Pre-print: Wolf, F. & Kuber, R. 2014: Developing Tactile Feedback for Wearable Presentation: Observations from using a Participatory Approach. In Extended Abstracts of Mobile HCI 2014, Toronto, Canada, 543-548.

Developing Tactile Feedback for Wearable Presentation: Observations from using a Participatory Approach

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MobileHCI '14, Sep 23-26 2014, Toronto, ON, Canada
ACM 978-1-4503-3004-6/14/09.
http://dx.doi.org/10.1145/2628363.2634230

Abstract
In this paper, we describe a participatory-based approach to developing tactile feedback for a head-mounted device. Three focus groups iteratively designed and evaluated tactile interaction concepts for user-generated use-case scenarios. Results showed productive design insights from the groups regarding approaches to tactile coding schemes addressing the scenario conditions, as well as method-innovations to participatory design techniques for interaction development in unfamiliar sensory modalities such as touch. The study has culminated in the development of a library of tactile icons relating to spatial concepts, which will be tested as part of future work.

Author Keywords
Participatory design; tactile; situational awareness

ACM Classification Keywords
H.5.2. User Interfaces: Haptic I/O

General Terms
Human Factors

Introduction
Tactile feedback has been widely researched for its potential to mitigate sensory overload by offering an additional sensory channel for users. The wide potential

Example Tactile Use-Case Scenarios (1-3 of 7)
1. Julia is a 22-year old, able-bodied college student. She is riding her bike, while wearing our prototype device, and receives a text message. How should that text event to be communicated to Julia by the device? 2. Julia is also expecting an important phone call while she is on her bike ride. How can that event be communicated by the device? How should the alert be different for another call from someone Julia does not consider urgent? 3. Julia's device visually detects an obstacle directly in front of her, in her direction of travel, a tree branch at head-height. How should the device alert her to this? Should this alert be different if the detected obstacle is on the ground?

Table 1. Example tactile use-cases derived from user survey responses

for using tactile stimuli to improve human users' spatial perception and decision making has been explored in rigorous real-world scenarios. In these cognitively and perceptually challenging work domains, such as aviation, industrial control, and military command and control, a user's perception, understanding, and ability to anticipate events in their environs, or situational awareness (SA), has also been the subject of active research and development [6]. A wearable tactile interface can offer considerable promise to provide this information. A review of the development of systems combining tactile feedback and situational awareness demonstrates that embedding tactile cues into control interfaces is a complicated human factors challenge, requiring care to avoid compounding common breakdowns in situational awareness. Creating these useful interactions requires research practices focused on the challenges inherent in assessing tactile feedback [1]. These challenges include eliciting detailed design ideas from users, due to the novelty of the task and the general difficulty of describing tactile feedback. A participatory design approach that accounts for the unfamiliarity of tactile signal parameters and descriptive terminology, and allows the user to work in concert with the tactile designer, could offer one method of helping overcome these barriers.

This paper therefore describes method-innovations and design conclusions from a participatory design process applied to the development of a tactile interface. This interface is intended to support the redirection of a user's attention via tactile cues to the head regarding realistic situational events such as spatial obstacles. Using a participatory approach, users were encouraged by several methods to take an active role in the tactile design process. These methods included an exercise to develop participants' shared descriptive vocabulary by associating tactile and sensory-related terminology with sample cues, and visual and tactile aids that overlaid user-generated use-case scenarios and tactile alert prototypes for an interface.

A head-mounted device was chosen for development for several reasons. Wearable head-mounted sensing devices are now entering broad use, and research on their potential as conduits for tactile alerting is limited compared to vest or belt-based approaches. Additionally, a head-mounted device supports study of attention redirection between a broad range of realistic, hands-free tasks, while providing valuable localized alerting to important situational events. As researchers have yet to focus in depth on the perceptual issues involved with presenting tactile cues to sites on the head, our studies aim to contribute to the knowledge in this area, and generally to effective participatory design approaches for unfamiliar modalities such as touch.

Related Work

Given its practical potential to augment other sensory channels and assist in maintaining spatial orientation, tactile feedback has been well-studied with regard to navigation. In their study of route navigation, Jacob et al. [1] found cognitively distracted users had better post-trial recall of their geographic environment when assisted by tactile cues in their task. Obrist et al. [5] utilized the explicitation interview technique to gather and analyze fourteen categories of user-structured vocabulary for the diachronic and synchronic structure of tactile signals presented to mechanoreceptors of the hand. Myles and Kalb [4] identified significant effects for scalp location and frequency threshold for vibration signals presented via a head-mounted tactile array. As research has yet to focus upon the design of cues which are most meaningful to users for head-based presentation, a study was developed to address this.

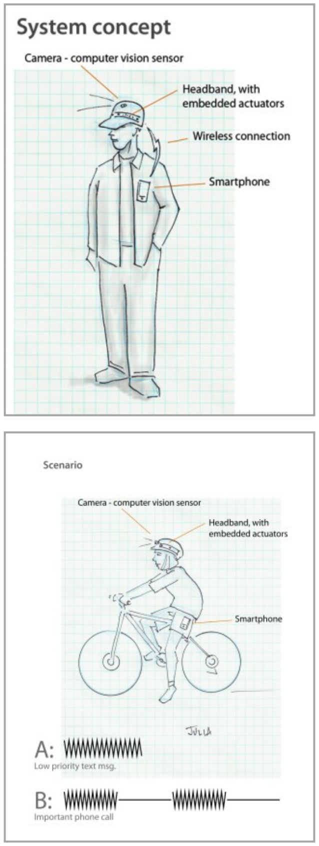

Figure 1. Visual aids presented to focus groups participants. At top, an initial system concept illustration. Beneath, a use-case scenario cartoon, with annotated waveform design concept created by a previous focus group.

Study Design

A participatory design approach was adopted, enabling the users to play an active role in the design process. The approach was also thought to reinforce consideration for real world usage contexts, aspects of which may be unfamiliar to the developer [2]. The method would also offer a means to obtain a greater buy-in from the user community, leading to an improved sense of contribution and confidence to the conclusions and products of the process [3]. Scenarios were presented to participants as part of the approach. These were intended to focus design teams on better helping and empathizing with the situational awareness needs of potential users.

In order to inform the design of scenarios, a twenty-question survey was first developed and administered online and in-person to collect user descriptions of real-world experiences in which their situation awareness and task performance had been impaired, and how their daily use of mobile technology impacted those scenarios. The attentional and environmental factors the survey participants described were then coded and categorized, yielding seven representative use-case scenarios (Table 1). These scenarios were then used as participatory design challenges, tasking users and developers with formulating tactile signals with which to convey contextualized situational cues addressing each realistic scenario and common multitasking conditions.

Three focus groups were assembled, with each group comprised of 3-5 participants (aged 21-49), who had experience in situations where additional spatial or situational awareness of surroundings or events would have helped them. Researchers familiar with tactile interface design were also present at the focus groups to offer insights on the types of feedback developed for other systems which had proved to be useful for purposes of interaction.

Focus Group Procedures

As part of the introduction of the focus group task, participants were encouraged to assume all aspects of the project, including the possible applications and hardware and interaction design, were open to their modification and suggestions. Terms such as situation awareness and tactile feedback were also defined. Participants were then asked to comment on several example vibration signals, in order to establish a common vocabulary regarding the parameters of these signals. This vocabulary exercise was intended to allow participants to share a descriptive basis for discussion and conceptualization. In contrast with auditory terms, tactile terms are known to be difficult to naturally verbalize.

The participants were prompted to comparatively describe the signals using a worksheet with four categories of tactile signal parameters and corresponding example terms (Table 2). Participants were asked to comment and elaborate upon those terms. These procedures were also employed at the outset of the two following focus groups. The sample tactile signals were presented in the first focus group through a standard Android smartphone using Immersion’s Haptic Effect Preview application, as it

Descriptive Term	Examples
Duration	Short, long, intermittent, repetitive
Amplitude	Low, mild, harsh, loud, variable
Waveform	Smooth, harsh, soothing, startling, rough, abrasive
Miscellaneous	Pleasant, unpleasant, distracting

Table 2. Tactile vocabulary worksheet

enabled the designer to develop and modify cues quickly. In successive groups, cues were then presented via the tactile actuators of the head-mounted device prototype (Fig. 2). The headset, originally described in detail in [7], presents signals up to eight sites on the user's head, controlled by software. Participants referred to the vocabulary sheet frequently, sometimes running a finger across the descriptive terms to evaluate its match with the participant's impression of the signal. The rapid uptake and use of the vocabulary was demonstrated by some participants' choice to directly reference the terms from the provided worksheet. This suggests that a longer list, explored by capturing and expanding upon participant responses in real-time, could have practical value in enriching the participants' design discussion.

The participants were then shown a simple sketch of the proposed tactile-SA system (Fig. 1), including a visual sensor mounted on the front of a hat, a headband with embedded tactors at cardinal points, and a wireless connection to a smartphone. Participants were encouraged to modify or critique the system in any way, without strict concern for engineering feasibility. Following the vocabulary exercise and introduction of the prototype illustration, the series of seven use-case design challenges were presented, depicting personas dealing with realistic spatial and situational alerts. These scenarios were generated from user surveys in the initial phase of the experiment. The scenarios were intended to progressively challenge design assumptions for tactile feedback to address realistic and increasingly rigorous situational, attentional, and environmental conditions. For example, participants would first be asked to devise a tactile alert for a basic spatial threat, such as an object in the path of a user, when the visual channel was occupied (e.g. when composing an SMS while ambulatory). This was based on the common survey observation of stumbling while walking head-down. The design problem would then be compounded with additional survey-based requirements to address simultaneous alerts, such as a non-spatial event alert, or an alert for a spatially oriented threat coming from a different direction or at a different rate of speed. This was intended to provoke discussion from the participants regarding the scope and nature of a complete tactile coding scheme, which could account for realistic issues such as complexity and de-conflicting simultaneous tactile alerts.

Sketches of each use-case scenario were used to reinforce the various conditions. Participants were also provided with drawing materials, and encouraged to sketch any concepts. Drawings produced by the participants included rudimentary waveforms, illustrations of variations in signal parameters such as amplitude or interval, and alternate hardware configurations for the head-mounted device. These suggestions were collected, coded and categorized, and then added onto the scenario drawings for subsequent focus groups. Participants in successive focus groups were asked to evaluate and iterate previously proposed design concepts for conveying information via tactile feedback (Fig. 1).

Results

A number of useful observations were made by the focus groups, with several consistent across all three, such as the need to generally maintain simplicity in a tactile coding scheme, and to reuse wherever possible familiar rhythms and patterns to limit cognitive workload when resolving cues. The groups also agreed

Figure 2. The outside and inside of the current head-mounted tactile device prototype [7].

that the design of a head-mounted device had to reconcile with social concerns, such as not being so noisy or visually conspicuous as to draw unwanted attention. In this regard, the inclusion of the experience and perspectives of numerous participants supported a broad and thoughtful consideration of the prototype design and the goal of collecting ideas for conveying, via the sense of touch, that which would otherwise be difficult to convey. The groups also agreed that a head-mounted system, when presenting spatial alerts, should account for the lateral and forward extension and flexion and longitudinal rotation of the head about the neck, relative to the vector of the approaching threat. The groups also differed on several conclusions. The second group prioritized the need to allow customization of tactile cues on any device, while the third group (citing their own experience with mobile technology) prioritized the need for optimal “out of the box” performance.

Beyond these comparisons, the focus groups were also able to successfully iterate concepts for applied uses of tactile feedback, the design of situational cues, and hardware layout. For example, the third focus group built upon use-case observations from the prior groups by suggesting that tactile encoding would be better served by modes for types of travel, such as pedestrian versus bicycle or automobile. This type of iteration also occurred with the descriptions of the waveforms. Sample tactile signals, based on the suggestions from the previous group for specific scenarios, were prepared and presented to the third group. Based upon these examples, the third group was able to provide more detailed suggestions regarding situationally appropriate waveforms and patterns for tactile cues.

Discussion and Design Implications

In addition to the design conclusions of the focus groups regarding the interface, several observations can be made about the tactile-specific innovations made to the participatory approach itself. For example, successfully prototyping in an unfamiliar sensory modality across consecutive focus groups was successful, but required establishing **exercises to produce common vocabulary**. Similarly, the ability of the focus groups to successfully iterate design ideas seemed dependent on providing **specific and richly contextualized detail** to subsequent focus groups. For example, annotating descriptive illustrations of the **use-case scenarios** with detailed visual and tactile descriptions allowed subsequent participants to comprehend and elaborate upon proposed tactile cues.

This was demonstrated when the participants were challenged to design a tactile alert for the head-mounted device for a scenario where two spatial threats existed, one low to the ground and one at head height. The first focus group described basic azimuth coding on one horizontal band of tactors in the direction of the obstacles, while the second group recommended additional horizontal rows of tactors around the head, which would allow relative vertical coding of alerts. Using combined use-case and design concept visual and tactile aids, the third group then iterated upon this concept by suggesting sequential signal patterns and waveform parameters that would be suitable to the scenario and the multi-row tactor layout. Similar evolutions in design occurred across the three groups for other tactile alert conditions, such as varying the waveform, amplitude, and time interval in tactile patterns to convey changing distance to an approaching spatial threat, and the number of threats detected.

Method-innovations related to participatory signal design
1. Utilize comparative introductory exercises to establish shared descriptive vocabulary for signal parameters 2. Provide examples illustrating potentially unfamiliar signal parameters 3. Provide realistic use-case scenarios to prompt thorough consideration of potential interactions of signals and user conditions 4. To support iteration between successive focus groups, produce specific, richly contextualized, multimodal prototypes for evaluation

Example tactile signals were also provided to participants. These were often referenced in later discussion, suggesting that these examples and the vocabulary of tactile terms were effective at seeding the participants' discussion with parameters for creating or modifying tactile alerts which might otherwise have been missed. The terms provided, however, were actually used as a checklist for evaluation in one case, suggesting that the direct influence on participants of the materials provided should be carefully considered in advance.

While the participants' breadth of experience yielded clear dividends to the tactile design process, the evaluation of some use-case scenarios might benefit from deliberately selecting participants that could offer a specific perspective. For example, one participant in the first focus group offered a unique insight on the spatial aspects of situational awareness and safety from a family member who uses a wheelchair. A need was identified to convey the position of pedestrians or wheel chair users in close proximity, to better indicate when it is safe to stop without injuring others.

Conclusion and Future Work

The participatory design sessions were effective at gathering unexpected solutions to challenging tactile feedback scenarios. The approach also suggested useful method-innovations for focus groups addressing unfamiliar sensory modalities or applied technologies. These insights will be applied to a follow-on study.

Existing studies, as well as focus group feedback, regarding tactile feedback have indicated that a user's body posture and concurrent physical activity can interact and interfere with their perception of tactile cues [1]. Given this, follow-on research proposes to engage users in physical activities to assess potential masking effects of biomechanical exertion on perception of tactile signals generated in these focus groups, concurrent to realistic "neck down" multi-tasking conditions.

Acknowledgements

This research is supported by the National Science Foundation – Award No. 1352924.

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