The Evaluation of a Tactile Display for Dismounted Soldiers in a Virtusphere Environment

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Here we describe the evaluation of the THATO (TeleHaptic Assistance for Tactical Operations) mobile tactile messaging system in a "virtusphere" environment. THATO was developed to aid dismounted soldier-to-soldier communications, situation awareness, and navigation during tactical operations. The THATO Android application stores tactile message designs that are instantiated with context specifics and played through its interface to Tactile Control Units (TCUs) when a command is received from another soldier, the soldier's location relative to a planned route or landmark/entity of interest triggers a message, or the soldier requests information (e.g. through voice recognition). Two previous evaluations of THATO and its evolving language produced promising results, but only six participants were involved in each and the fidelity was limited with participants simply standing and verbalizing their interpretations of messages played in a random order. Here the results of a lab experiment are presented where twenty participants were involved and fidelity was improved by having participants also respond to messages with appropriate physical behaviors within a 10 foot hollow sphere capable of rotating upon wheels placed beneath it. Overall, participants received twelve types of message, each with between one and four pieces of information, and recognized all parts of a message 95.9% of the time.

INTRODUCTION

Wireless communication technologies connecting soldiers who each have a mobile computing device and sensors (e.g. GPS, electronic compass, and health monitoring), have the potential to support the distribution of critical information when squads are engaged in tactical operations. However, there is also a need to enhance the communication modality options for receiving that information because tactical operations can impose significant demands on Soldier senses, limiting their ability to perceive and communicate through normal auditory and visual pathways (Hancock & Szalma, 2008). Noisy, murky, or bright conditions can hinder the ability to hear and see critical data directly or through communications technologies. Additionally, each time a soldier is using voice communications, or looks at a paper or electronic map, the ability to maintain awareness of what surrounds the soldier is potentially compromised.

The use of tactile displays to present directives and information about the surrounding area offers several benefits: 1) Tactile displays can enable their users to receive and interpret valuable information without compromising the simultaneous utilization of other modalities (Merlo, Stafford, Gilson, & Hancock, 2006), 2) Certain types of information can be more efficiently processed in a tactile form (Elliot, van Erp, Redden, & Duistermaat, 2010), 3) Tactile displays can be an effective way to cue users to process information using the visual and/or auditory modality (Ferris & Sarter, 2008), and 4) Tactile displays are non-illuminating and can potentially be made to be acoustically covert.

Collaborative Work Systems (CWS) Inc. has sought to identify high value tactical operations supporting information that can be communicated via a tactile display, what particular tactile form that information should take to be usable, and how it can be integrated in a practical mobile messaging system. Here the results of a controlled experiment are presented where the objective was to determine if a particular set of tactile messages could be taught efficiently and recognized accurately. The experiment was held at the United States Military Academy (USMA) where the participants were cadets and the Engineering Psychology program's "virtusphere" (http://www.virtusphere.com) environment was used to enable cadets to move in any direction when responding to tactile messages.

The Message Set

From soldier interviews and a review of field and training manuals (e.g. Department of the Army, 1987, 2001, 2004) three basic types of message that can support tactical operations were identified: (1) navigation for guidance along a route and to describe certain boundaries, (2) commands of the type currently communicated by arm and hand signals, and (3) entity descriptions of units, equipment, and certain "control measures" such as a minefield or observation post (Chapman et al., 2012). These messages involve relatively static information (such as a preplanned patrol route, Rally Point, or mission Phase Line) or dynamic information (such as the locations of mobile friendly or enemy units and equipment). In a networked mobile system such messages can be: (1) automatically triggered by programming logic (e.g. navigation guidance while proceeding along a route), (2) triggered when another soldier sends a command (e.g. by interaction with a touch screen or voice recognition system), or (3) triggered by a soldier "pulling" information from the technology such as the location of, or directions to, another soldier or other entity. However, for this experiment the focus was on evaluating tactile message learnability and recognition accuracy, rather than the user interface for sending messages or requesting guidance.

Particular messages were selected that were considered to be high value and/or could be frequently used in real-world operations. One constraint was participants' availability and the need to be able to obtain each participant's informed consent, collect demographic information, teach the language, test message recognition, and obtain survey data within an hour. This meant only approximately 20 minutes was available for actual training. Table 1 shows the set of messages that were used in the experiment.

Table 1 Summary of Messages Taught and Tested

Base	Additional Information
Move Out	Direction + Pace + Distance
Halt	
Rally	Direction + Pace + Distance
Take Cover	
Injured Soldier	Direction + Pace + Distance
Eyes On Me	Direction
Arrived at Waypoint	Direction + Pace + Distance
Arrived at Checkpoint	
Crossing Phase Line	
Inside Named Area of Interest	
Threat	Sub Category + Direction + Distance
Friendly	Sub Category + Direction + Distance

Eight directions, relative to the participant, were used in the language when it made sense to do so for a message. They were in-front, behind, left, right, and four directions in-between. These were referred to as the participant's north, south, west, east, north-west, north-east, south-east, and south-west. The pace the participant was to move at was described as "normal" or "quickly". The distance to go or of an entity (threat or friendly) was either "near" or "far. Three sub-categories for a threat were included - a unit, an observation post, and a minefield. Two sub-categories for a friendly entity were included - a unit and an observation post.

METHOD

Experimental Design

The primary goal of this experiment was to determine if participants could recognize the messages shown in Table 1 when they were played on a particular tactile display, after being trained on that language for approximately 20 minutes. Additionally, there was a goal to use a virtusphere to provide some fidelity in terms of physical behavior associated with each message even though the experiment was being conducted indoors and the intended context of use is outdoors. In two previous experiments (Chapman et al., 2012) each involving six participants and a similar set of messages, participants recognized the entire message played 86% of the time in one and 83% of the time in the other. However, better performance was predicted in this experiment because the previous experiments involved just 8 tactors and 24 tactors around the waist, whereas this one involved 40 tactors around the waist thus providing more options when designing the tactile messages. Additionally, the training planned was considered to have evolved with, for instance, images for metaphors being taught and a video of each tactile pattern shown to the participant before it was felt.

Hardware Configuration

The tactors used were Mide Corporation piezo tactors (shown in Figure 1). These tactors are relatively small, thin (<3mm including packaging) and light (5g), making it practical to create a high "resolution" of tactors in the tactor display.

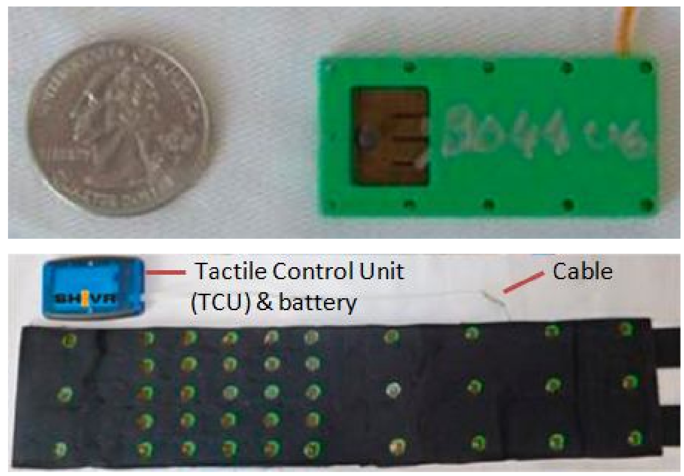

Figure 1 A single Mide piezo tactor (top) and forty tactors sown into a belt worn around the waist (bottom)

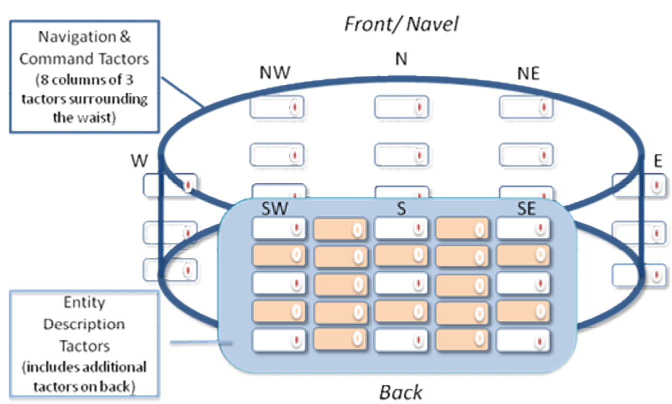

Figure 2 The 40 tactor arrangement used

CWS requested a particular number and arrangements of tactors (shown in Figure 2) for the tactor belt to support dismounted soldier messaging. This configuration facilitated receiving directional information in a natural way. For instance, eight columns of three tactors enabled messages to be designed that pointed the wearer in any of those respective directions and the take cover command was represented by playing the top layer of 8 tactors, then the middle layer, and finally the bottom layer to describe movement towards the ground. Metaphors were frequently used in the design of the messages or message elements. For instance, participants were told crossing a phase line was analogous to running through the tape at the end of a race, and that they would feel a sensation like that when that message was played. The grid of tactors on the back was used specifically for describing threat and friendly entities to further simplify message interpretation.

Two Mide constructed belts were used that held the tactors in place. One contained tactors with the 8 directional columns approximately 10cms apart and the other 10.5cms apart. The material used allowed some stretching, but it was known going into the experiment that the belt itself was a prototype and it would be difficult to align all eight columns correctly for all participants, and particularly those with a waist size greater than 32 inches. Thus, accuracy on the directional part of the messages was expected to be less than other parts. The messages were transmitted from the THATO software over a Bluetooth connection to a Mide Tactor Control Unit (TCU) clipped to the participant's belt or back pocket.

A Virtusphere to Enable Realistic Physical Responses

In order to support participants responding to directive messages, by actively moving in a particular direction at a certain pace, or by stopping their movement, a virtusphere was used (see Figure 3). This hollow ball is large enough for a human to stand in and can rotate in any direction, due to the fact it sits on multiple wheels.

Figure 3 The "virtusphere" used in the experiment

Participants

20 West Point cadets participated in the experiment in December 2012. Participant age ranged from 18 to 23, averaging 20 years old. The sample involved 18 males and 2 females. Participant self-reported waste size ranged from 26" to 40", with an average waste size of 32". There were no specified inclusion/exclusion criteria. Cadets received course credit for participation.

Post Testing Survey

A post experimental questionnaire was developed to assess: intuitiveness, ease of learning, comfort, and perceptions of utility in field operations.

Dependent Measures

Tactile message recognition was scored in two ways: first, the accuracy of message interpretation as a whole (base plus all qualifiers), and second, each individual message. In this way the accuracy of simple versus complex messages could be examined along with the effectiveness of the specific representation for each piece of information.

Procedures

The general procedures were consistent across participants. Upon arrival participants were presented with a consent form, asked to read the form, and sign if they wanted to participate in the experiment. Upon completion of the consent form a demographic questionnaire was administered.

Display familiarization then began. The set of messages were presented by category to describe what was in the language and the vocabulary of the language relative to tactical operations. This was followed by how each message is represented including a pictorial representations of any metaphor used, a video representation of each message played on the belt with change in color corresponding to tactor activation, followed by the participants actually feeling the message. Participants were then given a list of messages in the language and asked to describe the implementation. If any were described incorrectly or participants couldn't remember the representation it was reviewed. Participants then stepped into the virtusphere and a common sequence of messages where played for each participant so they could practice walking in the sphere and verbalization of their interpretation.

During testing participants received each base message one time, except for the move-out message which was presented four times (with varying qualifiers), the arrived at WP message which was presented twice (with varying qualifiers), and the threat and friendly entity awareness messages which were played once for each possible subcategory. Because of the time constraint there were only short gaps of a few seconds between messages, but when ordering the messages certain illogical sequences were avoided, such as a move-out when the participant was already moving, or back to back arrived at waypoint messages. At the conclusion of testing, participants completed a user feedback questionnaire.

RESULTS

Message and message sub-part recognition accuracy results are presented in Table 2. Overall, participant accuracy was 98.8% on the base part of the messages, 99.1% accuracy on pace information, 96.0% accuracy on sub categories for an entity, and 98.1% accuracy for the distance information. As was anticipated, there were belt alignment problems and ten participants made at least one error caused by them being one place off in the cardinal directions (e.g. stating south-west instead of south or south-east instead of east). In all cases, if they made more than one error of this kind it was consistent in the direction of the error, further suggesting the error was due to tactor alignment rather than not understanding the language.

Additionally, seven of the twenty participants confused west from east during testing. Two of those seven made that mistake twice. This verbalization error was common to many participants during training, and whenever this was pointed out to participants they indicated they had the names switched and they meant the correct direction. Thus, if the "raw" responses from participants are used in scoring the accuracy on the direction component the result is only 88.4% accuracy. However, if east-west errors and errors by one place in the cardinal directions are discounted participants scored 100% accuracy on the direction component. Similarly, when scoring total message recognition participants were completely accurate 84.9% of the time without this correction, but 95.9% accurate with it.

Table 2 Summary of Message Recognition Results

Command Messages

	Base	Pace	Direction	Distance	Entire Message (Unadjusted)	Entire Message (Adjusted)
Move-Out	80/80 (100.0%)	79/80 (98.8%)	75/80 (93.8%)	80/80 (100.0%)	75/80 (93.8%)	79/80 (98.8%)
Halt	20/20 (100.0%)					
Take Cover	18/20 (90.0%)					
Rally	19/20 (95.0%)	20/20 (100.0%)	18/20 (90.0%)	18/20 (90.0%)	15/20 (75.0%)	17/20 (85.0%)
Injured Soldier	20/20 (100.0%)	20/20 (100.0%)	19/20 (95.0%)	20/20 (100.0%)	19/20 (95.0%)	20/20 (100.0%)
Eyes on Me	20/20 (100.0%)		20/20 (100.0%)		20/20 (100.0%)	20/20 (100.0%)
All Commands	97.5%	99.6%	94.7%	96.7%	90.9%	95.9%

Navigation Messages

	Base	Pace	Direction	Distance	Entire Message (Unadjusted)	Entire Message (Adjusted)
Arrived at WP	40/40 (100.0%)	39/40 (97.5%)	32/40 (80.0%)	39/40 (97.5%)	30/40 (75.0%)	38/40 (95.0%)
Arrived at CP	20/20 (100.0%)					
Crossing PL	20/20 (100.0%)					
Inside NAI	20/20 (100.0%)					
All Navigation	100.0%	97.5%	80.0%	97.5%	75.0%	95.0%

Entity Awareness Messages

	Base	Sub Category	Direction	Distance	Entire Message (Unadjusted)	Entire Message (Adjusted)
Threat	60/60 (100.0%)	58/60 (96.7%)	47/60 (78.3%)	60/60 (100.0%)	46/60 (76.7%)	58/60 (96.7%)
Friendly	40/40 (100.0%)	38/40 (95.0%)	38/40 (95.0%)	39/40 (97.5%)	36/40 (90.0%)	38/40 (95.0%)
All EA Messages	100.0%	96.0%	85.0%	99.0%	82.0%	96.0%

All Messages

	Base	Pace	Sub Category	Direction	Distance	Entire Message (Unadjusted)	Entire Message (Adjusted)
All Messages	98.8%	99.1%	96.0%	88.4%	98.1%	84.9%	**95.9%**

Messages with one piece of information were recognized 98.0% of the time, messages with two pieces 100% of the time (i.e. the accuracy for the eyes-on-me message), and messages with four pieces 83.2% of the time without the direction error adjustment and 95.4% of the time with it. Given the accuracy only dropped by 2.6% when receiving four pieces of information compared to one, there appears to be some evidence the sequential presentation of information can work effectively in terms of recognition accuracy.

In the questionnaire participants were asked to indicate their level of agreement with the statements shown in Table 3 on a Lickert scale where 1 indicates "Strongly disagree" and 7 indicates "Strongly agree".

Table 3 Summary of Questionnaire Results

Statement	Mean	SD
1. Message training time was sufficient	6.10	1.02
2. Tactile messages were easy to learn	6.20	0.77
3. The tactile vibrations were uncomfortable	2.30	1.49
4. Tactile vibrations were strong enough	5.45	1.15
5. It was difficult to recognize messages while walking	4.30	1.72
6. The tactile pattern made sense given the message being communicated	6.45	0.76
7. Messages were too complex	2.15	1.09
8. It was easy to remember what the tactile signals meant	5.80	1.15
9. Overall this system would be useful to help soldiers in an operational setting	5.90	1.33

Despite the fact the participants did well recognizing the messages (and they knew it because they were told how many they got wrong before completing the questionnaire), the mean response to the statement "It was difficult to recognize messages while walking" was 4.30. Further, five participants responded with a 6 or 7. This is perhaps because walking in the virtusphere is not exactly the same as walking on a flat surface, or because the virtusphere is quite loud and there were trained in a quiet environment. When asked in an open ended question "what had the biggest negative impact on your performance?" participants provided further evidence of the challenge they felt performing both tasks simultaneously as eleven indicated walking in the sphere had the biggest negative impact, with two referencing its noise. Although the mean response to the statement "Tactile vibrations were strong enough" was 5.45, three participants answered the weaker strength of the signal on the back had the biggest negative impact on their performance. This might be solved by using a neoprene material for the belt to better fit the natural contour of the back. When asked what had the biggest positive impact on performance ten indicated the message designs and six how the training was conducted.

DISCUSSION

The recognition accuracy appears promising for the overall tactile language used, all three types of message, and each message subcomponent. The virtusphere environment enabled improved spatial and physical exertion fidelity compared to having participants simply verbalize their interpretation in a standing position, but a head-mounted display showing a virtual environment that changes in response to participant movement would add a further level of fidelity. This is planned for the next experiment where the same tactile language will be used but the participant inside the virtusphere will be immersed in a Virtual Battlespace 2 (Bohemia Interactive, 2013) scenario. This will support assessing performance in terms of mission objectives as well as language recognition. Additionally, THATO's support for sending messages will be evaluated as a second participant in another room will act as a remote teammate, with a birds-eye view of the battlespace, giving commands and providing information through voice recognition and a joystick.

The language X o'clock (e.g. 12 o'clock, 3 o'clock etc.) would follow military protocol more than "my north" or "my east" etc., but tactors at the north-east, south-east, south-west, and north-west don't map precisely to any of the twelve locations on a clock. For the next experiment either a different belt configuration will be used or combinations of tactors will be used to create directions where there are currently no tactors (e.g. playing the north and north-east tactors simultaneously to create the effect of a 1 o'clock tactor. Other than possibly allowing participants more time to become familiar with the virtusphere itself no other changes are planned to address the challenges added by having to move on sometimes ackward "terrain" and in a noisy environment as such physical and auditory challenges are realistic for soldiers in the field).

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REFERENCES

Bohemia Interactive (2013). *Virtual Battlespace 2.* Retrieved May 22, 2013, from http://products.bisimulations.com/products/vbs2/overview.

Chapman, R., Riddle, D., Puryear, J. Breeden, J., Ramirez, A., & Hall, D. (2012). The Design and Evaluation of THATO: A Mobile Tactile Messaging System to Assist Dismounted Soldier Tactical Operations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Boston, MA.

Department of the Army. (2004). *Operational Terms and Graphics*. (Field Manual No. 1-02). Washington, DC: Government Printing Office.

Department of the Army. (2001). *Map Reading and Land Navigation*. (Field Manual No. 3-25.26). Washington, DC: Government Printing Office.

Department of the Army. (1987). *Visual Signals*. (Field Manual No. 21-60). Washington, DC: Government Printing Office.

Elliot L. R., van Erp J. B. F., Redden, E. S., & Duistermaat (2010). Field-Based Validation of a Tactile Navigation Device. IEEE Transactions on Haptics. Vol. 3, No. 2. April-June 2010.

Ferris, T. K., & Sarter, N. (2008). Cross-modal links among vision, audition, and touch in complex environments. *Human Factors.*Vol 50(1) 17-26.

Hancock, P.A. & Szalma, J. (Eds.). (2008). *Performance Under Stress*. Williston, VT: Ashgate Publishing.

Merlo, J.L., Stafford, S.C., Gilson, R.D., & Hancock, P.A. (2006). The effects of physiological stress on tactile communication. *Proceedings of the Human Factors and Ergonomics Society*, San Francisco, CA.