# Guiding Smombies: Augmenting Peripheral Vision with Low-Cost Glasses to Shift the Attention of Smartphone Users

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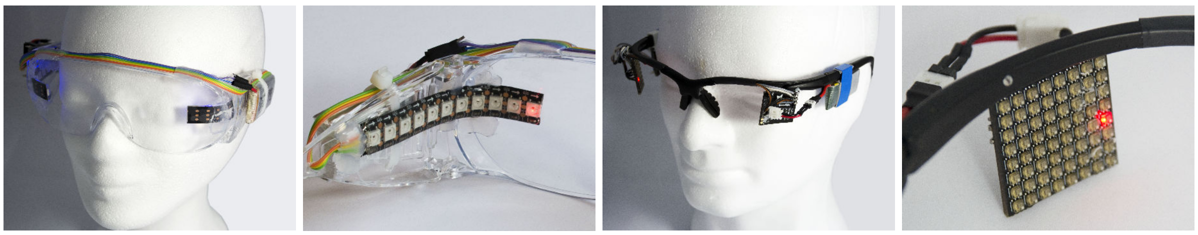

(a) First iteration of prototype. (b) Display of first prototype. (c) Second iteration of prototype. (d) Display of second prototype.

Figure 1: Iterations of glasses with peripheral vision for guiding smombies. *Best seen in color.*

### Abstract

Over the past few years, playing Augmented Reality (AR) games on smartphones has steadily been gaining in popularity (e.g., Pokémon Go). However, playing these games while navigating traffic is highly dangerous and has led to many accidents in the past. In our work, we aim to augment peripheral vision of pedestrians with low-cost glasses to support them in critical traffic encounters. Therefore, we developed a lo-fi prototype with peripheral displays. We technically improved the prototype with the experience of five usability experts. Afterwards, we conducted an experiment on a treadmill to evaluate the effectiveness of collision warnings in our prototype. During the experiment, we compared three different light stimuli (*instant*, *pulsing* and *moving*) with regard to response time, error rate, and subjective feedback. Overall, we could show that all light stimuli were suitable for shifting the users' attention (100% correct). However, moving light resulted in significantly faster response times and was subjectively perceived best.

**Index Terms:** Human-centered computing—Visualization—Visualization techniques; Human-centered computing—Visualization—Visualization design and evaluation methods

## 1 Introduction

Augmented Reality (AR) allows one to overlay digital content onto the real world, in order to alter the perception of it. This digital content can be explored by different kinds of devices (e.g., AR glasses or smartphones). Nowadays, smartphones are widely available and used for exploring AR content. There have been some studies by which the degree of fidelity (e.g., rendering quality [12, 27], refresh rate [13], and registration accuracy [18, 25], etc.) were not enough for the user to feel immersed. Thus, the presence of the real world overshadowed the virtual. However, the recent emergence of increasingly capable mobile hardware and the optimization of tracking solutions enormously enhance the fidelity of AR content. This is especially interesting with regard to AR games, which have recently gained more popularity (e.g., Pokémon Go[1] or Ingress[2]). Playing AR games on smartphones becomes problematic when it is done while navigating traffic (e.g., as a pedestrian [7] or as a driver [1]). Interestingly, the simplicity of the game is what makes it so popular [8] (besides the technically improved immersive experience of course). However, playing these kinds of games on small form factor devices makes the experience like looking through a keyhole while concentrating the user's focus on a single spot. In this case, higher immersion into the game is not beneficial. Although using a smartphone while driving a car or riding a bike is forbidden in most countries, it is still allowed for pedestrians. However, the combination of playing AR games on a smartphone or simply using a smartphone while navigating traffic is highly dangerous. Especially when the user is walking while using a smartphone [20, 26]. There are several accident reports that provide evidence for this, while the number of near or minor accidents is likely even higher [7]. In Germany, Smombie was the 2015 'youth word of the year'. It combines the words 'smartphone' and 'zombie' to refer to the intensely unaware state of people walking around staring at their phones like zombies[3]. This is worsened by the fact that navigating in traffic is a fundamental requirement of such games.

In this paper, we developed low-cost peripheral AR glasses to support pedestrians in critical traffic encounters and to evaluate different light stimuli for shifting user's attention. Our first iteration was based on safety glasses with attached LED strips. Thereafter, we developed a second iteration of our prototype based on feedback from five expert interviews. Then we conducted an experiment on a treadmill to evaluate the suitability of three different types of light stimuli (*instant*, *pulsing*, *moving*) (see Figure 2). Participants were given a smartphone game with an N-back task in order to engage them in a task and simulate workload. [11] on it.

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[1]`https://www.pokemon.com`, last retrieved: July 3, 2018
[2]`https://www.ingress.com`, last retrieved: July 3, 2018
[3]`https://en.wikipedia.org/wiki/Smartphone_zombie`, last retrieved: July 3, 2018

We ask the following research question: **(RQ) In how far can peripheral vision be augmented to visually shift the attention of pedestrians in critical traffic encounters?**

Our contribution includes:

1. A novel display which augments peripheral vision with warning information to draw the user's visual attention towards potential hazards.
2. An evaluation of three different stimuli to shift user's attention.

## 2 Related work

We built our work on three pillars of previous research (1) peripheral displays (2) peripheral perception characteristics and (3) visual cues for attention shifting.

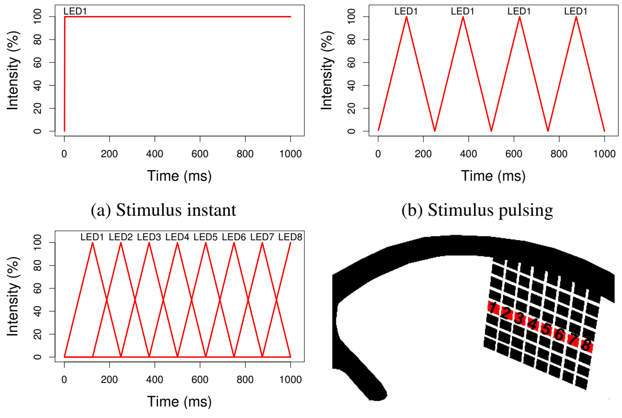
**Peripheral displays** An early peripheral display called Eye-q was developed by Constanza et al. [5]. The idea was to enable subtle, discreet and unobtrusive notifications to the user. The advantage over audio notifications is having non-disruptive and distraction-free stimuli both for co-located people and even for the user to whom they are directed. Further, they showed in an experiment that the notifications could be designed to meet specific levels of visibility and disruption for the wearer. However, although Eye-q is able to notify the user, it does not support interactions with notifications and cannot shift attention towards elements other than the notifications themselves. For discrete interaction with eyewear in public, NotifEye was suggested by Lucero et al. [15]. They investigated social network notifications and possible user interaction with these notifications in depth. However, their notifications could not convey directional information. Therefore, AmbiGlasses were introduced by Poppinga et al. [23]. They used twelve LEDs to illuminate the periphery of the user's field of view. By using a higher number of LEDs, it was possible to encode direction information. A user study showed that participants were able to locate the correct LED with 71% accuracy and estimate the rough location of the LED with 92% accuracy. However, AmbiGlasses did not have LEDs to directly point to the left or right side of the user. On the contrary, the smart glasses presented by Nakao and Kunze [19] use single-color LED matrices in the left and right periphery of the user. However, they did not investigate whether their displays are useful for shifting the user's attention to the left or right side. To explore the capabilities of LED displays for Augmented and Virtual Reality, Xiao et al. presented SparseLight. SparseLight consists of a matrix of LEDs placed in head-mounted Augmented Reality (SparseLightAR) and Virtual Reality (SparseLightVR). In their paper, they showed SparseLight's usefulness in conveying peripheral information, improving situational awareness, and reducing motion sickness. However, SparseLightAR restricts the field of view with a high number of LEDs. Therefore, it is not feasible to be worn in daily traffic. However, peripheral LEDs in general are useful for conveying information. We built our prototype based on the idea of the smart glasses presented by Nakao and Kunze [19]. Peripheral displays were also investigated in specific applications like alarms in critical care units [4] and warnings for skiers [21] which show their usefulness in real environments.

**Peripheral perception characteristics** Periphery perception can be differentiated from foveal perception by various factors (e.g., color, shape and text perception [10]). Furthermore, some areas can be perceived by one eye only (monocular vision) but most are perceivable by both eyes (binocular vision) [22]. In the work of Strasburger et al., the authors summarize the various strands of research on peripheral vision and relate them to theories of form perception [28]. A central topic of their paper is the recognition of characters in peripheral vision, both at low and high levels of contrast, and the impact of surrounding contours, known as crowding. Further, the recognition of more complex stimuli, such as textures, faces, and scenes, reveals the substantial impact of mid-level visual and cognitive factors. They report that peripheral vision is limited with regard to pattern categorization by a distinctly lower representational complexity and processing speed. Taken together, the limitations of cognitive processing in peripheral vision appear to be as significant as those imposed on low-level functions and by way of crowding. More specifically, Luyten et al. looked into visualization for near-eye out-of-focus displays, where they focused on specifying characteristics required to ensure good perceptibility. They found that having simple shapes and a small set of colors is important for improving perception and comprehension of what is being shown on such displays. Further, their findings showed that a usable visual language can be developed by making clever use of orientation and meaningful motion. However, motion is not only an influencing factor when it comes to moving stimuli in the periphery, but also if the user himself moves (e.g., as a pedestrian). To gain a better understanding of the perception of motion in computer-mediated realities, Bruder et al. investigated to what degree self-motion perception can be altered [3]. Interestingly, they found that their technique has the potential to make a user perceive self-motion as faster or slower than it actually is.

**Visual cues for shifting attention** In previous work, various positions have been investigated for placement of visual cues. Harrison et al. investigated the use of wearable visual cues on seven different body locations between the shoulders and feet and measured the respective reaction times [9]. 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 user's attention to information on a wrist-worn smartwatch [17]. They found statistically significant differences for size and frequency, which were positively correlated with length of reaction time. Renner and Pfeiffer investigated different peripheral and in-view Attention Guidance techniques for augmented reality applications [24]. Altogether, pointing towards targets out of view turned out to be the fastest and best rated guidance technique. To guide the attention of a user in a virtual reality scene, Danieau et al. designed four different virtual effects and investigated two of them in a user study [6]. Their results show that it remains challenging to implicitly drive the user's attention outside of the field of view. However, shifting user's attention towards targets out of view can also be achieved by combining light with another modality. For example, Löcken et al. [14] tested the combination of visual stimuli with audio cues. They showed that adding a sound cue results in faster response times. Furthermore, participants reacted faster to LEDs that faded in over time.

## 3 General Approach

To support pedestrians in critical traffic encounters, we aimed to augment the user's peripheral vision with low-cost glasses. In our approach, we limited ourselves to the most frequent traffic encounters, in which a car is either approaching from the left or right side of the user. For our proposed solution, we followed related work providing evidence for (a) good perception of peripheral displays (b) movement as a well-perceived stimulus in the periphery and (c) on-body visual stimuli successfully shifting users' attention. We implemented movement with a combination of LEDs positioned in such a way that they are unaffected by different head poses typical for smartphone users. We identified three different stimuli as possible candidates for visually shifting a user's attention. The first stimulus *instant* is our baseline condition, while the second *moving* and third stimuli *pulsing* are based on prior work that concluded that movement is well perceived in the periphery [14, 16, 17] (cf. Figure 2). To test the different conditions, we developed a prototype with peripheral displays, similar to the smart glasses from Nakao and Kunze [19]. Different to their approach our displays use multi-color




(a) Stimulus instant (b) Stimulus pulsing (c) Stimulus moving (d) LED order (right side)

Figure 2: Evaluated light stimuli. *Best seen in color.*

LEDs and are rotated towards the user for better perceptibility. As a first step towards the development of well-perceivable moving stimuli in the periphery, we tested a high-density LED strip attached to a pair of safety glasses. We discussed the prototype with usability experts and received recommendations for a technically improved version. As a second step, we built an improved prototype and evaluated its performance for displaying three different light stimuli in a lab study.

## 4 LED STRIP PROTOTYPE

We started to investigate whether animated stimuli are suitable for shifting attention towards either the left or right side of the user with a low fidelity prototype. This first prototype was based on the combination of safety glasses and LED strips. We used LED strips with the highest density available for consumers (144 LED per meter). They consisted of RGB LEDs of the type WS2812B[4]. The LED strips were positioned to be in the periphery of the user [10]. We added a NodeMCU developer board[5] with a low-cost Wi-Fi board attached and one Li-Po battery. These components are lightweight, affordable and allow mobile usage of the LED strip prototype. Further, we set up a web interface to manipulate the stimuli shown by the LED strips. The source code is available under MIT License on Github[6]. The LED strip prototype can be seen in Figure 1a) and 1b.

## 5 INTERVIEW WITH USABILITY EXPERTS

In order to gain early insights for our developed prototype, we conducted an interview with usability experts. In this interview, we wanted to explore if our lo-fi prototype is suitable to show animated stimuli for shifting user's attention. We further wanted to explore fitting parameters for our stimuli (e.g., speed of moving and pulsing stimuli).

### 5.1 Procedure

We decided to do the interviews about our first prototype with each usability expert separately in order to avoid them influencing one another. The interview consisted of two parts. In the first part, we introduced the expert to the problem we wanted to solve and our approach. The expert was then asked to give comments on the idea and our prototype. In the second part, the expert could try out the prototype and test the different stimuli. Therefore, they could change the different parameters (e.g., speed, movement direction, color, brightness). Each pretest lasted around 20 minutes.

### 5.2 Participants

We interviewed 5 experts (2 female), aged between 26 and 35 (M=30, SD=3.56). All of them had at least three years of experience in human-computer interaction research.

### 5.3 Results

Animated light stimuli For the animated stimuli, we asked if the stimuli should move towards the hazard or away from it. However, compared to other domains in which users preferred the stimuli pointing away (e.g., driving [2,29]) the experts agreed on the stimuli moving towards the hazard. One expert stated that he perceived the stimulus as if his head were being dragged towards the hazard.

LED placement All experts mentioned several aspects regarding the LED strip and its placement. All experts agreed that the distance between the different LEDs was too big to be perceived as movement in the periphery. Further, it became clear that the LED strip used for the first iteration of our prototype did not need to extend very far into the periphery, as the outer LEDs could not be perceived. Furthermore, two experts had the problem that the LED strips were not in line with their eyes. Therefore, they perceived the stimuli as too high or too low.

Usability Three experts stated that no lenses are necessary for the functionality of the first prototype. Therefore, they suggested that we remove them, to both decrease the weight and avoid possible reflection of the light stimuli. Further, it was mentioned that the user loses the ability to perceive peripheral information to some extent due to clutter.

## 6 LED MATRIX PROTOTYPE

To overcome the limitations of the first prototype, we decided to use an LED matrix instead of an LED strip and to remove the glasses (see Figure 1c). By taking this approach, we could increase the LED density to 200 LEDs per meter per row (4 LEDs per square centimeter). Further, with an LED matrix, it is possible to adjust the stimuli to the user's line of sight by picking a different row on the matrix for stimuli presentation. However, with the bigger dimensions of the matrix, the problem of too much clutter in the periphery remains. The type of LED was the same as in the LED strip prototype.

## 7 EXPERIMENTAL EVALUATION

To evaluate the performance of animated stimuli in our low-cost peripheral vision glasses (second prototype cf. Figure 1c), we conducted a within-subjects controlled laboratory study in Augmented Reality with an Android smartphone.

### 7.1 Study design

Our study's only independent variable was peripheral stimulus, with three levels (*instant* vs. *pulsing* vs. *moving*), where *instant* is the baseline condition. We used quantitative methods to evaluate user performance, taking response time and error rate as our dependent variables. Response time is measured as the time from the presentation of a stimulus on the peripheral vision glasses to the participant's verbal identification of a letter appearing on a display laterally behind them. We recorded this response in two ways: (1) the director of the study pressed a button (2) voice activation stopped a timer. The error rate is specified as the percentage of stimuli to which a user wrongly reacted. For this study, we asked:

**In how far can peripheral vision be augmented to visually shift the attention of pedestrians in critical traffic encounters (RQ)?**

[4]https://cdn-shop.adafruit.com/datasheets/WS2812B.pdf, last retrieved: July 3, 2018

[5]https://en.wikipedia.org/wiki/NodeMCU, last retrieved: July 3, 2018

[6]https://github.com/UweGruenefeld/GuidingSmombies

$H_1$: **We expect the stimulus *moving* to result in faster response times than *instant*.**
$H_2$: **We hypothesize that the stimulus *instant* results in the highest error rate.**

### 7.2 Apparatus

Our apparatus consisted of a treadmill and two displays positioned laterally behind the participant, one on the left and one on the right side. The displays were placed 135° to the left and right to avoid participants perceiving changes on the display. @shepherd removed figure of apparatus.

### 7.3 Participants

We recruited 8 participants (2 female), aged between 22 and 31 (M=26, SD=3.25). None of them suffered from color vision impairment. All had normal or corrected to normal vision. Participants with corrected to normal vision wore contact lenses.

### 7.4 Procedure

In the beginning, the experimenter explained the procedure and asked the participant to sign a form of consent. Then the participant put on the peripheral vision glasses and went on the treadmill. A safety clip attached to the participant's clothing ensured an emergency stop of the treadmill in the event that a participant tripped. In addition, there was an emergency stop button always reachable for the participant. To ensure that the participant could always press the emergency stop button, we did not use any additional hand-held device other than the smartphone. The speed of the treadmill was fixed at 2.5 kmh.

The participant was holding a smartphone in his/her dominant hand, playing a two-position-back memory game (primary task). The other hand was free to hold on to the treadmill or press the stop button. Every 20-40 seconds, the peripheral vision glasses displayed a randomized stimulus to the left or right side. Simultaneously, the respective display displayed a random uppercase letter for a duration of five seconds. The participant was instructed to immediately react to the stimulus and read the letter out loud (secondary task). There were 30 stimuli in total, all stimuli were represented equally.

In the end, the participants were asked to answer a questionnaire, rating the three stimuli on a five-point Likert scale for the statements: "I could see the light stimulus very quickly", "I felt the direction indicated by the light stimulus as intuitively understandable", and "I found the light stimulus alarming". Further, we asked the participants to pick their favorite stimulus and collected demographic data. Experiment sessions lasted approximately 30 minutes.

### 7.5 Results

Error rate We consider the effects of three different conditions (*instant*, *pulsing*, *moving*) on error rate (where error rate means how frequently participants did not react to a given stimulus or stated the wrong letter). Participants were correct in 100% of the trials independent of different conditions and therefore it resulted in 0% error rate.

Response time We consider the effects of three different conditions (*instant*, *blinking*, *moving*) on participants' response time. We measured the response time using the key press of the director of studies only and discarded the vocal response times due to frequent noise (e.g., squeaking of shoes on the treadmill) resulting in false positives. However, there was a significant positive correlation between key press response time and voice response time (Spearman ($\rho$) = 0.46, $p<0.001$). The mean response times for the different conditions were: instant = 2.29 s (SD = 0.48), pulsing = 2.28 s (SD = 0.53) and moving = 2.15 s (SD = 0.54). A Shapiro-Wilk-Test showed that our data is not normally distributed ($p < 0.001$). We therefore ran a Friedman test, which revealed a significant effect of different conditions on response time ($\chi^2(2)$=6.93, p = 0.031, N=8). A post-hoc test using Wilcoxon Signed-rank with Holm-Bonferroni correction showed significant differences between some conditions, which are shown in Table 1. The response times are compared in Figure 3. To conclude, moving is significant faster than instant and pulsing, while there were no significant differences between instant and pulsing.

| Comparison | P-value | Effect size r |
|---|---|---|
| instant vs. pulsing | 0.640 | 0.04 |
| instant vs. moving | 0.032* | 0.19 |
| pulsing vs. moving | 0.032* | 0.20 |

Table 1: Pairwise comparison of different conditions (*p<0.05).

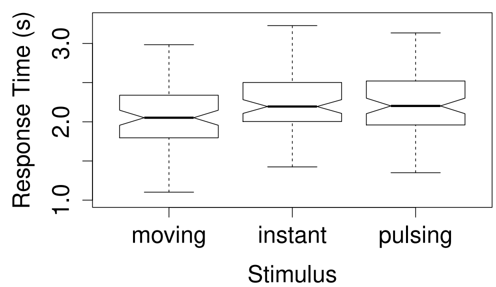



Figure 3: Response times of different stimuli.

Subjective questionnaire At the end of the study, we asked participants to answer three questions for each condition (*instant*, *pulsing*, *moving*). The questions were five-point Likert items. Participants stated that they could see the light stimulus very quickly for *instant* (Md=3.5, IQR=2.25), *pulsing* (Md=4, IQR=1.25) and *moving* (Md=5, IQR=0). They stated that they felt the direction indicated by the light stimulus as intuitively understandable for all stimuli equally (Md=5, IQR=0). Furthermore, they stated that they found the light stimuli alarming for *instant* (Md=2.5, IQR=1.5), *pulsing* (Md=4, IQR=1.25) and *moving* (Md=3.5, IQR=1). Overall, seven participants preferred *moving* while one participant preferred *instant*.

## 8 Discussion

Advantages of peripheral stimuli Visual stimuli presented in the periphery using a head-mounted device offer the possibility for shifting user's attention on-demand without cluttering the main visual field. Our results showed that light stimuli are easily perceivable in the periphery. In our hypothesis $H_2$, we expected the instant stimulus to result in a higher error rate. However, participants did not make any errors. Therefore, we cannot accept our hypothesis $H_2$.

Perception of movement Based on prior work, we hypothesized that movement, specifically movement over position, would result in faster response times $H_1$ (cf. [14, 16, 28]). Therefore, we investigated two different stimuli that change over time (where *pulsing* changes the intensity and *moving* changes the position over time). Our results showed that *moving* resulted in significantly faster response times than *pulsing* or *instant*. Therefore, we can accept our hypothesis $H_1$.

Further applications Besides using our developed prototype for shifting a user's attention towards approaching cars, we can also imagine using the peripheral displays for less critical scenarios (e.g., notifications, navigation). This is highlighted by previous work that already showed the usefulness of such head-mounted displays for unobtrusive notifications [5], alarms [4], warnings [21] or navigation tasks [23].

## 9 Conclusion

In this paper, we evaluated three different light stimuli for shifting the attention of walking smartphone users to the left or right side. The stimuli were presented in the periphery of the user using our peripheral vision prototype, which was developed in two iterations. Our results showed that light stimuli are well suited for shifting the attention of smartphone users and that a moving stimulus results in significantly faster response time. In the future, we would like to combine it with image processing and machine learning for detection of approaching cars in traffic situations, as well as evaluate moving stimuli under more realistic circumstances. Furthermore, it might be interesting to combine our solution with existing AR glasses.

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