Towards One-Pixel-Displays for Sound Information Visualization

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ABSTRACT
Deaf people or people with a situational auditory disability (e.g. wearing headphones) have limited access to surrounding sounds, such as fire alarms or people approaching them from behind. Prior work has applied sensory substitution to provide information about sound presence, type and direction to deaf people. However, there are many ways to present sound information through an alternative modality. In this paper, we investigated whether a relationship between light behaviour and sound types exists for one-pixel-displays among deaf and hearing persons. We found the *Staircase Blink* pattern to be strongly preferred for *Alarm Sounds* and the *Blink Slow* pattern for *Notification Sounds*. We believe that the preliminary findings of our work will inform future design of one-pixel-displays for sound information visualization.

Author Keywords
Assistive technology, deaf, sound visualization, one-pixel-display, sensory substitution

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Sound keeps us aware of our surroundings, such as locating people around us, detecting a dripping faucet or recognizing that someone is knocking at the door. However, deafness or situational auditory disability, such as wearing headphones, limits the access to auditory information. This can result in uncomfortable situations, such as people approaching us from behind, to dangerous situations, such as missing a car horn when crossing the street or ignoring a fire alarm. Representing auditory information through an alternative sensory channel could potentially avoid these situations.

Previous work has investigated ways to inform deaf people about presence, type and direction of sound through visual displays, such as one-pixel-displays, screens and head-mounted displays, as well as haptic displays (Ho-Ching et al., 2003; Jain et al., 2015; Matthews et al., 2005; Tan et al., 2003; Yeo et al., 2013). Although one-pixel-displays seem to have limited resolution compared to regular screens, Harrison et al. showed that they can be used to convey a device's informational state through illumination patterns (Harrison et al., 2012). Inspired by this work, we were interested to understand how one-pixel-displays can be used to provide information for different sound types such as alarming sounds. From existing work, it is not clear whether there is a relationship between pixel colour and sound type or illumination pattern and sound type. Furthermore, it is not clear whether the position of the one-pixel-display influences these relationships. Hence, the contribution of this paper is to investigate the following research questions:

Is there a relationship between pixel colour and sound type?

Is there a relationship between illumination pattern and sound type?

Does the position of the one-pixel-display have an influence on these relationships?

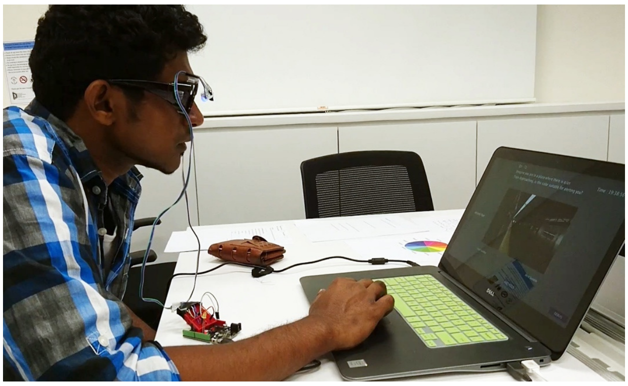

Figure 1. Study setup: participant rating the suitability of pixel colours and illumination patterns for sound samples.

We designed and conducted a preliminary study with 6 deaf and 10 hearing participants to investigate the above research questions. For the study, we compiled a list of sounds that deaf people want to be informed, based on literature and interviews. We displayed 4 contextual videos representing a subset of these sounds to deaf and hearing participants accompanied with a pixel colour or illumination pattern presented through a one-pixel display (see Figure 1). Our findings indicate that participants had stronger preferences for specific patterns across sound categories namely, *Staircase Blink* for alarm sounds and

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Blink Slow for notification sounds. We also found a stronger preference for the pixel colour *Red* for alarming sounds. These preferences for sound types point to relationships that may hold potential value in the design of sensory substitution systems.

BACKGROUND

Prior work suggests that deaf people want to know about sound at any place, especially at home, at work, in the car, and while walking (Matthews et al., 2005). They want to know about alarm sounds that requires their immediate attention, such as emergency alarms, car horns, and intruders at home. Also sounds, such as wake-up alarms, doorbell, sound based appliances (e.g. dripping faucets) are reported to be interesting to deaf users. (Matthews et al., 2005; Ho-Ching et al., 2003). Moreover, deaf participants indicated that they prefer smaller displays for sound visualization (Matthews et al., 2005).

One-pixel-displays (e.g. RGB LED) are very small displays that are cheap, durable and can be turned easily into wearables due to their form factor. However, their expressive dimensions are limited to (1) one emitting colour and (2) illumination brightness over time (pattern). Yet they have been shown to be able to provide information about a device's state to users (Harrison et al., 2012). Furthermore, one-pixel-displays have been used for presenting sound to deaf people. For example, VisAural (Gorman, 2014) supports sound direction cueing through two LEDs integrated into glasses (one LED on either side) that are turned on and off depending on the sound's direction. Another work used one LED in combination with a haptic display attached to the hair and mapped the sound signal to vibration intensity and LED brightness for providing continuous access to sound (Honda and Okamoto, 2014). Moreover, StickEar (Yeo et al., 2013) is able to classify different kinds of sounds and inform a deaf user about sound events through the in-built RGB LED. However, it is not clear from these works whether a relationship exists between pixel colour & sound category or illumination pattern & sound category.

METHOD

We conducted a preliminary user study with 16 participants to investigate the research questions outlined in the introduction. The participants were between the age of 20 and 40 years and were divided into two groups on the basis of their hearing status. The first group consisted of 10 persons with hearing reported to be within normal limits (referred to as PNL). The second group consisted of 6 persons, members at a local deaf association, with 70 dB hearing loss or higher as reported (referred to as PwD). Participants from both groups volunteered to participate in the study.

Stimuli

Through preliminary interviews with deaf people and prior work (Ho-Ching et al., 2003; Matthews et al., 2005), we selected 4 sounds that could occur in daily situations: (1) an ambulance approaching, (2) a car accident, (3) a microwave beeping, and (4) a person calling from behind.

To make the context of the sound available to deaf participants, we used a video for each sound (e.g. an ambulance with flashing light approaching) that represents its context. The videos were presented through a user interface as shown in Figure 2.

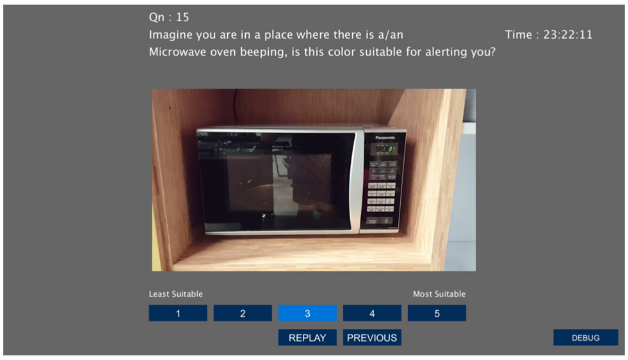

Figure 2. The user interface that was used to display the videos to the participants and collect their score.

The visual feedback was conveyed through 2 RGB LEDs mounted to a spectacle frame that was worn by the participant (one LED for each side). We presented the visual feedback from 2 positions to investigate the position preferences (see Figure 3).

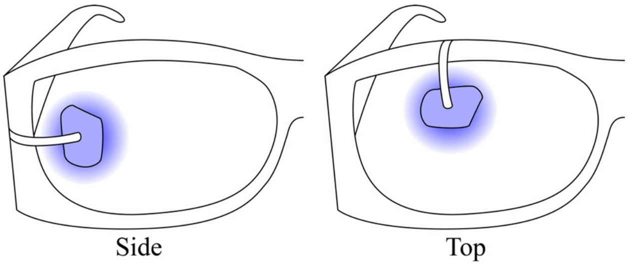

Figure 3. Two different positions of the one-pixel-display on a spectacle frame: (1) *side* and (2) *top*.

To investigate the relationship between pixel colour and sound type we chose five colours: (1) blue, (2) green, (3) magenta, (4) red and (5) yellow (see Figure 4).

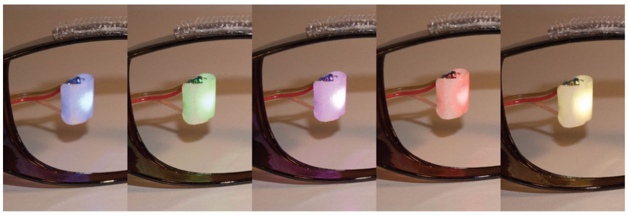

Figure 4. The pixel colours that were used in the study: blue, green, magenta, red and yellow.

For the illumination patterns, we selected 5 patterns from Harrison's work that we perceived as easy to discern (see Figure 5): (1) Alternate On & Dim, (2) Blink Increasing, (3) Blink Slow, (4) Pulse, and (5) Staircase Blink. The illumination patterns were presented with white light.

Design and Procedure

At the start of the study, each participant was screened for visual acuity and hearing status/severity of hearing loss through a questionnaire. In addition, Ishihara Colour Blindness test was conducted to rule out any colour-blindness. The study consisted of two sessions: (1) assessing the suitability of pixel colour and illumination pattern for a specific sound using a rating scale, and

(2) identifying/naming the most preferred colour and illumination pattern for a given sound.

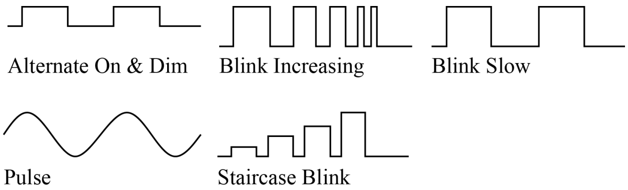

Figure 5. The illumination patterns that were selected from Harrison's work (Harrison et al., 2012).

Session 1: Suitability of Colours and Patterns

Each participant was fitted with the spectacle frame (see Figure 1). The participant was then asked to watch the 4 videos that appeared in random order. For a given video, all five pixel colours were presented followed by all five illumination patterns. The order of the colours and patterns was randomized between participants. After watching each pixel colour/illumination pattern, the participant had to rate its suitability for the presented sound/context on a 5-point Likert scale (1 being least suitable and 5 being most suitable colour or pattern). For the illumination patterns there was a minimum break of 5 seconds between patterns to avoid any masking effects. This process was done with the one-pixel-displays mounted on the *side* and on the *top* (see Figure 3) of a pair of spectacles.

Session 2: Most Preferred Colour and Pattern

In this session our aim was to collect the most preferred pixel colour and illumination pattern for a specific sound. The participants were asked to watch the 4 videos (in random order) again. After each video they were shown a set of colours and patterns and asked to choose one colour and one pattern that they preferred the most for that context. The colours and patterns that the participants could choose from were the same as in session 1 with some additions in both colours (Cyan, Light Blue, Light Green, Orange, Pink, Purple and Spring Green) and patterns (Gradual Build, Pulse Fast, and Random Brightness). These additional pattern choices were also taken from Chris Harrison's work.

At the end of the study, we collected general feedback about the pixel colours and illumination patterns that were used, and whether the sound associations made sense for the participants.

RESULTS AND DISCUSSION

In total we collected 1280 data points from session 1. After looking at the data, we observed similar ratings for the context "Ambulance" and "Car Accident" as well as "Microwave" and "Person Calling". Hence, we grouped them into two sound categories: (1) *Alarm Sounds* (Ambulance and Car Accident) and (2) *Notification Sounds* (Microwave and Person Calling). Figure 6 shows the overall results of the 1st session. Furthermore, we analysed the frequently preferred pixel colours and illumination patterns for these categories from the 2nd session, as shown in Figure 7. Our findings and preliminary observations are lined out in the following:

Pixel Colour vs. Sound Type

Session 1 of the study gave us insights into the colours that are perceived as being suitable for each sound type. For PNL, two-way ANOVA revealed an interaction for pixel colour and sound category ($F(4, 389) = 11.306$, $p < 0.01$). Post-hoc analysis indicates that *Red* was significantly rated highest for alarm sounds ($p < 0.01$ for all pair-comparisons). For PwD, there was no significant interaction between colour and sound type. However, *Red* was also rated highest for alarm sounds ($M = 3.4167$, $SD = 1.501$) and significantly different from all colours ($p < 0.05$) except for *Yellow* ($M = 2.708$, $SD = 1.517$). For notification sounds, though we found that *Green* seemed to be more preferred to other colours (see Figure 6), we did not find any dominating pixel colour for both PNL and PwD. This might be due to individual preference for colours for non-alarming situations.

In the 2nd session of the study, most of the PNL and PwD had chosen *Red* to be the most preferred colour for alarming sounds. This is consistent with the 1st session of the study and suggests that *Red* is a good colour to represent alarming sounds. For notification, PNL mostly preferred *Green* or *Green*-like colours, which is consistent with the 1st session of the study. However, PwD seem to associate notifications more with *Cyan*.

Illumination Pattern vs. Sound Type

For illumination patterns a two-way ANOVA revealed an

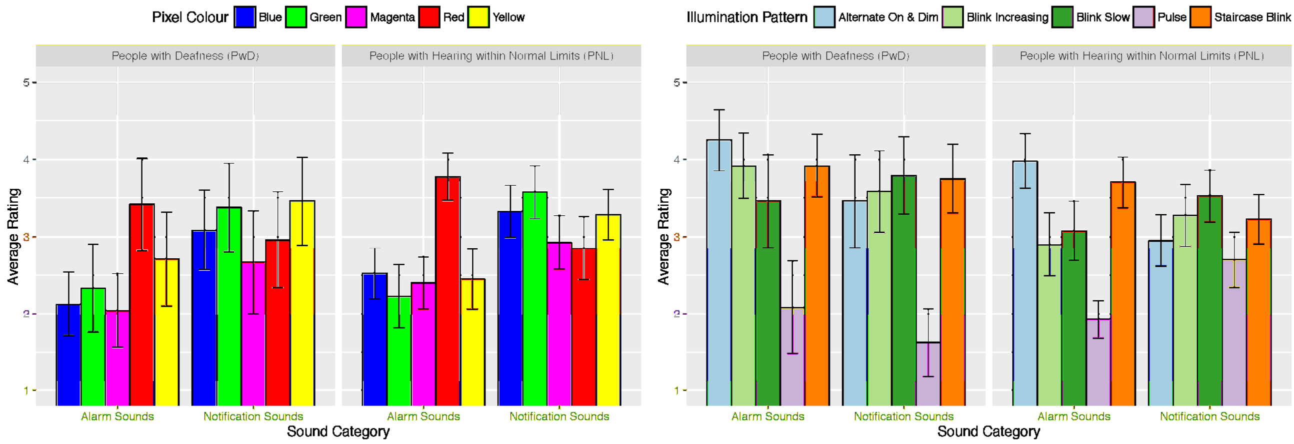

Figure 6. Average rating for suitability of pixel colour and illumination pattern for sound categories.

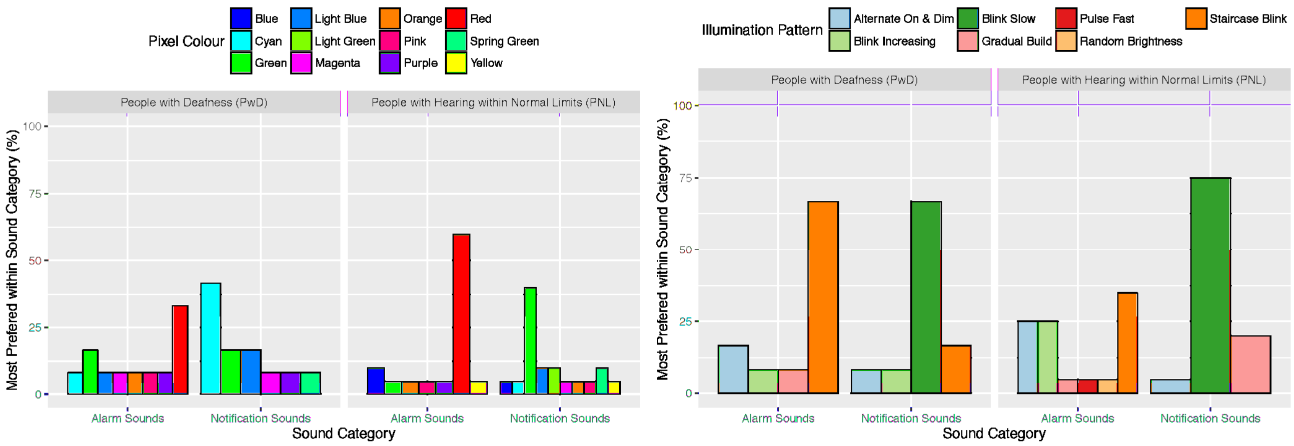

Figure 7. Most preferred pixel colour and illumination patterns in percentage for each sound category.

interaction between illumination pattern and sound category for PNL (F(4, 390) = 8.724, $p < 0.01$), but not for PwD. For alarm sounds, PNL rated the *Alternate On & Dim* pattern (M = 3.975, SD = 1.1432) significantly higher than all patterns ($p < 0.01$) except *Staircase Blink* (M = 3.7, SD = 1.067). For PwD this was not the case. For notification sounds, the *Blink Slow* pattern (PNL: M = 3.525, SD = 1.0857; PwD: M = 3.792, SD = 1.2503) was rated highest for PNL and PwD, but not significantly different from the other patterns. Furthermore, we found that the *Pulse*-pattern (PNL: M = 2.3125, SD = 1.0625, PwD: M = 1.8541, SD = 1.321) was significantly different from all other patterns (PNL & PwD: $p < 0.01$) across both sound categories for PNL and PwD. It was rated lowest and therefore might not be suitable to represent alarm or notification sounds.

In the 2nd session of the study, we found that most PwD preferred the *Staircase Blink* pattern, which is consistent with the 1st session. For PNL, *Staircase Blink* was also the highest rated pattern; but apart from that, *Alternate On & Dim* as well as *Blink Increasing* were rated high. For notification sounds, the *Blink Slow* pattern seems to be a very good candidate since it was preferred by both PNL and PwD, which is consistent with the 1st session.

Display Position
We did not find a significant difference between the possible display positions when we grouped the participants together (i.e. to explore global effect). However, when we looked at each participant separately, we found one PwD (D1), and three PNL (P2, P7, and P9) had significantly different ratings for different positions. D1 and P9 had higher ratings for the *side* position, and P2 and P7 for the *top*. This could be an indication that people have an individual preference for the position of the one-pixel-display. In the post interviews, 5 participants reported that they preferred the light to be positioned at the side, whereas 5 other participants preferred the light to be positioned at the top. The other participants did not comment on the display position.

Pixel Size
In open ended questions, participants had commented about the size of the one-pixel-display. 8 participants preferred a larger light, whereas 2 participants preferred a smaller one. The display size seems to be a consideration factor (Matthews et al., 2005) and indicates that pixel size should be customizable to meet the user's preference.

CONCLUSIONS, LIMITATIONS AND FUTURE WORK
In this paper, we conducted a preliminary study to explore the relationships between pixel colour and illumination pattern of one-pixel-displays for different sound types. Overall, illumination patterns received higher ratings compared to pixel colours, suggesting patterns might be more intuitive. The position and size of the one-pixel-display seems to depend on the personal preferences and therefore, should be customizable.

However, due to the small sample size and limited number of sounds used in this study, the results has to be seen as preliminary results. Nevertheless, they gave us insights for follow up studies, such as making the position adjustable for the participants and illumination patterns that could be potentially ruled out.

Based on our results, the question about customizability for one-pixel-displays for sound information visualization arises. Shinohara (Shinohara and Tenenberg, 2009) found that assistive technology for people with disabilities seldom is universal, since disabilities vary. Hence, customizability has to be also considered in the design process of one-pixel-display as assistive technology. While our findings thus far reveal that position and size of one-pixel-displays may need to be customized, we are interested to find whether even colour of these displays need to be customized as well. We plan to investigate this further by conducting follow-up studies to confirm the preliminary findings of this work.

We envision that wearable one-pixel-displays in combination with sound type detection algorithms, such as for alarming sounds (Ellis, 2001), will provide valuable information about surrounding sound not only to deaf people but also to people with a situational hearing disability.

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