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The effect of hair density on the coupling between the tactor and the skin of the human head

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ABSTRACT

The purpose of this study was to determine the effect of hair density on vibration detection thresholds associated with the perception of low frequency vibration stimuli applied to the head. A host of tactile sensitivity information exists for other parts of the body, however the same information is lacking for the head. Thirty-three college students, age 18-35, were recruited for the study. A mixed design was used to evaluate the effect of hair density, head location, and frequency on vibration detection thresholds. Results suggest that hair density might slightly impede vibration signals from reaching the scalp and reduce vibration sensitivity, for the least sensitive locations on the head. This research provides design recommendations for head-mounted tactile displays for women and those with hair that can be used to convey directional cues for navigation and as alerts to critical events in the environment.

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1. Introduction

When the quantity of information transmitted through one sensory modality increases, the information channel may become overloaded and the person will likely become incapable of processing future incoming information via that mode. As a result, situation awareness and overall user performance will decrease. In such a situation, tapping into and making use of the different perceptual resources of other modalities will lessen the chance of decrements in user performance, and reduce the chance of any one sensory mode becoming overloaded with information (Wickens, 2002). Oviatt (1999) provided an excellent description of the system effectiveness that can be obtained via the simultaneous transmission of information via several sensory modalities: “well-designed multimodal systems integrate complementary modalities to yield a highly synergistic blend in which the strengths of each mode are capitalized upon and used to overcome weaknesses in the other” (p. 74). Thus, save for the visual and auditory modalities, the skin has also been emphasized as an input modality that can be beneficial for the transmission of information, especially in adverse environments (de Vries, Van Erp and Kiefer, 2009; Elliott et al., 2010; Ferris and Sarter, 2009; Jones et al., 2006; Jones and Sarter, 2008; Oskarsson et al., 2012; Piateski and Jones, 2005; Raj et al., 2000; Van Erp, 2001; Verillo, 1966). One example of using the skin to communicate is the tactor-based Tactile Situation Awareness System (TSAS), which was developed to help military pilots mitigate accidents attributed to spatial disorientation. Spatial disorientation occurs when a pilot is unaware of his orientation in space and cannot interpret if the aircraft is heading up or down. The TSAS was introduced as an alternative (to a visual or auditory system), torso-based, tactile solution designed to help pilots overcome spatial disorientation (Rupert, 2000). Through a series of test flights, pilots were able to successfully perform basic maneuvers through the sole use of tactile cues via the TSAS with no visual cues available (Rupert, 1997, 2000). As Oviatt (1999) declared, the TSAS's strength compensated for the perceptual and situation awareness shortfalls experienced by pilots using aircraft visual displays, which according to Rupert (2000) were sometimes a result of the physiological and cognitive changes that occur during flight.

Tactile systems have also improved the quality of care in the operating room and aim to increase the safety of occupants in automobiles. Researchers developed a waist-mounted tactile display and analyzed its capability in helping anesthesiologists to reduce their response times in treating simulated incidences of anaphylaxis (Ford et al., 2008). Diagnosis and treatment response times for

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anesthesiologists using the waist-mounted display were significantly lower than for anesthesiologists who used standard methodology to diagnose and treat anaphylaxis. A tactile (via seat vibrations) crash avoidance system has been reported as being better in alerting drivers to the location of a potential crash threat than an auditory-only crash avoidance system (Fitch et al., 2007). Scott and Gray (2008) explored the benefit of using tactile signals to warn drivers of a pending rear-end collision compared with visual and auditory warnings, and reported that tactile signals were most effective in warning of a potential rear-end collision. Mohebbi et al. (2009) extended the work of Scott and Gray (2008) to cell phone use while driving, and also found that a tactile rear-end collision warning system was more effective for drivers engaged in cell phone conversations than visual and auditory rear-end collision warning systems.

Most of what is known regarding the tactile modality is based on the research of tactile stimulation of the fingers and hands (Bolanowski et al., 1988; Morioka et al., 2008; Rabinowitz et al., 1987; Stuart et al., 2003; Verrillo, 1962; Wilska, 1954), and on the results of the applied studies in which the tactors were placed on the torso, abdomen, or arm (Bodenhamer et al., 2012; Cholewiak et al., 2004; Cholewiak and Collins, 2003; Morioka et al., 2008; Ooshima et al., 2008; Piateski and Jones, 2005; van Erp, 2005). For example, the potential for limited soldier-to-soldier communication due to degraded visual conditions on the battlefield prompted the design of a torso-based tactile communication system for conveying Army hand-arm signals (Brill et al., 2006). Eriksson et al. (2008) designed a 12-tactor torso belt to test its capability to substitute for a standard visual GPS display for soldier land navigation. Similar to the objective of Eriksson et al. (2008), Dorneich et al. (2006) designed an eight-tactor, torso belt. In the last decade, a good amount of research, knowledge, and work has been expended on improving tactile devices for torso and arm applications (e.g., Brill et al., 2006; Dorneich et al., 2006; Enriquez et al., 2001; Ford et al., 2008; Rupert, 2000; Van Erp, Van Veen, Jansen and Dobbins, 2005) in the hope of alleviating high mental workload often associated with the concurrent use of systems that rely on the same sensory modality (Wickens, 2002).

As a result of the exclusive placement of tactors on the torso to facilitate tactile communication, there is a large gap in knowledge (e.g., tactile sensitivity, detection thresholds, localization accuracy) regarding guidelines for the use of tactile devices anywhere other than on the torso, most notably on the human head. Therefore, significant research is needed to identify psychophysical measures and guidelines to build effective tactile devices for stimulation of the human head, such as those studied by the U.S. Army Research Laboratory (ARL) for use by the U.S. Army infantry soldier. For head-mounted tactile displays, tactors are placed on the head and low frequency pulsing tactile signals are used to convey directional cues for navigation or to alert soldiers to critical events in the environment (e.g., direction of sniper fire). Although the head has been currently accepted by a few researchers as a viable location for placing tactile devices (Bikah et al., 2008; Gilliland and Schlegel, 1994), this is still a fairly uncharted body location for providing information via tactile signals.

While a host of tactile sensitivity information exists for other parts of the body, the same information is lacking for the region of the head. Objective tactile sensitivity data for the head are scarce but are needed to ensure that tactile systems designed for the head are compatible with the sensitivity of the user. The most comprehensive data for tactile sensitivity of the head are provided by the early work of Weber (1834/1978), Weinstein (1968), and Wilska (1954), with almost no follow-up studies within 40 years. Weber (1834/1978) observed that the entire head/scalp is not equally sensitive, and that the crown of the head is less sensitive than the skin near the forehead, temples, and lower part of the back of the head. Weinstein (1968) reported that the face (forehead included) was most sensitive to pressure and for point localizing when a point of reference was used. Wilska (1954) revealed that displacement thresholds for the head were higher than 70% of all the other body locations tested, with thresholds for the head ranging from 4 μm at 200 Hz to 19 μm at 50 Hz. Following this early repertoire of research, Gilliland and Schlegel (1994) are the only contemporaries to report human perceptual measures associated with the detection and localization of tactile signals applied to the head. They reported a detection threshold of 17.5 V (130 g force) for the parietal region of the head. Similar to the findings of localization for the torso (Cholewiak et al., 2004), Gilliland and Schlegel (1994) found that localization accuracy on the head increases as the number of localization sites decreases. In an attempt to mount a tactile system on the head as an alert mechanism to warn users of the presence of radiation in the environment, Bikah et al. (2008) evaluated a number of body locations to use for such a tactile system and reported low frequency (.68–.80 Hz) vibration thresholds for various regions of the head. More of this type of objective tactile information is needed to design, implement, and advance tactile devices for the head.

More recently, Myles and Kalb (2009, 2010) have obtained tactile detection thresholds for the head perimeter and the scalp, and confirmed the findings of Weber (1834/1978), but only for those with little to no hair. They also reported tactile detection thresholds for all regions of the head extending the work of Gilliland and Schlegel (1994). Aligned with the research motives of Gilliland and Schlegel (1994), this study obtained data to improve a head tactile display—specifically, a display to convey directional cues for navigation or to alert soldiers to critical events in the environment. The current study extends Myles and Kalb (2009) and is aimed at determining the effect of hair density on detection thresholds associated with the perception of low frequency vibration stimuli applied to the head. In addition, this study extends the use of head tactile technology to women and men with dense hair by ensuring tactile signals are appropriately amplified for the user population with hair.

2. Method

2.1. Apparatus and stimuli

2.1.1. Headband and tactors

Seven C2 tactors from Engineering Acoustics Inc. were mounted in a headband designed to hold one tactor at each of seven chosen head locations (Fig. 1). The locations were selected from the set of locations used in the international electroencephalography (EEG) 10-20 system of electrode placement (Jasper, 1958) and are shown in Fig. 1. Head locations were randomly chosen such that when combined, a representative from each head region was included: F3 and F8 (frontal region), CZ (central region), PZ (parietal region), T3 and T4 (temporal region), and O2 (occipital region). To accommodate the differences in the head size among the participants, three headbands of size small (50–54 cm), medium (54–58 cm), and large (58–62 cm) were used in the study. Tactor placement at each head location was fixed for each headband.

2.1.2. Vibrotactile signal

The computer-generated vibration signal consisted of three pulses of 32, 45, or 63 Hz tone shown in Fig. 2 consisting of three parts—rise, sustain, and fall—each having the same durations. Rise and fall both followed a raised cosine response, while the sustained level was equal to 1.5 V. The signal produced at the output of the computer was sent to an external circuit board for power level