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.

Keywords: Head-worn displays, Google Glass, monitoring, attention, perception.

Précis: Several factors can change the noticeability of stimuli when viewed peripherally: distance of stimuli from the primary task, stimulus brightness and degree of tilt. These effects are stronger when peripheral stimuli are displayed on a monocular HWD than on a screen.

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 in a variety of high-tempo contexts such as manual assembly tasks (Büttner, Funk, Sand, & Röcker, 2016), controlling unmanned aircraft (Belenkii, Sverdrup, DiRuscio, & Taketomi, 2017), flight data for pilots (Winterbottom, Patterson, Pierce, Covas, & Winner, 2007; Winterbottom, Patterson, Pierce, & Taylor, 2006), infantry navigation data for soldiers (Glumm, Marshak, Branscome, McWesler, & Patton, 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 (see Dougherty and Badawy (2017) for a review) an anesthetist could regularly monitor the HWD for changes in a patient's vital signs, rather than visually scanning equipment around the room (Liu, Jenkins, Sanderson, Fabian, & Russell, 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 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, Remington, & Johnston, 1992). HWD use will inevitably rely on both aspects of attentional control, but for the purposes of this study, we were selectively interested in exogenous attention to test the potential for HWDs to mobilize 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 & Yantis, 1994; Nikolic, Orr, & Sarter, 2004; S. Yantis & 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 & Thomas, 1986; Wolfe, O'Neill, & 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, Beck, & Konstantinou, 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, Cosman, Vatterott, & Roper, 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.[1] Using a foveal HWD, Winterbottom, Patterson, Pierce, Gaska, and Hadley (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

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[1] Attention capture is formally described as the involuntary capture of attention by stimuli through the properties of the stimuli alone (Theeuwes, Olivers, & Belopolsky, 2010; Steven Yantis & 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.

attract attention. Costanza, Inverso, Pavlov, Allen, and Maes (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, Billinghurst, and Helton (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, Dixon, & Seppelt, 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, 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, Perrault, Matthies, & Zhao, 2016; Sawyer, Finomore, Calvo, & Hancock, 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 the both devices can negatively affect driving performance, albeit in different ways. Furthermore, Mustonen, Berg, Kaistinen, Kawai, and Hakkinen (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), S. 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$, $Mdelta = .558$, $SD = .362$, $r = .74$, $\alpha = .05$, $\beta = .80$). Applicants 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. During each block, participants performed eight six-minute trials of an ongoing task presented on a computer monitor while they detected changes to peripheral stimuli on either the computer monitor (simulated HWD) or the real HWD. The changes 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. Figure 1 shows the setup of the chinrest and headrest.

Figure 1. Each participant's head was fixed using a chinrest as well as a forehead-rest. After aligning the real HWD with the simulated HWD, the participant was instructed to maintain that position for the remainder of the block.

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., Mountain View, CA), a monocular see-through HWD that is visible to only the right eye, but not directly in the forward field of view.

The participant made their inputs on a standard keyboard whose relevant keys were covered with a small patch of Velcro, fuzzy side up, to make them easier for the participant to feel and therefore use without having to look down to check their finger location.

2.4 Calibration

Before the experiment was conducted, a calibration study was run to equalize, as much as possible, the colors and brightness of the simulated HWD display on the computer screen and of the real HWD display. A black background on the HWD does not actually look black, but instead appears as a desaturated rust color (approximated in Figure 2) that was also affected by whatever it overlaid in the environment—in our case, the black screen of the computer monitor. In addition, before the calibration, the stimuli on the HWD appeared less bright than those on the computer display. We did not have access to a spectrophotometer to perfectly match the colors used on the two displays (Google Glass versus computer monitor); so, our calibration study used the psychophysical method of adjustment to equalize the stimuli on the displays.

A separate sample of 11 students from the same participant pool as the main study participated in the calibration study. Participants viewed both displays and made color adjustments to the background of the simulated HWD displayed on the computer monitor. Their goal was to match the background color of the simulated HWD to the background color of the real HWD. The participant then adjusted the brightness of the stimuli on the real HWD to match their brightness on the simulated HWD. Because the distance between the HWD display and the computer screen was fixed, given the chinrest and headrest, the stimuli on the simulated HWD and real HWD appeared to be the same size and at the same degree of eccentricity from forward gaze. The calibration study produced color values and intensities for use in the current experiment that equalized the colors and brightness of the stimuli on the two displays. The procedure and full findings of the calibration study are reported in Appendix A.

2.5 Stimuli and Tasks

For all blocks of the current study, participants performed two tasks. The first task was an ongoing perceptual task that required a “left” or “right” keypress depending on which of two stimuli had a larger gap on one side. The second task was a peripheral detection task that required a keypress when any target change occurred.

The ongoing task was presented in yellow font in one of two locations on the computer monitor (near or far) (see Figure 2). Two squares (Landolt stimuli) were displayed side-by-side. Each square had a disconnected side with gaps of different widths. Using their left hand, participants indicated whether the gap in the left or right square was larger, by pressing the “A” key for the left square, or the “S” key for the right square. Participants were instructed to focus on this task. The task was self-paced but stimuli advanced if no response was received within 6 seconds.

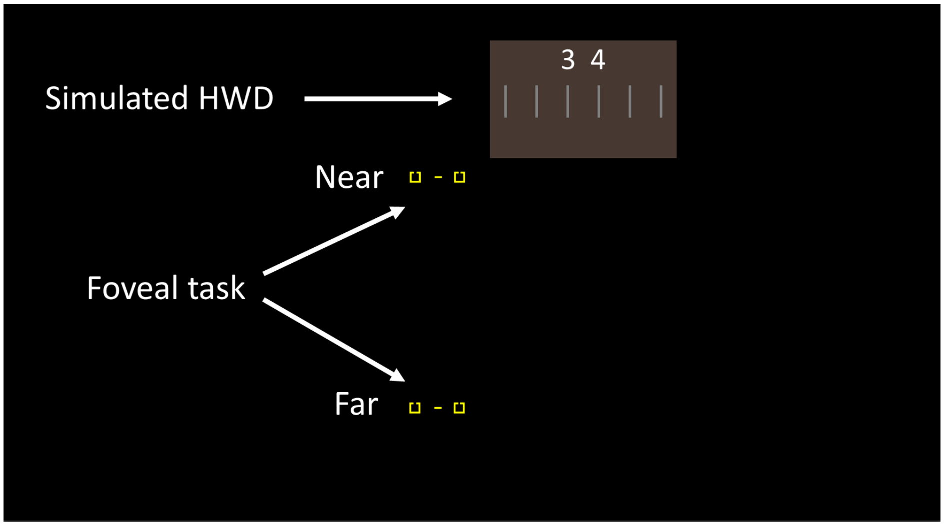

Figure 2. Simulated HWD stimuli appeared in a constant screen location, and were designed to be viewed in peripheral vision. One of the middle bars (3 or 4) would briefly change to one of the five target states in Figure 3. The ongoing task was presented at either a near or far location with respect to the peripheral stimuli. Annotations, arrows, and bar numbers "3" and "4" were not shown during the experiment.

The peripheral detection task was in a constant location above and to the right of the ongoing task, presented on either the simulated HWD or real HWD (Figure 2; visual angles from the foveal task to each bar are listed in Table 1). The stimuli to be detected in the periphery comprised six vertical bars that simulated a simple multiple-process display that might be seen on an HWD. In their default state, the bars were vertical and dark gray. Occasionally, a target stimulus was generated by briefly changing the tilt (i.e., apparent motion) and/or brightness of the third or fourth bar, which were selected to keep the visual angle between the ongoing task and target stimuli as consistent as possible without always using the same bar. The target stimulus was an uppercase "I" in Lucida Grande font, either roman or italicized with a tilt of 11.5 degrees from vertical to produce "*I*". Brightness levels on the simulated HWD were dark gray (hex code: #808080), light gray (hex code: #c0c0c0), or white (hex code: #ffffff). Altogether, there were five kinds of target stimuli, varying in brightness and/or tilt from the dark gray and vertical default bars: dark gray and tilted, light gray and vertical, light gray and tilted, white and vertical, and white and tilted (see Figure 3).

Table 1

Measure of the visual angles from the foveal task to each bar on the peripheral display, at each eccentricity

Eccentricity	Visual Angle (degrees)					
	Bar 1	Bar 2	Bar 3	Bar 4	Bar 5	Bar 6
NEAR task	9	10.2	11.8	13.5	15.2	17.1
FAR task	24.3	24.7	25.3	26	26.9	27.8

In each six-minute experimental block there were 15 appearances of target stimuli (three of each kind of stimulus) that were un-cued and that occurred between 17.1 and 30.9 seconds apart, with a mean of approximately 24 seconds apart. Target stimuli were timed to appear 400 milliseconds after the onset of an ongoing task (Landolt C) trial and they persisted for 200 milliseconds before returning to the default state. The duration of 200 milliseconds was chosen because it is faster than the average time to react to and make a saccade from the ongoing task to the HWD, allowing us to measure the detection of a change when the HWD display was viewed in peripheral vision, and not when viewed directly. Using their right hand, participants pressed the semicolon key when they detected a target stimulus.

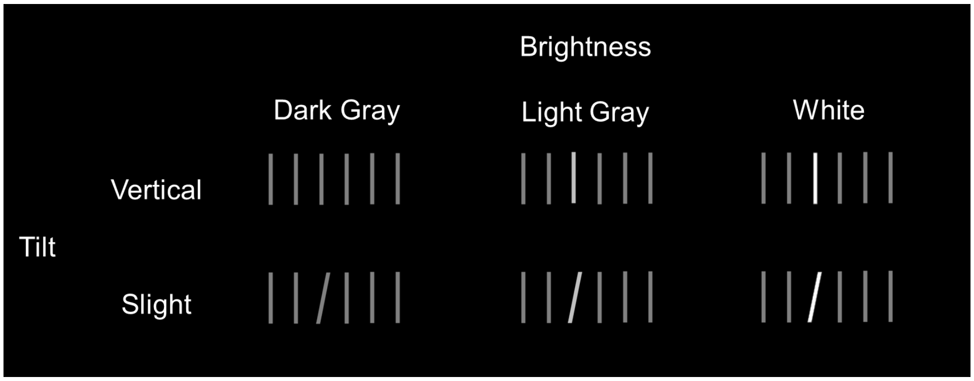

Figure 3. Examples of the five possible target changes in Experiment 1 compared with the default, non-target state (top left).

2.6 Procedure

The HWD was offered to the participant who put it on. In the real HWD condition the participant adjusted the angle of the HWD display screen until the stimuli were clearly visible. Participants then adjusted the height of their chair and location of the headrest to overlay the real HWD display comfortably over the simulated HWD so that the location of the display, relative to the foveal task, was matched across the two display conditions at test. Participants were instructed to maintain that position throughout each block.

Instructions and practice trials were presented using a timed Microsoft PowerPoint (Microsoft Corporation, Redmond, WA) presentation with a recorded narration. Participants then worked through the eight experimental blocks, in which they performed both the ongoing task and peripheral target change detection task with either the simulated or the real HWD. Before the start of each block, the software instructed the participant to put on or take off the HWD in preparation for the upcoming block. Participants were given one-minute breaks between blocks. The entire experiment lasted approximately 60 minutes.

2.7 Analyses

Analyses were directed at identifying whether participants' ability to detect targets (changes in peripheral stimuli) was affected by the display mode, the eccentricity of the HWD stimuli from the foveal task, and the deviation (in brightness and/or tilt) of the target from the dark gray and vertical default. Initially, the detection data (target detected or target missed) were transformed to accuracy values (percentage detected) for each combination of the independent variables. An ANOVA was used to analyze these data, but subsequent analyses of the residuals revealed that the data did not fit a normal distribution and did not have equal variances. Thus, target detection data were analyzed using a mixed effects logistic regression, which does not rely on normally distributed or homoscedastic data and, furthermore, is the method best suited to handle the original binary outcome variable.

The final logistic regression model was selected based on the best fit to the data, as described in Marewski and Olsson (2009). Thus, in the model to be presented, any interactions omitted did not significantly influence the explanatory power of the model, but may have influenced the strength of the slope-coefficient of the remaining variables. The fixed effects of the final model included display, eccentricity, target stimuli, and the interactions (denoted by a “x” in the table) between display/eccentricity, and display/stimulus, with participants as a random effect. The regression model was then used to generate the predicted probability that each color/tilt combination would be detected on each display, and at each eccentricity.

Table 2 shows the results of the logistic regression. The baseline condition was coded as the dark gray and tilted target stimulus, on the simulated HWD, at the near eccentricity. Each line in Table 2 describes a specific deviation from that baseline set of conditions, and the subsequent change in the odds of detection (fixed effects). The last row reports the inter-participant variability (random effect).

3 Results

Table 2

Results of the mixed effects logistic regression, “x” indicates interactions

Change from baseline (simulated HWD, near, tilted, and dark gray)	Odds Ratio	SE	z	p
Intercept (baseline)	6.44	1.06	11.36	< .001
Real HWD	0.11	0.02	-14.28	< .001
Far	0.64	0.08	-3.84	< .001
Real HWD x Far	0.51	0.08	-4.38	< .001
Light gray and vertical	1.36	0.20	2.11	0.035
Light gray and tilted	3.62	0.65	7.13	< .001
White and vertical	3.85	0.71	7.33	< .001
White and tilted	10.16	2.56	9.20	< .001
Real HWD x Light gray and vertical	7.27	1.43	10.07	< .001
Real HWD x Light gray and tilted	4.34	0.99	6.44	< .001
Real HWD x White and vertical	5.04	1.18	6.92	< .001
Real HWD x White and tilted	3.31	0.99	4.01	< .001
Random effect - Participant	0.75	0.16		

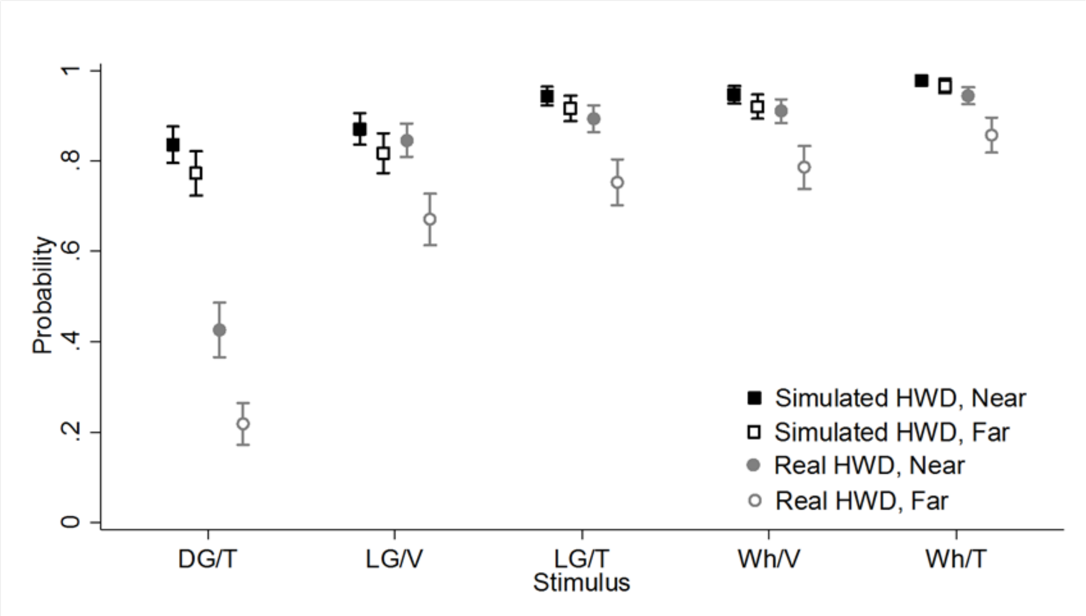

Figure 4. Predicted probability and 95% confidence intervals of detecting each target stimulus on the simulated HWD versus the real HWD, and at the near versus far eccentricity. DG/T = dark gray and tilted, LG/V = light gray and vertical, LG/T = light gray and tilted, Wh/V = white and vertical, and Wh/T = white and tilted.

Figure 4 shows the predicted probabilities of detecting each target stimulus when displayed on the simulated HWD versus the real HWD, and at the near versus far eccentricity. It shows that the odds of detecting four out of the five target stimuli (excluding light gray and vertical) on the real HWD were significantly less than for the simulated HWD. Moreover, when target stimuli were presented further into the periphery on the HWD, detection rates were reduced to a greater degree than when presented further into the periphery on the simulated HWD. However, as stimuli increased in brightness and tilt, the likelihood of being detecting increased.

4 Discussion

The purpose of this study was to investigate differences in people's ability to detect changes to peripheral stimuli displayed on a real HWD versus their ability to detect peripheral stimuli on a regular computer screen simulating an HWD. The size of targets, contrast from background, and position in the visual field were all controlled to be as similar as possible across the real and simulated HWD displays. By equating colors and brightness across displays as much as possible, our goal was to lessen the chance that any difference in detection rates between the simulated HWD and real HWD conditions would be due to simple device-related differences such as target size, brightness, color, or color contrasts between the stimuli and the background. Accordingly, any difference in detection rates probably reflects differences unique to the two display devices themselves.

Our hypotheses were confirmed. The HWD reduced participants' ability to detect peripheral targets when compared with detection using the simulated HWD display. Moreover, the disadvantage of the HWD was stronger when targets were farther in peripheral vision and when targets were only minimally different from their default dark gray and vertically oriented form. However, the disadvantage of the HWD was nearly eliminated when targets were at their most distinct, such as when they were light gray and tilted, and when they were white and tilted.

Several factors might explain the present findings, that are consistent with prior research in the area. No single factor explains the findings, but a combination of factors may do so. One explanation for the differences in detection performance between the simulated and real HWDs is that the real HWD stimuli were seen by only one eye. When stimuli are seen by both eyes simultaneously, the images are fused resulting in binocular summation (Blake & Fox, 1973), which results in gains in contrast sensitivity, brightness sensitivity, flicker perception and visual acuity. Stimuli presented to only one eye are subject to binocular rivalry (Patterson, Winterbottom, Pierce, & Fox, 2007)—the unconscious prioritization, and continual switching, of stimulus perception from one eye over the other. If the image from the eye viewing the real HWD had been temporarily suppressed when the target stimuli were being displayed, it would account for the reduction in target detection rates on that display.

A second explanation for the differences in detection between the simulated vs. real HWD may be that fixated objects take perceptual priority over proximate objects that obstruct the field of view (Arnold (2011). Moreover, if objects within the image coming from one eye do not match the view of the other eye, those objects are likely to be suppressed. For our study, the real HWD obstructed part of the view of the computer screen that displayed the perceptual task (the fixated object), and the HWD only obstructed the image from the right eye. As a result, the visual system may have intentionally suppressed that area of the visual field of the right eye (the location of the real HWD), to favor the view of the fixated screen and task, reducing the likelihood that stimuli on the real HWD would be detected.

A third explanation for the differences between detection rates on the simulated vs. real HWD may lie in the differences between the focal plane of the target stimuli on the real HWD and the focal plane of the ongoing task. Winterbottom et al. (2007) found that focal depth can affect the detectability of stimuli as well as visual comfort, and that the optimal focal depth should be the midpoint of the range of distances of potential stimuli. These distinctions, however, are for HWD imagery presented directly in the forward field of view, rather than peripherally. Moreover, Google Glass is not focusable, but the apparent focal distance can vary, depending on a range of subjective factors.

A fourth explanation for the difference in detection rates between simulated vs. real HWDs might be that the relationship between the ongoing task and peripheral stimuli was always fixed when participants viewed the peripheral stimuli on the simulated HWD, but variable when viewed on the real HWD. When participants viewed the peripheral stimuli on the real HWD, head motion was constrained by the chinrest and headrest, but the stimuli could still move slightly with respect to the ongoing task when small head movements occurred, which may have reduced participants' ability to perceive the targets. According to Gestalt theory, stimuli that have common fate or 'shared movement', are chunked together and experienced preattentively as being a single object (Koffka, 1935). Attention, chunking can influence how efficiently our visual system attends to objects in view, and whether or not attention needs to be divided across multiple perceptual objects (Duncan, 1984). This might suggest that the simulated HWD and ongoing task were viewed as a single object because they were viewed on the same computer screen, thereby not requiring a division of attention. The imagery on the real HWD, however, may have functioned as a separate object from the ongoing task, causing a greater division in attention load than for the simulated HWD. Therefore, the items on the real HWD may not have been monitored as effectively as the items on the simulated HWD.

The differences in the rates of detection between stimuli were driven by the differences in contrast. Stimuli that share fewer similarities with the background will stand out to the perceptual system to a greater degree; an example is a black bear walking on snow versus a polar bear walking on snow. Our data extend previous findings of the effects of contrast on traditional displays (S. Yantis & Jonides, 1984) and HWDs (Winterbottom et al., 2015) by revealing an increased risk of detection failure for stimuli that are very low in contrast. The dark gray and tilted stimulus (the stimulus with the least amount of contrast) in the current experiment was detected least often, but the effect was much stronger on the HWD than with the traditional display.

An explanation for the differences between near vs. far stimuli lies in the fact that peripheral stimuli naturally receive less attention than stimuli positioned at fixation. This is because there are fewer physical receptors on peripheral areas of the retina, but also because there is an attentional bias for stimuli in central areas of the retina (Wolfe et al., 1998).

Putting it all together, the hyperadditive disadvantage seen for peripheral stimuli on the real HWD may be explained by an increase in peripheral suppression for monocularly viewed stimuli. Blake, O'Shea, and Mueller (1992) have reported that peripheral zones of rivalry tend to be larger than foveal zones. When combined with the perceptual priority phenomenon described in Arnold (2011), the binocularly unmatched image from the real HWD in the right eye would be expected to be more susceptible to suppression when it is viewed further into the periphery. Stimuli high in contrast from the background can break through some of that suppression, but as contrast from the background decreases, the stimulus is more susceptible to the increased suppression.

Whatever the reasons for worsened performance with the real HWD, our findings show that peripheral, monocular, optical see-through HWDs may require stronger stimuli to attract exogenous attention than are needed with a conventional screen, especially when the HWD is further in the periphery. This is a factor that designers of information displays for HWDs should consider. Despite this concern, it may still be better for mobile workers to use an HWD than not to do so. Without an HWD, a mobile, multitasking worker might have no information at all about a process they must monitor, or the information might not be ready to hand, which is arguably worse than having access to information on an HWD that is sometimes indistinct and therefore occasionally missed. In a nursing context, for example, clinically-relevant patient changes could be signaled on an HWD in a way that ensures they would be noticed, but without the kind of auditory alerts that could contribute to alarm fatigue (Cvach, 2012; Graham & Cvach, 2010; Ruskin & Hueske-Kraus, 2015).

4.1 Limitations.

One limitation of the current experiment is that it tested participants' ability to detect simple visual changes occurring over a very short period. The stimuli we tested are not intended literally as designs for representing changes that might happen within a monitored system. For example, changes in a work context might occur as a trend over seconds or minutes. Prolonged changes, however, can still be missed. For example, Liu, Jenkins, and Sanderson (2009) found that anesthetists failed to recognize a slow change in a waveform depicting a change to a patient's condition over 3 minutes, which the authors attributed in part to inattentional blindness (Simons & Chabris, 1999). Strong changes in brightness or apparent motion may still be an effective way to attract attention to such trends, but further work is needed to explore different display configurations and stimuli.

A further limitation is that the current study focused on identifying conditions for effective exogenous orienting of attention, but endogenous orienting of attention towards the HWD display could potentially develop after some use and familiarity with the behavior of the information sources. Many studies have shown that monitoring behavior tends to adapt to the likelihood of relevant information from a source (Sheridan, 1970). For patient monitoring, relevant information may be the relative likelihood that a patient's status will deteriorate. Thus, as familiarity with specific patients and their vital signs increases, clinicians may not need to rely on exogenous cueing. Instead they may notice deteriorations sooner, before a warning or critical threshold is met, and thus may be able to treat them sooner, and with more diagnostic context.

A final limitation is that participants may not have maintained the correct positioning of the real HWD against the black background. The chinrest and the headrest were initially adjusted so that the real HWD was placed in the same location relative to the ongoing task stimuli, but participants could potentially have shifted their heads in any number of ways to misalign that placement. A shift could have increased the eccentricity of the HWD stimuli from the foveal task, making target changes harder to detect. Alternatively, a shift could have brought the real HWD closer to the ongoing task stimuli, reducing eccentricity and making target changes easier to detect.

4.2 Future considerations

HWDs offer advantages and disadvantages for monitoring tasks. In many work environments, such as those where a worker is mobile or in a specialized space, a normal computer screen may not be continuously present or readily available. As a result, the worker's situation awareness is limited to their immediate surroundings. With an HWD, however, detailed information from local and remote sources could be accessed through simple changes in gaze, allowing the worker to maintain a broader awareness of the systems for which she or he is responsible. In that case, the disadvantages of an HWD compared with a conventional screen might seem to be a minor concern. However, if participants fail to notice critical stimuli on an HWD, while depending on it for information, the level of concern increases. Considerable further research is required to determine how users might use an HWD to monitor for trends rather than abrupt changes, and what the best interplay is of exogenous and endogenous cueing of attention via both visual and auditory channels. With such information, the designer will have a more theoretically grounded set of principles with which to design stimuli and displays for HWDs used in work contexts where mobile users must handle multiple simultaneous tasks.

Key Points

- Stimuli presented via monocular HWDs are generally less noticeable than when presented via a normal computer display.
- Stimuli with low visual contrast are significantly less noticeable on a monocular see-through HWD than on a normal computer display.
- Visual stimuli presented via HWD, alone, may not be sufficient in capturing attention.
- Care is needed when designing displays to be monitored on head-worn devices to ensure appropriate capture of attention.

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7 Appendix A

7.1 Calibration Study

The stimuli on both displays needed to be modified so that the colors and contrasts on Google Glass matched that of the simulated HWD, and vice versa. Specifically, the background of the simulated HWD on the computer screen, using red, green, and blue (RGB) levels as well as opacity (transparency). Then the brightness of the bar stimuli on Google Glass (dark gray, light gray, and white) were modified to match those presented on the newly defined simulated HWD background by adjusting the intensity of the “whiteness”.

A group of 11 participants, separate from the participants in the main study but selected from the same pool, wore Google Glass throughout the entire procedure. Starting at two different RGB values, which they adjusted the colors and opacity of each stimulus. One condition began with all color and contrast values set well above the expected range (Red: 255, Green: 240, Blue: 240, Opacity: 90, Stimuli: 150), while the other began with all values well below the expected range (Red: 255, Green: 150, Blue: 150, Opacity: 180, Stimuli: 30). These blocks were counterbalanced so that the starting values of the first block alternated across participants. During the second block, the values were hidden so that participants could not simply match the values they arrived at in the first block.

The resulting RGB and opacity values for the background of the simulated HWD were 255, 204, 182, and 72 respectively. These were the averages from both blocks of adjustments. Similarly, for the dark gray, light gray, and white bars on Google Glass, the values were 45, 87, and 113 respectively. For the color of the bars, the value (e.g. 45) was used for all three RGB values (e.g R: 45, G: 45, B: 45) and the opacity was locked at the maximum. Participants’ adjustments resulted in a simulated HWD background that more closely resembled a light rust color rather than black, which closely resembled what is visible on Google Glass, under the controlled lighting conditions in the testing environment. In other settings with different light, the Google Glass background, if a static color, would probably be very different from the results presented here. If used in a dynamic environment, the Google Glass background would be ever-changing.