



Localization of Tactile Signals as a Function of Tactor Operating Characteristics

**by Elizabeth S. Redden, Christian B. Carstens, Daniel D. Turner,
and Linda R. Elliott**

ARL-TR-3971

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Aberdeen Proving Ground, MD 21005-5425

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Human Research & Engineering Directorate, ARL

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14. ABSTRACT Throughout experiments investigating the utility of tactile displays, tactors with varying engineering specifications have been used. Some of these tactors may have been more effective than others in terms of the ability of the wearer to localize the position of the individual tactors and to feel the tactile stimulation during dynamic situations. This study compared Soldiers' abilities to localize three different configurations of tactors: an inertial shaker motor and a C-2 vibro-tactile transducer that was set at two different intensities. The correct signal detection and localization rates were fairly high for all three systems during static trials, ranging from 86.1% to 91.8% correct, and there were no significant differences among the three systems in terms of signal detection and localization in this event. The ability to correctly identify tactor location was degraded during the dynamic event, and differences among the three systems emerged. On the individual movement techniques course, tactor localization was best with the higher intensity C-2 vibrotactile transducer (78.7%) and worst with the inertial shaker motor (48.8%). Localization was best when the Soldier was moving upright or in a kneeling firing position, and localization was degraded when the Soldier's torso was in contact with the ground or when he was climbing an obstacle. Differences were also found in localization rates at different positions around the waist. Tactor location detections were highest at the front of the body and lowest at the sides.					
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1. Introduction

1.1 Background

This effort was conducted as part of the Army Technology Objective (ATO) for Enhanced Unit of Action Maneuver Team Situational Understanding (SU), sponsored by the U.S. Army Research Laboratory (ARL). The intent of the SU ATO was to demonstrate information system interfaces that would improve Soldier SU, decision making, and mission planning.

Human factors studies of an array of military roles have shown significant overloading of visual and auditory channels (Mitchell, Samms, Glumm, Krausman, Brelsford, & Garrett, 2004). This demand for focal visual and auditory attention diminishes the capacity for task sharing and attention allocation, especially in the context of unexpected changes and events. Several experiments funded by the SU ATO investigated the potential for other sensory modalities to be effectively used to provide situational awareness (SA) in a military environment. The hypothesized benefits were significant increases in survivability, information flow, and mission achievement.

Tactile interfaces provide information (e.g., alerts, communication signals, orientation feedback) usually through vibrotactile means or by raised interfaces (e.g., Braille). Of the many sensations that the skin can recognize (pressure, shape, electricity, chemicals, and thermal), vibrotactile sensation seems to serve well for signaling by touch because the skin is well adapted to recognizing the movement in a vibrotactile display. A common example is the vibration mode in cell phones and pagers. More complex tactile interfaces use patterns of vibratory feedback through the placement of vibrating tactors. Although the sense of feel is not typically used as a communication channel, researchers are beginning to realize the high potential it represents. Van Erp (2005a) has demonstrated that an intuitive body-referenced organization of vibrotactile stimuli can portray complex and dynamic patterns that are effective in numerous situations.

Tactile displays have been shown to reduce overall workload when the design and display are easy to interpret, intuitive, and can convey information without diverting the user's attention away from the operational task at hand. In military applications, tactile displays have been shown to enhance pilot orientation and navigation in land, sea, and air and to provide improved SA to operators of advanced weapon platforms (e.g., to improve their ability to spatially track targets and sources of information) (Carlander & Eriksson, in press; Chiasson, McGrath, & Rupert, 2003; Dobbins & Samways, 2002; van Erp & van Veen, 2003, 2004; van Erp, Veltman, van Veen, & Oving, 2002).

Many experiments have investigated the utility of tactile displays, with varying results. One reason may be that tactors with varying engineering specifications have been used in different

experiments. Some of these tactors may have been more effective than others in terms of the ability of the wearer to localize the position of the individual tactors and to feel the tactile stimulation during dynamic situations. Previous studies in tactor localization have focused on mapping the sensitivity of various parts of the body to determine how far apart tactors must be to be felt as separate (Gemperle, Ota, & Siewiorek, 2001; van Erp, 2005a). In these studies, many tactors were placed in an area of the body and then sequentially activated. The subject was asked whether a tactor activation was to the left, to the right, or in the same location as the previous activation. In this way, torso sensitivity was mapped (van Erp, 2005a). However, these studies did not address the effectiveness of various tactor types and tactor specifications, encompassing such factors such as stimulation area (and depth), intensity, frequency, onset characteristics (rise time to reach full activation), reliability, weight, power, and cost. Thus, the question is raised concerning what type of tactor and what signal intensity level is optimal for imparting information in operational environments.

A search of the literature revealed that two types of tactors have commonly been used in previous experiments. The most frequently used tactor type was the low-cost inertial shaker motor, which is present in most cell phones and pagers. Shaker designs usually use an electromagnetic drive configuration and may in some designs include a spring to introduce resonance, which limits the operating frequency but may increase overall efficiency (Cholewiak & Wollowitz 1992; Zetts, 2006). The other type of tactor discussed in the literature was the C-2 vibrotactile transducer. In this design, the contactor is the predominant moving mass and drives the skin with perpendicular movement (Zetts, 2006). Although engineering specifications can be used to describe and predict the effectiveness of these tactor types, we could not find a report of a comparison of tactor types that was conducted in an operational context.

For this experiment, we held tactor mounting location constant. The torso has shown great potential as an effective location for mounting tactors (van Erp & Werkhoven, 1999; Lindeman, Yangida, Lavine 2003), and the waist specifically has been shown as an effective location that is more sensitive than the back (van Erp & Werkhoven, 1999). The waist has also demonstrated great potential for providing intuitive directional signals (Elliott, Redden, Pettitt, Carstens, van Erp and Duistermaat, 2006; van Erp, 2005b) and intuitive communication (Pettitt, Redden & Carstens, in press). The waist-mounted tactor belt does not appear to interfere with Soldier clothing and equipment or with the Soldiers' abilities to perform their dismounted duties. Tactors positioned at the waist appear to stay in place (Pettitt, Redden, & Carstens, 2006).

The number of tactors used on the different parts of the body had to be carefully considered. Cholewiak, Brill, and Schwab (2004) found that for the torso, a ring of eight loci of vibration is the most that could be resolved with accuracy exceeding 90%. Thus, for Army operations, we chose a waist-mounted tactor belt that consisted of eight tactors. This was considered sufficient to communicate direction and basic signals. Instead of "mapping" every centimeter of the torso, we wanted to ascertain the effectiveness of each type of tactor, in the context of an eight-tactor array.

1.2 Overview of the Experiment

This report describes an investigation with two types of tactors: the inertial shaker motor and the C2. Both were embedded in similar systems (e.g., tactor torso belt). In addition, the C2 tactor, which is programmable, was set at two different frequencies: (a) the frequency that the developer considered optimal for human perception, and (b) the frequency that is more comparable to the inertial shaker motor type. The purpose of this experiment was to provide an evaluation of different tactor types and settings to determine the tactile signal type that is more easily localized. Soldiers were given tactile signals while they were standing still (static condition) and while they were moving through a woodland individual movement techniques (IMT) course (dynamic condition). Soldiers wore their fighting loads including interceptor body armor (IBA) outer tactical vest (OTV), with front and back small arms protective insert (SAPI) ceramic plates, and carried their personal weapons (M4). After being trained to use the tactile systems, each Soldier completed the static and IMT course trials three times, once with each of the three tactile signal conditions. The tactile signal manipulations were evaluated based on objective performance data, data collector observations, and Soldier questionnaires.

1.3 Objectives

- Which tactile signal type is more accurately localized by the Soldiers in a static environment?
 - Which tactile signal type is more accurately localized by the Soldiers in the dynamic environment of the woodland IMT course?
-

2. Procedures and Methodology

2.1 Overview

This evaluation was executed over a period of four days in May 2006 at ARL's woodland IMT course at Fort Benning, Georgia. Thirty target audience Soldiers were trained in the use of two versions of the tactors: Tactile Communications Systems (TACTICS) with two operating modes and the wireless tactile control unit (WTCU). The Soldiers responded to the three signal types while in a static position and while traversing the IMT course. The signal types were evaluated by means of performance data, Soldier questionnaires, and observations by ARL representatives.

2.2 Participants

Thirty Soldiers from the 3/11th Officer Candidate School (OCS) Infantry Regiment participated in the assessment. Six groups of five participated in the experiment for one half day each. The assessment was conducted over a four-day period. It was made clear that Soldier participation in the study was voluntary. We ensured the voluntary nature of participation by providing copies of

the consent form to all participating subjects who were given an opportunity to (a) review the assessment objectives, (b) have any of their questions answered by the investigators, and (c) sign a consent form indicating their informed voluntary consent to participate. The Soldiers were informed that if they chose not to participate, they could convey that choice privately to the assessment manager. The assessment manager would then inform that Soldier's unit supervisor, without elaboration, that the Soldier did not meet study criteria. All tasks planned for this study were tasks that are a normal part of the Soldier's job and all the Soldiers volunteered for the assessment.

The Soldiers completed this assessment using the tactile belt systems while wearing their Army combat uniform (ACU) and standard fighting load, as detailed in table 1. They carried their M4s.

Table 1. Standard fighting load.

Item Description
Underclothing and socks
Army combat uniform
Belt with buckle
Boots
Army combat helmet (ACH)
IBA OTV with front and rear SAPI plates
1-quart canteen with water and cover, (two each)
Inert hand grenades (two each)
Individual first aid kit
M4 rifle
Ammunition pouches (two each)
Elbow and knee pads (two of each)

Soldiers did not wear deltoid auxiliary protection, throat protectors, yoke/collar protectors, side plate carriers, or side plate inserts for this experiment.

2.2.1 Pre-Test Orientation and Volunteer Agreement

The Soldiers were given an orientation about the purpose of the study and their participation. They were briefed about the objectives and procedures for each exercise, as well as the equipment they were required to use throughout the investigation. They were also told how the results would be used and the benefits that the military can expect from this investigation. Any questions the subjects had regarding the study were answered. In addition, the volunteer agreement affidavit was explained and its contents were verbally presented. The Soldiers were then given the volunteer agreement affidavit to read and sign if they decided to volunteer.

2.2.2 Medical Review and Screening

At the outset of the assessment, the investigators asked the Soldiers if any of them had a medical profile or history that would jeopardize them if they participated in the study. Soldiers were also asked to complete the medical status form.

2.3 Instruments and Apparatus

2.3.1 Tactile System Descriptions¹

2.3.1.1 TACTICS 1

This tactile system was developed by the University of Central Florida (UCF) under a Defense Advanced Research Projects Agency (DARPA) contract number DAAE0703CL143. The system consisted of a tactile display belt worn around the waist with a receiver unit that was stowed in the cargo pockets of the Soldiers (see figure 1). The display consisted of eight tactile drivers, each using the C-2 vibrotactile transducer (Engineering Acoustics). The tactors were G1.2 inches in diameter. The contactor was the predominant moving mass, driving the skin with perpendicular sinusoidal movement that was independent of the loading on the housing (Zetts, 2006). Only the “inner circle” vibrated, while the outer ring was still, thus stopping the “spread” of vibrations. The C-2 was designed to create a strong localized sensation on the body and worked like a plunger. The tactors can be activated individually, sequentially, or in groups to provide a specific sensation or to create unique patterns of vibration. The control unit received wireless signals and converted them into recognizable patterns of vibration. In the system designated as TACTICS 1, the tactors vibrated at 250 Hz. The TACTICS 1 system was set to vibrate at gain level 4 (approximately 24 dB above mean absolute threshold).



Figure 1. TACTICS belt and control unit.

¹All goggle descriptions were provided by the contractors. Details concerning such information as algorithms used in the systems are not included because of their proprietary nature.

For this experiment, the tactors were activated individually for 500 ms. Although Gescheider, Hoffman, Harrison, Travis, and Bolanowski (1994) found that durations longer than 200 ms did not add to salience, we used 500-ms burst durations of vibration to assist in cue signal detection primarily because of the functional limitations of the pager motors. They have a 50- to 70-msec rise time, whereas the C2 system has about a 2-msec rise time to full activation. As such, the pager motor stimulus would have been, in effect, 25% shorter in duration than the C2 tactors, resulting in an unfair comparison. In other words, using the 200-msec stimulus would have resulted in an unfair comparison. With a long-duration (500 msec) stimulus, any failures in detection would not be attributable to stimulus duration but to some other aspect of the stimulus or system. Although it is true that sensory adaptation occurs after 400 to 500 msec of exposure to a vibratory stimulus, the interstimulus intervals were long enough to allow for recovery of the skin receptors. Moreover, the 200- to 300-msec “ideal” was created from research conducted in pristine laboratory conditions, and the field is a more difficult condition.

The system was configured so that the tactors directly contacted the special t-shirt provided (see figure 1). The tactor belts were worn over the t-shirt and under the uniform blouse and the OTV.



Figure 2. C-2 linear actuator: photograph (left) and operational schematic (right).

2.3.1.2 TACTICS 2

The UCF team modified a TACTICS 1 system, designated as the TACTICS 2. The purpose of this adjustment was to equate the signal strength of the TACTICS and WTCU systems while comparing the different tactor operating characteristics. The TACTICS 2 system was identical to the TACTICS 1 system, with a vibrating frequency of 250 Hz, except that the gain level was reduced to approximate the signal strength of the WTCU. The setting for this adjustment of perceptual loudness was determined by psychophysical techniques (method of adjustment and method of limits) in the laboratory.

A convenience sample of eight college student volunteers (seven males, one female) served as participants in the UCF adjustment of the TACTICS 2 system. Using the WTCU tactor as the

benchmark stimulus, the experimenter activated the WCTU and TACTICS 2 tactors in series. The intensity of the TACTICS 2 tactor was adjusted until the two stimuli were judged equal in “apparent loudness” or overall intensity. Participants (every single one) judged the output of the WTCU pager motor and the TACTICS 2 at gain level 3 as equivalent. Gain level 3 is approximately 20 dB above mean absolute threshold.

During the ARL test at Fort Benning, the TACTICS 2 system was configured so that the tactors directly contacted the special t-shirt provided (figure 1). The tactor belts were worn over the t-shirt and under the uniform blouse and the OTV.

2.3.1.3 Wireless Tactile Control Unit (WTCU)

The WTCU was developed at the Massachusetts Institute of Technology (MIT) under the Advanced Decision Architectures Collaborative Technology Alliance (ADA CTA). The tactile sensors were commercial off-the-shelf inertial shaker motors that used the same DC “pancake” motor present in cell phones (see figure 3). The tactors on the WTCU system were manufactured to vibrate at 80 Hz. Each signal consisted of one tactor vibrating for 500 ms. Each tactor was sealed with glue and then molded in a plastic block 18.4 mm long, 17 mm wide, and 6 mm thick. The plastic encasement was designed to make the motor more robust and increase the contact area between the motor and the skin. For this experiment, the system was configured to be worn around the waist (with the same belt system that was used with the TACTICS 1 and 2 systems) with eight tactors at the eight map cardinal point positions around the Soldiers’ waists. The system was configured so that the tactors directly contacted the special t-shirt provided (see figure 4). The tactor belts were worn over the t-shirt and under the uniform blouse and the OTV. The control unit received wireless signals from a laptop and converted them into recognizable patterns of vibration. Figure 4 displays a picture of the WTCU belt system used during the experiment. The tactile display was powered by a 9-V battery or a rechargeable 7.2-V lithium-ion battery.

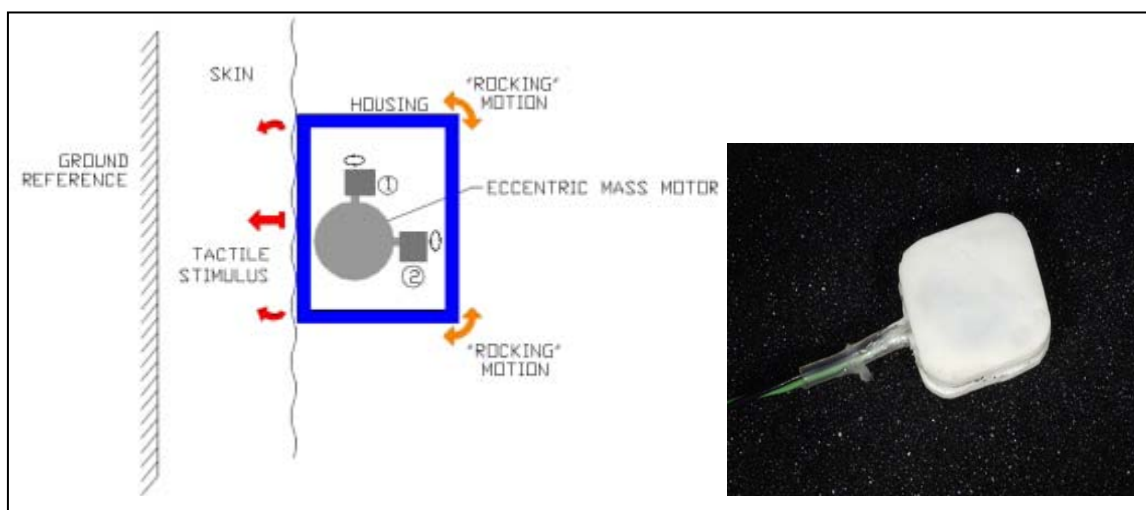


Figure 3. Inertial shaker motor tactor.

The system was configured so that the tactors directly contacted the special t-shirt provided (figure 4). The tactor belts were worn over the t-shirt and under the uniform blouse and the OTV.



Figure 4. Wireless tactile control unit belt.

2.3.2 Infantry Task Courses

The following provides a description of the environments used for this study.

2.3.2.1 Static Station

The Soldiers were evaluated on their ability to determine the location of tactor signals in a static position. During this event, the Soldiers received random tactor signals and were asked to identify the position of each signal using the clock position method. Figure 5 shows a Soldier at the static station with the controllers at the top of the mound.



Figure 5. Static station.

2.3.2.2 Individual Movement Techniques (IMT) Course

The woodland IMT course provides a methodology for assessing IMT performance that enables control, standardization, and repeatability. The course design requires Soldiers to use most urban and non-urban tactical maneuvers and IMTs. A diagram of the IMT course is shown in appendix A. It requires Soldiers to execute a variety of individual movements and assume a variety of positions while maneuvering through, over, under, and around obstacles. Soldiers initially walked through the course, and each obstacle and position was explained before they ran the first record trial. A description of each event and instructions for executing the event are provided next. Because there was difficulty in maintaining a communication link with the wireless connectivity technology, the crawling events were conducted beside the obstacle. This prevented interference from the metal structures on the pipe, the low crawl, and the high crawl.

The obstacles were categorized according to the type of activity required and the position assumed. The obstacle categories were walking, kneeling, prone position movement, climbing movement, and crawling movement (up on knees or feet with hands on the ground).

- Start (walking obstacle). The starting point (see figure 6) is clearly marked with a white line that spans the width of both lanes on the course. The course requires the Soldier to begin in the upright standing position with his weapon held “at the ready”. Upon the command “go” from the data collector, the trial begins and the Soldier moves approximately 30 meters to obstacle A.



Figure 6. Start run.

- Pipe Crawl (crawling obstacle). The pipe is 6 m long by 1 m in diameter and made of corrugated steel. It has a ridged surface, but because of interference with the system communications, the Soldiers crawled alongside the pipe, as shown in figure 7.



Figure 7. Pipe crawl beside the pipe.

- Zigzag (walking obstacle). The zigzag is 1.6 m tall, 14 m long, and approximately 1 m wide. It consists of three turns (approximately 90 degrees each) within the lane. The framework is constructed of wood with mesh wire installed between the two lanes and on the outside framework of each lane. The zigzag requires the Soldier to proceed through the obstacle as quickly as possible without causing any injury to himself or damage to his equipment (see figure 8).



Figure 8. Zigzag.

- First Bend (walking obstacle). The Soldier walks from the zigzag to the next obstacle.
- Two-foot Wall Kneeling Firing Position (kneeling obstacle). Upon arrival at this station, the Soldier assumes a kneeling supported firing position (see figure 9).



Figure 9. Two-foot wall.

- Low Crawl (prone obstacle). The low crawl is 13 m long and 3 m wide with an overhead cover of mesh wire approximately 0.6 m off the ground. The Soldier completes the obstacle as quickly as possible using correct low crawl techniques. Because of communications interference with the wire mesh on the low crawl, the Soldiers performed the low crawl adjacent to the obstacle, as shown in figure 10.



Figure 10. Low crawl.

- Second Bend (walking obstacle). The Soldier walks from the low crawl to the next event.
- Combat Roll (prone position obstacle). The combat roll station is about 6 m long and 2 m wide. The Soldier hastily assumes the prone position immediately after entering the station. He then executes a full combat roll in the opposite direction, pushes off the ground using the butt stock of the weapon, executes a 3- to 5-second rush, and returns to the prone. The Soldier then executes a full combat roll in the opposite direction and pushes off the ground using the butt stock of the weapon (see figure 11).



Figure 11. Combat roll.

- High Crawl (crawling obstacle). Each lane of the high crawl is 13 m long and 3 m wide with an overhead cover of mesh wire approximately 1 m off the ground. The Soldier moves as quickly as possible, using correct high crawl procedures, to negotiate the full length of the obstacle. Because of communications interference, the Soldiers performed the high crawl adjacent to the obstacle, as shown in figure 12.
- Kneeling Firing Position (kneeling obstacle). The kneeling firing position station provides a wooden support 2 m wide, 1 m tall, and 13 cm deep for the Soldier to support the weapon against during target acquisition and engagement. Upon entering the station, the Soldier assumes a kneeling supported firing position, as shown in figure 13.
- 4-Foot Wall (climbing obstacle). The high wall is made of wood, is 1.4 m tall, 1.8 m wide, and 13 cm deep (see figure 14). The Soldier climbs over the obstacle without causing any personal injury or damaging equipment while maintaining control of the weapon at all times.



Figure 12. High crawl.



Figure 13. Kneeling firing position.

- Prone Supported Firing Position (prone position obstacle). The prone firing position station is 2 m long by 1 m wide with sandbags provided to support the weapon. The Soldier enters the station and assumes a prone supported firing position, as shown in figure 15.



Figure 14. Four-foot wall.



Figure 15. Prone position.

- Urban Wall Window Kneeling Firing Position (kneeling and climbing obstacles). The urban wall replicates several urban obstacles (see figure 16). Upon reaching the wall, the Soldier assumes a kneeling firing position at the opening that represents a window.
- Ladder (climbing). The Soldier climbs up one side of the wall and down the other while maintaining control of his weapon, as shown in figure 16.
- Stairs and Platform (climbing). The stairs are made of wood. Five steps lead up to a platform and five steps lead down (see figure 17).
- End Point (walking obstacle). The Soldier moves approximately 30 meters and completes the IMT course.



Figure 16. Urban wall and window.



Figure 17. Stairs and platform.

2.3.2.3 Questionnaires

Questionnaires were designed to elicit Soldiers' opinions about their performance and experiences with each of the systems. The questionnaires were designed to enable Soldiers to rate the devices on a 7-point semantic differential rating scale ranging from "extremely good/easy" to "extremely bad/difficult". Questionnaires were administered to each Soldier at the completion of each of the trials with each of the devices and at the completion of the day's activities.

2.4 Methodology

How do the operating characteristics of the tactors affect the ability of the Soldier to detect and localize the tactile signal while static and while performing IMTs?

2.4.1 Sampling of Identification Methods

Before starting the experiment, 35 personnel from the 3/11th (not the Soldiers used in the experiment) were queried to determine their preference of the two proposed tactor location identification schemes. Each Soldier was independently briefed about the experiment and asked which method of identifying the tactor location would be easier. The methods presented were

1. Identifying the activated tactor with the positions of a clock with 12 o'clock being the front position, 6 o'clock being the back position, and 3 and 9 o'clock being the sides positions, etc. (Note, the four positions between the 12, 3, 6, and 9 o'clock positions were identified as 1/2, 4/5, 7/8, and 10/11 o'clock.)
2. Identifying the activated tactor with the compass points with north being the front, south being the back, etc. (Note, Soldiers were given the choices of north, northeast, east, southeast, south, southwest, west, and northwest for the eight points.)

2.4.2 Psychophysics Pilot Test

The purpose of the adjustment of the second TACTICS system was to equate its signal strength to that of the WTCU system. A brief psychophysics excursion was conducted by the ARL team at the test site as a check to see what effect this adjustment had on the felt signal intensity of the tactile belt systems. Four subjects who were not participants in the experiment proper were asked to evaluate the three tactile belt systems in terms of felt signal strength.

This pilot test was conducted before the experiment proper. The participants were volunteers from the 3/11 Infantry (OCS). The participants were tested individually. Each participant was fitted with the three tactile belt systems in the sequence shown in table 2 with each of the eight tactors, designated by clock position, as shown in table 3. Each tactor activation was a duration of 500 msec.

Table 2. Treatment assignment, psychophysics pilot test.

Subject	Iteration		
	1	2	3
1	WTCU	TACTICS 1	TACTICS 2
2	TACTICS 2	WTCU	TACTICS 1
3	TACTICS 1	TACTICS 2	WTCU
4	TACTICS 2	TACTICS 1	WTCU

Table 3. Tactor sequence, psychophysics pilot test.

Tactor activation	Iteration		
	1	2	3
1	1:00/2:00	4:00/5:00	9:00
2	12:00	7:00/8:00	3:00
3	6:00	12:00	4:00/5:00
4	3:00	1:00/2:00	1:00/2:00
5	4:00/5:00	9:00	12:00
6	10:00/11:00	6:00	7:00/8:00
7	9:00	3:00	10:00/11:00
8	7:00/8:00	10:00/11:00	6:00

After each tactor activation, the subject was asked to rate the intensity of the tactile stimulation using the 0- to 100-point scale illustrated in table 4.

Table 4. Tactile stimulation intensity scale.

Scale	Description
100	Painful
95	
90	Uncomfortable
85	
80	
75	Intense
70	
65	
60	
55	
50	Optimal
45	
40	
35	
30	
25	Easily detectable
20	
15	
10	Barely detectable
5	
0	Not detectable

2.4.3 Demographics

Demographic data were taken for each Soldier. Data concerning their infantry experience and training were included in the demographic data sheet. The demographic data sheet results are shown in appendix B.

2.4.4 Training

The requested Soldiers were in a military occupational specialty that required performance of mobility and portability maneuvers (movement to contact and assault maneuvers) and movement as a dismounted element that is associated with their profession. No specialized experience was

required. However, the Soldiers were shown how to negotiate the IMT course safely and were trained in specific procedures as required. Additionally, the Soldiers were provided the opportunity to walk through the course at a slow speed to better familiarize them with the course, as well as reduce risk during actual course execution.

Before they received training, the Soldiers received a roster number, which was used to identify them throughout the assessment. A representative from ARL presented a course about the use and fit of the tactile belt systems. As part of the training, each Soldier donned the tactile belts and experienced some familiarization signals. Upon completion of the training, the Soldiers were given a questionnaire designed to assess their perception of the training adequacy, and the results are shown in appendix C.

2.4.5 Static Trials

Experiment personnel assisted each Soldier in donning the tactile belt systems. Each Soldier completed the static trial and IMT course three times using TACTICS 1, TACTICS 2, and WTCU once each. The Soldiers were assigned to treatments according to the matrix in table 5. This matrix was constructed of a series of Latin squares, with the restriction that each successive Soldier used a different system in each iteration. This restriction was needed in order to accommodate a limited number of each type of system.

Soldiers identified the eight tactors by clock position, as shown in figure 18.

The controllers transmitted the tactile signals from a station in the middle of the IMT course, on top of the mounds (see figure 5). The systems were controlled with a laptop computer (figure 19) and transmitted via a wireless network to the Soldiers on the course. A data collector was stationed with both controllers (one for the WTCU and one for the two TACTICS systems). For the static trials, the Soldier was escorted to the appropriate controller. The Soldier stood at the bottom of the mound for the static trials. The controllers' tables were arranged so that the Soldier could not see the controller activating the tactile signaling device.

During the static trials, each Soldier received eight tactile signals, one with each tactor, spaced an average of 10 seconds apart, according to the random matrix shown in table 6. Each signal consisted of the activation of a single tactor, approximately 500 msec in duration. After each signal, the Soldier told the data collector of the location of the tactor signal. The data collector recorded whether the Soldier made the correct identification.

Table 5. Treatment assignments.

Roster	Iteration		
	1	2	3
1	TACTICS 1	WTCU	TACTICS 2
2	WTCU	TACTICS 2	TACTICS 1
3	TACTICS 2	TACTICS 1	WTCU
4	WTCU	TACTICS 2	TACTICS 1
5	TACTICS 2	TACTICS 1	WTCU
6	TACTICS 1	WTCU	TACTICS 2
7	TACTICS 2	TACTICS 1	WTCU
8	WTCU	TACTICS 2	TACTICS 1
9	TACTICS 1	WTCU	TACTICS 2
10	WTCU	TACTICS 2	TACTICS 1
11	TACTICS 2	TACTICS 1	WTCU
12	TACTICS 1	WTCU	TACTICS 2
13	TACTICS 2	TACTICS 1	WTCU
14	TACTICS 1	WTCU	TACTICS 2
15	WTCU	TACTICS 2	TACTICS 1
16	TACTICS 1	WTCU	TACTICS 2
17	TACTICS 2	TACTICS 1	WTCU
18	WTCU	TACTICS 2	TACTICS 1
19	TACTICS 2	TACTICS 1	WTCU
20	WTCU	TACTICS 2	TACTICS 1
21	TACTICS 1	WTCU	TACTICS 2
22	TACTICS 2	TACTICS 1	WTCU
23	WTCU	TACTICS 2	TACTICS 1
24	TACTICS 1	WTCU	TACTICS 2
25	WTCU	TACTICS 2	TACTICS 1
26	TACTICS 1	WTCU	TACTICS 2
27	TACTICS 2	TACTICS 1	WTCU
28	TACTICS 1	WTCU	TACTICS 2
29	TACTICS 2	TACTICS 1	WTCU
30	WTCU	TACTICS 2	TACTICS 1

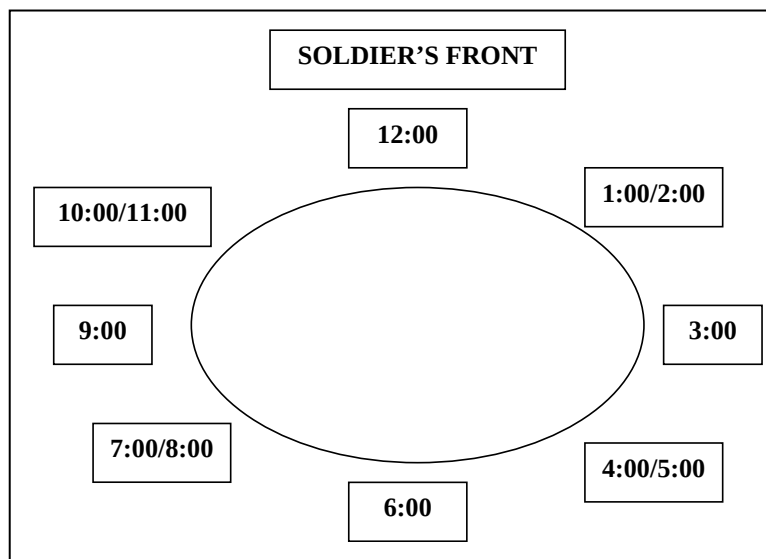


Figure 18. Tactor designation.



Figure 19. Wireless communication from a laptop.

Table 6. Order of tactile stimulation, static trials.

Tactor activation	Iteration		
	1	2	3
1	9:00	1:00/2:00	4:00/5:00
2	3:00	12:00	9:00
3	7:00/8:00	9:00	10:00/11:00
4	12:00	6:00	1:00/2:00
5	4:00/5:00	4:00/5:00	6:00
6	10:00/11:00	7:00/8:00	7:00/8:00
7	6:00	10:00/11:00	3:00
8	1:00/2:00	3:00	12:00

2.4.5 Dynamic Trials

Following completion of an iteration of the static trials, the Soldier moved through the IMT course. He was accompanied by a data collector. Tactile signals were sent by the controller on the mounds in the middle of the course. The data collector stationed with the controller began timing when the signal was activated and stopped timing when the Soldier reported the location of the tactor. If the Soldier's voice could not be heard, then the data collector accompanying the Soldier repeated the call to the center of the course where the controllers were situated on the mounds.

Upon each iteration of the IMT course, the Soldier received one signal for each of the eight tactors, as shown in table 7. Each signal consisted of the activation of a single tactor, approximately 500 msec in duration. The tactor sequences were random, with the restriction that tactor activations were distributed across all five obstacle types. As soon as the Soldier received the signal, he reported which tactor was activated. Data collectors recorded whether the Soldier accurately located the signal and the time from the initiation of the signal to the Soldier's response. Data collectors initiated timing on their stopwatches simultaneously with the signal initiation and stopped the watches when the Soldier began speaking the location position. At the completion of each course trial, a subjective questionnaire was administered. In addition, data

collector observations were recorded for each trial. If specific obstacles or positions were more difficult or time consuming to execute, the reasons were determined and documented so that corrective actions could be taken in equipment design or procedures.

Table 7. Sequence of tactor signals, IMT course.

Obstacle	Type	Iteration		
		1	2	3
Start run	Patrol	10:00/11:00		
Pipe crawl	Pipe Crawl		4:00/5:00	12:00
Zigzag	Patrol		7:00/8:00	
First bend	Patrol		3:00	1:00/2:00
2-ft jump	Kneel	6:00		
Low crawl	Prone	3:00	1:00/2:00	
Second bend	Patrol	12:00		
Combat roll	Prone	9:00		
High crawl	Prone			7:00/8:00
Kneeling fire	Kneel		12:00	9:00
High wall	Climb	4:00/5:00		3:00
Prone fire	Prone	1:00/2:00		
Window	Kneel		10:00/11:00	10:00/11:00
Ladder	Climb		9:00	
Stairs	Climb	7:00/8:00	6:00	6:00
End run	Patrol			4:00/5:00

2.5 Experimental Design

2.5.1 Independent Variables

This study used a within-subjects design. The independent variables were activity mode (static versus dynamic) and tactor belt system (TACTICS 1, TACTICS 2, or WTCU).

2.5.2 Dependent Variables

The dependent variables for the static and IMT trials were

- Data collectors' observations of the Soldiers during the static and IMT trials;
- Whether the Soldier made the correct response to each signal during the static and IMT trials;
- Time to respond correctly to each signal during the IMT trials;
- Soldiers' overall ratings of detecting each type of signal from the static position and on the IMT course.

3. Results

3.1 Sampling of Identification Methods

In the pre-test side event to determine which identification scheme was preferred, 34 of the 35 Soldiers queried chose the clock method of identifying the eight cardinal compass points.

3.2 Psychophysics Pilot Test

Table 8 shows the mean ratings of signal intensity, on a 0- to 100-point scale, for each system. A repeated measures analysis of variance (ANOVA) indicates that the difference among the three systems was not statistically significant: $F(2,6) = 3.18$, $p = .115$, $\eta^2_p = .51$. It is, of course, very difficult to obtain statistical significance with a sample size of four. The effect size (η^2_p) value of 0.51 suggests that system type had a substantial impact on perceived signal intensity, with the TACTICS 1 system being rated strongest and TACTICS 2 and WTCU being more similar.

Table 8. Mean signal intensity ratings on a 0- to 100-point scale (n = 4 soldiers).

System	Mean	SD
TACTICS 1	23.6	5.2
TACTICS 2	15.1	1.4
WTCU	18.9	5.8

These data suggest that the adjustment of the TACTICS 2 system to make it comparable in perceived signal intensity to the WTCU system was somewhat successful. They also suggest that all of the systems' intensities were rated lower than the optimal level and the intensities could be raised substantially before the Soldier began to feel pain.

3.3 Demographics

All Soldiers were from Alpha or Bravo companies of the 3rd Battalion OCS, 11th Infantry Regiment. They had a mean age of 28 years and a mean self-reported general technical (GT) score of 121. They were from diverse military backgrounds with mean time in service of 8 years and 6 months and a mean time in their duty positions of 3 years and 3 months. Their scores on their most recent physical fitness tests averaged 293 of a possible 300. Of the 34 Soldiers participating (four in the psychophysics test and 30 in the experiment proper), there were 27 males and 7 females. One Soldier had a profile prohibiting running and jumping, but she agreed to be a subject since there was no requirement for running and jumping during the experiment and she wanted to be a participant. The complete summation of the demographic data is presented in appendix B.

3.4 Training

All Soldiers answered the training questionnaire upon completion of all events. This allowed them time to better understand the systems and give them time to evaluate each. Each Soldier was asked to rate the level and adequacy of training based on a 7-point Likert scale, with 1 being extremely bad and 7 being extremely good. The results are shown in table 9. The Soldiers indicated that the training was adequate and they were comfortable with the use of the systems. The complete results for the training questionnaires are in appendix C.

Table 9. Mean responses to adequacy of training.

	Mean Response	
	TACTICS 1 & 2	WTCU
Length of training	5.78	5.71
Explanation of concepts	5.78	5.59
Adequacy of training aids	5.95	5.70
Mix of lecture to hands-on exercise	5.67	5.94
Training facilities	5.83	6.05
Overall quality of training	5.91	5.95

3.5 Static Trials

Figure 20 shows the proportion of correct signal localizations, summed across all three systems, as a function of tactor location. Because of the low observed frequencies in some cells of the detect/no-detect table, it is not appropriate to conduct a χ^2 test on these data. Tactor localization was best for the 12:00, 4:00/5:00, and 10:00/11:00 positions.

During the static trials, there was a high proportion of correct responses for all three systems (see table 10). For all three systems, most of the incorrect responses were off by only a single tactor location. The difference among systems for proportion of correct responses was not statistically significant: χ^2 (df=2) = 4.47.

3.6 Dynamic Trials

Figure 21 shows the proportion of correct signal localizations, summed across all three systems, as a function of tactor location. (Positions with two designations such as 10:00/11:00 are indicated with only one of the numbers for brevity.) The differences in correct localization rates for the different tactor locations are statistically significant: χ^2 (df=7) = 34.8, $p < .001$. Tactor localization was best for the tactors in the 12:00 and 10:00/11:00 positions.

Table 11 shows the mean response latencies on the IMT course for the three systems. A repeated measures ANOVA indicates that there was no significant difference among the systems for response times: $F(2,44) = 1.64$, $p = 0.205$, $\eta^2_p = .07$.

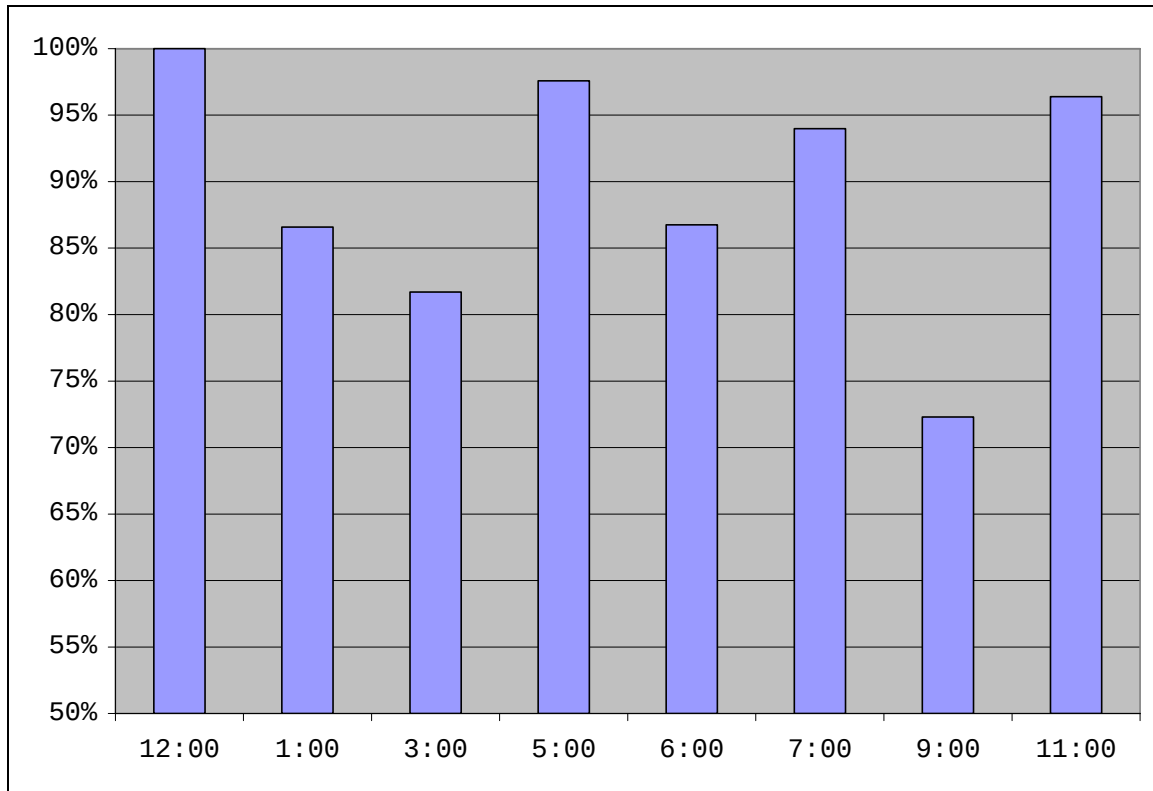


Figure 20. Percent correct detections as a function of factor location static trials.

Table 10. Response frequencies for static trials.

Response	TACTICS 1	TACTICS 2	WTCU
Correct detections	196	191	204
One tactor location off	19	14	26
Two or more tactor locations off	0	2	2
No detect	1	1	5
No data (system malfunction or recording error)	24	32	3
Total	240	240	240
Number of signals administered	216	208	237
Percent correct	90.7	91.8	86.1

Table 11. Mean response latencies (seconds) for IMT course.

System	n	Mean	SD
TACTICS 1	26	2.13	0.31
TACTICS 2	25	2.35	0.72
WTCU	30	2.28	0.33

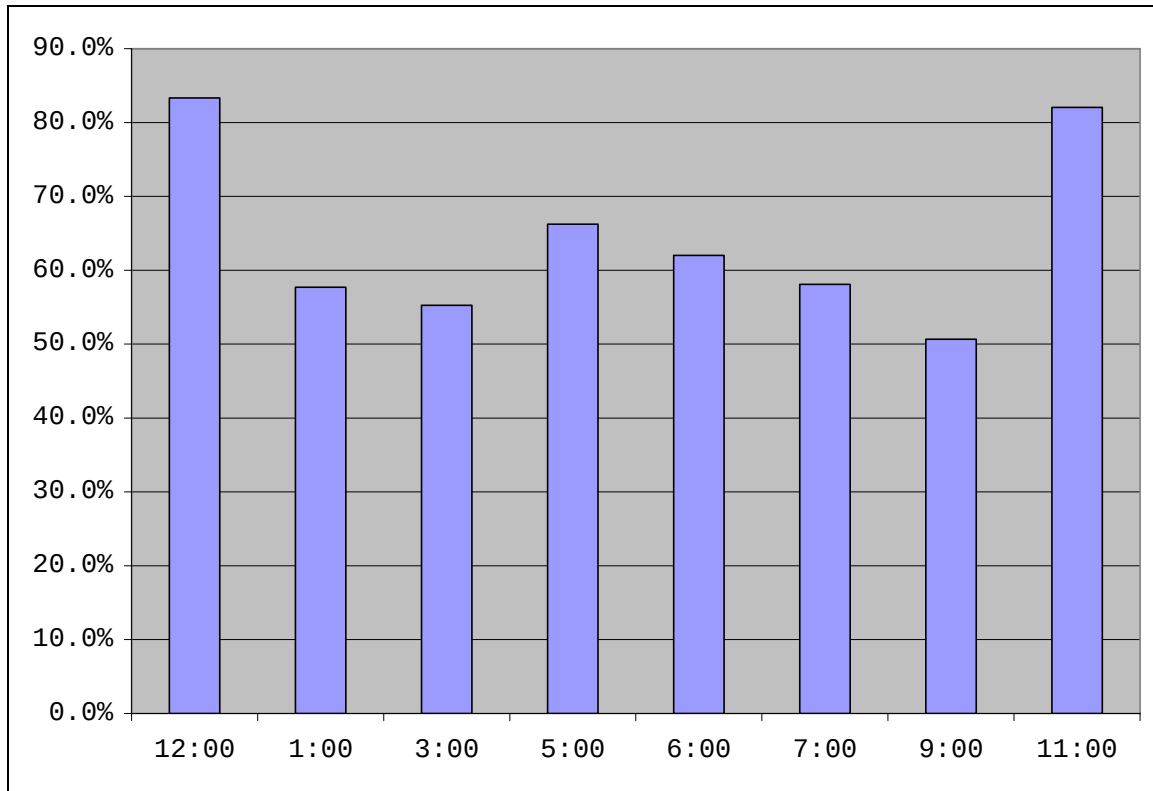


Figure 21. Percent correct detections as a function of factor location IMT course trials.

As shown in table 12, there were many system malfunctions with the TACTICS 1 and 2 belts but no malfunctions with the WTCU system. The system malfunctions were all failures of the wireless connectivity technology on the TACTICS systems. The reason for the wireless malfunction is unclear; the TACTICS systems worked perfectly when tested in Florida before and after this experiment. Whatever the cause, the failure of the wireless technology became worse toward the end of the experiment. There were 14 system malfunctions on the first day, 7 malfunctions on the second day, and 84 on the third day. As a result of the wireless technology failures, some Soldiers missed entire iterations of the IMT course (see table 14).

Table 12. Completed iterations of the IMT course (x = not completed).

Roster	A	B	C
1 thru 21	Yes	Yes	Yes
22	Yes	x	Yes
23	Yes	Yes	Yes
24	Yes	x	Yes
25	Yes	Yes	Yes
26	Yes	x	Yes
27	x	Yes	Yes
28	x	x	Yes
29	x	Yes	Yes
30	x	x	Yes

Whenever the wireless connection was lost while a Soldier was traversing the IMT course, that Soldier was instructed to halt while the connection was re-established.

Table 13 shows the response frequencies by system for the IMT course. The proportion of correct signal detections was highest for the TACTICS 1 system (78.7%) and lowest for the WTCU system (48.8%). The difference among the three systems in terms of percent correct responses was statistically significant: χ^2 (df=2) = 52.0, $p < .001$.

Table 13. Response frequencies for IMT course.

Response	TACTICS 1	TACTICS 2	WTCU
Correct detections	155	125	117
One tactor location off	27	16	20
Two or more tactor locations off	4	2	7
No detect	11	35	96
No data (system malfunction)	43	62	0
Total	240	240	240
Number of signals administered	197	178	240
Percent correct	78.7	70.2	48.8

Ensuing comparisons indicate that there was no statistically significant difference in the proportion of signals detected for the two TACTICS: χ^2 (df=1) = 3.10. The proportion of signals detected was significantly lower with the WTCU as compared with TACTICS 1 (χ^2 (df=1) = 40.0, $p < .001$) and as compared with TACTICS 2 (χ^2 (df=1) = 18.4, $p < .001$).

It is possible that some of the non-responses attributed to failure of the wireless connectivity technology may have actually been simple failures to detect. If this were the case, the localization analysis presented would be biased in favor of the TACTICS and against the WTCU system. In order to control for this possible source of bias, two additional analyses were conducted. First, we identified every Soldier who had any TACTICS 1 system malfunction recorded on the IMT course. These nine Soldiers were deleted from the data set. Table 14 shows the signal detection data for the TACTICS 1 and WTCU systems for the remaining 21 Soldiers. There was a significantly higher correct detection rate for TACTICS 1 than for WTCU: χ^2 (df=1) = 27.3, $p < .001$.

Table 14. Response frequencies IMT course trials, TACTICS 1 system malfunction cases deleted.

Response	TACTICS 1	WTCU
Correct detection	131	84
One tactor location off	24	14
Two or more tactor locations off	4	4
No detect	9	66
Total	168	168
Percent correct	78.0	50.0

This analysis was repeated for the TACTICS 2 system: any Soldier who had any TACTICS 2 malfunction was deleted from the data set. Table 15 shows the signal detection data for

TACTICS 2 and WTCU for the remaining 14 Soldiers. The proportion of correct tactor localizations was significantly higher for the TACTICS 2 system: χ^2 (df=1) = 6.04, $p < .025$.

Table 15. Response frequencies IMT course trials, TACTICS 2 system malfunction deleted.

Response	TACTICS 2	WTCU
Correct detection	77	58
One tactor location off	9	3
Two or more tactor locations off	2	3
No detect	24	48
Total	112	112
Percent correct	68.8	51.8

These two analyses confirm the conclusion that correct signal localization rates were lower with the WTCU system than with the TACTICS systems.

Table 16 shows the proportion of correct responses by event type on the IMT course. The same data are depicted in figure 22. There was a statistically significant difference in correct response rate for the different event types: χ^2 (df=4) = 89.6, $p < .001$. The highest detection rates occurred when the Soldier was walking upright or in a kneeling firing position. The lowest detection rates occurred when the Soldier's torso was in contact with the ground. Tactor detection and localization ability were also degraded when the Soldier was climbing an obstacle.

Table 16. Percent correct by IMT event type.

Type	Event	Percent Correct
Walk	Start run	85.7
	Zigzag	
	First bend	
	Second bend	
	End run	
Pipe crawl	Pipe crawl	62.3
Kneel	2-ft wall kneel and fire	78.0
	Kneel and fire	
	Window fire	
Prone	Low crawl	37.1
	Combat roll	
	High crawl	
	Prone fire	
Climb	High wall	54.0
	Ladder	
	Stairs	

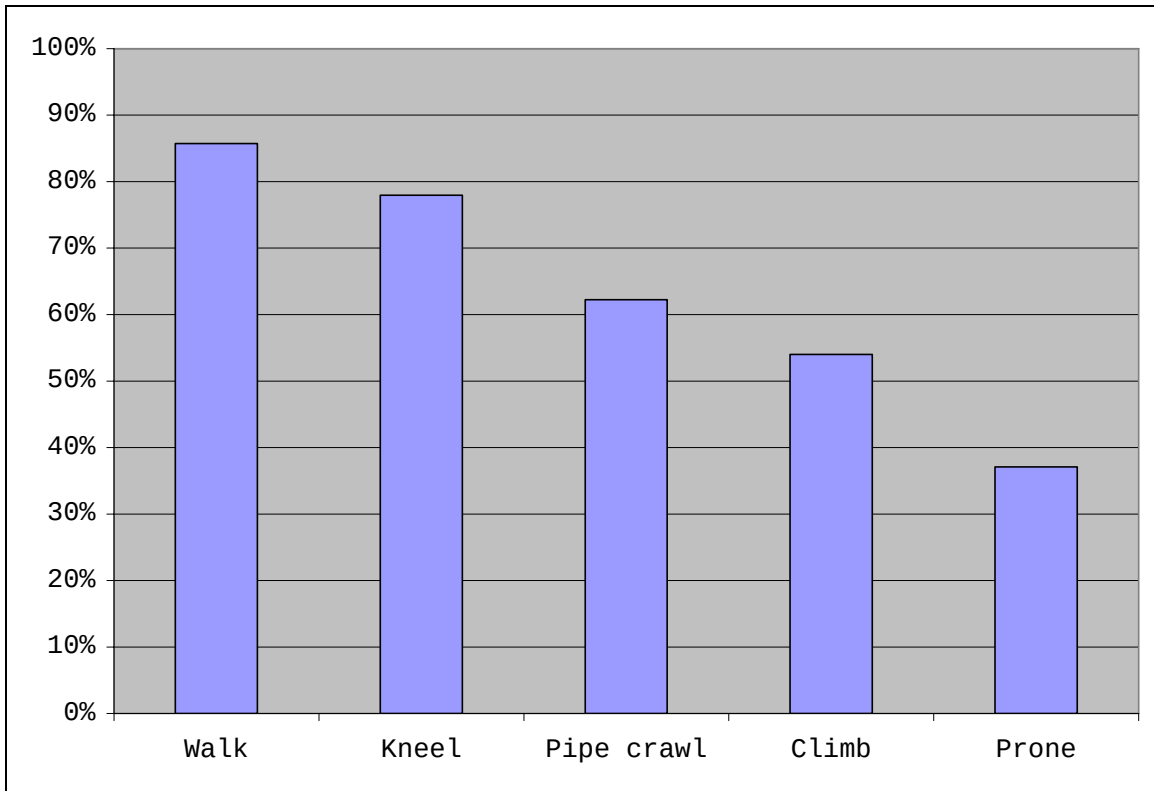


Figure 22. Percent correct response by IMT event.

Figure 23 shows the proportion of correct signal detections as a function of tactile belt system and course event type. The pattern is the same for all three systems: signal detection capability is degraded when the Soldier is climbing an obstacle or when his torso is in contact with the ground.

The Soldiers' responses to subjective questions administered upon completion of each iteration are presented in appendix D. When asked how difficult or easy it was to detect and localize the tactile signals while on the IMT course, the Soldiers all reported TACTICS 1 to be the easiest (see table 17). The WTCU signals were noticeably more difficult to detect. The Soldiers reported that for all three systems, detection and localization of signals was easier in the static trials than on the IMT course. Soldiers reported more difficulty in detection of the signals when conducting movement, especially the more difficult movements that involved crawling, rolling, or climbing.

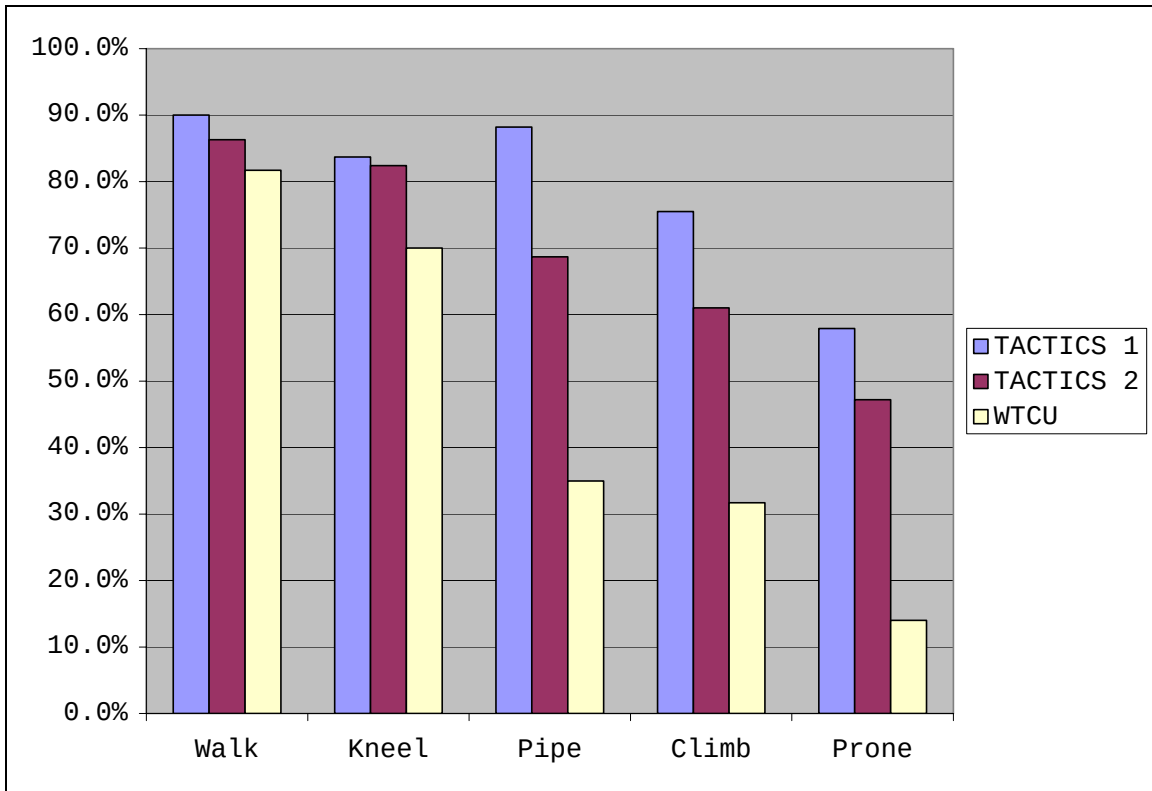


Figure 23. Percent correct responses as a function of event type and system.

Table 17. Mean ratings of difficulties or ease of detecting and localizing tactile signals.

Event	TACTICS 1	TACTICS 2	WTCU
Static trials	6.25	5.80	4.97
IMT course	5.53	4.85	3.49

The Soldiers were asked to give their overall evaluation of the tactile system they used for each iteration. Their mean responses are shown in table 18. They rated TACTICS 1 slightly over TACTICS 2 and even more over WTCU.

Table 18. Soldiers' mean responses to system preference.

Mean Response		
TACTICS 1	TACTICS 2	WTCU
5.67	4.95	3.77

After completing all iterations, the Soldiers were administered an end-of-experiment questionnaire. The complete results for this questionnaire are given in appendix D. After using all three systems, the Soldiers continued to rate the TACTICS 1 system highest. The Soldiers were asked to rate ease of difficulty of identifying where they were being buzzed and the intensity of that buzz in both the static trials and IMT trials. The results are shown in table 19. In all cases, the Soldiers reported less difficulty with TACTICS 1 than with the other two systems. It is also interesting to note that

they reported more difficulty with all systems in the moving exercises (IMT event) than the static event.

Table 19. Mean signal detection and localization ratings.

Trials	Question	TACTICS 1	TACTICS 2	WTCU
Static	Ease of feeling signal	6.44	5.52	4.13
	Ease of localizing signal	6.41	5.70	4.37
IMT	Ease of feeling signal	6.04	4.92	3.10
	Ease of localizing signal	5.81	5.04	3.33

Finally, the Soldiers were asked which system was best overall and which system was the worst (see table 20). The Soldiers in the “no response” category did not have an opportunity to complete iterations with all three systems because of system malfunction of the wireless connection. One additional Soldier chose not to respond to the “best” question. The Soldiers overwhelmingly reported TACTICS 1 to be preferred and best overall.

Table 20. Number of soldiers rating system as best.

	TACTICS 1	TACTICS 2	WTCU	No Response
Best	18	4	0	8
Worst	1	5	17	7

4. Discussion and Conclusions

During the psychophysics pre-test, the Soldiers were asked to rate the signal intensity of the three systems using a 0 to 100 scale, with 0 representing an undetectable stimulus, 100 a painful stimulus, and 50 the optimal level of stimulation. The mean ratings ranged from 15.1 to 23.6. This indicates that the signal strength of all three systems is well below the *optimal* level for Soldiers equipped with body armor and ceramic insert plates. Further work should be performed that investigates the benefits of increasing signal strength, as well as to determine if there are any associated problems, such as desensitization after prolonged use, spurious noise generation, or appreciable increases in power consumption.

The correct signal detection and localization rates were fairly high for all three systems during the static trials, ranging from 86.1% to 91.8% correct. There were no significant differences among the three systems in terms of signal detection and localization in this event. The ability to correctly identify tactor location was substantially degraded during individual movement, and differences among the three systems emerged when the Soldiers conducted the IMT course. On the IMT course, tactor localization was best with the TACTICS 1 system and worst with the WTCU system, and localization was best when the Soldier was moving upright or in a kneeling firing position. Localization was degraded when the Soldier’s torso was in contact with the ground or when he was climbing an obstacle.

There were no significant differences among Soldier performance with the three systems in terms of response latencies on the IMT course.

In both the static and IMT trials, localization was best for tactors in the ventral positions (12:00 and 10:00/11:00) and lowest at the sides (3:00 and 9:00). This finding is consistent with van Erp's (2005a) finding that acuities between 2 and 3 centimeters were found around the torso except for the body midline where a more precise acuity of 1 centimeter was found. They are also consistent with van Erp and Werkhoven's 1999 finding that ventral acuity is better than dorsal acuity.

There were a large number of malfunctions in the wireless connectivity technology for the two TACTICS. The reason for these malfunctions is unknown. No such malfunctions occurred with the WTCU.

It is important to note that the Soldiers in this investigation were not equipped with side insert ballistic plates. Further research is needed to determine whether the side plates interfere with the detection and localization of tactile signals.

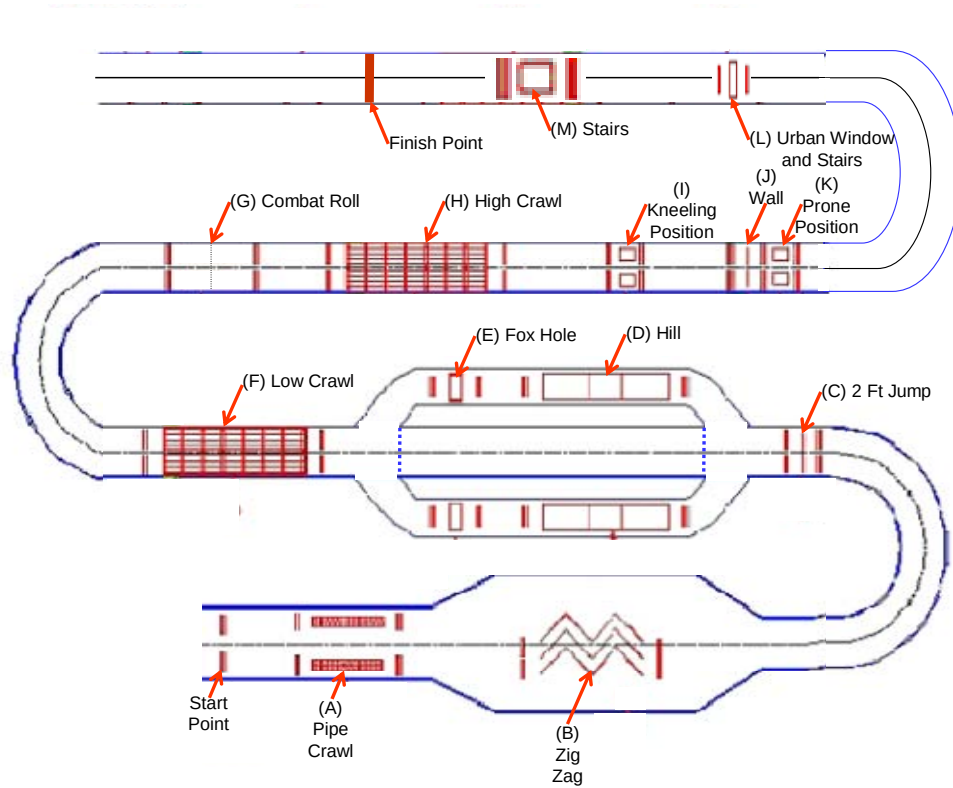
5. References

- Carlander, O.; Eriksson, L. Uni- and Bimodal Threat Cueing With Vibrotactile and 3D Audio Technologies in a Combat Vehicle. *Proceedings of the 2006 Human Factors and Ergonomics Society*, San Francisco, CA, (in press).
- Chiaasson, J.; McGrath, B.; Rupert, A. *Enhanced Situation Awareness in Sea, Air, and Land Environments*; DTIC Technical Report. ADP013874; Naval Aerospace Medical Research Laboratory: Pensacola, FL, 2003.
- Cholewiak, R. C.; Brill, J. C.; Schwab, A. Vibrotactile Localization on the Abdomen: Effects of Place and Space. *Perception and Psychophysics* **2004**, 66 (6), 970-987.
- Cholewiak, R. C.; Wollowitz, M. The Design of Vibrotactile Transducers. In I. R. Summers (Ed.), *Tactile Aids for the Hearing Impaired*, London: Whurr Publishers Ltd, 57-82, 1992.
- Dobbins, T.; Samways, S. The Use of Tactile Navigation Cues in High-Speed Craft Operations. *Proceedings of the RINA Conference on High Speed Craft: Technology and Operation*, pp 13-20. London: The Royal Institution of Naval Architects, 2002.
- Elliott, L. R.; Redden, E. S.; Pettitt, R. A.; Carstens, C. B.; van Erp, J.; Duistermaat, M. *Tactile Guidance for Land Navigation*; ARL-TR-3814; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2006.
- Gemperle, F.; Ota, N.; Siewiorek, D. Design of a Wearable Tactile Display. *Proceedings of the International Symposium on Wearable Computers (ISWC'01)*, IEEE, Zurich, Switzerland, 5-12, 2001.
- Gescheider, G.A.; Hoffman, K.E.; Harrison, M.A.; Travis, M.L.; Bolanowski, S.J. The Effects of Masking on Vibrotactile Temporal Summation in the Detection of Sinusoidal and Noise Stimuli. *Journal of the Acoustical Society of America* **1994**, 95, 1006-1016.
- Lindeman, R.; Yangida, Y.; Lavine, R. Effective Vibrotactile Cueing in a Visual Search Task. *Proceedings of the Ninth IFIP International Conference of Human-Computer Interaction (INTERACT 2003)*, 2003.
- Mitchell, D.; Samms, C.; Glumm, M.; Krausman, A.; Brelsford, M.; Garrett, L. *Improved Performance Research Integration Tool (IMPRINT) Model Analyses in Support of the Situational Understanding as an Enabler for Unit of Action Maneuver Team Soldiers Science and Technology Objective (STO) in Support of Future Combat Systems (FCS)*; ARL-TR-3405; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2004.

- Pettit, R. A.; Redden, E. S.; Carstens, C. C. *Comparison of Hand and Arm Signals to a Covert Tactile Communication System in a Dynamic Environment*; ARL-TR-3838; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2006.
- van Erp, J.B.F. Vibrotactile Spatial Acuity on the Torso: Effects of Location and Timing Parameters. *Proceedings of Worldhaptics*, pp. 80-85, IEEE Computer Society: Los Alamitos, CA, 2005a.
- van Erp, J.B.F. Presenting Directions With a Vibrotactile Torso Display. *Ergonomics* **2005b February**, 48 (3), 302-313.
- van Erp; Van Veen Vibrotactile In-Vehicle Navigation System. *Transportation Research part F: Human Factors* **2004**, 7, 247-256.
- van Erp, J.B.F.; Van Veen, H.A.H.C. A Multi-Purpose Tactile Vest for Astronauts in the International Space Station. *Proceedings of Eurohaptics 2003*, pp. 405-408, Trinity College: Dublin, Ireland, 2003.
- van Erp, J.B.F.; Veltman, J. A.; Van Veen, H.A.H.C.; Oving, A. B. Tactile Torso Display as a Countermeasure to Reduce Night Vision Goggles Induced Drift. *NATO RTO Conference on Spatial Disorientation* **2002**, 15-17.
- van Erp, J.B.F.; Werkhoven, J. P. Spatial Characteristics of Vibrotactile Perception on the Torso. *TNO Report TM-99-B007*, TNO Human Factors: Soesterberg, Netherlands, 1999.
- Zetts, G. Personal communication. Engineering Accoustics, Inc.: Winter Park, FL, May 2006.

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Appendix A. IMT Course Layout



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Appendix B. Demographics

DEMOGRAPHICS SAMPLE SIZE = 31

<u>SEX</u>	<u>MOS</u>	<u>RANK</u>	<u>AGE</u>
Male – 24 Female – 7	9S – 12 91D – 1 11B – 5 91K – 1 25Q – 1 91W – 1 31B – 2 91X – 1 420A – 1 97B – 1 74D – 1 98G – 1 88M – 1 Signal – 1 88Z – 1	E5 – 20 E6 – 9 E7 – 1 Other – 1	28 years (mean)
TIME IN SERVICE: 8 years; 6 months (mean)			
TIME IN CURRENT DUTY POSITION: 3 years; 3 months (mean)			
LATEST APFT SCORE: 293 (out of 300)			
GT SCORE: 121 (mean)			

1. What is your height? 70 inches (62-73 range)
2. What is your weight? 170 pounds (118-250 range)
3. With which hand do you most often write? 1 Left 30 Right
4. With which hand to you most often fire a weapon? 3 Left 28 Right
5. Have you ever served in a combat or hostile fire zone? If yes, where?
10 Yes 21 No

6. Using the following scale, rate your own knowledge, skills, and abilities (KSA) in each of the areas indicated:

Poor	<-----		Average	----->		Excellent
1	2	3	4	5	6	7

	Mean Response
Infantry tactics, techniques, & procedures (TTPs)	4.23
Small unit tactics	4.10
Communication equipment and procedures	3.94
MOUT operations	3.90
Land navigation	5.16
Map reading	5.39
Map orientation in field setting	5.17
Clock method of identifying locations, e.g., “target at 3 o’clock”	5.45
Leadership skills	5.68

7. Which of the following military training have you received?

	Number of Responses
Basic training	30
PLDC	17
ANCOC	1
BNCOC	10
Ranger	1
Sniper	1
Combat Life Saver	7
Advanced Infantry Training	3
Airborne	4
Bradley Leaders Course	0
ICC	0
Master Gunner	0
Other	See below

Air assault
 Air Mobility Operations
 OCS (4)
 Aviation Life Support School
 Aviation Safety School
 Basic Language Courses in Spanish and Mandarin Chinese
 Drug and Alcohol Counselor
 EMT-B, TOW Missile Gunnery
 Field Identification of Biological Weapons Course (FIBWA)
 Field Sanitation, NBC Defense, SATS Training, Unit Armors Course, UPL
 Navy Leadership PO course
 NBC room ops, radiation NCO
 SERE, JUMPMaster, SOT
 Switching Communications, Radio & Satellite Transmissions
 US Navy Law Enforcement
 WOCS, WOBC

Appendix C. Training

System	Description
A	Tactile Communication System (TACTICS) A
B	Tactile Communication System (TACTICS) B
C	Wireless Tactile Control Unit (WTCU)

TRAINING SAMPLE SIZE = 25

1. Using the scale below, please answer the following questions based on the training you received.

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

	Mean Response	
	A & B	C
Length of training	5.78	5.71
Explanation of concepts	5.78	5.59
Adequacy of training aids	5.95	5.70
Mix of lecture to hands-on exercise	5.67	5.94
Training facilities	5.83	6.05
Overall quality of training	5.91	5.95

Comments

No. of Responses

<u>A & B</u>	
Didn't notice significant difference between system A and B.	1
System A worked great.	1
I like the signals given with the A and B belt systems.	1
The signal on these two systems was much more efficient and easy to read than C.	1
Easy to identify buzzers, and did not feel safety risks.	1
Good brief on what it was going to happen over the 2 iterations.	1
I am not sure what to say about this portion of the overall data entry. Simply because the systems seem very simple to understand and use. Not too much training is required.	1
Easier to feel than system C.	2
I liked the fact the pack for the system was smaller and less bulky than System C.	1
Alpha system seemed to have a stronger signal, but I do not think it helped me with the overall detection of that signal during movement.	1
Belt may have slipped a little doing movement techniques. I noticed the 12 o'clock may have slipped into the 11 o'clock position.	1
A and B belts have difficulties issuing signals at 5:00, 6:00, and 7:00. They are easy to detect, however. If the buzz were stronger, it would be better.	1

Comments**No. of Responses**

It appears that the A and B belts had some difficulty.	1
Probably would benefit to add a trench with some water.	1
Rear sensors not as easily detected.	1
System B was a bit harder to recognize at the 2,5,7,and 11 o'clock positions.	1
I did not use system B.	1
<u>C</u>	
Signal strength for belt C was good, and 12 o'clock through 12 o'clock could be easily detected.	1
System C had a good overall weight performance by comparison of A & B.	1
Hard to feel vibrations.	1
I didn't care for the lower frequency of the vibrators on system C. They seemed slow, which caused a very lackadaisical response from me.	1
I had less buzzers on this one than I did in the others.	1
The tactors were difficult to detect.	1
This system had the weakest signal of the three. It was difficult to determine the direction and location of the signal.	2
The strength of the buzz was weak and I found myself concentrating so I wouldn't miss a signal and not thinking about the obstacle course.	1

2. Did you notice anything about the systems that would make them unsafe to use?

	A & B	C
Yes	1	1
No	24	23
NR	0	1

<u>A & B</u>	
As I've said it before, the wire harness between the box and the pocket is a snag hazard.	1
Yes, the weight and the thick cable that runs down your leg. Although I am sure that these issues will be fixed in the final stages as this is only the test phase of this equipment.	1
<u>C</u>	
No comments.	

3. Using the scale below, evaluate how easy or hard it was to learn to perform each of the following tasks.

1	2	3	4	5	6	7
Extremely hard	Very hard	Hard	Neutral	Easy	Very easy	Extremely easy

	Mean Response	
	A & B	C
Detecting which tactor is activated,	5.67	3.83
Reporting (12:00, 3:00, etc.) which tactor is activated	5.46	3.70

Comments

No. of Responses

<u>A & B</u>	
Too easy!	1
Easy to feel the vibrations.	2
I liked the vibrating frequency of both system A and B. It was faster which initiated a faster response.	1
I think that the tactors on A were good.	1
Signal strength for 5, 6, and 7 o'clock was weak. 3, 9, and 12 o'clock were strong.	1
This system was good for alerting the wearer to the direction of the signal. Overall strength was adequate to the environment.	1
Had to stop and think about which tactor was activated due to tactors being close together on the body.	1
I did not use system A.	1
Usually no problems with detecting any of the sensors only the 7 and 9 were a little confusing on which one was going off at times	
<u>C</u>	
The signals themselves were good.	1
Difficult to detect.	3
System C was a lot harder to feel the sensor activation than the System B.	1
I felt the body armor vibrating once when I should have felt the vibration on the body.	1
Hard to feel while going through course.	1
I'd like to see this product with only 4 tactors. For a direction between 3, 6, 9, and 12, activate two tactors to indicate that quadrant.	1
I did not like the tactors on System C.	1
Make the buzz stronger and more noticeable.	2
Only sensor I felt was the 12 sometimes; some of the others were felt but very hard to notice.	1

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Appendix D. Questionnaire Results

Section D-1	PSYCHOPHYSICS PILOT TEST
Section D-2	POST-TRIAL
Section D-3	END OF EXPERIMENT

System	Description
A	Tactile Communication System (TACTICS) A
B	Tactile Communication System (TACTICS) B
C	Wireless Tactile Control Unit (WTCU)

SECTION D-1
PSYCHOPHYSICS PILOT TEST
SAMPLE SIZE = 4

1. Which of the following statements best describes how easy it was to feel the signals from the A and B systems?

A and B:	Frequency
System A was much easier to feel than System B	1
System A was a little easier to feel than System B	1
There was no difference in how easy it was to feel the signals with Systems A and B	1
System A was a little more difficult to feel than System B	0
System A was much more difficult to feel than System B	1

2. Which of the following statements best describes how easy it was to feel the signals from the A and C systems?

A and C:	Frequency
System A was much easier to feel than System C	2
System A was a little easier to feel than System C	2
There was no difference in how easy it was to feel the signals with Systems A and C	0
System A was a little more difficult to feel than System C	0
System A was much more difficult to feel than System C	0

3. Which of the following statements best describes how easy it was to feel the signals from the B and C systems?

B and C:	Frequency
System B was much easier to feel than System C	1
System B was a little easier to feel than System C	0
There was no difference in how easy it was to feel the signals with Systems B and C	1
System B was a little more difficult to feel than System C	2
System B was much more difficult to feel than System C	0

4. Using the scale below, rate how weak or strong the signals felt with each system.

1	2	3	4	5	6	7
Extremely weak	Very weak	Weak	Neutral	Strong	Very strong	Extremely strong

Mean Response		
A	B	C
3.50	3.25	2.75

Comments

No. of Responses

Signal needs to be much stronger.	1
System three (Charlie) seemed like the signal was much stronger.	1
Should be a little stronger if going to be used while in full battle rattle and running.	1

SECTION D-2
POST-TRIAL
SAMPLE SIZE = A/B – 28
C - 30

1. Using the scale below, rate how difficult or easy it was to detect and localize the tactile signals during the STANDING (STATIC) trial.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

Signal Location	Mean Response		
	A	B	C
12:00	6.81	6.58	5.63
1:00	6.04	5.68	4.83
3:00	6.56	6.14	5.13
5:00	6.07	5.17	4.77
6:00	6.33	6.00	5.27
7:00	5.85	5.27	4.77
9:00	6.41	5.91	5.33
11:00	6.15	5.55	4.70
Mean	6.28	5.79	5.05

Comments

No. of Responses

<u>A</u>	
Strongest, easiest vibration of three systems used.	1
Easier to detect all locations.	3
Good signals; came thru clear.	5
Stronger signal than Bravo system.	1
3, 6, 9, & 12 are easier to remember; I felt delayed responding to the 5 & 7 because I was trying to remember the # (5&7 are used less often when telling someone where to go or look); just not used to it.	1
Detection was just fine; however, I really had to think about which direction when it buzzed on the 7, 11, 1, and 5 o'clock positions.	1
Get rid of those buzzers, and then actuate buzzers on both sides of those positions.	1
I like a belt most though signals clockwise from 3 o'clock and counterclockwise from 9 o'clock were more difficult to detect.	1
Pretty good to feel; the 7 and 9 were hard to tell apart.	1
When low crawling and high crawling, the vibrations were difficult to distinguish.	2
I was concentrating more to feel the buzzer after the first iteration. I focused less on the obstacle or firing position. Recommend doing the course without being tested in order to get familiar with the system and know how the vibration will feel.	1

The hardest part is thinking about which call to give the data collection team. Although I knew where the signal came from, it took a moment to vocalize my response with the correct location for 5, 7, 2, & 11.	1
Only error might be in my ability to quickly choose between 5, 6, and 7 o'clock.	1
<u>B</u>	
All signals were very easy to discern.	3
The Bravo system did very well with indication, it was clear and well defined.	1
More aggressive vibration on Bravo, easier to feel.	1
I like the B belt better then the C belt. Though it was tighter (which I did not like), the vibrators seemed to be more effective. Higher frequency.	1
The 3, 6, 9, & 12 were easily identifiable. The 1, 5, 7, & 11 were identifiable, but a little harder to detect.	1
Determined the 12 o'clock and the 6 o'clock extremely well, but the rest were not as strong as the others.	1
It was quite easy to detect the 12, 3, 6, 9 o'clock positions but the other positions were a bit harder. The pulsing was much more faint when I felt them; if I felt them at all. There did seem to be a few that did not read.	1
The 5 o'clock and 7 o'clock were not as easily detected.	1
It was mostly easy to localize besides the 6 position.	1
Hard to feel 7 o'clock.	1
I could not feel signals at 5, 6, 7 o'clock at all. Signals 3 o'clock and 9 o'clock were very weak. Signal 12 was very strong, signals 11 o'clock and 1 o'clock were moderate.	1
The 6 o'clock and the 5 o'clock felt faint the last time I noticed them. I believe they lost good contact with my body.	1
System malfunction.	1

<u>C</u>	
During the static test, it was extremely easy to recognize the direction the signal came from.	1
It was easy to detect.	2
Easy to detect when standing still.	1
Even when static, it took one vibration to understand what I should be "feeling" for. (That is to say, it was so subtle that on the first signal sent, I hadn't realized the belt was vibrating.) From that point on, it was relatively straight forward.	1
Initial test I could feel all the vibrations in their respective positions.	1
Faint signal on all locations.	1
Not sure if there were a lot of signals but, the ones I received were strong except my last 6 o'clock signal. I think it was not in good contact with my body.	1
I found the Charlie System to have a less intense signal indication than the Alpha System. It was hard to detect unless it was directly off of the 3, 9, 12 & 6. I am not sure if the complete set of signals was sent for the 1, 11, 7 & 5.	1
It was harder on this system than it was on the others.	1
Signal was not as strong as the other belts.	2
These signals were a lot weaker than my first iteration.	1

2. Using the scale below, rate how difficult or easy it was to detect and localize the tactile signals while you were on the IMT course.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy
Location & Signal:				Mean Response		
				A	B	C
				n=10	n=7	n=10
First Iteration						
Start run: 11:00				6.00	6.33	4.20
2-ft wall kneel fire: 6:00				5.60	5.50	4.20
Low crawl: 3:00				4.20	3.33	3.00
Second bend: 12:00				5.70	4.83	5.00
Combat roll: 9:00				3.80	2.17	3.00
High wall: 5:00				5.30	2.67	3.13
Prone fire: 1:00				4.60	4.17	3.00
Stairs: 7:00				5.89	2.83	4.56
Mean				5.14	3.98	3.76

Second Iteration				A	B	C
Pipe crawl: 5:00				6.00	5.13	3.22
Zigzag: 7:00				5.25	4.33	3.11
First bend: 3:00				5.63	6.00	4.00
Low crawl: 1:00				5.50	5.00	2.33
Kneeling fire: 12:00				6.63	5.33	5.00
Window: 11:00				4.88	5.22	4.60
Ladder: 9:00				5.50	4.78	3.40
Stairs: 6:00				6.38	5.00	4.10
Mean				5.72	5.10	3.72

Third Iteration	A	B	C
Pipe crawl: 12:00	6.67	5.71	3.30
First bend: 1:00	5.78	5.57	3.50
High crawl: 7:00	5.00	3.67	2.50
Kneeling fire: 9:00	6.00	4.86	3.40
High wall: 3:00	6.44	4.71	2.90
Window: 11:00	6.11	5.43	4.20
Stairs: 6:00	6.33	4.86	2.90
End run: 5:00	6.22	4.86	4.00
Mean	6.07	4.96	3.34

Comments

No. of Responses

<u>A</u>	
Able to detect the signal much better than the others.	1
Signal was easy to detect and determine direction.	1
Alpha system was much better then Bravo. I felt that the signals came much stronger than before.	1
Buzzer can be heard.	1
Had success on this system and could feel the buzzer.	1
The vibrations are strong enough to be felt when low crawling. Even at the end of the course when you're tired and less focused on the beeps, the beeps are still very distinct.	1
Focusing on expecting the vibration rather than completing the course.	1
When you are in the process of completing an obstacle that requires a bit more physical effort you are more focused on the obstacle than trying to detect a signal.	1
Just fine. Signal strength was adequate, however I think with a heavy ruck being very active, I think the tactors on ALL systems were a bit weak.	1
Just too much moving around to feel the signals on high crawl. Otherwise, as expected from static test, easiest belt to feel.	1
I did not feel any signals on the low crawl.	1

Comments**No. of Responses**

I did not feel the signal in the directions stated above at the specific locations.	1
Hard to tell apart the 7 and 9 sensors.	1
System did not function properly.	1
The window signal felt closer to 11 o'clock.	1
B	
The system was good and easy to determine where the signal was coming from.	
Very easy to detect signals while on the move.	1
It was pretty easy to localize the location on the IMT.	1
The strength of the signal was much stronger, even during movement and periods with increased respirations the vibrations were considerably easier to detect.	1
Either did not feel the difficult vibrations or the belt was not signaled to vibrate.	1
Fair enough signal through the course, as far as I could tell. There were a couple places I expected to receive a buzz, but did not.	1
I didn't feel most of the signals.	2
I still think the "A" had the best vibrations and I didn't have problems with the belt slipping.	1
System failed and had to stop test.	1
System malfunction.	2
The only downside was that the system was not functional the entire time.	1
If you could lighten the weight a bit and make the system more reliable than it would be my choice.	1
This iteration was very hard to distinguish, especially when moving.	1
While doing combat tactics it was difficult to detect the signals.	1
While the Bravo system is easier to feel than Charlie, vibration of movement/gear/heavy breathing makes it difficult at times to feel the signal.	1
C	
The overall system was lighter.	1
No problem with detection.	1

Comments**No. of Responses**

When the soldier is standing still, the system is easy to read and determining the location of the signal is simple. As soon as there is even a minimal amount of exertion determining where the signal came from is difficult and forces the soldier to concentrate more.	1
It felt like the belt was shifting. I didn't feel most of the vibrations. Not sure if it was me or a technical problem.	1
I only felt two signals during the entire course. This may be because only two signals were issued. If other signals were issued, they were not felt.	1
Very difficult to feel while moving.	1
With the vibration of movement, I couldn't feel anything at all. Belt signals were far too subtle to distinguish from my gear bouncing and my body movement.	1
Most difficult to detect when rolling.	1
It was hard to feel the signals during the high and low crawls.	1
When doing certain IMT it was very difficult to determine where the signal was coming from if I felt it at all.	1
Did not feel any of the signals when actively engaged in a physically demanding IMT.	4
Difficult to feel.	1
Hardly felt anything. Difficult to discern specific location when I did feel a buzzer.	1
Signal not strong.	2

3. Did you notice any potential safety problems with the tactile system you used for each iteration?

	A	B	C
Yes	1	1	0
No	26	23	30
NR	1	4	0

<u>A</u>	
Electrical tether is a snag hazard.	1
<u>B</u>	
Excess tether into the pocket causes a snag hazard. Also the box in my pocket was uncomfortable during the combat rolls.	1
It's water proof right?	1
<u>C</u>	
None.	

4. Did the tactile system you used malfunction during the Standing (Static) trial or while you were on the IMT course?

	A	B	C
Yes	3	8	4
No	24	16	26
NR	1	4	0

Comments

No. of Responses

<u>A</u>	
I had to stop after the low crawl because of a problem with the system.	1
Malfunction (some sort of connection lost with computer) just after second high-crawl station. The individual on the hill fixed the issue on his end.	1
Only felt a couple of "buzzes" on the IMT course.	1
<u>B</u>	
Not that I know of. Seemed to work alright.	1
Would not alarm when on course but tested fine elsewhere.	1
I couldn't feel any signal but 12 o'clock during the course.	1
I think that some of the signals were not going through. Adjustments were made.	1
While on the IMT course, only had three signals before I had to stop due to system malfunction.	1
Signal was not reaching the belt-had to restart the walk before continuing on to the second kneeling position.	1
I think two of the vibrations did not transmit.	1
It didn't go off at several of the points.	1
There seemed to be an issue with signal received from the transmission site. It was solved by my coming into the open and the engineer sending a new one and continuing forward.	1
<u>C</u>	
No problem with signal detection.	1
I felt the initial vibration. I didn't feel another vibration until a few obstacles later. When I arrived at the kneeling fire before the wall climb, they adjusted the equipment in my cargo pocket. From then on, I could feel the vibrations.	1
Bad battery connection.	1
Immediately there was a problem with a reliable power source. Once I got on the course the plugs almost immediately came detached from the system and it failed.	1
It quit buzzing.	1

5. Using the scale below, what is your overall evaluation of the tactile system you used for each iteration?

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

MEAN RESPONSE		
A	B	C
5.67	4.95	3.77

Comments

No. of Responses

<u>A</u>	
The system performed extremely well. The vibrations are distinct; even while walking, standing still, crawling, and kneeling.	2
This system was easy to detect and monitor the direction it was giving.	1
Although the signal felt stronger than the Bravo system, I felt that the sense of detection was the same.	1
It was easy to tell which sensors were going off most of the time.	1
System A and B were so similar in performance it is hard to articulate one being better than the other; however, I would default to system A if I had to choose.	1
It was good, but I would not feel comfortable relying on it.	1
Feeling the vibration was easy; however, it has too many locations on the body it will be coming from. For example, it is hard to distinguish the seven o'clock from the nine o'clock while actively engaged. When I felt the vibration I was distracted.	1
Could use some improvement with the low crawl.	1
Even having the strongest signal of the three systems, I think it would be better if it was more highly adjustable. If I could get it tighter around the waist (and keep the sensors in their respective clock positions), it would probably work fine.	1
<u>B</u>	
Easiest to feel so far.	1
Besides the 6 position which was a little hard to feel, it was a good system.	1
It is easier to detect signals in contrast to the first iteration.	1
The increased strength of the system meant that the soldier could continue to concentrate on his operating environment. While detecting communication through the system.	1

Comments**No. of Responses**

The signal itself was very clear when it worked. Much better than belt C. The only problem is, belt B's signals didn't work consistently.	1
Just make it a bit lighter and more reliable and it would be the system that I would choose.	1
Could not evaluate due to system malfunction.	1
Needs to be a stronger signal in order to get my attention.	1
Not the best of the three, I would rank them a, b, & c.	1
Once again, why so much low crawling? My elbows and knees hurt. Secondly, the higher frequency vibrators were more stimulating which motivated me to call out my o'clock position faster.	1
The reception is neither consistent enough nor strong enough to be useful when going all out either in training or real life. Its the kind of sensation that you could possibly ignore.	1
<u>C</u>	
Stronger signal.	1
I could feel the vibrations better and had no malfunctions during the first iteration with "A". During this iteration, I felt like it was more comfortable of a belt (smaller vibrators).	1
The 12, 3, 6 and 9 o'clock positions were the easiest to detect in either static or moving positions.	1
Worked the way it was intended to work.	1
Signal wasn't intense enough to indicate response. However, the overall system was lighter.	1
I thought the system worked well, but hard to detect if its the equipment (scraping across the dirt) or the sensor when high crawling.	1
Difficult to detect.	1
I did not feel the signal was strong enough to catch my attention while on the obstacles.	1
I was so busy concentrating on whether there would be a signal issued that I lost focus on the obstacle course.	1
It was harder than the other systems. I did not have as many signals.	1
Simply couldn't feel anything during movement.	1
Very poor. Hard to feel vibrations while moving.	1
When doing my movement drills it was extremely difficult to feel the vibration if I felt them at all when doing the certain movements.	1

APPENDIX D-3
END OF EXPERIMENT
SAMPLE SIZE = 30

1. Using the scale below, rate the three systems in terms of how easy or difficult it was to feel the tactile signals during the Standing (Static) trials.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE		
	A	B	C
Signal intensity - Static	6.44	5.52	4.13

2. Using the scale below, rate the three systems in terms of how easy or difficult it was to know which particular factor was buzzing during the Standing (Static) trials.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE		
	A	B	C
Signal localization - Static	6.41	5.70	4.37

3. What are your comments on signal intensity and localization – static trials?

Comments

No. of Responses

A was the best to work with.	1
Belt A was the best. If you could mix the buzz strength of belt A with the signal strength of belt C it would be a perfect belt.	1
System A created a broad, distinct easily detected vibration.	1
System A had the best signal detection of the three.	1
A and B provided the best signal detection of the systems.	1
A and B were a lot easier.	1
Buzzers on system A and B were of a higher frequency. I liked that. It was stimulating as apposed to just being there. I'd also like to see the product with only the 3,6,9, and 12 o'clock tactors.	1

Comments**No. of Responses**

8

System B created a sharp, easily localized sensation.	1
C just simply did not have a strong enough signal.	1
Belt C had less intense vibrations.	1
Only Charlie system was difficult to tell which sensor was going off.	1
System C created a broad, dull vibration which was hard to localize and feel.	1
In the static position, both systems were easy to recognize the location and the signal.	1
The ease of detection was not necessarily due to the equipment. I felt it had more to do with the familiarity of the equipment to the user.	1

4. Using the scale below, rate the three systems in terms of how easy or difficult it was to feel the tactile signals during the IMT course trials.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE		
	A	B	C
Signal intensity - Static	6.00	4.96	3.10

5. Using the scale below, rate the three systems in terms of how easy or difficult it was to know which particular factor was buzzing during the IMT course trials.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN RESPONSE		
	A	B	C
Signal localization - Static	5.81	5.04	3.33

6. What are your comments on signal intensity and localization – IMT trials?

Belt A was easier to feel than belt C.	1
During IMT A and B were detectable. Direction was a bit hard to determine accurately but you could at least feel the signal.	1

Comments**No. of Responses**

It was almost impossible to detect which sensor was going off with the Charlie system during this test.	1
I could easily identify which direction the signal was from when I could feel the signal. I had trouble feeling the signals though.	1
Once again, get rid of the 1,5, 7, and 11 o'clock positions. They are too close to the cardinal directions and harder to differentiate.	1
The signal strength at 6 o'clock on all belts was weaker than 12:00. If all the signals were as strong as 12 o'clock, the belt would be easier to use, and I would feel confident using it.	1

7. Which system is the BEST overall?

No. of Responses			
A	B	C	NR
20	5	1	4

System A was easier to identify. Buzzers were stronger.	3
The signal in system A was by far the strongest and easiest to localize, especially when movement and heavy breathing began to interfere with my ability to notice the signal.	2
A was easy to tell when it was buzzing, the belt did not seem to move at all when going over or through obstacles.	1
A's strength of signal and ease of detection.	1
With A I could feel the system signals the strongest and got the most signals.	1
System A signals were stronger and easier to identify than system B and C. In addition, there was a clearer signal that I felt even during the low-crawl station; the other systems I did not felt in that station.	1
You could feel the signal of A better when going through the obstacles.	1
Vibrations were more intense on belt A.	2
System A was the best overall due to the ease of detecting the 6 o'clock position's vibration.	1
Both systems felt about the same as far as the signals go. I chose System A because the pack that went into the pocket was smaller.	1
Even though I had a hard time telling apart the 7 and 9 sensors, A was easier than B system.	1
A and B were so very closely rated, I can't explain my selection for A. However, that is what it is.	1

Comments**No. of Responses**

I liked the buzz on belt A. It was a pinpoint sensation and most points gave a strong buzz.	1
System A's belt stayed put and the intensity of the vibrations were felt better than the other two.	1
I did not use System A.	1
I found Bravo system to be the best because of the level of signal intensity. Although I could feel the signals from the Alpha system better, I believe it was a little distracting and did not help with the overall detection of the signals during movement.	1
I liked the clarity signal indication for Systems A & B. B however, was a technical pain and failed here and there. But I still liked B the most.	1
B had the best signals both tactical and while walking.	1
System C had a good weight but a poor tactile indication.	1

8. Which system is the WORST overall?

No. of Responses			
A	B	C	NR
1	5	20	4

With A, the signals were weak.	1
I did not use system A.	1
B had system malfunctions, weak or no signal.	3
B kept malfunctioning, and I could not feel from 5 to 7 o'clock at all.	1
C	
Process of elimination. I only tested two and A was better than C.	1
I was only able to test belt A and C. Belt C was very hard to feel the vibrations.	1
Indication for System C was weak in intensity.	1
Some of System C's signals were not very strong. One of the signal I felt was so weak that I could not properly identify the clock direction.	1
System C was the worst overall due to the dull, broad vibrations which were more difficult to localize and seemed weaker.	1
Couldn't feel anything.	1
Difficult to feel if felt at all. Once I felt the vibration on the equipment rather than on me.	1

Comments**No. of Responses**

Exact opposite to system A. The signal was so light it was difficult to feel even when standing perfectly still in the static trial. I had to FOCUS on the belt in order to notice the signal, and during the IMT course I was more focused on not falling.	1
I believe it had malfunctions.	1
I could not even feel the sensors that were going off when I was doing the IMT.	1
I could not feel some of the buzzers.	1
I rarely felt the vibrations after the initial trial prior to the IMT.	1
I would say it was the worst only because the buzzer was so faint, so while I was going through an obstacle it was hard to tell if the buzzer was going off or not.	1
Next to no signal.	1
Only able to detect two signals during the course.	1
Signal not intense enough and too low of a frequency to be able to discern a signal from the rubbing of the equipment I was wearing.	1
Slow frequency and soft vibrators.	1
The signal was hard to detect because of how light it was during the course. When low crawling or moving it was hard to detect the signal.	1
Weakest pulse vibration.	1

9. What improvements, if any, would you like to see in a tactile belt communication system?

All sensors should be tested ahead of time to ensure that the soldier is confident in buzzer locations.	1
As a suggestion, I feel that vibration signals are best felt in a pulse type fashion. As an analogy, when my cell phone is on vibrate and someone calls me, I usually do not feel the phone ringing until it stops vibrating and then starts again.	1
Better security of the belt to the wearer.	1
I think that a more detectable signal needs to be used.	1
I would love to see improvement in signal strength and signal traveling distance. If better distance and strength is achieved, there is great tactical potential and will improve the element of surprise for missions where it is essential.	1
Increase the intensity of the vibrations.	2
Increasing the power of the signal would allow the wearer to maintain awareness of his operating environment.	1

Comments**No. of Responses**

Instead of pulsing in a point area, it should be a pulse over a larger area. The point pulse causes the wearer to jump at times and that could have potential problems later on.	1
Make the buzz stronger from 5 - 7 o'clock, and 1 and 11 o'clock.	1
Obviously software issues need to be improved (can't worry about loss of blue tooth connectivity when in combat scenario), but that's not my lane. For the purposes of the wearer, it needs to be more highly adjustable in order to allow a more customized fit.	1
Place sensors on body parts, i.e., right arm for 3, left arm for 9.	1
Smaller belts.	1
Smaller power pack, shorter or no electrical tether, and only put 4 tactors on the belt. I'd like to have the belt a bit lower on my abdomen or even on an upper thigh.	1
Some kind of way to make stronger signals for the low and high crawl. Overall It seemed that the signals were undetected while doing combat tactics.	1
Stronger buzzer on the Charlie belt and maybe a way to make the belt not shift as much so that the individual does not get confused on the direction he or she is suppose to be heading.	1
Wear the belt higher. Probably easier to detect the signals at the sternum.	2

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