at the present time?

Yes 1 No 19

If yes, please describe.
1 Left knee, Patellar Tendonitis

2. Are you presently on a profile of any type?

Yes 1 No 19

If yes, please describe your current limitations.

1 No walking fast or running

3. If the APFT were held today, could you obtain a passing score on it?

Yes 18 No 2

4. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by wearing a haptic belt (for example, poison ivy, insect bites, rash, etc.)?

Yes 0 No 18 No Answer 2

5. On a scale from 1 to 5, how ticklish are you? (chest/waist area) 2.25 (mean)

6. Age: 27.25 years (mean)   7. Gender: Female 6   Male 14

a. How many years have you been in the military?

3 months – 3
4 months – 2
9 months – 1
10 months – 1
<1 year – 4
1 year – 4
5 years – 3
8 years – 1

Current rank (E-4, 14; E-5, 6).

b. What is your MOS?
09S – 13
35 (Military Intelligence) – 1
91B – 1
91J – 1
OC – 1
MP –1

c. Please list most recent combat deployments (Iraq, Afghanistan, etc.) and the length (Years/Months) of each.

1 Iraq, Speicher, 12 months
1 Iraq, 7 months; Afghanistan, 7 months

Appendix B. Mean Recall Accuracy for Taction Categories

This appendix appears in its original form, without editorial change.

Mean Accuracy for Taction Categories

	Posture S=Stationary M = Movement	AM=0	Mean	Std. Deviation	N
SS	M	.0	.9342	.16334	19
		1.0	.9688	.12500	16
		Total	.9500	.14603	35
	S	.0	.9250	.18317	20
		1.0	.9853	.06063	17
		Total	.9527	.14237	37
	Total	.0	.9295	.17157	39
		1.0	.9773	.09609	33
		Total	.9514	.14315	72
SC	M	.0	.8860	.13947	19
		1.0	.8750	.12172	16
		Total	.8810	.12987	35
	S	.0	.9292	.10907	20
		1.0	.8725	.14166	17
		Total	.9032	.12655	37
	Total	.0	.9081	.12507	39
		1.0	.8737	.13031	33
		Total	.8924	.12776	72
DS	M	.0	.9737	.07883	19
		1.0	.9141	.16278	16
		Total	.9464	.12605	35
	S	.0	.9562	.14776	20
		1.0	.9779	.06607	17
		Total	.9662	.11655	37
	Total	.0	.9647	.11806	39
		1.0	.9470	.12512	33
		Total	.9566	.12081	72
DC	M	.0	.9605	.11824	19
		1.0	.9062	.16771	16
		Total	.9357	.14339	35
	S	.0	.9500	.13079	20
		1.0	.9779	.06607	17
		Total	.9628	.10568	37
	Total	.0	.9551	.12330	39
		1.0	.9432	.12919	33
		Total	.9497	.12528	72

Appendix C. Final Questionnaire Comments, Experiment 2

C.1 Training Effectiveness

C.1.1 Positive Comments

- Some of the signals felt similar, but we only worked with the belt for a limited time and I'm sure if you train someone with it longer, it will become like second nature to them.
- Considering the short training, 12 signals were generally easy to recall. Given more time 12 or even more signals wouldn't be difficult to remember. If necessary perhaps 20 or more signals could be used, the creativity and simplicity of the vibrations would be the key factors in accomplishing this.
- The training on how to use the belt was more than sufficient and was clear and concise. I would have liked to learn a little bit more about the application of it, but I can see how that doesn't pertain to this testing.
- Was a fun experience. Maybe a couple more rounds of training would have been useful.
- It is a good training especially constantly going through each tactile signal made it more effective training.

C.1.2 Issues/Suggestions

- I should have positioned the belt the same way as the first. My mistake.
- I feel that in a combat environment this would not be effective, due to the situation that may arise in a firefight. This is based upon being able to feel instead of see and soldiers could get the signal mistaken verses seeing the command with their own eyes.
- Some of the vibrations were similar. I confused 2 or 3.
- As far as testing the knowledge of the participant, the commands were tested in order so if you're good at memorization, it was easy. Doing them out of order would be a better test of retention.
- If I had to use it in an operation today, I'd like a bit more practice with it.
- Very curious to see the effectiveness and capability of the belt in a combat scenario.

C.2 Comfort and Fit

C.2.1 Positive Comments

- The belt fit great, was extremely comfortable. I did not feel discomfort from the technology inside. Extremely lightweight
- It fits great and very light
- I think the system is pretty comfortable and fit.

C.2.2 Issues/Suggestions

- I wasn't uncomfortable with having the belt on, but I wasn't wearing any other gear or equipment.
- Consideration of how the belt will be worn in conjunction with the IOTV is a must. The wear of the belt for duration with the added pressure of a vest will certainly cause problems.
- Longer Velcro patches to allow for better adjustments. Just putting the battery pack in the pocket and having the cord hang out could present a problem. Would having an option of a smaller version, while it would reduce the full number of signals but still enough to cover essentials so a wrap could fit around a leg? Perhaps the quad area so it wouldn't be another piece of equipment on the torso.
- Put it on every time where it'll be on the same position every time.
- The belt was comfortable and fit well, but I wonder how well it will stay put/in place when in a physically demanding setting. Perhaps implement over the shoulder straps?
- Have a one size fits all
- The belt needs to be tested wearing full battle gear.
- If possible make it slimmer. It sat high on my small waist. That would be uncomfortable in the heat.
- Integrate belt into other equipment that may otherwise need to be worn over the belt.
- If the item permits, make the vibrations that were similar, more pronounced or different from each other.
- The belt fit fine, but if cleared, would need to be made out of more durable material. If the overall belt could be smaller but still provide the same level

of sensitivity that would be good. I also recommend instead of a battery, to use a small solar cell. I assume this will be used in areas with lots of sun, so it might help to reduce the system's overall profile.

- It felt a little too wide.

C.3 Ease of Feeling Tactions

C.3.1 "Easiest" Comments

- These were very distinct and different patterns and were therefore easy to differentiate. (10)
- The easy signals seemed to have distinct patterns that isolated a particular side of the body at a time.
- Simplicity, there was little use of counting vibrations, just recognizing a pattern. These were one-part signals and not rushed. Understanding that time is a factor however, it makes a difference to use more direction-based vibrations.
- Easy to remember/link to known hand/arm gestures. (2)
- Looming had a strong end. Freeze was easy to count. Roger that was only on one side.
- The strength of signal and simplicity i.e. "NBC" = left and right alternating, "PointRight" was a strong signal only on the right.
- There are some spots, they vibrates on which makes it easier. For example, point right, it vibrates on the right side of your waist and so it's very easy to know.
- Simplicity as well as relatability to real life similarities. (2)
- The crisp vibrations and patterns made them easy to remember.

C.3.2 "Most Difficult" Comments

- The difficult signals were so because of their similarity to other signals. (16)
- While not complex, these three selections were quite similar. Perhaps an intense direction oriented vibration for target detected. MoveUp might not need to start in the front, maybe start in the back and cycle around both sides with a prolonged vibration in the front and perhaps only having the quick alternation of vibrations on the side for WheelSpin.

- The difficult patterns were such because they were very faint and only slightly different. MoveUp would be easier if the front vibrator were firmer so as to more strongly suggest forward movement. The other two could be more specific locations, rather than scattered, to be more recognizable.
- Other signals with a similar pattern and more difficult to distinguish while moving
- WheelSpin and MoveUp were too complex
- The softness of the vibrations made it a little difficult but overall, they were clean.

C.3.3 Positive Comments

- Overall, I think it was easy to feel each tactile signal even while walking.

C.3.4 Issues/Suggestions

- When played in a predictable manner, the signals are very easy to understand and differentiate, but add movement and distraction, and it becomes more difficult.
- When walking on the beam and concentrating on balance it was harder for me after the break.
- Had issues with 3 already mentioned
- The signals were very strong. If anything they could be stronger to account for combat gear/conditions. Simplify and differentiate those few signals and it's good in my book.

C.4 Other

C.4.1 Suggestions for Additional Useful Soldier-to-Soldier Communications

- Freeze, Rally, directions
- Alert
- Telling soldiers which direction to travel or whenever communication should be limited due to noise discipline
- I would use the belt primarily for squad and platoon tactics communication, namely during operations and missions. The signals I can already see being helpful pertain to movement, esp. Rally, stop/freeze, and point right.

- What type of formation to get into (file, wedge, etc.). I think it would be useful to have a button on the belt that could replay the last command given or have a button that lets the sender know you received the command.
- Shift fire; lift fire; LOA; soldier down (injured)
- Basic commands such as push right or left, halt, move forward.
- Perhaps a "say again" command if the first signal was not understood.
- Land navigation practice for new recruits. Only low stress missions
- The signals could be used for signaling a change in formation; however, the belt may not be specific enough for all of them.
- Moving from one objective to another as a firing squad. Crossing a danger area, road, etc. This belt would make it easier for SLs or PLs to communicate more quietly with their team even in the dark.
- Morse code might be useful, in a situation where silence is necessary. During combat, using this to signal another squad when they're "in position" or "Lift Fire" or "shift Fire" would be extremely useful.
- I think instead of hand and arms signals being used during combat operations among soldiers, the tactile belt will be more effective. It will be very easy to communicate to one another without making noise.
- Lay down, shoot/engage the enemy
- Injury, LDA, LODA, SODA
- Tactical formations (wedge, file, etc.)
- Danger looming; contact left, right, front and back; watch your step (in a road march scenario); man down
- To tell one soldier how much ammo he/she has left.

C.4.2 Suggestions for Additional Useful Robot-to-Soldier Communications

- Target detection, WheelSpin
- Staying on track for navigating
- The application of this could be very extensive, from recognizing battle alerts from a robot about the terrain, enemy patterns, suggestions on tactics,

etc. of the signals used today, each one would be very useful, esp. ones pertaining to safety, i.e. IED, target detected, NBC, or looming.

- Loss of power, loss of signal
- Error (other error, communication, malfunction, etc.)
- “Battery Dying”
- Rally, Roger that, Looming, IED.
- Indications of any change in movement from the robot, such as speed of slope of travel or need to move around an object.
- A robot can let a soldier know the safest route to an objective. It could also lead the soldier to the objective (if it had that capability - like GPS).
- If they could integrate the “target detected” command with a drone’s GPS, so as to provide a direction to contact, a “patrol” signal/mode to tie the drone's AO to the wearer; it stays within a set distance around the user. An “area secured” command.
- Stop, freeze, Rally, target detected.
- Low battery, enemies
- Inclement weather, tough terrain, cover/concealment opportunity, enemy near
- To tell a soldier how close in meters how far away the enemy is.

C.4.3 Future Concept

Soldiers were asked to report how useful this capability would be in operations if it were developed to be combat ready using a Likert scale of 1= Extremely negative to 7 = Extremely positive. Overall they rated it relatively positive at 5.41 (SD = 1.12).

C.4.4 Communication Use

Soldiers provided the following comments when asked when/where they would consider using this type of communication:

- It provides good noise discipline and would work well at night or in dense vegetation where it would be difficult to see the team/squad leader.
- It would be ideal for cold-weather training. Figure it would be difficult in hot weather, especially when deployed.

- Patrol operations, land navigation, dark areas where pulling out a map a flashlight would be dangerous. Anywhere where keeping eyes forward is needed.
- When noise discipline is needed and when verbal communication is not possible or is helpful to the enemy. Also, this kind of comm. would useful as a secondary cue, so the soldier can be focused while recognizing non-verbal, non-visual alerts that could be mission critical.
- In areas that require no talking and/or low visibility
- In deliberate combat engagements when soldier movement is planned; in spontaneous engagements once the unit/system is well practiced/integrated.
- It would be useful for the drivers of a convoy or mission at night when troops are dispersed and have limited visibility.
- I would see this being used for patrolling and low noise operations. However in any type of combat situation, I do not feel it would be highly effective due to adrenaline and other external factors (gunfire, yelling, etc.)
- Transportation, EOD
- When moving ground troops from location to location, typically before engaging in combat.
- After improvements were made and training given, I think this would be very helpful in communications in the field.
- Definitely on patrol if a scaled up personnel-wise, could be useful on a base in case of emergency.
- During combat operations.
- I have no prior experience in a real military operation; I'd like to think in cities where even your hand signals can be seen by the enemy.
- A time when it is optimal to have silence.
- In an environment where you can't verbalize.
- I imagine this equipment being useful in patrol operations especially at night or when everyone is dispersed and you need to get everyone on the same page at the same time.
- In the field that is hard to use hand signals.

List of Symbols, Abbreviations and Acronyms

ANOVA	analysis of variance
EAI	Engineering Acoustics, Inc
EMR	eccentric-mass rubber
NBC	nuclear, biological, chemical
SD	standard deviation

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