Chapter 13

HAPTIC: Haptic Anatomical Positioning to Improve Clinical Monitoring

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Abstract

Hospitals are inundated by the sounds of patient monitoring devices and alarms. These are meant to help, yet also create a stressful environment for physicians and patients. To address this issue, we consider the possibility of delivering complementary haptic alarm stimuli via a wearable tactile display. This may reduce the necessity for the plethora of audible alarms in the Intensive Care Unit and Operating Room, potentially decreasing fatigue among clinicians, and improving sleep quality for patients. The study described here sought to determine a suitable anatomical location where such a tactile display could be worn. Although the wrist is an obvious default, based on the success of smartwatches and fitness monitors, wearable devices below the elbow are disallowed in aseptic procedural environments. We hypothesized that haptic perception would be approximately equivalent at the wrist and ankle, and confirmed this experimentally. Thus, for a healthcare setting, we suggest that the ankle is a suitable alternative for the placement of a tactile display.

Keywords: multisensory integration, tactile displays, medical alarms, clinical performance, patient monitoring

1. Introduction

Hospital environments (ICU) are stressful in large part due to the proliferation of auditory alarm systems, with a typical multibed care area generating 30 different alarm sounds [1]. Despite advances in medicine, the numerous alarms in the operating room (OR) and intensive care unit (ICU) are mostly unnecessary. With only 17% of alarms having clinical relevance [2, 3], these are more often the cause of information overload, clinician fatigue, and sleep deprivation among patients [4]. These problems are exacerbated by the high sound pressure level (loudness) of alarms, typically approximately 51 dB, or 15–20 dB louder than the level recommended by the World Health Organization (WHO) [4].

The excessive resulting noise in the OR and ICU can also cause physicians to suffer from alarm fatigue, the phenomenon of diminished response due to desensitization to the alarm stimulus [5]. As a result, alarms no longer serve their purpose, and instead, may place the patient's safety in jeopardy. Alarm fatigue is an issue that must be addressed: the MAUDE database of the US Food and Drug Administration (FDA) reported 500 alarm-related patient deaths from 2010 to 2015 [6].

One approach to reduce the negative impact of alarm systems would be to implement a personalized and multimodal system that would combine both auditory and haptic cues to communicate physiological information. The result of adding haptic cues to an auditory interface has been shown to increase the bandwidth of information transfer in complex settings [7]. The question then is where such a display should be placed.

To address this issue, the experiment we describe in this chapter examined human perception with haptic input presented to either the wrist or ankle. The former was chosen because of the current literature and success of wrist-worn devices, such as personal fitness monitors, in the commercial market. However, the wrist is not a feasible option for the OR and ICU setting, due to the need for an aseptic environment. Thus, we examined the ankle as a potential site, as it shares several properties with the wrist, which is easily accessible, and is not subject to the same sterility requirements.

2. Literature review

Tactile displays are tools that use vibrotactile (VT) and electrotactile (ET) stimulation technology to employ the sense of touch for the representation of information [7]. These displays are often used for the purpose of sensory substitution, that is, compensating for missing or impaired sensory functions such as sight. For example, visual cues can be provided through an arrangement of tactor pins that give feedback about the users' surrounding environment [8]. Tactile displays can also be used to augment typical sensory function, e.g., to provide an error signal in the sway of an individual, helping them correct their posture and improve balance [9]. The compensation of impaired sensory function and augmentation of typical sensory function occurs by manipulating vibration frequency patterns to give feedback and encourage a closed-loop communication of tactile input and human response. The vibrational stimuli known as tactons are essentially the tactile equivalent of visual icons. Tactons have a wide array of uses, from medical devices that help guide the visually impaired to the communication of non-visual information in electronic devices.

Both Sato and Gescheider et al. found that vibration perception is affected by two factors: frequency and ambient temperature [10, 11]. The lowest threshold of perception on the fast-acting skin receptors was measured in the frequencies of 150–300 Hz under conditions of ambient temperature of 21–26°C [10].

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The method of communication via vibrational stimuli has been shown to be an effective manner of attracting attention in a subtle way, especially in loud and crowded environments without other environmental interference [12]. Although tactile displays have had success in locations all over the body, the most common commercial applications involve wearable devices on the wrist. In medical environments such as the OR or ICU, this may be problematic, since the hands and lower arm are often required to be free of any accessories. The WHO recommends surgical hand scrub/preparation using antimicrobial soap and water to maintain the least contamination of the surgical site during a procedure [13]. Any device worn from the elbow and distal toward the hand compromises the hygiene of the surgical environment and yields the possibility of contamination. This motivates our research into tactile displays that could be worn at other body locations than the wrist.

A possible solution to the concerns of asepsis in the OR and ICU with wearable devices was explored by McNulty et al. with a tactile display device worn on the upper arm. An elasticized sleeve with tactors in three distinct positions (upper, middle and lower) communicated physiologic information such as heart rate (HR) and oxygen saturation (SpO_2) to subjects, who were asked to operate a foot pedal and report the change they noticed in either HR or SpO_2 [14]. An integrated display mapped HR to spatial location of the tactor, whereas, SpO_2 was mapped temporally to the rate at which the tactors were vibrated.

One of their experiments compared two strategies for conveying heart rate, using two pairs of tactors, located at the upper and lower positions. The first strategy vibrated a single tactor in response to a heart rate that was higher or lower than normal, and vibrated both tactors in the pair for *very* low or *very* high HR. The second strategy vibrated both tactors in the pair for any heart rate higher or lower than normal. Little to no difference in identification accuracy was observed relative to the previous integrated method experiment in which both HR and SpO_2 were recorded. The differentiation of high/low and very high/very low resulted in reduced response accuracy. This could be due to the additional cognitive load of discerning whether one or two tactors were producing the vibrational stimuli. The experimenters noted that subjects experienced great difficulty interpreting the location of vibrational stimuli on the arm. This could be attributed to several factors such as tactors being placed too close together.

McNulty et al. also tested a flipped-integrated display, in which heart rate was mapped temporally to the rate at which the tactors were vibrated, whereas oxygen saturation levels were mapped to the tactor location on the arm, thus, the opposite of the mapping strategy adopted for the integrated display trial. However, the flipped-integrated display did not lead to more accurate results. This also could be attributed to issues with the discrimination of spatial information.

A study by Enriquez et al., employing the sense of touch for information representation, demonstrated that the addition of a tactile stimulus to an auditory stimulus can increase the bandwidth of information transfer in complex and data-rich environments [12]. We were thus motivated to test the hypothesis that by integrating auditory and haptic inputs, the auditory threshold of perception could be lowered, allowing for the reduction of alarm volume in the OR and ICU setting. Given the need for sterility of the wrist, we investigated the efficacy of integrating haptic stimuli at the ankle position with a non-speech (medical alarm) auditory stimulus [15]. The results, however, did not support our hypothesis. Rather, no discernable difference was observed between the measured threshold under auditory-only and auditory-haptic conditions [15].

A possible factor in McNulty's results, as well as the inconclusive results of our study, may have been the interference of haptic input with the subject's auditory perception. In McNulty's latter experiment, issues were experienced with spatial discrimination due to potential interference between both tactors. Difficulties in the task were also attributed to the interaction between the subject's motor and tactile sensory function. This suggests that interactions between sensory systems must be observed and addressed if multisensory integration is to be exploited in a wearable display device.

Sensory interference may be harder to prove as a confounding factor than finding the perfect combination of sensory input. During auditory-haptic discrimination tasks, where participants indicate perception of unisensory or multisensory stimuli above and below their perceptual threshold, there were an equal number of subjects who were biased toward the auditory stimuli as they were toward the haptic stimuli [16]. Similar factors may have been at play in the lack of significant results seen in our study [15], and we cannot yet offer a conclusion as to whether one modality enhances the perceptual effect of the second modality. This can be attributed to Bayesian inference principles—either the haptic or auditory modality may be imperfect and therefore supported by the other sense to give a complete picture. Due to the random nature of which sensory modality dominates, multisensory integrative displays may have to be tailored to the individual interacting with the display technology.

3. Experiment design

This study was approved by the Research Ethics Board at McGill University in Montreal, Canada. Before the experiment, the participants signed a consent form and completed a pre-test questionnaire consisting of demographic information and whether they have health issues affecting their sense of touch and vibration perception. The subjects (n = 9, 6 male, 3 female, ages 21–44 years of age) were members of the Shared Reality Lab in the McConnell Engineering building at McGill University and took part in the study voluntarily. The duration of the experiment was 20 min long and the participants received no compensation for their participation.

To compare haptic perception between two different anatomical locations on the body, we conducted pilot tests in our laboratory environment, using a random double-staircase method. The subject is presented with two staircases: one starts with an intensity above the vibration perception threshold, and the other with an intensity below the threshold. The superiority of this method over the upward staircase method, as used by Williams et al. [17] to measure perception thresholds, has been discussed by Cornsweet [18]. With the upward staircase method, subjects tend to be biased in their subsequent responses after several identical responses.

Each stimulus was delivered randomly within a 10 s window following the previous one. The intensity of the vibration increases when a stimulus is not perceived by the subject and decreases otherwise. To ensure fast convergence of the two staircases, the step size was relatively large at the beginning, and reduced as the two staircases approach. Subjects had to respond within 1 s following stimulus presentation by clicking on a button displayed on the user interface; otherwise it was assumed that the stimulus was not perceived. The threshold measurement was terminated when six reversals were recorded, i.e., after six negative responses followed by a positive one, or vice versa. The threshold was then calculated as the mean of the twelve intensity values over the period covered by the six reversals.

The vibration stimulus presented in each step of the staircase was generated using a 1-s sine wave at a frequency of 175 Hz, delivered by a Tactile Labs Haptuator Mark I (Montreal, Canada) [19], attached to the ankle by a Velcro strap, as shown in **Figure 1**. The motor was connected to a Sparkfun TP2005D1 audio amplifier (Boulder, CO, USA), and controlled by a script written in MATLAB R2016a (MathWorks, Natick, MA, USA).

The independent variable was the choice of delivery location of the vibration: either to the subject's leg or arm, as shown in **Figure 2**. For the leg condition, the strap was attached snugly to the ankle with the exact position of the vibrating motor, chosen to minimize discomfort caused by the vibration. For the arm condition, the position of the vibrating motor on the subject's wrist corresponds to similar placement for watches or fitness monitors. Participants were asked to keep their leg and arm stable when the vibrating band was attached.

During the experiment, pink noise, commonly used to mask background distracting sounds, was delivered to the participants through a pair of Beats Solo3 headphones.

Figure 1. The vibrating band used in the study consists of a Haptuator attached to a Velcro strap.

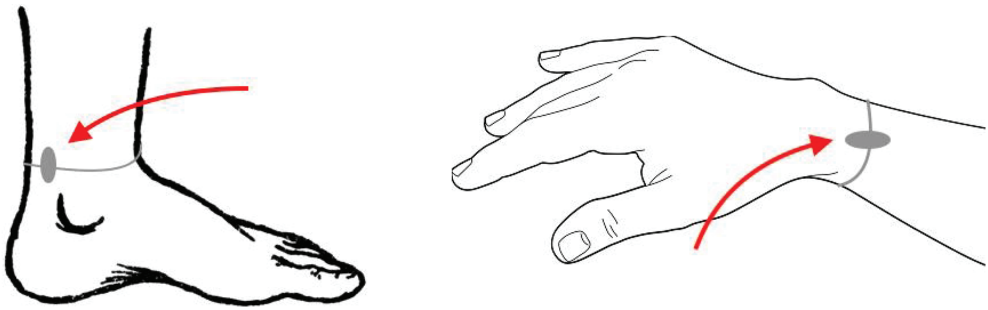

Figure 2. Position of the vibrating motor on the participant's ankle and wrist.

4. Results

Figure 3 illustrates the staircases obtained with the vibrating band attached to the ankle and wrist of one participant. Note that the units of measurement were dependent on the specific combination of equipment and software used.

The threshold and standard deviation of the intensity values over the last six reversals in both cases were calculated, as described above. An ANOVA was then performed to test the influence of position of the display device on the threshold of perception or the standard deviation of perceived intensities during the last six reversals. Excluding the data from one outlier participant who suffered from a wrist injury, the ANOVA showed that the null hypothesis cannot be rejected: device position did not produce a significant difference in either threshold ($p > 0.1$) or standard deviation ($p > 0.5$). These results support our decision to work with the device worn at the ankle position.

5. Conclusions

In the OR and ICU, an aseptic environment is required to prevent potential surgical site infections, which may harm or jeopardize the health and safety of the patient. To ensure an aseptic environment is maintained, all equipment is sterilized and any individual handling the equipment or involved in the surgical procedure must perform a surgical hand scrub. Thus, all wearable devices below the elbow are prohibited as options for a haptic display device. In this study, we have shown that the ankle offers a location for which haptic perception properties are similar to the wrist. It is therefore a more suitable anatomical position for a tactile display device because of the lack of interference with standard surgical sterilization and hygienic practices and guidelines.

Future experiments will test the efficacy of monitoring several different physiologic parameters, such as heart rate, oxygenation, and blood pressure. Communication of important physiologic data via a haptic modality may allow for fewer audible medical alarms as clinicians are aware of the trend of a patient's status and gain a new-found ability to provide proactive and safe patient care.

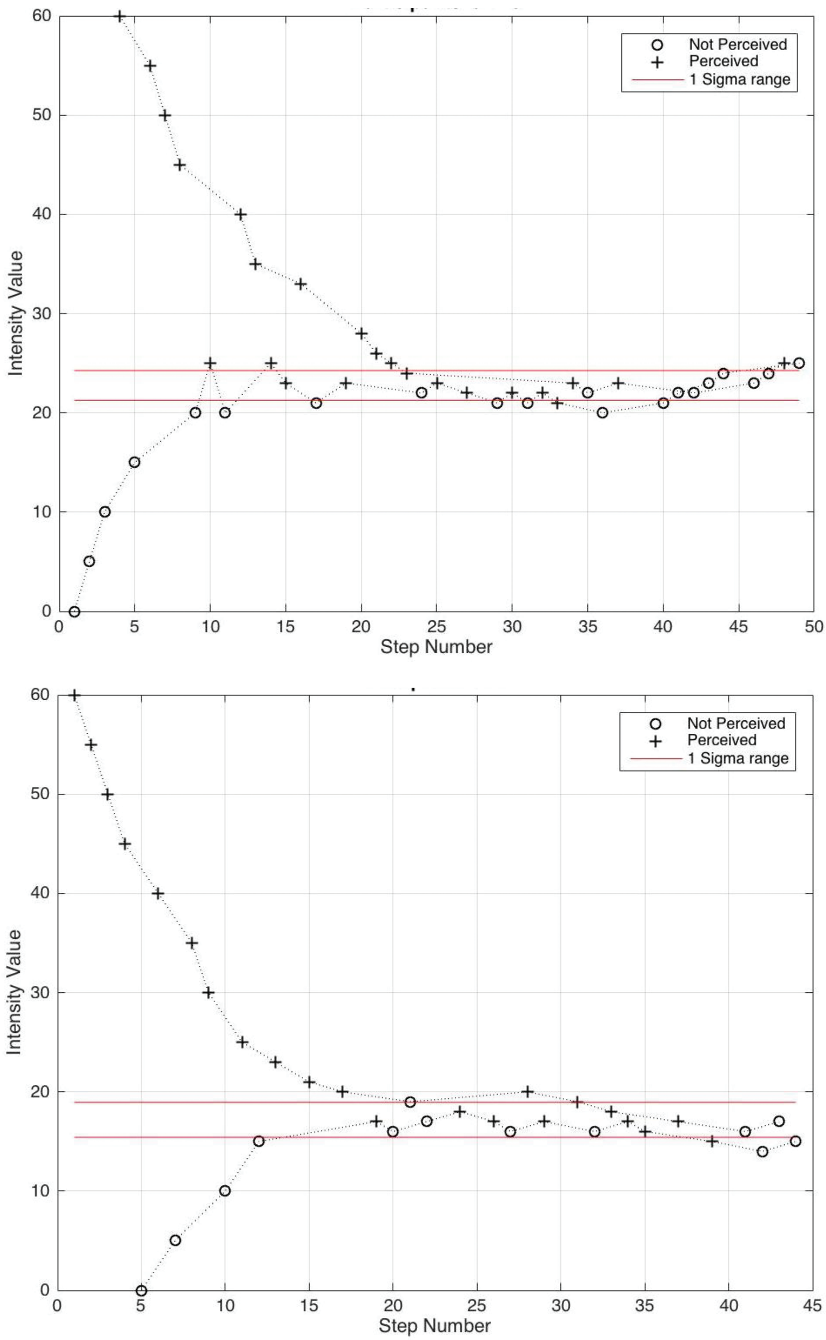

Figure 3. Sample staircase of participant's responses to the vibration stimuli delivered to the ankle (top) and wrist (bottom).

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