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Developing a head-mounted tactile prototype to support situational awareness

Flynn Wolf, Ravi Kuber*

UMBC, 1000 Hilltop Circle, Baltimore MD 21250, USA

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ABSTRACT

In this paper, we describe the design and evaluation of a head-mounted tactile prototype and multi-parameter coding scheme to support situational awareness among users. The head has been selected as the location for the interaction because it has been relatively under-researched compared to the torso or hands, and offers potential for hands-free attention direction and integration with new head and eyewear technology. Two studies have been conducted. The first examined the user's ability to discern three-parameter tactile signals presented at sites on the head. Findings highlighted that while multi-parameter cues could be interpreted with low error, challenges were faced when interpreting specific combinations of waveform and interval type, and when performing identification of interval pattern and stimulation location while visually-distracted. A second study investigated how use of the three-parameter tactile coding scheme impacted participants' situational awareness under several exertion conditions. Significant interaction was found between the exertion conditions and subjective cognitive workload. The relationship between situational awareness phases of participant SAGAT assessment scores were consistent between conditions, with perception and prediction phases outpacing comprehension. This suggests, pending further study of the suitability of situational awareness evaluation methods for tactile perception, that quickly trained participants may struggle to understand multi-parameter coding intended to convey changing events. Interpretations of coding schemes were found to vary, highlighting the importance of carefully selecting and mapping signals for presentation. Insights from our study can support interface designers aiming to heighten levels of spatial and situational awareness among their users through use of the tactile channel.

1. Introduction

Research into tactile stimulation suggests potential for this sensory channel to play a valuable role in supplementing overloaded visual and auditory channels in interfaces to aid spatial and situational awareness. Development of real-world applications in work domains, such as aviation and pedestrian navigation, also indicate potential for practical tactile aids to support effective attention direction in a wide array of vexing scenarios where users are often distracted by multitasking and sensory overload (Wickens, 2008). Additionally, tactile cues (also referred to as 'tactile signals' or 'tactons' in this paper) offer a "private channel" to provide feedback more inconspicuously and unobtrusively in loud or threatening situations than visual or auditory options (Jones and Sarter, 2008). Research involving wearable tactile devices, in forms such as belts and bracelets offering vibrational feedback, demonstrates considerable potential for improving spatial and situational cognizance. This potential may apply to performing everyday pedestrian navigation tasks, as well to cognitively and perceptually demanding industrial and military situations, where vision may be restricted or unavailable (Raj and Braithwaite, 1999). Situational awareness in the context of this research generally refers to a graduated model, including *perception* of what is happening in the vicinity, *comprehension* of that information, and *prediction* of its impact on one's goals and objectives (Wickens, 2008). Decisions or judgments can be made, once an understanding of the situation has been gained. However, measurement of decision making is notably difficult to perform, as valid reproducible conclusions depend on both process and outcome measures, and assessment of process often depends on the user's limited ability to consistently define and report their own cognition.

While the role of situational awareness has been examined within challenging work domains such as air traffic control, military navigation, and aviation, research has yet to focus intensively on ways to support the user in developing and maintaining awareness when performing day-to-day attention-demanding tasks, where the visual channel may not be fully available to monitor the wider environment. Research has also been generally limited regarding tactile interaction through head-mounted devices (HMD) compared to other wearable forms. This avenue of inquiry has generally been concerned with assistive applications for

* Corresponding author.
E-mail addresses: flynn.wolf@umbc.edu (F. Wolf), rkuber@umbc.edu (R. Kuber).

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distracted or visually impaired pedestrians, or for users in loud or stressful environments. Despite these research trends, the head holds promise as a location for tactile interaction research, given the large cutaneous surface area and potential for intuitive integration with hands-free eye and headwear. These types of devices, including networking and augmented vision capabilities which could integrate with tactile alerting, are entering the consumer and professional market.

This paper describes two experiments conducted with the intent of measuring how effectively a tactile coding scheme might be understood by users of a wearable, head-mounted device under realistic conditions. The **first study** was a perceptual experiment, conducted using the head-mounted device, to explore three aspects of user interaction with 3-parameter tactile cues. Firstly, we assessed user precision in interpreting 3-parameter tactile cues (hypothesis H1.1: Identification error rates will be no higher than 15% for a three-parameter tactile stimuli identification task, similar to rates identified in other studies (e.g. Qian et al., 2014) where three-parameter tactons were presented). Secondly, we examined the effect of a realistic distraction condition on accuracy of parameter identification (hypothesis H1.2: When the user is engaged in a visually demanding task, performance accuracy of a tactile signal identification task will decline, compared to a visually unencumbered condition), and upon subjective cognitive workload measures (hypothesis H1.3: When a user is engaged with a visually demanding task, perceived cognitive workload levels will be higher, compared to a visually unencumbered condition). These hypotheses are described in Section 3.1. The parameters of location, waveform, and interval (essentially, the rhythmic pattern of pulses in a signal) were manipulated, with the aim of identifying combinations which are easier to discern. The **second study** investigated two aspects of users' ability to maintain understanding of a realistic pedestrian scenario ("tactile storyline") portrayed through multi-parameter tactile icons, presented through a HMD. Firstly, we measured whether levels of realistic exertion (sitting stationary, walking slowly, and walking quickly) increased self-reported cognitive workload when identifying tactons (hypothesis 2.1), and secondly, whether those exertion conditions reduced 3-level situational awareness measures in a SAGAT method assessment (Hypothesis H2.2). These hypotheses are described in Section 4.1. In our first study, we conclude that: (a) users can identify 3-parameter signals with relatively low error despite difficult combination effects (conclusion C1.1, Section 3.5), and (b) visual and cognitive distraction impacts pattern and location parameter identification (conclusion C1.2). In our second study, we conclude that: (a) exertion does impact CW and should be carefully accounted for (conclusion C2.1, Section 4.5), and that (b) users' improvised interpretations of coding should also be carefully accounted for in tactile applications (conclusion C2.2), and that (to support user situational awareness) parameters for dynamic tactile signals should be chosen to map intuitively to realistic conditions (conclusion C2.3).

2. Related work

This research attempts to join and build upon existing studies on design of tactile cues, and their suitability to wearable applications under real world conditions. Additionally, we discuss how this type of tactile design has been combined with performance measurement from the domain of situational awareness. Specifically, we survey several methods utilized to attempt to quantify situational awareness conditions (i.e. perception, comprehension, prediction).

2.1. Wearable tactile interfaces

Tactile wearable displays, given their practical potential to augment other sensory channels and assist in maintaining spatial orientation and situational awareness, have been studied in many forms, such as belts, vests, bracelets and gloves. Many of these wearable devices have been torso-based, to take advantage of natural circumferential mapping and hands free configuration. Examples include research by Chiasson et al. (2003) on the Tactical Situation Awareness System – Special Forces (TSAS-SF), and van Veen and van Erp's (2003) research on a tactile vest for pilots. The TSAS-SF is a belt-based spatial orientation and navigation system fielded by the U.S. military in different configurations for pilots, scuba divers, and land navigation. Chiasson et al. assessed efficacy in improving situational awareness by scattering small test objects across a navigation course. A TSAS-enabled group outscored a control group equipped with handheld GPS units, 9.25 versus 5.25 out of 20, in spotting and tallying the objects while crossing the course. van Veen & van Erp researched spatial cues to trainee helicopter pilots in simulated hover and low level flight tasks, using a vest with 128 embedded tactors. Across several modes of spatial cues, the tactile display improved pilot performance. Performance with a parallel auditory memorization task was also found to be more resilient with the tactile aid (van Veen and van Erp, 2003).

While most tactile feedback solutions examined have been torso-based, other innovative locations have been studied. These forms included wrist-mounted displays to guide users' physical articulation (Weber et al., 2011; Sergi et al., 2008), or convey robot interaction (Scheggi et al., 2012). In a review by Lindeman et al. (2005), the researchers describe the studies by Yano et al. (1998), which involved presenting tactile information at the thighs and palms, and Kume et al. (1998), where stimuli were presented at the soles of the feet. In the latter study, users wore a slipper-like interface embedded with tactile actuators.

2.1.1. Head-mounted displays

Head-mounted tactile displays are a focus of this study. Research suggests that the head offers considerable potential as a location for presenting tactile cues to spatial and situational hazards. For example, Gilliland and Schlegel (1994) found that participants' accuracy at localizing directional cues presented on the head increased as the number of localization sites decreased (93% accuracy for 6 sites, to 47% accuracy for 12 sites, across the parietal meridian of the head). Sand et al. (2015) also studied tactile augmentation of Oculus Rift virtual reality headwear, as a location for entry and interpretation of gestural input. Similarly, Cassinelli et al. (2006) found additional qualitative support for this type of interaction. 87% of their participants, equipped with a head-mounted "haptic radar" device, could easily adopt tactile signaling to avoid unseen hazards.

Participants in the study by Dobrzynski et al. (2012) were presented with tactile cues via a head-mounted array. Findings revealed that participants were able to accurately localize the position of multiple tactors concurrently. Identification accuracy differed significantly for different locations on the head, and declined as the number of tactors increased, suggesting that displays with simultaneous signals may be difficult to interpret. Myles and Kalb (2010) also identified that certain regions of the head (parietal, occipital and temple regions) were found to be the most sensitive to vibration stimuli, and consequently more accurate in perceiving cues from HMDs. The researchers suggested optimal frequency ranges for the head, and found recommended auditory and tactile signal frequencies for scenarios masking auditory effects (e.g. noisy industrial or military conditions). Further research undertaken by Myles and Kalb (2010) regarding perceptual thresholds for the scalp confirmed glabrous skin was generally more sensitive than the scalp, and identified effective frequency ranges for those thresholds.

2.2. Situational awareness

There has been a relatively limited amount of research into the interaction of situational awareness constructs with tactile coding through wearable tactile devices. This is despite the relatively unobtrusive form of most tactile displays, and their access to a generally underutilized sensory mode. Prasad et al. (2014) examined the use of a 3×3 grid of tactile actuators attached to a handheld device to examine interpretation of haptic icons, to support soldiers' situational awareness through