Tactile Situation Awareness System (TSAS) as a Compensatory Aid for Sensory Loss

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Abstract – The Tactile Situation Awareness System (TSAS) began as a sensory cue to counteract pilot spatial disorientation. More recent adaptations of TSAS provide feedback for postural instability and spatial cues for persons with hearing loss. This demonstration included a brief presentation on past TSAS developments and recent applications. Attendees experienced an interactive demonstration of the TSAS hover-drift countermeasure for helicopter pilots, as well as recent applications of vibrotactile cues for looming, for postural stability, and for aiding target localization in pilots with noise-induced hearing loss.

OBJECTIVES

The purpose of this demonstration was to educate human factors and ergonomics (HF/E) professionals about recent developments and applications of the Tactile Situation Awareness System (TSAS; Rupert, 2000). The presentation summarized the origins of TSAS and efforts to expand its utility within the aviation and medical domains. The presentation was followed by interactive demonstrations with audience members.

BACKGROUND

The benefits of providing users with vibrotactile cues have been increasingly recognized over the past 15 years. Vibrotactile displays have been adopted for supplementing or replacing degraded visual, auditory, or kinesthetic information in several contexts. Applications include presenting alerts and alarms (Bliss, Liebman, & Brill, 2012), communicating symbolic icons (Brewster, & Brown, 2004; Brill, Terrence, Stafford, & Gilson, 2006; Lawson, 2014), providing spatial orientation cues (Rupert, 2000), providing directional threat information (Brill, Gilson, Mouloua, Hancock, & Terrence, 2004), providing navigation cues (van Erp, van Veen, Jansen, & Dobbins, 2005), enhancing simulation and training (Coles, Meglan, & John, 2011), and communicating verbal language (Tan, Durlach, Rabinowitz, Reed, & Santos, 1997).

There are multiple advantages of tactile communication, including omnipresence, omnidirectionality, covertness, effectiveness under degraded visual conditions, effectiveness in acoustically noisy environments, and the ability to be used by persons with the most common forms of sensory disability (e.g., impaired vision, impaired hearing) (Brill, in press). Tactile displays can also benefit attentional processing, particularly if the presentation of additional visual or auditory information would overload an information channel (Lu, Wickens, Sarter, & Sebock, 2011; Scerra & Brill, 2012; Wickens, 2008).

The development of TSAS represented a major advancement in the domain of vibrotactile displays. Its initial application was to provide a ground-referenced orientation cue to pilots in order to prevent mishaps associated with misleading vestibular sensations experienced in degraded visual environments. Regardless of an aircraft's spatial orientation, TSAS allowed the pilot to feel which way was "down" via an intuitive earth-referenced vibrotactile cue. The system was later adapted for helicopter pilots to assist with maintaining stable hover; whenever the helicopter began to drift, negative feedback cues "repelled" the pilot, as though he or she was drifting into an invisible barrier. See Figure 1 for the latest incarnation of TSAS, which consists of a belt for cueing lateral drift (depicted), plus seat vibrators and shoulder-strap-mounted vibrators for cueing altitude (not depicted).
Recently, TSAS has been adapted for three new applications. First, the vibrotactile stimuli provided by TSAS can provide looming cues, i.e., indications that an object approaching the user even when the user is not able to see the object (e.g., due to distraction during vehicle operations or sensory loss associated with blindness). Second, TSAS has been adapted to provide subtle vibrotactile cues to patients with balance disorders and elderly people with insensitivity to endogenous vestibular postural cues. The system detects when a person with such sensory loss enters a state of postural instability and provides vibrotactile feedback so a person may take corrective action before a fall occurs. Third, TSAS is being adapted to provide navigation cues for pilots in noisy environments and for pilots with noise-induced hearing loss.

**SPECIFIC DEMONSTRATIONS**

The principles behind the four demonstrated applications of TSAS are as follows:

1) **Helicopter Hover-Drift.** Using a tablet computer, participants tried to maintain a stable hover of a virtual on-screen helicopter while receiving vibrotactile feedback. The helicopter is controlled by tilting the tablet. Whenever, the virtual helicopter drifts out of a stable hover, vibrotactile feedback will be presented. Taking effective corrective action in the direction opposite the vibrotactile cue will stop cue presentation.

2) **Looming.** Participants are presented vibrotactile cues yielding the perception an object is closing in on them. A vibrotactile transducer (called a "tactor") is put on a participant's forehead using an elastic strap, much like a sweatband. Vibrotactile pulses sweep from low to high frequency, providing a tactile signal analogous to the pitch and loudness change naturally associated with an approaching auditory signal and consistent with the perception of looming (Lawson, 2014). The participant perceives that a clear tactile signal (tacton) consistent with looming has occurred, just as change in pitch and loudness is a clear audicon for looming.

3) **Balance.** Participants hold a tablet computer against their chest and close their eyes. Postural sway tends to increase once a person closes his or her eyes. The accelerometer of the tablet computer provides data regarding postural sway to the TSAS, which in turn, provides vibrotactile feedback. For example, when the participant sways slightly to the right, he or she will get a vibration cue on the right side of the body indicating that sway has occurred. The participant then corrects back to the left to stay upright.

4) **Localization/Navigation Cues for the Hearing Impaired.** For this demonstration, participants attempt to use three sets of 3-dimensional audio localization cues through headphones. One set of 3D audio cues consisted of normal "full frequency" audio files, and the other two sets will be modified to simulate common profiles of unilateral and bilateral noise-induced hearing loss. Participants point in the apparent direction of the cue. Accuracy is typically poor, especially during simulated hearing loss. The TSAS display is then activated to provide simultaneous 3D audio and vibrotactile cues, demonstrating the improvement in localization accuracy, even under degraded auditory conditions.

**APPARATUS**

The demonstrations used the following equipment:
Motorola Xoom™ 10.1 inch Android™ Tablet Computer. The Motorola Xoom™ tablet weighs approximately 1.61 lbs. and has a full-color high resolution touch-screen display.

Engineering Acoustics Inc., (EAI; Casselberry, FL) Wireless Tactile Control Unit with Model C2 Tactors. The EAI wireless tactile display consists of a control unit with an internal rechargeable battery and an umbilical port for attaching a vibrotactile array (see Figure 2).

For the hover-drift and navigation demonstrations, an 8-tactor array is used. Model C2 tactors are commercially available vibrating stimulators (1.2 in. diameter by 0.31 in. tall; 17 g). The tactor array is contained within an adjustable belt capable of fitting a wide range of girths. The belt is worn around the abdomen, just above navel height. The looming and balance demonstrations use a single C2 tactor attached to an elastic hook-and-loop belt (see Figure 3).

Sennheiser Model HD280 Headphones. Studio quality circumaural headphones are used to present 3D audio cues. The Sennheiser headphones offer the advantage of sound attenuation, which helps ensure participants can hear the cues.

POSSIBLE APPLICATIONS

The applications above exist already. The TSAS hover drift cue has been demonstrated successfully in laboratory experiments, simulator flight, and real flight. It is under evaluation for potential acquisition by the Army. The tactile looming cue has been demonstrated in a laboratory experiment. The localization/navigation cue has been demonstrated in one laboratory study and is about to be tested in a second study. These looming and localization applications are not mature yet, but the authors feel that the hover drift application is ready for use in the cockpit now.

There are innumerable additional military and commercial applications of vibrotactile display technology that could be pursued. A few are listed below:

Navigation systems for first responders. First responders, such as firefighters could use an adaptation of TSAS to follow virtual breadcrumbs out of burning buildings. Moreover, police offers and SWAT members could follow tactile cues through unfamiliar environments.

Tracking unmanned vehicles. Vibrotactile displays could be adapted to give unmanned vehicle operators an intuitive sense of their vehicles' location and geographic orientation.

Spatial orientation systems for astronauts undergoing extravehicular activity (EVA). Space is an inherently disorienting environment due to the effects of microgravity on the vestibular system and the lack of a consistent visual cue for the upright. TSAS could be used to help "ground" astronauts and alleviate spatial disorientation.

Covert navigation for civilians. A version of TSAS could be developed to provide land and
vehicle navigation cues to civilians who are travelling out-of-town, but who want to avoid regularly looking at GPS and map devices.

SUMMARY

The Tactile Situation Awareness System began as a countermeasure for pilot spatial disorientation. Although its original purpose is retained, TSAS has been expanded in recent years to include applications for persons with sensory impairment, such as balance disorders, general postural instability, and most recently, noise-induced hearing loss. By providing interactive demonstrations, the authors hope HFES attendees learned more about novel applications of TSAS and understand the potential benefits of vibrotactile displays. The authors are happy to advise participants on the applications of TSAS to their own work.

DISCLAIMER

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REFERENCES


