Exploring Vibrotactile and Peripheral Cues for Spatial Attention Guidance

Tim Claudius Stratmann
University of Oldenburg
Oldenburg, Germany
tim.claudius.stratmann@uol.de

Andreas Löcken
University of Oldenburg
Oldenburg, Germany
andreas.loecken@uol.de

Uwe Gruenefeld
University of Oldenburg
Oldenburg, Germany
uwe.gruenefeld@uol.de

Wilko Heuten
OFFIS - Institute for IT
Oldenburg, Germany
wilko.heuten@offis.de

Susanne Boll
University of Oldenburg
Oldenburg, Germany
susanne.boll@uol.de

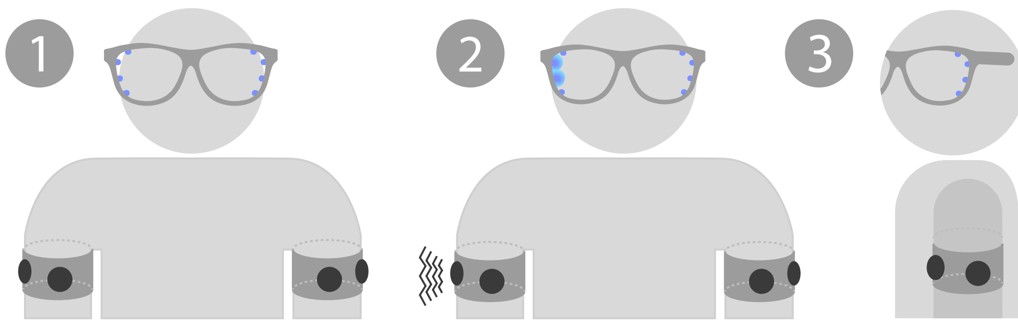


Figure 1: Person wearing a vibrotactile and a peripheral light display (1). Visual or vibrotactile cues arouse and direct the individual's spatial attention (2). The person follows the cue to find the information in demand of attention (3).

ABSTRACT

For decision making in monitoring and control rooms situation awareness is key. Given the often spacious and complex environments, simple alarms are not sufficient for attention guidance (e.g., on ship bridges). In our work, we explore shifting attention towards the location of relevant entities in large cyber-physical systems. Therefore, we used pervasive displays: tactile displays on both upper arms and a peripheral display. With these displays, we investigated shifting the attention in a seated and standing scenario. In a first user study, we evaluated four distinct cue patterns for each on-body display. We tested seated monitoring limited to 90° in front of the user. In a second study, we continued with the two patterns from the first study for lowest and highest urgency perceived. Here, we investigated standing monitoring in a 360° environment. We found that tactile cues led to faster arousal times than visual cues, whereas the attention shift speed for visual cues was faster than tactile cues.

PerDis '18, June 6–8, 2018, Munich, Germany

ISBN 978-1-4503-5765-4/18/06...$15.00
DOI: https://doi.org/10.1145/3205873.3205874

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Attention Guidance; Peripheral Vision; Light; Vibro-tactile.

INTRODUCTION

Cyber-physical systems can be described as systems of collaborating computational elements controlling physical entities such as automated cars, medical monitoring systems, autonomous ships, or process control systems [9]. As automation in these cyber-physical systems increases, we face the challenge of interacting with them in potentially complex physical environments. Instead of a single screen with a focused area of attention, we see multiple displays, devices, and interfaces loosely orchestrated into a larger, more complex, and potentially spacious cyber-physical system.

Receiving critical information currently often depends on perceiving primitive and unspecific alerts. This information can easily be missed in noisy and spacious environments. Even if it is perceived, it leaves the individual with the demanding task of identifying and localizing the problem, which usually increases cognitive load and alert fatigue. In these cases, the situation awareness is negatively affected because of a lacking perception of relevant information [8]. In the past, many serious incidents happened due to a lack of situation awareness [24]. The complexity of cyber-physical systems or simple time pressure, demands more efficient human response to avoid further incidents. Humans interacting with the system should be able to perceive relevant information without using their cognitive resources on retrieving them.

We aim to shift attention by augmenting the user with on-body vibrotactile and peripheral displays. Instead of signaling the human with visual or auditory signals located at the information, we propose to shift the attention to the position of the information by cueing the user with on-body displays.

We designed two tactile displays placed on the upper arm and a visual display placed in the periphery. The vibrotactile displays consist of three vibration motors each. The visual display consists of a pair of safety glasses with eight integrated RGB LEDs. We conducted two user studies investigating four basic patterns on both displays.

Our paper proposes two research contributions:

1. We designed two on-body displays, a visual and a tactile display, for attention shift in spacious environments.
2. We evaluated the displays with four cue patterns in a 90° seated scenario and a 360° standing scenario.

RELATED WORK

Shifting the visual attention includes spatially orienting it to the new target [20]. Posner and Petersen describe three phases of attention shift: The Disengagement from the current target, the shift of attention from one stimulus to another and the focus of attention to a new target [21]. Several existing works apply the concept of attention shift for attention guidance. There are different approaches to design and place cues.

Visual Cues in the Environment

Booth et al. used projected visual cues on different parts of the environment to shift the user's attention to the position of the projected cue [2]. The results of their user study showed that they could effectively guide the user's gaze in a real-world environment using projected visual cues. Tscharn et al. studied the influence of different ambient light conditions on gaze directions for attention guidance [25]. They found that even though the participants did not notice the effect, their gaze was drawn towards the side that was more illuminated by the ambient light. Gutwin et al. studied visual popout effects in the human field of view and the accuracy of locating these manipulating different visual parameters. They used a three monitor setup to display their visual stimuli. As a result, they identified motion as a strong popout effect and found that the location accuracy for shape and color decreased rapidly across visual angles [10].

On-body Visual Cues

Renner and Pfeiffer investigated different peripheral and in-view Attention Guidance techniques for augmented reality applications [23]. Danieau et al. designed four different virtual effects to guide the attention of a user in a virtual reality scene and investigated two of them in a user study [6].

Apart from augmented and virtual reality applications, on-body visual cues are used in wearable peripheral displays. Poppinga et al. studied a pair of glasses with 12 LEDs placed in the periphery of the user's field of view [19]. They found that the user could identify the rough position of LEDs with 92% accuracy and that their technique is suitable to encode directions. Other examples for peripheral displays in glasses are the works of Costanza et al. [5] and Lucero et al. [17].

On-body visual cues have also been explored for other body locations than the head. Harrison et al. investigated wearable visual cues on seven different body locations between the shoulders and feet and measured the respective reaction times [11]. They measured average reaction times over 15 seconds for all investigated body locations. However, they found that the response times were faster when a user observed the state change of the light. Lyons investigated different visual parameters to draw the users attention to information on a wrist-worn smartwatch [18]. Ashbrook et al. measured device access times for three on-body locations [1].

On-body Tactile Cues

Vibrotactile feedback has been explored on various body locations to encode directions in navigation tasks. Tsukada et al. and Heuten et al. used wearable vibration integrated into a belt to encode directions [26, 13]. Dobbelstein et al. investigated vibrotactile cues on a wristband for navigation [7]. Kaul and Rohs created HapticHead, a system for haptic spatial guidance. It consists of multiple vibrotactile actuators distributed around the head. They compared it to auditory cues (generic head-related transfer function) and visual cues as a baseline. While their system did not perform better than the visual baseline, it was faster and more accurate than the auditory cues [14].

Complementing related work, we designed four light patterns inside a pair of glasses and four vibrotactile patterns which are located on both upper arms. We tested how effective these patterns can direct attention without annoying the wearer.

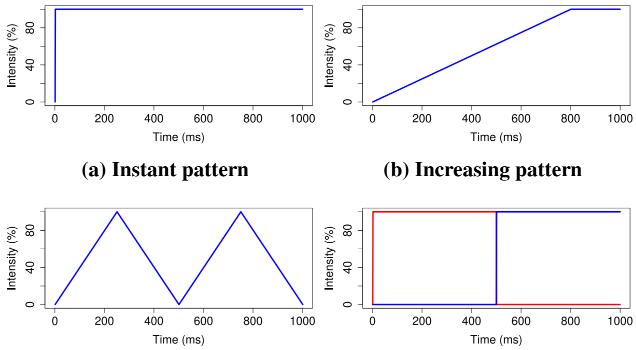
DIRECTIONAL CUE DESIGN

Based on the findings of Harrison et al., we decided to use visual stimuli using light in the peripheral field of view to ensure the immediate perception of the cues [11]. Further, we were interested in the differences between the modalities for similar cues in different body worn positions. In the following, we describe the four patterns that were used in our experiments. All of them use intensity as a parameter that changes over time, as sketched in Figure 2.

The simplest patterns are *InstaLight* and *InstaVibe*. As soon as the cue is triggered, the intensity of the outer actuators is instantly increased to the maximum defined level as depicted in Figure 2a). This cue is commonly used as status indicator.

IncLight and *IncVibe* use an increasing intensity for the first 800 ms and stay at the maximum level (see Figure 2b). The duration is based on findings by Löcken et al. [16]. We expect this smoother activation to be perceived as less annoying than *InstaLight* and *InstaVibe*.

PulseLight and *PulseVibe* use triangular functions with a peak at 250 ms and 750 ms (see Figure 2c). We expect pulsing



(a) Instant pattern **(b) Increasing pattern** **(c) Pulsing pattern** **(d) Moving pattern**

Figure 2: Intensity of vibration or blue light channel, respectively, over time for all four cues. The blue lines represent the outer actuators and the red line the inner actuators, which were only used in the *Moving* cue pattern. *Best seen in color.*

cues to be perceived as more annoying but to result in faster response times.

MovLight and *MovVibe* first activate the inner actuators for 500 ms and then activate the outer ones at full intensity. The sequence for both actuator groups is shown in Figure 2d. We designed this kind of cue to explore how using the spatial dimension affects reaction times and perceived annoyance.

We used flat 3V cellphone vibration motors of the type C0834B011F[1] to implement our tactile patterns and RGB LEDs of the type WS2812B[2] on pre-assembled stripes to implement our light patterns. As the vibration of the motors is created by an eccentric rotating mass, they have a latency range from 40-60 ms. The patterns on the armband used at least one vibrotactile motor, while the cues in the glasses used at least two LEDs with blue lights. We decided to use blue light as it is the best perceivable color in the periphery of human perception [3]. Apart from one cue design, all designs use the two most left or right LEDs in the glasses or the vibrotactile motors pointing away from the participant, as sketched in Figure 1. The inner actuators are one LED closer to the participant on the glasses or the vibrotactile motors that are pointing towards the participant, respectively.

As the related work shows, position and intensity of the cue are appropriate parameters for orientation and notification purposes when using light displays [22]. Hence, we used these parameters. We did not change the color of the light or the frequency of the vibrotactile display. The intensities for the vibrotactile cues ranged from 17.6% to 100% and the brightness of the blue channel of the LEDs from 0% to 19.6%. However, these borders are specific to our hardware and were chosen to range from “just noticeable” to “still bearable” by two participants in a pretest.

[1] https://www.mpja.com/download/19229md.pdf, last retrieved: April 6, 2018

[2] https://cdn-shop.adafruit.com/datasheets/WS2812B.pdf, last retrieved: April 6, 2018

LAB STUDY: SEATED 90°

We performed a lab study in order to assess the effect of our attention shift cues on reaction time in a multitasking environment with induced workload. We simulated a monitoring workplace environment with two displays. We equipped participants with our LED-glasses and our vibrotactile armbands.

Design

Our lab study compared nine conditions. All conditions were counterbalanced using a balanced Latin Square. They were presented in three slots, one slot with four visual cues, one slot with four vibrotactile cues and one slot without any cue support. The dependent variables were button response time, perceived annoyance, perceived urgency, perceived alarmingness, and perceived pleasantness.

Participants

We recruited 20 participants (6 females), aged between 21 and 65 years ($M = 28.4, SD = 8.92$). Only people without color blindness and normal or corrected to normal vision participated.

Apparatus

The laboratory study was conducted in a controlled environment. The ambient lighting was kept constant per participant. Figure 3 shows a sketch of the setup. It consisted of two spatially separated 19” LCD screens on a table. The distance between them was about 130 cm. The participant was sitting in front of the screens at a distance of 90 cm to each screen. A 10" Android tablet was placed in front of the participant.

A laptop controlled the two LCD screens displaying a large random number within the range of one to three in white font on a black screen. The tablet PC was used to display a visual 1-position-back task [15] and a questionnaire between the conditions. We further equipped the participants with the glasses or armbands, depending on the task. A remote control was handed to the participants to respond to the response task as described in the next section. The remote control was wireless and consisted of three buttons.

Procedure

The participant was asked for demographic data. Each participant started either with the glasses, the armbands or without any support.

Each of the four cues was tested for 5 minutes, followed by a short questionnaire. In the questionnaire, the participants had to rate four statements on Likert items from one to six (*strongly disagree* to *strongly agree*). The statements were: "I perceived the cue as annoying.", "I perceived the cue as urgent.", "I perceived the cue as alarming.", "I perceived the cue as pleasant."

Within these 5 minutes slots, each cue was shown twice directing to the left and twice directing to the right in a counterbalanced manner. A cue is triggered randomly every 55 to 65 seconds. At the same time, a random number appears on the corresponding screen left or right to the participant. The participant is instructed to react as quickly as possible to a cue via pushing the correct button on the remote control.

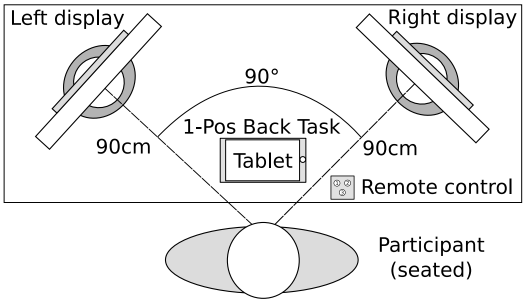


Figure 3: Sketch of the study setup. The participant sat in front of a tablet PC and two 19" screens to the left and right.

If the user does not respond within 5 seconds, the missing response is logged, and the system continues with the next cue. To increase the participant's workload and ensure that his or her attention does not stay at the screens, participants are also instructed to perform a visual 1-position-back task on the tablet PC as good as possible during each trial.

In a debriefing interview, the participants had to vote for the condition with the highest experienced workload. Any qualitative remarks by the participants were recorded. Overall, the experiment took about 60 minutes per participant.

Results

Shapiro-Wilk tests showed that our data is not normally distributed ($p < .001$). Hence, we performed non-parametric tests to identify significant differences. We performed Friedman rank sum tests and posthoc Wilcoxon signed rank tests with Holm-Bonferroni adjustments for pairwise comparisons.

Error rate

We measured the error rate of the shift in attention by counting the number of wrong button presses. Overall, the participants did not respond to 10 out of a total of 720 stimuli (1.4%). Nine of these misses occurred in the condition *without* cues and one miss in the *InstaLight* condition. Therefore, the error rate was 0% for all conditions except *without* (11.25%) and *InstaLight* (1.25%).

Response times

A Friedman test revealed significant differences in response time between conditions ($\chi^2(6) = 20.30, p < .01$). Post-hoc Wilcoxon tests showed significant differences between *InstaVibe* and *IncLight* ($p < .01, r = .80$), *InstaVibe* and *MovLight* ($p < .01, r = .89$), and *InstaVibe* and *PulseLight* ($p < .01, r = .79$). The median response times are shown in Figure 4. Without cues, the mean response time was 2.48s ($SD = .89$). The mean reaction times for most other cues were slower. Only using *InstaVibe* resulted in a slightly faster button response time with a mean value of 2.41s ($SD = .71$). Comparing modalities, reaction times with cues using light are slightly slower than reaction times with vibrotactile cues.

Subjective measures

Looking into *Annoyance*, all cues were rated below three on average, indicating that most participants did not perceive the cues as annoying. The most annoying cue is *movVibe* ($M = 2.8, SD = 1.4$), while the least annoying cue is *instaVibe* ($M = 1.75, SD = .91$). A Friedman test indicated that there was a significant effect of the *cue* on *perceived annoyance* ($\chi^2(7) = 20.41, p < .01$). However, a pairwise comparison using Wilcoxon tests did not reveal any significant differences between individual cues.

With an average above four for most cues, most participants seem to perceive the cues as *urgent*. The least urgent cue is *IncLight*. With a mean rating of 3.6 ($SD = 1.19$), more participants agreed with it being urgent than not. The most urgent cue is *MovVibe* ($M = 5, SD = .79$). The Friedman test indicated significant differences in *perceived urgency* between the cues ($\chi^2(7) = 20.65, p < .01$). However, pairwise comparisons using Wilcoxon tests did not show significant differences.

All cues were rated to be less *alarming* than *urgent*. *MovVibe* ($M = 4.25, SD = 1.37$) is the most alarming cue, while *IncLight* ($M = 2.75, SD = 1.48$) was rated to be the least alarming cue. Looking into the distributions, most cues seem to be neither alarming nor not alarming, which is reflected in the mean values between three and four for most cues. However, we were able to observe a significant difference between the cues for *perceived alarmingness* ($\chi^2(7) = 20.47, p < .01$). A Wilcoxon test showed significant differences between *IncLight* and *MovVibe* ($p < .05, r = .77$).

With averages above four, all cues were perceived as *pleasant* to some extent. The most pleasant cue is *IncVibe* ($M = 5.2, SD = .77$). The least pleasant cue is *MovVibe* ($M = 4.25, SD = 1.33$). There was a significant effect of the *cue* on *perceived pleasantness* ($\chi^2(7) = 20.48, p < .01$). Pairwise comparisons showed no significant differences.

All Participants stated that they experienced the highest workload in the condition without any supporting cues.

Discussion

Our results show that all investigated cues were on average rated as urgent but not annoying. The annoyance level depends on the individual cue. Also, as our participants remarked, the brightness of the visual display and the intensity of the tactile stimuli should dynamically adjust to the environment. The cues have to be obtrusive enough to build up the trust of the

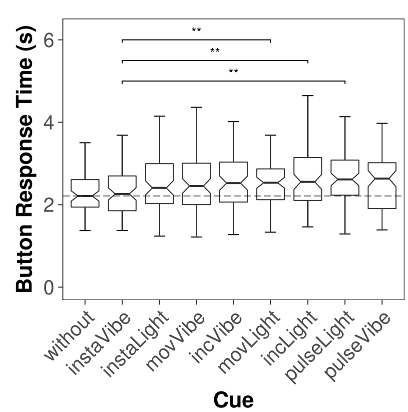


Figure 4: Response times for button press. The dashed line marks the median for the *without* condition ($p < .01$).**

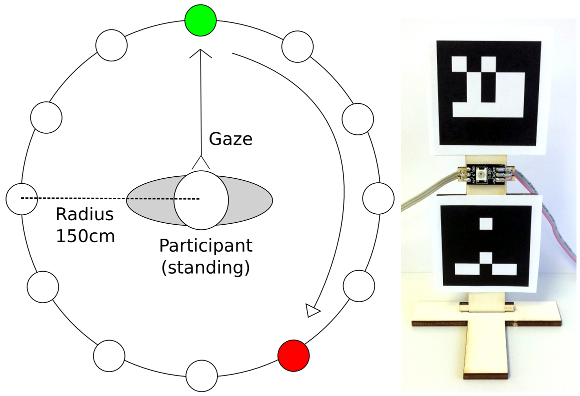


Figure 5: Sketch of the second study setup. The participant is placed in the center of a 150 cm radius circle with 12 RGB LED pillars. Each Pillar consists of two optical markers from an ARuco dictionary and one RGB LED. ***Best seen in color.***

user, the user will not rely on cues he or she fears to miss. With only one miss for the visual display, the placement of the visual and tactile display ensured a high perception rate of the presented stimuli. The low error rates for conditions with cue support compared to no support suggest that cue support results in a performance improvement of the user. Interestingly, we can observe a clear difference in *perceived urgency* between increasing and constant patterns as well as pulsing and moving patterns for visual and tactile stimuli.

LAB STUDY - STANDING 360°

We performed a second lab study to test our patterns for targets in 360°. This included targets in the field of view of the user as well as targets outside of it, e.g. behind the user. In this study, we again equipped our participants with our LED-glasses and our vibrotactile armbands.

Design

The experiment was a 2 x 3 within-subjects design. All conditions were counterbalanced using a balanced Latin Square. The patterns for this study are *increasing* and *pulsing*. The pattern *increasing* derived from *incVibe* and *incLight* as the most effective patterns with low urgency ratings for each modality. The pattern *pulsing* derived from *pulseVibe* and *pulseLight* as the highest urgency patterns with low annoyance ratings for each modality. The two independent variables were pattern (*increasing*, *pulsing*) and modality (*light*, *vibration*, *light + vibration*). The dependent variables were time to target acquisition, gaze response time, usability and perceived workload. Each condition was repeated 12 times in slots, resulting in a total of 72 measurements per participant.

Participants

We recruited 20 participants (8 females), aged between 20 and 65 years ($M = 28.85, SD = 9.06$) without color blindness and normal or corrected to normal vision.

Apparatus

The laboratory study was conducted in a controlled environment. The ambient lighting was kept constant per participant. Figure 5 shows a sketch of the setup, which consisted of 12 circular equidistantly placed pillars. Each pillar consists of two optical markers from an ARuco dictionary[3] and one WS2812B RGB LED (Figure 5). The radius of the resulting circle was 150 cm. During the experiment, the participant was located in the center of the circle. The participant was wearing eye-tracking glasses to interact with the pillars through his or her gaze. We defined the interaction area of each LED as a circle with the LED as the center and a radius of the distance between the centers of the upper and lower marker of the pillar.

Procedure

Each participant was asked for demographic data. Afterward, the head-worn eye-tracker, a Tobii Pro Glasses 2[4], was calibrated. The modality was counterbalanced, hence, a participant started either with the glasses, the armbands or both. The pattern was counterbalanced as well.

The task of the participant was to focus on the currently highlighted green LED and shift his or her focus to the next highlighted LED, when he or she perceived a cue from the current prototype(s). The cue lasted until the target was acquired. It always gave the direction to the target LED and the target LED was highlighted in red. When the participant's gaze reached the area of the target LED it turned green and the previously focused LED was turned off. This was repeated 12 times per slot with five seconds delay between the end of a shift and the start of the next shift. The start LED changed per slot in a counterbalanced manner. After each slot, the participants were asked to complete two questionnaires, a System Usability Scale [4] and a RAW-TLX form [12].

In a debriefing interview, the participants had to pick a favorite. Any qualitative remarks by the participants were recorded. Overall, the experiment took about 60 minutes per participant.

Results

Shapiro-Wilk tests showed that our data are not normally distributed ($p < .001$). Hence, we performed non-parametric tests to identify significant differences. We performed Friedman rank sum tests and posthoc Wilcoxon signed rank tests with Holm-Bonferroni adjustments for pairwise comparisons.

Speed to Target

As the distance between targets varied between one to six pillars, it was necessary to normalize the time until the target was acquired by the individual distance. The result is the *speed to target*. There were no significant differences in *speed to target* between cues, modalities, and patterns.

Further, we looked for differences in *speed to target* for targets within and without the field of view. We defined targets with a distance greater than three pillars (> 180°) as outside the participant's field of view. A Wilcoxon test revealed significant differences in *speed to target* between targets within and targets without the field of view ($W = 241220, Z = 19.96, r =$

[3] https://www.uco.es/investiga/grupos/ava/node/26, last retrieved: April 6, 2018

[4] https://www.tobiipro.com/product-listing/tobii-pro-glasses-2/, last retrieved: April 6, 2018

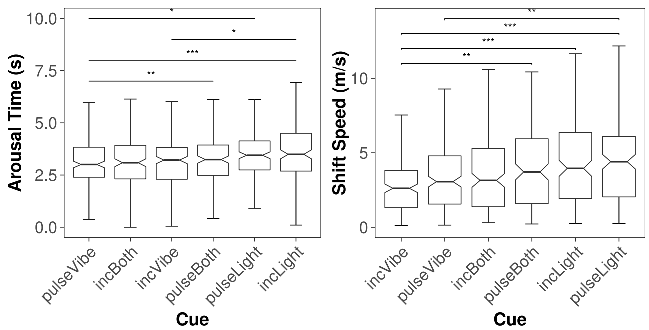


Figure 6: Arousal time and shift speed per cue.

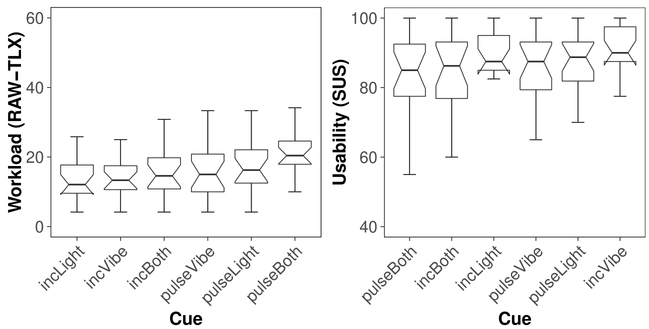


Figure 7: Perceived workload and usability of the cues.

$4.46, p < .001$). The *speed to target* was higher for targets without the field of view.

We split the time to acquire the target into *arousal time* and *shift speed*. The *arousal time* was the time between triggering the cue and the gaze leaving the interaction area of the LED. The *shift speed* was the time between the gaze leaving the interaction area of the LED and the gaze entering the interaction area of the target LED normalized over the distance like *speed to target*. Figure 6 shows the differences in *arousal time* and *shift speed* between the different investigated cues.

Arousal Time

A Friedman test revealed significant differences in arousal time between conditions ($\chi^2(5) = 30.49, p < .001$). A pairwise Wilcoxon test revealed that *incLight* was slower than *incVibe* ($p < .05, r = .67$) and *pulseVibe* ($p < .001, r = .99$). Also, *pulseBoth* was slower than *pulseVibe* ($p < .01, r = .84$). Further, *pulseLight* was slower than *pulseVibe* ($p < .05, r = .70$). All in all, tactile patterns corresponded to shorter median *arousal times* than visual pattern. There were no significant differences in *arousal time* between modalities or patterns.

Shift Speed

A Friedman test revealed significant differences in arousal time between conditions ($\chi^2(5) = 17.34, p < .01$). A pairwise Wilcoxon test showed, the shift speed of *incVibe* was significantly lower than *incLight* ($p < .001, r = 1.00$), *pulseBoth* ($p < .01, r = .77$) and *pulseLight* ($p < .001, r = .99$). The shift speed of *pulseLight* was significantly faster than *pulseVibe* ($p < .01, r = .78$). Overall, the visual cues were faster than tactile cues regarding the median shift speed. Figure 6 shows a boxplot of *shift speed* for all cues.

Workload

Friedman tests indicated significant differences in *perceived workload* between *cues* ($\chi^2(5) = 25.52, p < .001$) and *modalities* ($\chi^2(2) = 15.11, p < .001$). The *perceived workload* for *incVibe* and *incLight* was clearly lower than for *pulseBoth* (see Figure 7). However, pairwise comparisons showed no significant differences. The *perceived workload* for the modality combination *light + vibration* was significantly higher than for the modalities *light* ($p < .05, r = .51$) and *vibration* ($p < .05, r = .64$) alone. The perceived workload for the pattern *pulsing* was significantly higher than for the pattern *increasing* ($W = 1133, Z = 3.32, r = .74, p < .001$).

Usability

The *usability* of the cue *incVibe* ($M = 90.88, SD = 7.75$) was rated greater than all other cues. There were no significant differences in *usability* between modalities or patterns.

In the debriefing interview, eight out of 20 participants liked *incVibe* the most. Six participants liked *incLight* the most. Two participants liked *incBoth* the most and four were undecided.

Discussion

In our experiment, tactile cues led to faster *arousal times* than visual cues, whereas the *shift speed* for visual cues was faster than tactile cues. However, the total response time from cue trigger to target acquisition was shorter for tactile cues than visual cues. As there is no significant difference in arousal time and shift speed between *increasing* and *pulsing*, the decision which pattern to use should also incorporate the subjective measures *perceived workload* and *usability*. The combination of modalities led to significantly increased *perceived workload* compared to single modalities. Therefore, the combination of tactile and visual cues should be avoided for low urgency attention shifts and only be considered for high urgency attention shifts. We recommend *incVibe* for low urgency attention shifts and *pulseBoth* for high urgency attention shifts.

CONCLUSION

We implemented and tested four cue pattern on a visual and a tactile on-body display, as well as the combination of two of them. Except for *instaLight* (one missed cue), all cues successfully shifted the attention of the user in 100% of the cases. We found that tactile cues led to faster *arousal times* than visual cues, whereas the *shift speed* for visual cues was faster than tactile cues. The combination of visual and tactile cues led to increased workload and should be avoided in situations and environments, where the workload is already high. Instead of the concurrent combination of modalities, we propose to combine modalities consecutively and use vibration for attention arousal and peripheral light for the shift. As for the use of single modalities, tactile cues tend to have a faster total response time than visual cues.

As the cues are located on-person and on positions that allow an easy integration into clothing, they are applicable in various cyber-physical system environments. Our current results are transferable to seated and standing workplaces.

REFERENCES

1. Daniel L. Ashbrook, James R. Clawson, Kent Lyons, Thad E. Starner, and Nirmal Patel. 2008. Quickdraw: The Impact of Mobility and On-body Placement on Device Access Time. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08)*. ACM, New York, NY, USA, 219–222. DOI: http://dx.doi.org/10.1145/1357054.1357092
2. Thomas Booth, Srinivas Sridharan, Ann McNamara, Cindy Grimm, and Reynold Bailey. 2013. Guiding Attention in Controlled Real-world Environments. In *Proceedings of the ACM Symposium on Applied Perception (SAP '13)*. ACM, New York, NY, USA, 75–82. DOI:http://dx.doi.org/10.1145/2492494.2492508
3. J K Bowmaker and H J Dartnall. 1980. Visual pigments of rods and cones in a human retina. *The Journal of Physiology* 298, 1 (1980), 501–511. DOI: http://dx.doi.org/10.1113/jphysiol.1980.sp013097
4. John Brooke and others. 1996. SUS-A quick and dirty usability scale. *Usability evaluation in industry* 189, 194 (1996), 4–7.
5. Enrico Costanza, Samuel A. Inverso, Elan Pavlov, Rebecca Allen, and Pattie Maes. 2006. Eye-q: Eyeglass Peripheral Display for Subtle Intimate Notifications. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI '06)*. ACM, New York, NY, USA, 211–218. DOI:http://dx.doi.org/10.1145/1152215.1152261
6. F. Danieau, A. Guillo, and R. Doré. 2017. Attention guidance for immersive video content in head-mounted displays. In *2017 IEEE Virtual Reality (VR)*. 205–206. DOI:http://dx.doi.org/10.1109/VR.2017.7892248
7. David Dobbelstein, Philipp Henzler, and Enrico Rukzio. 2016. Unconstrained Pedestrian Navigation Based on Vibro-tactile Feedback Around the Wristband of a Smartwatch. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. ACM, New York, NY, USA, 2439–2445. DOI: http://dx.doi.org/10.1145/2851581.2892292
8. Mica R Endsley. 1995. Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 37, 1 (1995), 32–64. DOI: http://dx.doi.org/10.1518/001872095779049543
9. Eva Geisberger and Manfred Broy. 2015. *Living in a networked world: Integrated research agenda Cyber-Physical Systems (agendaCPS)*. Herbert Utz Verlag.
10. Carl Gutwin, Andy Cockburn, and Ashley Coveney. 2017. Peripheral Popout: The Influence of Visual Angle and Stimulus Intensity on Popout Effects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 208–219. DOI: http://dx.doi.org/10.1145/3025453.3025984
11. Chris Harrison, Brian Y. Lim, Aubrey Shick, and Scott E. Hudson. 2009. Where to Locate Wearable Displays?: Reaction Time Performance of Visual Alerts from Tip to Toe. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 941–944. DOI: http://dx.doi.org/10.1145/1518701.1518845
12. Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (2006), 904–908. DOI: http://dx.doi.org/10.1177/154193120605000909
13. Wilko Heuten, Niels Henze, Susanne Boll, and Martin Pielot. 2008. Tactile Wayfinder: A Non-visual Support System for Wayfinding. In *Proceedings of the 5th Nordic Conference on Human-computer Interaction: Building Bridges (NordiCHI '08)*. ACM, New York, NY, USA, 172–181. DOI: http://dx.doi.org/10.1145/1463160.1463179
14. Oliver Beren Kaul and Michael Rohs. 2017. HapticHead: A Spherical Vibrotactile Grid Around the Head for 3D Guidance in Virtual and Augmented Reality. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 3729–3740. DOI: http://dx.doi.org/10.1145/3025453.3025684
15. Wayne K Kirchner. 1958. Age differences in short-term retention of rapidly changing information. *Journal of experimental psychology* 55, 4 (1958), 352. DOI: http://dx.doi.org/10.1037/h0043688
16. Andreas Löcken, Sarah Blum, Tim Claudius Stratmann, Uwe Gruenefeld, Wilko Heuten, Susanne Boll, and Steven van de Par. 2017. Effects of Location and Fade-in Time of (Audio-)Visual Cues on Response Times and Success-rates in a Dual-task Experiment. In *Proceedings of the ACM Symposium on Applied Perception (SAP '17)*. ACM, New York, NY, USA, Article 12, 4 pages. DOI: http://dx.doi.org/10.1145/3119881.3119894
17. Andrés Lucero and Akos Vetek. 2014. NotifEye: Using Interactive Glasses to Deal with Notifications While Walking in Public. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE '14)*. ACM, New York, NY, USA, Article 17, 10 pages. DOI:http://dx.doi.org/10.1145/2663806.2663824
18. Kent Lyons. 2016. Visual Parameters Impacting Reaction Times on Smartwatches. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16)*. ACM, New York, NY, USA, 190–194. DOI:http://dx.doi.org/10.1145/2935334.2935344
19. Benjamin Poppinga, Niels Henze, Jutta Fortmann, Wilko Heuten, and Susanne Boll. 2012. AmbiGlasses – Information in the Periphery of the Visual Field. In *Mensch & Computer 2012: 12. fachübergreifende*

Konferenz für interaktive und kooperative Medien. interaktiv informiert – allgegenwärtig und allumfassend!? 153–162. DOI: http://dx.doi.org/10.1524/9783486718782.153

20. Michael I Posner. 1980. Orienting of attention. *Quarterly journal of experimental psychology* 32, 1 (1980), 3–25. DOI:http://dx.doi.org/10.1080/00335558008248231
21. Michael I. Posner and Steven E. Petersen. 1990. The Attention System of the Human Brain. *Annual Review of Neuroscience* 13, 1 (1990), 25–42. DOI: http://dx.doi.org/10.1146/annurev.ne.13.030190.000325
22. Maria Rauschenberger, Andrii Matviienko, Vanessa Cobus, Janko Timmermann, Heiko Müller, Andreas Löcken, Jutta Fortmann, Christoph Trappe, Wilko Heuten, and Susanne Boll. 2015. Lumicons: Mapping Light Patterns to Information Classes. In *Mensch und Computer 2015 – Proceedings*, Sarah Diefenbach, Niels Henze, and Martin Pielot (Eds.). De Gruyter Oldenbourg, Berlin, 343–346.
23. P. Renner and T. Pfeiffer. 2017. Attention guiding techniques using peripheral vision and eye tracking for feedback in augmented-reality-based assistance systems. In *2017 IEEE Symposium on 3D User Interfaces (3DUI)*. 186–194. DOI: http://dx.doi.org/10.1109/3DUI.2017.7893338
24. Tim Claudius Stratmann and Susanne Boll. 2016. Demon Hunt-The Role of Endsley's Demons of Situation Awareness in Maritime Accidents. In *International Conference on Human-Centred Software Engineering*. Springer, 203–212. DOI: http://dx.doi.org/10.1007/978-3-319-44902-9_13
25. Robert Tscharn, Nam Ly-Tung, Diana Löffler, and Jörn Hurtienne. 2016. Ambient Light As Spatial Attention Guidance in Indoor Environments. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct (UbiComp '16)*. ACM, New York, NY, USA, 1627–1630. DOI: http://dx.doi.org/10.1145/2968219.2968524
26. Koji Tsukada and Michiaki Yasumura. 2004. *ActiveBelt: Belt-Type Wearable Tactile Display for Directional Navigation*. Springer Berlin Heidelberg, Berlin, Heidelberg, 384–399. DOI: http://dx.doi.org/10.1007/978-3-540-30119-6_23