Augmenting Soldier Situation Awareness and Navigation Through Tactile Cueing

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Abstract. The objective of this study was to evaluate the effectiveness of a dual-row tactile belt comprising two different types of advanced tactors to communicate both navigation information and incoming alerts, during a waypoint navigation night operations scenario. Navigation information was provided to the Soldier by providing a pulse pattern on the torso corresponding to the direction towards the next waypoint. At the same time, the Soldier received incoming situation awareness alerts regarding threat and robot status indicators. Each Soldier participated in two comparable navigation scenarios, where the task performance with a front-mounted visual map display was used. A tactile assisted interface was also part of the Soldier ensemble, such that the tactile system was turned on during one navigation scenario, and turned off for the other. When using the tactile system, Soldiers reported being more situationally aware of their surroundings and having better control of their weapon. They also navigated more quickly, and very rarely consulted their visual dispay, when the tactile system was turned on.

Keywords: Soldier performance · Navigation performance · Tactile cueing tactile display · Tactile communication

1 Introduction

It has been established that dismounted Soldiers consistently experience heavy cognitive and visual workload, not only during combat operations, but also during navigation and patrol [1–3]. At the same time, the Soldier must master new technology that have high demand for visual focal attention, such as smart phone/tablet map displays and various controller and communication devices. Emerging technologies assessed for Infantry Soldier combat teams during the Army Expeditionary Warrior Experiment (AEWE) included a variety of sensor-based information from aerial and ground vehicles, all which must be integrated in comprehensible fashion [4].

While these advanced technology devices are meant to assist the Soldier, care must be taken not to further overload him or her with additional demands or distracters.

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Given the high demands for visual attention, consideration turned towards off-loading attentional demands to other sensory channels, as this has been demonstrated to ease workload [5, 6]. Tactile displays present an opportunity to provide direction and alerting cues that are both intuitive and covert [7, 8]. Studies have showed the effectiveness of tactors and recent research has proposed combinations of different types of tactors to provide a wide range of perceivable features [9, 10]. In this paper, we summarize findings of a user-based evaluation of a dual-row tactile belt comprising two different types of advanced tactors, to communicate both navigation information and incoming alerts. The system was integrated with a chest-mounted tablet display similar to NettWarrior concepts for the future Soldier.

2 Equipment

The NavCom user hardware comprises a smart phone with integral visual display and touch screen interface, a dual row tactor belt array, and a commercial off the shelf (COTS) GPS/inertial sensor (INS). The smart phone was mounted in a MOLLE (Modular Lightweight Load-carrying Equipment) vest. Soldiers could flip down the display to check their visual map display or read incoming text alerts (Fig. 1).

This experiment used commercially-available tactors which are relatively small, light, salient, sturdy and bio-isolated available from Engineering Acoustics, Inc. (EAI). Figure 2 shows the EAI C-2 tactor that has been proven effective in previous experiments, along with the newer, and smaller, C-3 tactor, and a low frequency motor based tactor, the EMR tactor. These tactors are based on a linear actuator design that is more resistant to loading effects typical of more widely used eccentric mass motors [13]. The C-2 and C-3 are almost equivalent in vibratory output and believed to be equivalent in sensation. The C-3 (6 g) is substantially lighter than the C-2 (18 g).

In this experiment, the EMR tactor was used primarily for navigation signals. For incoming alerts, C-3 tactors were used, programmed at the frequency that is optimal for

Fig. 1. NavCom tactile belt showing tactor placement (left) and chest-mounted visual display (right).

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

Table 1. Characteristics of C-3 and EMR tactors

Characteristic	C-3 tactors	EMR tactors
Mechanism	Moving magnet linear actuator	Motor-based actuator
Diameter	0.8″	1.00″
Thickness	0.25″	0.4″
Main frequency	200–300 Hz (but can operate at lower frequencies)	50–140 Hz,
Peak displacement	0.016″	0.03″
Material	Anodized aluminum, polyurethane	Polycarbonate and ABS plastic

human perception (250 Hz). The C-3 produces a highly salient, “sharp” sensation. Both types of tactors create a strong localized sensation on the body by utilizing a moving contactor that is located within the tactor housing and works like a plunger. Table 1 provides a description of characteristics of each type of tactor.

3 Taction Patterns

The navigation information was provided to the Soldier during navigation legs by providing a pulse pattern on the tactor sector corresponding to the direction towards the next waypoint. As the Soldier moved closer to the waypoint, the tactor pulse repetition rate increased until the waypoint was reached, upon which the Soldier was notified with a tactor message pattern.

Soldiers also received incoming alerts (“threat ahead”; “NBC threat”) and status updates (“robot wheels are spinning”, “robot battery low”). In the Visual-only condition, the alerts were communicated through text messages accompanied by an audio alert. In the Tactile-visual condition, they were communicated by tactile patterns based on the C-3 tactors.

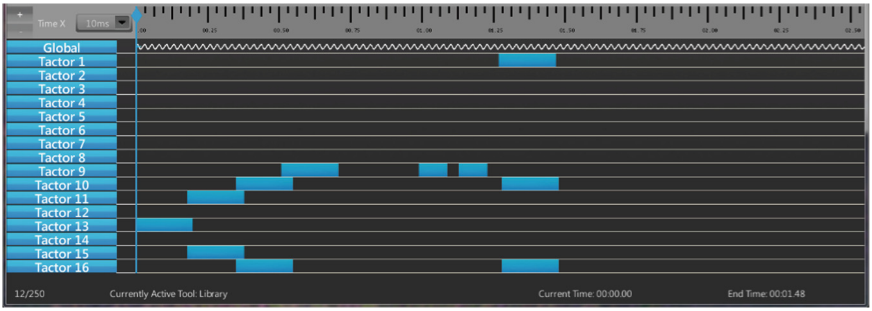

Fig. 3. "Threat ahead" taction: 100–200 ms pulses moving form the back and ending on a large area on the front torso, activating one EMR (tactor 1) and several C-3 tactors.

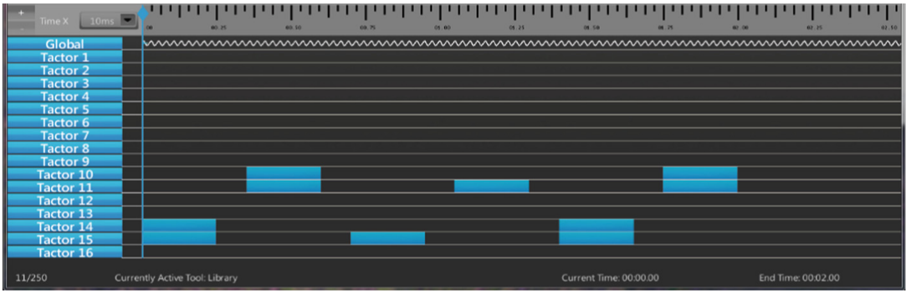

Fig. 4. "NBC detected" taction: 250 ms pulses on diagonal C-3 tactors emulating the hand signal for this command.

Tactile patterns have been developed and validated, using Soldiers in static postures and dynamic movements [11, 12]. These patterns were intended to be salient (e.g., easy to perceive and interpret). Figures 3 and 4 shows how characteristics of two tactions, "threat ahead" and "NBC detected", were programmed, using the EAI taction Creator editor. Tactors 1-8 were EMR while tactors 9-16 were C-3.

4 Experiment Design

Two equivalent 900 m routes were developed, comprising 3 major waypoints, each indicating the end of a navigation leg. Each Soldier navigated these routes twice: once with the tactile system turned off (i.e., Visual condition) and once with the tactile system turn on (i.e., Tactile/Visual condition). Experiment conditions were counter-balanced for order and for navigation course.

During the first navigation leg, each Soldier navigated while also receiving incoming alerts. During the second leg, each Soldier navigated while avoiding exclusion areas. During the third leg, each Soldier navigated while receiving incoming alerts and searching for silhouette targets (Fig. 5).

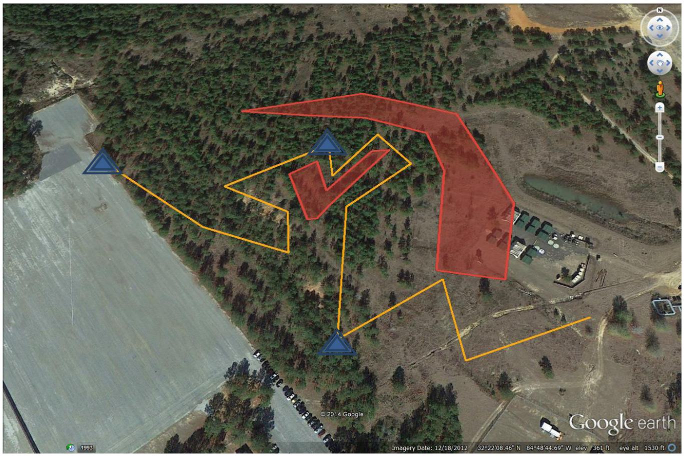

Fig. 5. Photograph of course A with navigation path and exclusion zones (shaded red area) (Color figure online).

5 Results

Data were collected on thirty-six Soldiers who volunteered to perform in this experiment-based evaluation during night operations.

Results showed that missions performed with the tactile system turned on were associated with significant ($p < 0.05$) differences with regard to reduced mission times (35.61 min tactors off vs. 28.05 min tactors on) (Fig. 6).

Table 2 provides the means and SD for the times (min) associated with each leg, by condition. The Visual condition was associated with slower times, for each leg.

Differences in navigation times were more pronounced for leg 2 (navigation with exclusion area) and leg 3 (navigation with alerts and target detection), indicating that the contribution of the tactile system was more pronounced when attention demands on

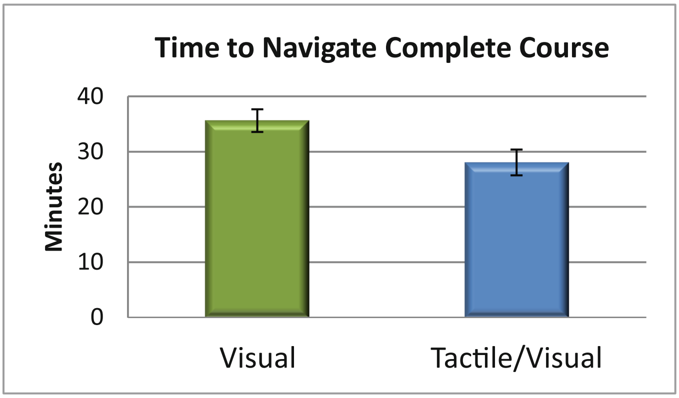

Fig. 6. Mean time to navigate complete course. Error bars represent 95 % confidence interval

Table 2. Mean time and standard deviation to complete each leg by condition

	Means and SD for time to navigate (min)			
	Leg 1	Leg 2	Leg 3	N
Visual	8.504 (2.303)	11.896 (2.879)	15.212 (2.766)	36
Tactile/visual	7.029 (1.986)	8.578 (2.765)	12.447 (3.759)	36

the Soldier are higher. In leg 1, the route was more linear and the terrain not as challenging; thus, the need for rerouting was potentially lower.

The total distance walked by each Soldier was significantly shorter when Soldiers used the tactile system, indicating that the use of the Tactile/Visual system decreased the navigation path each Soldier walked to complete the course. The navigational cues felt by the Soldier around their torso allowed Soldiers to route plan and move more directly to the next waypoint leading to shorter distances between waypoints. Results by leg were similar to that of navigation time: Soldiers were significantly aided by the tactile system for legs two and three, where there were greater demands for attention (e.g., rerouting, target detection).

Results also showed that the tactile capability was associated with significantly increased navigation accuracy (1.40 vs. 1.65 path ratio), and significantly lower reported experience of cognitive workload, effort, and frustration using the NASA TLX scale (see Table 3).

Table 3. Comparison of NASA-TLX means and standard deviations for visual and tactile/visual conditions.

	Mental	Physical	Temporal	Effort	Frustration
Visual	4.50 (2.42)	3.17 (1.97)	3.17 (1.98)	4.03 (2.26)	3.44 (2.67)
Tactile/visual	3.00 (2.03)	2.67 (1.80)	2.78 (2.17)	2.75 (1.98)	2.06 (1.69)

Results also showed that Soldiers were able to perceive and correctly interpret tactile patterns representing incoming alerts and status reports, with high (i.e., 92.7 %) accuracy, while on the move. This is impressive given that each signal was presented only once; there were no repetitions. Ratings regarding the ease of feeling the tactors showed that Soldiers found the tactors to be easy to feel, with means ranging from 6.33 to 6.69 (7 pt scale). The NBC signal was most frequently reported as being more easily felt. Soldiers did suggest adding a "please repeat" button as an improvement.

Soldiers provided feedback on many aspects of equipment use. They rated both systems highly for characteristics related to comfort and fit, with ratings ranging from 6.08 to 6.57 based on a 7.0 semantic differential scale, with 7 = extremely comfortable/effective. Soldiers also provided many comments regarding the system. Typical positive statements include:

- "It has the ability to send signals quickly and silently. You can do land navigation with no thought involved."
- "A faster way to get to one point to another and it's a lot quieter than a radio."

- "It is way more effective and faster than conventional land nav. It allows the Soldiers to stay more effective towards threats."
- "Using the belt required less screen use. This prevented my eyes having to readjust to the night."
- It takes a lot less time; you can pay more attention to your surroundings and be more aware of your surroundings.

At the same time, Soldiers provided insightful comments with regard to how to make the system more combat-ready. The system must be durable, weatherproof and reliable. Battery and power usage will also be important. Soldiers suggested that the tactors should be adjustable, such that tactor intensity and noise levels can be changed to fit situation demands. Soldiers also suggested that tactile messages should be repeated until the Soldier acknowledges understanding (e.g., push a button, etc.). Some Soldiers tended to stop in order to better interpret the tactile signal. Repeated signaling would reduce the need to stop.

When using the tactile system, Soldiers reported being more situationally aware of their surroundings and having better control of their weapon. Soldiers reported that they were able to keep their hands on their weapons instead of a display resulting in hands free aspect. They also reported that not having to look down at a display screen to navigate or receive incoming alerts resulted in increased situation awareness and an eyes free aspect to their mission. Additionally, Soldiers reported not having to be concerned with tasks such as pace count or declination resulting in mind free task requirements.

The most compelling finding between groups was the number of visual display checks (17.7 tactile off vs. 1.3 tactile on). When the tactile capability was "on", the Soldiers predominantly used the tactile information resulting in low rates for visual display use. This in turn, is associated with greater light security (e.g., threat from enemy observations), higher preservation of night vision (e.g., glancing at a lighted display degrades night vision), and more attention available to attend to surroundings.

6 Conclusions

This experiment-based evaluation of tactile display technology compared the efficacy of a chest-mounted visual display, when used with, and without, an integrated tactile display. Core conclusions include:

User preference. When Soldiers had the tactile system available for use, they used it almost exclusively. They assigned the tactile capability high ratings for effectiveness and operational relevance.

Enhanced performance. The tactile system improved navigation performance, with regard to distance and time.

Hands-free performance. The tactile system allowed interpretation of both navigation information and incoming alerts without having to consult a visual display. When the tactile capability was on, Soldiers consulted the visual display an average of 1.3 times, compared to an average of 18.2 times when the tactile capability was not available.

Lower workload. Soldiers also reported less workload when using the tactile system. Mean ratings were significantly lower for frustration, effort, and mental workload.

Increased safety. Use of the visual display breaks light security, revealing Soldier position (e.g., to the enemy). It also disrupts night vision. Soldiers rarely consulted the visual display when the tactile capability was on.

In summary, these results augment collected findings with regard to development of tactile displays for dismount Soldier performance. Further research is planned to investigate issues affecting the salience (i.e., ease of perception) of tactile cues, following up on recent data collection (Elliott et al. in review). Further investigations are also warranted with regard to ease of learning and recognition, as moderated by tactile characteristics.

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