Development of Dual Tactor Capability for a Soldier Multisensory Navigation and Communication System

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Abstract. Development of new multisensory Soldier display systems requires context-driven evaluation of technology by expert users to assure generalizability to operations. The capture of Soldier performance demands is particularly challenging in this regard, as many factors converge to impact performance in actual usage. In this paper, we describe new capabilities for tactile communications that include an authoring system, use of android-driven displays for control and map-based information, and engineering tactors with differing salient characteristics. This allows development of a dual-tactor display that affords a larger variety of tactile patterns for communications, or TActions. These innovations are integrated in a prototype system. We used the system to present navigational signals to combat-experienced soldiers to guide development of tactile principles and the system itself. Feedback was positive for the concept, operational relevance, and for ease of interpretation.

Keywords: Tactile displays, Haptic displays, Soldier navigation, Soldier performance, Multisensory displays, Intuitive displays, Salience.

1 Introduction

Multisensory tactile display systems for military performance have demonstrated their potential for performance and tactical advantage across a number of applications. Experiments and demonstrations have been conducted across a wide range of settings, from laboratory tasks to high-fidelity simulations and real-world environments [1]. Operators of these various tactile systems have successfully perceived and interpreted vibrotactile cues even in adverse, demanding, and distracting situations. The improvements in performance are explained by two theory-based schools of thought: alleviation of sensory overload [2] and/or alleviation of cognitive deliberation [1]. In related research, it has been suggested that tactile events may be processed preattentively - tactile information is processed preferentially by the nervous system under conditions of divided attention [3]. This preferential processing may also account for the enhanced performance.

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The US Army Research Laboratory, Human Research and Engineering Directorate (ARL/HRED) conducted experiments with systems using tactile displays for Soldier navigation and communication. First, task analytic investigations identified key situations in which Soldiers are visually overloaded, such as missions requiring land navigation [4]. Several HRED studies were then conducted within the context of soldier land navigation, to investigate effects of tactile cues in context [5]. The studies demonstrated that Soldiers could detect not only single alerts but also patterns of multiple tactors to represent different messages. It is particularly promising that the soldiers could perceive these patterns during strenuous movements [6]. Three additional HRED experiments demonstrated the efficacy and suitability of a torso-mounted tactile belt for Soldier navigation [7]. Given this series of results from land navigation studies, it is evident that tactile navigation displays can be used in strenuous outdoor environments and can outperform visual displays under conditions of high cognitive and visual workload. In addition, Soldier feedback (e.g., after-action reviews, comments, and structured rating scales) was very positive, indicating core advantages of the system was that it was "hands-free, eyes-free, and mind-free."

The experiments described above establish the potential of tactile systems for supporting Soldier performance while easing workload and gaining high user acceptance. At the same time, Soldiers have provided many suggestions for device design before a system can be practically used in combat. Specifically, the device must be made to be lightweight, comfortable, rugged, and easily maintained. The device must enable reliable communication among Soldiers. Currently, Soldiers use visual hand signals to communicate and coordinate movements and target detection. Tactile systems can build upon these techniques, by enabling commanders to easily and covertly signal Soldiers regarding alerts or movements. This would build upon battlefield visualization techniques now common to command and control, by enabling the commanders to quickly relate critical communications as to where to go or where to shoot. In this way, distributed tactile communications could enable dynamic battle maneuvers with covert and intuitively understood signals that can be understood in high-noise, high-stress, and/or low-visibility contexts.

While considering soldier's recommendations, HRED researchers have also recognized the need for the development of tactile systems that can enable further applied research on multisensory performance issues relevant to soldier performance. These systems should provide the means by which task performance can be easily assessed, with capabilities that can track communications, time-stamp performance events, and track GPS-enabled assessment of navigation time and accuracy. This paper describes the development of one such system developed by Engineering Acoustics Inc. (EAI), to illustrate the advantage to Soldier performance in mission context, while offering a testbed for research. The resulting capabilities should generalize to many other navigation contexts: military, government, first-responder, and commercial (e.g., hiking, hunting, tourist) applications.

2 Tactile Salience

One of the general problems in all sensory perception is information overload, but humans are adept at using selective attention to quickly prioritize large amounts of information and thus give their attention to that which is the most important [2]. Historically, tactile stimuli and patterns have been described using dimensions such as the frequency, intensity, force, rhythm, location and duration of the signal [8,9]. However, these definitions and their associated thresholds are of little value in determining the effectiveness of tactile systems because they do not account for user and application specific environmental factors. For example, one cannot consider the salience of a tactile cue or message construct by signal properties alone, without consideration of physical task demands and external noise.

One of the factors that influences prioritization of sensory information by humans is Salience. Salience is the property of a stimulus that allows it to stand out and be noticed. Salience is widely used in describing visual system performance but typically has not been applied to the tactile modality. Salience models potentially can describe how attention is focused onto particular elements in complex scenes, based on both endogenous properties of the object (bottom-up saliency) as well as cognitive processes (top-down) [10]. Therefore salience allows us to potentially compare tactile symbology in a multimodal environment. A conceptual model framework for salience is described in Figure 1.

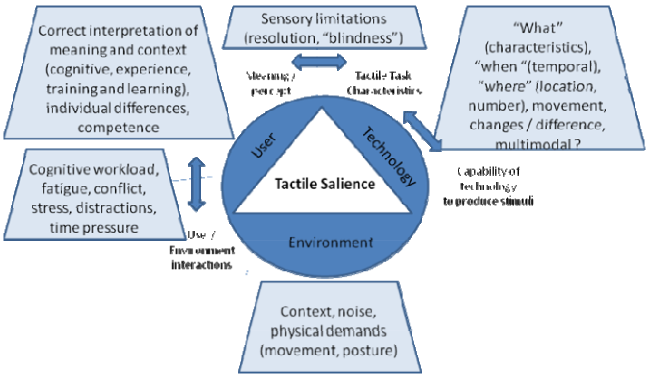

Fig. 1. Model for tactile salience. Tactile salience is situational depending on the user, environment, technology and tactile parameters.

Tactile salience depends on the user, the technology, and the environment. To be salient for diverse users, tactile display technology should provide a wide range of recognizable touch characteristics, and do so in a small lightweight, efficient system that is not limited by the mounting or usage. Features such the abrupt onset (or changes) in stimuli and high frequency (200-300 Hz) tone burst vibrations are known to be naturally salient. Touch is also arranged somatotopically (i.e., point to point correspondence of body areas to the nervous system), leading to an intuitive mapping of direction and spatial constructs [11] on the surface of the body. There are also well known sensory processing limitations that limit tactile discrimination [12]. Further external factors such as environmental noise, and human factors such as individual differences, training and experience, emotional reactivity, cognitive resources and even posture all have an effect on salience.

Tactile salience is complex and situation-dependent. Thus, predictions and principles must consider and articulate the critical situational factors that interact to effect performance with tactile systems. Design and testing of tactile array systems must replicate the intended environment and user characteristics while measuring salience. A cognitive task analysis should preface development of any system, to provide developers with information about the nature and type of information processing and environmental demands the system users are likely to encounter. In this case, the users were soldiers and therefore, the first step was to identify the mission tasks that would most benefit from a multisensory tactile approach. Consideration of mission and task context then informs tactile display requirements (e.g., tactile display must be easily perceived when performing combat maneuvers). Measurement of tactile salience may be measured through direct task performance (e.g., response times, accuracy, etc.) and also subjective reporting (e.g., confidence scales).

2.1 Dual Tactor Capability

Engineering Acoustics, Inc. (EAI) has a long history of tactile system development for many applications (including situation awareness support for aircraft pilots [13]). Currently, EAI is developing the ATAC (Active Tactile Array Cueing) Navigation Communication (NavCom) system. This system for soldiers has focused on combining two different types of tactors (C-2 or C-3 (operating at 250 Hz) and EMR) with varying characteristics, to provide a system that enables intuitive communications as well as direction information. In addition, the C-2 tactor was optimized for higher-frequency tactile signals that are easily and quickly perceived, even during strenuous movements [6]. The C3 is a smaller, lighter, and more covert version of the C-2. The EMR is a new motor-based design with an operating frequency range of 60-250 Hz. This design is able to produce a wide range of perceivable tactile features ranging from a strong “alert” to a “soft” pressure pulse or “nudge”. Therefore we have designed the EMR to be capable of producing substantial peak displacements of up to 1.2 mm p-p (as measured against a phantom with the mechanical impedance of skin). In contrast, the C-2 or C-3 would typically only be driven to peak displacements of about 0.5 mm p-p owing to the relatively high PC channel displacement sensitivity. Figure 2 shows the EAI tactor types.

Fig. 2. The EAI C-2, C-3 and EMR vibrotactor transducers (left to right respectively)

The simplest informational requirements for soldiers completing a navigation task are the direction to and distance from the waypoint, and this information can be presented to them on a torso-worn tactor array. Directional information is naturally mapped to corresponding sectors on the torso, and studies [14] have shown that an array of 8 tactors in a single row around the body, is sufficient for accurate navigation (e.g., more tactors would not result in higher precision). Therefore the two tactors types are mounted in two rows within a dual flexible belt, each sector comprising an array with a C-2 (or C-3) and an EMR.

2.2 ATAC NavCom

Figure 3 shows a block diagram for the ATAC NavCom system. The system comprises visual display hardware (e.g., a smartphone), EAI tactor controller and dual belt array, a COTS (Commercial off the shelf) GPS / compass sensor interfaced directly to the tactor controller and software components. Wireless task management and recording (using a cloud based database) are also provided for mission management and data collection.

Fig. 3. Block diagram for the proposed ATAC-NavCom system

Our experimental focus is on determining the effectiveness and salience of multiple tactors and tactile patterns, or TActions [15], for critical communications. Thus the NavCom system and the research it enables are expected to support the core critical demands for Soldiers – to move, to shoot, and to communicate.

The TActions were developed as easily recognizable (salient) tactile representations of the standard hand and arm “command” signals, shown in table 1.

Table 1. Arm and Hand Signals and Corresponding Tactile Signal Patterns. The illustrations are from US Army Field Manual 21-60.

Arm / Hand Signal	Tactile Pattern	Visual Pattern
Halt	Four tactors simultaneously actuated on the sides of the body	
Rally	Sequenced activation of all tactors creating a circular motion around the body	
Move Out	Sequenced back-to-front activation of tactors creating movement from each side of the body which converges in the front	
Nuclear Biological Chemical (NBC) threat	Sequenced activation on both sides simultaneously creating three distinct impulses on the sides of the body	
Take Cover	Simultaneous activation of 4 tactors (two on each side) followed by a sequenced activation of a series of tactors to indicate movement	
Attention, Prepare	Sequenced activation of four tactors in the front, emulating side to side movement	

3 Some Preliminary Findings

Several combat-experienced soldiers used the ATAC NavCom system for performance trials and provided feedback on perception and interpretation of direction and command cues, the ease of use, and issues regarding operational relevance and use. The participants were eight Soldiers from the 150^{th} ARS (Army Reconnaissance Squadron) West Virginia Army National Guard, all of whom had combat experience (at least one tour in Iraq). Their military occupational specialty (MOS) was 19D, associated with armored vehicles, such as the Bradley, Abrams, and Stryker vehicles. All had combat dismounted experience as well (e.g., urban patrols). All of the Soldiers were male, ranging in age from 23 to 40 years. Height ranged from 60 (1^{st} percentile) to 77 (99th percentile) inches, indicating a range of body size. Their total years in the military ranged from 3 to 21, and rank ranged from E4 (SPC Specialist or CPL Corporal) to E6 (Staff Sergeant). An additional soldier from Fort Benning with equivalent experience also participated. The experience level of the soldiers was critical for their feedback with regard to operational use.

Single cues. Each soldier was introduced to the system and was trained on the components and concept of use. Single-tactor location cues on the body were identified by *o'clock* positions, which are familiar concepts to all soldiers. After a brief introduction to each tactor position, soldiers demonstrated their proficiency through a training set of direction cues. In the absence of visual cues, they were to respond to a set of tactile single direction cues, presented with the EMR tactors, as well as with the C-2 tactors. The EMR tactors were as effective (mean = 0.5 errors) as the C-2 tactors (mean = 0.62 errors) for direction cues. Examination of the error types show no particular pattern. The total number of errors were low and most of the participants had none. Most of the errors were accounted for by two participants.

Commands. Each soldier was then trained on six hand and arm signal patterns used during land navigation (Attention, Move out, Take cover, NBC, Rally, Halt) presented with the tactors belt. The trainer introduced two signals, had the soldier identify each correctly, then would add another signal, until the soldier could correctly identify each of the three (twice). This protocol continued, adding a signal to the group until the soldier could correctly identify all six. They were trained to proficiency in less than five minutes. Some of these patterns were modified versions of those developed in previous efforts [16]. The Soldiers then responded to a set of 24 counterbalanced tactile cue patterns, presented through C-2 tactors. All Soldiers identified all patterns correctly.

Commands and Directions. After completion of training on the set of tactile Commands, each soldier learned a set of counterbalanced cues that mixed tactile commands (C-2 tactors) with tactile direction cues (EMR tactors). Most of the soldiers performed with a perfect score. One soldier confused "Take Cover" with "Move Out", and a second soldier confused direction 6 with direction 4_5.

Robot commands. Because soldiers sometimes use robotic assets during land navigation, a notional set of six commands were developed for communication from a robot to the operator (Look at display, Wheels are spinning, Road is rocky, Steep incline left, Steep incline right). Soldiers were introduced to the tactile patterns representing these messages, as before, and practiced until they were proficient, taking less than five minutes to do so. They were then presented with a randomized counterbalanced set to identify. All soldiers identified all cues correctly.

Soldier comments. Soldiers provided comments and ratings (using a 7 point semantic differential scale in which 1 = very difficult, very ineffective, strongly disagree to 7 = Very easy, very effective, strongly agree; etc.) with regard to system features and operational relevance. Table 2 provides mean Likert ratings of effectiveness. All ratings were positive, ranging from a mean of 4.75 for daytime route navigation to a mean of 5.88 for night operations. Soldiers agreement was high for positive statements (e.g., it was easy to feel) and low for negative statements (e.g., the signal was annoying).

Table 2. Mean degree of agreement (7pt Likert scale) to statements regarding system features

Degree of agreement with:	Mean rating
It was easy to feel each tactile signal	6.38
The tactile signal should be stronger	3.25
The tactile signal was annoying	2.62
It was easy to understand what each signal meant	5.25
I was very certain what each signal meant	5.63
I recognized each signal immediately	5.50
The tactile cues are a good means of silent communication	5.63
The tactile cues are too noisy for regular patrols	3.25
The tactile cues are too noisy for covert missions	4.50
The tactile cues are a good substitute when radios cannot be used	5.63
The tactile cues help keep my attention on my surroundings	5.00
The tactile cues can be a useful way for soldiers to communicate	5.88

Soldier comments. Soldiers offered many comments with regard to the advantages and issues dealing with the tactile interface. Soldiers particularly valued the hands-free aspect, as it allows them to keep weapons in hand. They also commented on the usefulness of the tactile cues for situations where visibility is limited, such as night operations and combat (e.g., smoke). In such situations it was felt that the tactile direction alerts could be easily perceived and intuitively followed, allowing the soldier to maintain attention on their environment and sources of threat. Soldiers listed several missions where this capability would be useful, such as urban operations, dismount patrol, room clearing, area and zone reconnaissance, and guard patrol.

Soldiers also pointed out issues that may be relevant in certain missions. They noted the noise, while tolerable for normal operations, may not be acceptable for covert missions. In this evaluation, the tactile signal strength was high, and this is associated with a slight buzzing noise. The signal can be reduced, when appropriate. In addition, caution should be taken with regard to the number of commands, to keep TActions to critical communications that are very easily distinguished. These issues are being addressed through the TAction authoring system and adjustability of the system to lower the volume of the signals. A critical aspect to such a soldier system is to afford the soldier the ability to adjust signal patterns and strength, or make new signals to best accommodate the mission at hand.

4 Discussion

Multiple experiments and demonstrations have supported the theory-based predictions regarding advantages of haptic and tactile cues to support performance in high-workload situations, particularly multi-tasked situations with high demands for focal visual attention. Task analysis models identified that Soldiers have very high demands for visual attention, particularly when they are moving or shooting. Subsequent experiments proved the value of tactile systems to support their navigation and communication. As tactile displays are increasingly used for communication of more complex and multiple concepts, it will become evident that tactile and multisensory systems in general must be designed for salience (i.e. rapid and easy comprehension). This paper described efforts underway toward the goal of effective support of Soldier performance, and the development of a system that can also be used for grounded research (i.e. high generalizability to military operations) in multisensory perception and comprehension. With regard to operational use, flexibility is critical. While default settings can be engineered to be effective in most situations, Soldiers need and want the ability to create their own signals and adjust the "volume", to best accommodate specific mission goals and requirements.

References

1. Van Erp, J.: Tactile displays for navigation and orientation: Perception and behavior. Mostert& Van Onderen, Leiden (2007)
2. Wickens, C.: Multiple resources and mental workload. Human Factors 50(3), 449–454 (2008)
3. Hanson, J.V.M., Whitaker, D., Heron, J.: Preferential processing of tactile events under conditions of divided attention. Neuroreport 20(15), 1392–1396 (2009)
4. 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). US Army Research Laboratory, Aberdeen Proving Ground, MD (2004)
5. Elliott, L.R., Redden, E., Krausman, A., Carstens, C.: Multi-modal displays to support Army Infantry Decision making and performance. In: Proceedings of the 2005 International Conference on Naturalistic Decisionmaking, Amsterdam, NL (June 2005)
6. Redden, E.S., Carstens, C.B., Turner, D.D., Elliott, L.R.: Localization of Tactile Signals as a Function of Tactor Operating Characteristics. Technical Report ARL-TR-3971. US Army Research Laboratory, Aberdeen Proving Ground, MD (2006)
7. Elliott, L., van Erp, J., Redden, E., Duistermaat, M.: Field-Based Validation of a Tactile Navigation Device. IEEE Transactions on Haptics 3(2), 78–87 (2010)
8. Loomis, J.M., Lederman, S.J.: Tactual perception. In: Boff, K., Kaufman, L., Thomas, J. (eds.) Handbook of Perception and Human Performance, vol. II, ch. 31 (1986)
9. Jones, L.A., Sarter, N.B.: Tactile Displays: Guidance for Their Design and Application. Human Factors: The Journal of the Human Factors and Ergonomics Society 50(1), 90–111 (2008)
10. Itti, L., Koch, C.: Computational modelling of visual attention. Nat. Rev. Neurosci. 2(3), 194–203 (2001)
11. Van Erp, J.B.: Tactile displays in virtual environments. Report No. ADP010788. TNO Human Factors Research Institute, Soesterberg (2001)
12. Cholewiak, R.W., Collins, A.A.: Sensory and Physiological Bases of Touch. In: Heller, M.A., Schiff, W.R. (eds.) The Psychology of Touch, pp. 23–60. Lawrence Erlbaum Associates, Hillsdale (1991)
13. Rupert, A.H., Graithwaite, M., McGrath, B., Estrada, A., Raj, A.: Tactile Situation Awareness System Flight Demonstration. Aeromedical Resaerch Lab, Fort Rucker, AL. Report No. A891224 (2004)

14. Cholewiak, R., Brill, J., Schwab, A.: Vibrotactile localization on the abdomen: Effects of place and space. Perception & Psychophysics 66(6), 970–987 (2004)
15. Mortimer, B., Zets, G., Mort, G., Shovain, C.: Implementing Effective Tactile Symbology for Orientation and Navigation. In: 14th International Conference on Human Computer Interaction, HCI (2011)
16. Redden, E., Elliott, L., Pettitt, R., Carstens, C.: A tactile option to reduce robot controller size. Journal on Multimodal Displays (2009), http://www.springerlink.com/content/r735q86146218446/
17. Stafford, S., Gunxelman, K., Terrence, B.C., Gilson, R.: Constructing tactile messages. In: Gilson, R., Redden, E., Elliott, L. (eds.) Remote Tactile Displays for Future Soldiers, ARL-SR-0152. US Army Research Laboratory, Aberdeen Proving Ground, MD (2007)