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Detection of visual stimuli on monocular peripheral head-worn displays

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ABSTRACT

Objective: To compare people's ability to detect peripherally presented stimuli on a monocular head-worn display (HWD) versus a conventional screen.
Background: Visual attention capture has been systematically investigated, but not with respect to HWDs. How stimulus properties affect attention capture is likely to be different on an HWD when compared to a traditional computer display.
Method: Participants performed an ongoing perceptual task and attempted to detect stimuli that were displayed peripherally on either a computer monitor or a monocular HWD.
Results: Participants were less able to detect peripheral stimuli when the stimuli were presented on a HWD than when presented on a computer monitor. Moreover, the disadvantage of the HWD was more pronounced when peripheral stimuli were less distinct and when the stimuli were presented further into the periphery.
Conclusion: Presenting stimuli on a monocular head-worn display reduces participants' ability to notice peripheral visual stimuli compared to presentation on a normal computer monitor. This effect increases as stimuli are presented further in the periphery, but can be ameliorated to a degree by using high-contrast stimuli.
Application: The findings are useful for designers creating visual stimuli intended to capture attention when viewed on a peripherally positioned monocular head-worn display.

1. Introduction

When people are engaged in mobile work, head worn displays (HWDs) can provide real-time access to information that might otherwise be unavailable or difficult to access. HWDs have been used to augment the worker's view with additional streams of hands-free information in a variety of high-tempo contexts such as manual assembly tasks (Büttner et al., 2016), controlling unmanned aircraft (Belenkii et al., 2017), flight data for pilots (Winterbottom et al., 2007; Winterbottom et al., 2006), infantry navigation data for soldiers (Glumm et al., 1998) as well as other augmented views of battlefields (Livingston et al., 2011). The intention is that the information provided by the HWD, often adapted to the location or context, will improve the worker's ability to carry out their tasks.

In the field of healthcare an anesthetist could regularly monitor the HWD for changes in a patient's vital signs, rather than visually scanning equipment around the room (Dougherty and Badawy, 2017; Liu et al., 2010). In addition, the HWD could alert the user to an important event happening some distance away from the current task. For example, a nurse focusing on medication preparation in one location might be notified, via HWD, that a patient in another location has a critically low heart rate. If the nurse is not actively attending to the HWD, a change in the display might capture the nurse's attention. If an HWD is to alert workers to significant changes, it would be important for designers to know how visual stimuli on an HWD capture attention to ensure that the alert is effective. However, many HWDs use peripherally-positioned monocular displays. The purpose of the experiment reported in this paper was to compare people's ability to detect peripherally-located stimulus changes across two display media; specifically, a monocular see-through HWD versus a conventional computer screen.

Researchers have distinguished goal-driven attention (voluntary or endogenous) and stimulus driven attention (involuntary or exogenous) (Folk et al., 1992). HWD use will inevitably rely on both aspects of attentional control, but for the purposes of this study, we were

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selectively interested in exogenous attention to test the potential for HWDs to convey unexpected alarm/alert stimuli. On the one hand, the capture of exogenous attention can be driven by stimulus-related factors. For example, color, brightness, or motion may be manipulated to enhance visual discriminability, thereby increasing the likelihood of capturing visual attention (Hillstrom and Yantis, 1994; Nikolic et al., 2004; Yantis and Jonides, 1984). Likewise, increases in the peripheral eccentricity (distance from foveal vision) of the stimuli will reduce people's ability to notice target changes due to the organization of receptors on the retina (Nikolic et al., 2004; Olzak and Thomas, 1986; Wolfe, O'Neill and Bennett, 1998). On the other hand, the capture of exogenous attention can be influenced by task-related factors. For example, concurrent perceptual tasks will reduce people's awareness of distractor stimuli more than concurrent cognitive tasks will (Lavie, 2005, 2010; Lavie et al., 2014). However, when unexpected distractor stimuli match the participants' expectations, they are more likely to capture attention than those that do not match the participants' expectations (Folk et al., 1992; Vecera et al., 2014). Taken together, the above studies provide a basis for designing visual displays that effectively capture exogenous attention. If characteristics of a head-worn device introduce additional limitations, however, special considerations may be needed.

To date, only a few studies have investigated attention capture with HWDs.[2] Winterbottom et al. (2015) found that target stimuli presented in the forward field of view were detected less often when they were presented via monocular HWD than via binocular HWD, and that the stimuli required greater visual contrast to attract attention. Costanza et al (2006) showed that increases in task loading reduced how effectively attention was captured by an array of light emitting diodes (LEDs) located peripherally at the hinge of a normal pair of regular glasses. Woodham et al (2016) found that rock climbers were less likely to notice words presented on a monocular, peripheral HWD while climbing than while sitting, unless they were presented with a simultaneous auditory cue. This is because auditory cues have a preemptive quality (Wickens, 2008; Wickens et al., 2005) that can aid target detection, but for that reason, they can also be potentially distracting, and are not always appropriate or desirable, particularly in an environment that is already rich with sounds, like a hospital ward. Even without the inclusion of redundant auditory stimuli, however, HWDs can influence task performance.

HWDs that attract too much attention, whether by visual, audio or both means, may compromise participants' ability to perform their ongoing task. For example, participants wearing and using an HWD in simulated driving tasks failed to maintain lane positioning and executed emergency braking slower (Chua et al., 2016; Sawyer et al., 2014). Similarly, He et al. (2018) found that drivers wearing HWDs controlled the vehicle's steering better, and were faster to engage in a distraction task compared to drivers who were engaging with a normal smartphone. The HWD drivers, however, had significantly greater speed deviations, suggesting that both devices can negatively affect driving performance, albeit in different ways. Furthermore, Mustonen et al. (2013) found that participants' walking performance suffered when they attempted to simultaneously detect changes on a HWD; the dual-task requirements of walking and attempting to view the HWD resulted in more walking errors as well as more missed target changes. Additionally, Woodham et al. (2016) found that participants climbed rocks more slowly, less efficiently, and covered less distance when they were simultaneously attempting to view and recall words on an HWD, compared to climbing with the HWD shut off. These studies suggest that the information on an HWD can sometimes be distracting, which has the potential to do more harm than good.

It is still unknown whether the impact of peripheral presentation is more or less extreme for presentation on an HWD than on a traditional computer display. The purpose of the current study was to compare participants' ability to detect visual changes on the HWD with their ability to detect equivalent changes on a conventional computer screen. The study we report was designed to examine participants' performance when peripheral stimuli with differing levels of brightness and orientation were presented on a simulated HWD (computer screen, binocular) versus on a real HWD (monocular), and at near versus far eccentricities. We predicted that the probability of detecting target stimuli would be significantly reduced (a) when participants viewed the peripheral stimuli on the real HWD rather than on the simulated HWD, (b) when the peripheral stimuli were at the far eccentricity rather than near, as in Nikolic et al. (2004) and Wolfe et al. (1998), and (c) when target stimuli shared more visual characteristics with non-target stimuli, following Jonides (1981), Yantis and Jonides (1984), and Hillstrom and Yantis (1994).

2. Method

2.1. Participants

72 students from The University of Queensland participated in exchange for AUD$10 gift cards. The sample size was determined by a power analysis using the results of a pilot study with a comparable design ($M = .642$, $Mdelta = .558$, $SD = .362$, $r = .74$, $\alpha = .05$, $1-\beta = .80$). Potential participants wearing corrective eyeglasses were excluded prior to enrollment. This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at The University of Queensland. Informed consent was obtained from each participant.

2.2. Design

The experiment used a within-subjects design, investigating the effects on peripheral target detection of display medium (simulated HWD versus real HWD), peripheral eccentricity (near versus far), apparent motion of target stimuli (none: vertical versus movement: tilted), and brightness of target stimuli (dark gray versus light gray versus white). The study was conducted in eight blocks of trials. Each block was six minutes long and consisted of a self-paced perceptual task, presented on a computer monitor, and a peripheral detection task, presented on either the computer monitor (simulated HWD) or the real HWD. The changes to peripheral stimuli occurred at random-appearing intervals.

2.3. Apparatus

The participant sat in an adjustable chair in front of a computer monitor, which was positioned on a small stand (10 cm high). The participant maintained a constant viewing distance from the center of the computer monitor by resting their chin in a chinrest. The distance of the chinrest to the monitor screen remained constant (51 cm) across participants. The participant's head was further stabilized using a headrest. Each participant positioned their forehead against the headrest to maintain the angle at which the image on the HWD would be seen against the background of the computer, when the HWD was worn. Both the chinrest and headrest were adjusted vertically for each participant so that the HWD image overlaid, as closely as possible, the position on the screen where the simulated HWD was otherwise presented. Fig. 1 shows the setup of the chinrest and headrest.

The ongoing task and simulated HWD stimuli were presented on a 27-inch iMac computer display (Apple, Cupertino, CA), with a black background and a calibrated background (see below), respectively. The real HWD stimuli were presented on Google Glass (Google Inc.,

[2] Attention capture is formally described as the involuntary capture of attention by stimuli through the properties of the stimuli alone (Theeuwes et al., 2010; Yantis and Egeth, 1999). In our case, participants have been asked to respond to the stimuli in question, and it is unknown whether the stimuli would by themselves capture attention. However for present purposes we use the term attention capture in the latter slightly different sense.