Safety and Comfort of Eyeglass Displays

Erik Geelhoed, Marie Falahee[1], Kezzy Latham[1]
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E-mail: M.Falahee@aston.ac.uk
erik_geelhoed@hp.com

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[1] School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK.
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Erik Geelhoed[2], Marie Falahee[1], and Kezzy Latham[1]
[1] School of Life and Health Sciences, Aston University, Birmingham B4 7ET, UK.
E-mail: M.Falahee@aston.ac.uk
[2] Hewlett-Packard Laboratories, Bristol, BS34 8QZ. U.K.
Email: erik_geelhoed@hp.com

Abstract. An eyeglass display features two micro displays and both eyes are presented with the same image. This configuration is safer than virtual reality helmets, which give rise to severe vision problems and nausea. They are also safer than monocular displays, which impair judgement of distance, speed and size. Current eyeglass display products are occluded and are likely to produce vergence lock, a potential health hazard. We suggest that eyeglass displays should allow good peripheral vision and should be used in relatively light environments to counteract vergence lock.

1. Introduction

In most wearable computer research programs Head Mounted Displays (HMD) have played a prominent role, e.g. [1], [2]. Applications feature helmet style systems to facilitate augmented reality or immersion in Virtual Reality (VR) environments. Use of the rather cumbersome and heavy HMD is at odds with the need for ultra portable, wearable or otherwise "unconsciously" worn systems. In addition there are some serious health and safety issues that need to be addressed . In this report we describe eyeglass displays as a much lighter alternative for HMD. In addition we present results from health and safety studies of eyeglass displays use , carried out at Hewlett Packard research laboratories.

A number of studies have demonstrated changes to the visual system [3], [4], [5], [6] and reported symptomatic changes such as increased nausea, dizziness and headaches, and eyestrain [7], [8], [9], [10] as a result of using HMDs for VR immersion. These adverse effects are similar to those reported for other three-dimensional / stereoscopic display appliances, such as flight simulators [11], night vision goggles [12], stereo-microscopes [13], and monocular displays [14]. Monocular displays, such as those developed for use by Apache helicopter pilots, have also been shown to result in distortions of size, distance, and motion perception [14].

The symptoms which result from using VR appliances are similar to the symptoms of motion sickness, and both are generally thought to be caused by conflicts between the information received by two or more sensory systems [15]. In the case of immersive VR, conflict is caused by either the time lag for the virtual scene to be updated following a head movement, or the impression that the world is moving visually whilst no physical movement of the body is occurring (known as visually-induced motion sickness), or both [5].

An eyeglass display is an appliance featuring two micro displays and both eyes are presented with the same flat (two dimensional) image. The virtual screen is a simulation of a computer screen or a TV. The simpler configuration of eyeglass displays means that they tend to be smaller and lighter than VR helmets. Because of the enhanced portability of eyeglass displays, they may be very suitable for use with some mobile computing applications (e.g. notebooks), for example, offering the user a lightweight, more private alternative to their computer screen. Eyeglass displays also have potential value for home entertainment (e.g. viewing DVD / videos; playing computer games). Although exactly which applications / tasks are (not) suitable for use of eyeglass displays is an empirical matter which has yet to be addressed in the research literature, we believe that eyeglass displays have a role to play in the realm of Handheld and Ubiquitous Computing (HUC).

Given the mounting list of alarming reports on the adverse effects of VR helmets and similar applications, it is essential to explore the possibility that eyeglass displays may be prone to similar problems. However, this has been the focus of very few researchers. Furthermore, the results of the few existing relevant studies (reviewed below) are inconsistent, and we have no theoretical framework in which to place their findings. What the researchers are agreed on, though, is that, compared to the effects of virtual reality helmets, the effects of eyeglass displays are mild. There are two main themes that run through the publications. These are: vergence lock and nausea.

When you stare at a particular point in space for a prolonged period of time, there is a slight tendency towards rigidity in vergence, called *vergence lock*. This happens sometimes when we are absorbed in a book for a long time [16]. Simply looking away from the book, around us, counteracts vergence lock, and we recover rapidly. When we use eyeglass displays for watching a feature length movie, and eyeglass displays are often occluded, it is true to say, that we do look at the same distance, that is the focal distance determined by the optics of the eyeglass display, for a prolonged period of time, with little opportunity to give our eyes a break by looking around. This is in stark contrast to the highly fluid accommodation and vergence activities of the visual system under normal conditions. There is clear evidence that eyeglass displays give rise to vergence lock in adults and children e.g.[17], [18], [19]. These experiments describe single experimental sessions only and participants recovered rapidly, but these findings raise questions about what would happen if people regularly use (occluded) eyeglass displays. The effects of extended use may be of particular concern for the developing visual systems of children.

Neveu et al [20], could not find strong evidence that the same happens with accommodation, although they found a significant increase in latency to relaxation of accommodation after eyeglass display use, indicating that some rigidity in accommodation might come into play.

Howarth and Costello [5] investigated the occurrence of simulator sickness-type symptoms after one hour of using a HMD which had been configured as a personal viewing system (Vs. a conventional VDU screen) to play a chess game. Their comparison of the HMD and conventional viewing systems is somewhat problematic, however, given that the VDU condition employed a much higher resolution screen than the HMD device. The HMD condition produced a greater frequency of symptom reports than the VDU condition. They also reported that malaise ratings increased steadily throughout the experimental session using the HMD. The authors explain these results in terms of the sensory conflict associated with the HMD device - head movements are not accompanied by changes in the visual scene - however, no measurements of head movement were included in this research design. In contrast, Peli [17] found no indication of nausea in his study, which compared a conventional VDU display with HMD conditions for both monoscopic and stereoscopic viewing. The same task was carried out by participants in all three conditions (30 minutes of playing a computer game). Peli reported no significant differences between the monoscopic HMD use and the VDU. The only significant difference found for the subjective impression of comfort was between the VDU and stereoscopic conditions.

This paper presents results from a series of experiments carried out at Hewlett-Packard Laboratories, Bristol, to investigate the effects of using eyeglass displays for different tasks (reading vs. video watching) on objective and subjective measures of visual functioning, and on subjective reports of sickness and discomfort. Evaluation of a prototype eyeglass display appliance (figure 1) developed at Hewlett-Packard Laboratories highlighting the importance of configuration issues is also included.

Fig 1 : HP prototype

2.Method

2.1.Measures

We used a variety of measures. For the purpose of clarity I will only describe those measures that had a strong bearing on the results and conclusions.

2.1.1. Questionnaire

We used a standard questionnaire that consists of three sections : 1. What you see, 2. Your eyes feel, 3. Discomfort. The first section (What you see) asks subjects about blurred vision, double vision and speed of focus change. The second section (Your eyes feel) asks subjects how their eyes feel, e.g. tired, watering, hot, itchy etc., whereas the third section (Discomfort) asks about other sorts of discomfort, e.g. neck and shoulder pains, dizziness and nausea.

2.1.2. Dissociated Phoria

When looking at a target, the eyes are not perfect in pointing in the direction of the target, i.e. some people's eyes over-shoot (exo-phoria), some under-shoot (eso-phoria), few are actually right on the mark (ortho-phoria) (figure 2).

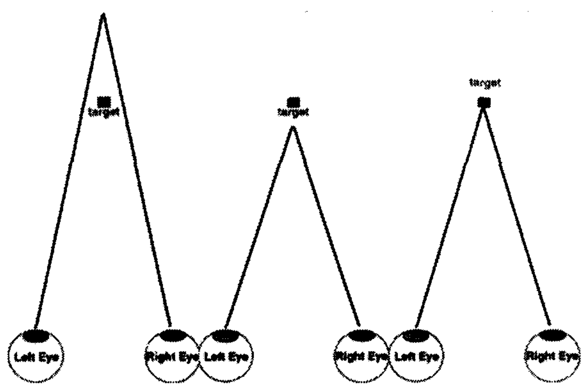

Fig. 2 : over shooting, under shooting and on-the-mark
exo-phoria, eso-phoria, ortho-phoria

Even though vergence is not perfect, the brain is very good at fusing images (and compensating for imperfections) from the left eye and right eye into one (relatively) clear and sharp picture.

For healthy eyes, when we look around us, the eyes move in tandem. When we cover one eye (e.g. with a pirate's patch) and we look around us with the remaining seeing eye, the covered eye (even though it cannot see anything) still moves in tandem with the one seeing eye. This situation is called dissociated phoria and we can measure this via the Maddox Rod test, [21]. The dissociated phorias measure has proved to be a good indicator for vergence lock.

2.1.3. Inter Pupillary Distance (IPD)

To ensure that subjects' eyeglass displays were configured correctly we measured the distance between the pupils of the left eye and the right eye.

2.2. Participants

Experimentally naïve participants (mean age 30.5 years) were screened by a professional optometrist to make sure that they were visually healthy enough to take part. This did not mean that the visual systems of the people who took part were perfect. In addition we took a "visual profile", screening measures that might predict individual differences in people's reactions to eyeglass display use.

2.3. Apparatus

For the early work we employed the, then state-of-the-art, albeit rather cumbersome, Kaiser Head Mounted Display (HMD). Later, as the much lighter Sony Glasstron eyeglass display became available, we used this to benchmark the prototype against. For listening subjects used very comfortable high quality padded headphones (Sennheiser HMD 25-1).

The Kaiser ProView 30 Head Mounted Display features two VGA resolution adjustable LCD displays. The focal distance was set at optical infinity (5.5 meters). The Sony Glasstron plm s-700 features (emissive) LCD glasses for viewing videos and contains two SVGA quality 0.7 inch LCD displays. The focal distance is set at 1.2 meters. The Glasstron allows some degree of see-through, but this mode was disabled. The optional "blinkers" to make the experience more immersive were not used in the experiment. The optics of Glasstron have a wide exit pupil. This allowed for an eyeglass displays where individual adjustments need not, and indeed, cannot be made. The prototype features (non see-through) reflective LCD micro displays of XGA resolution (1024 * 768 pixels). The focal distance is set at 1 meter. Compared to existing eyeglass displays products which are occluded, the prototype has a small form factor which allows for a generous peripheral vision. Enabling this small form factor (and a low level of illumination) is a much smaller exit pupil than the Sony Glasstron, necessitating individual adjustments of the inter screen distances. The housings of the two screens (optics blocks) were set at a slight angle, resulting in a vergence distance, depending on inter pupillary distance, of between 85 and 90 cm.

3. Three Experiments

3.1. Experiment 1 : Reading Vs. Video watching

Task differences have not been studied in the realm of eyeglass display research. Since video watching and using eyeglass displays for computer tasks are two applications under consideration, this experiment was designed to compare the effects of these two different tasks.

3.1.1. Procedure

Ten volunteers, eight females and two males, took part in three separate sessions, all three lasting under an hour, on different days. The first session aimed to establish a visual profile for each subject, the next two sessions were the experimental sessions, the reading and video watching tasks, balanced for order, i.e. five subjects did the reading task first and five did the video watching task first.

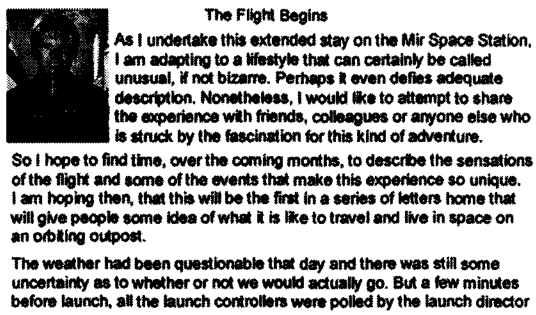

Fig. 3. Reading task

The reading task consisted of a series of screens of text, Arial 18 point alternately accompanied by a small image in the top left corner measuring 115 * 150 pixels or as a sheet of text only (figure 3). Subjects were asked to read the text aloud while being reassured that this was not a performance task. At the end of every screen the experimenter "turned" the page. The task lasted 20 minutes.

The video watching task consisted of subjects watching an animation consisting of sophisticated computer graphics changing rapidly in a "roller coaster ride" fashion accompanied by music for 20 minutes.

3.1.2. Results

Vergence Lock. Although we only found minor changes we did get some indication that after 20 minutes of exposure there was a tendency for the eyes to be locking into the focal distance of the eyeglass display, i.e. there was a significant, $p = .018$, difference between the pre- and post measures where the dissociated phorias were significantly raised after subjects performing the tasks (irrespective of task or distance) into an exo-phoric direction.

Nausea. Even though the video watching task concerned a virtual roller coaster ride, none of the subjects were experiencing serious nauseous feelings. We included a questionnaire about susceptibility to motion sickness. One or two subjects felt slightly queasy, but they had never had any problems with travel sickness, whereas the subjects who had suffered as a child or were still susceptible to motion sickness did not report any such nauseous feelings. It does not seem likely that there is a link between travel sickness and HMD induced nausea.

Task Differences. The visual symptoms questionnaire demonstrated some mild changes that were, however, significant. Video watching produced increases in watering eyes and dizziness. Comparing video watching to reading we found significant higher scores for video watching with regards to itchy eyes and feelings of drowsiness and a possible trend to have more hot / burning eyes.
Dissociated phorias were more affected by the reading task. Here we must bear in mind that the reading task required subjects to explore all corners of the screen as they went from top left to bottom right. In addition, as the task required subjects to read out loud, the HMD wobbled with the movement of people's jaws. As a consequence there is the possibility that subjects eyes were not entirely lined up to the centre of the lenses. If spherical lenses are not lined up to the centre of the screen, people effectively look through a prism. Since prisms do test the vergence system, the changes in phorias might be as a result of this wobble. A valuable lesson that can be learned from this though is that if we explore possibilities of integrating eyeglass displays with a communicating wearable system (e.g. mobile telephones) this wobble as a result of people talking must be addressed.

Predictors. The symptoms were too mild to find predictors of people predisposed to adverse effects. Neither did the profiling measures provide indicators for (un-)successful HMD use. We did find however, that when people are not well, this may be reflected in vision parameters which, as a result of using an eyeglass displays, may exacerbate.

3.2. Experiment 2: A Comparison of the HP Prototype Vs. Sony Glasstron

3.2.1. Procedure

Eleven volunteers, seven male, four female watched 20 minutes of video on the Sony Glasstron and then at a later stage they watched 20 minutes of video on the prototype. On both occasions they sat comfortably on a sofa in day light conditions (figure 4). The Sony glasses allowed subjects to see the outside world from the corners of their eyes. Wearing the prototype allowed for even more peripheral vision. Whereas the previous experiment was conducted in a room without windows, testing took place in a room *with* windows which looked out onto a corridor, during normal office hours. In the corridor, regularly there were people walking by the experimental room. Hereby, we aimed to distract subjects so that they would regularly divert their gaze outside of the virtual environment, with the objective of counteracting vergence lock. We took ophthalmic measures (before and after usage) and also carried out a structured interview afterwards discussing likes and dislikes and usage issues.

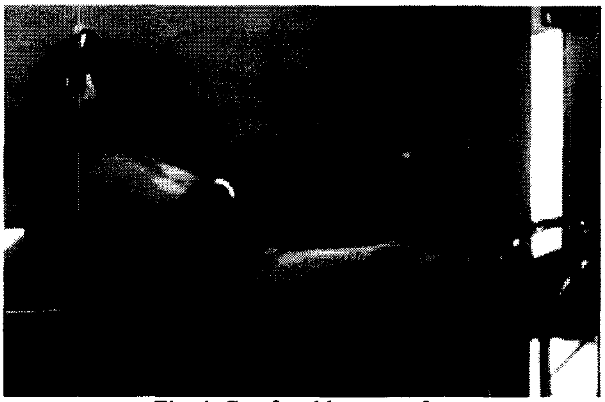
Fig. 4. Comfortably on a sofa

3.2.2. Results

The Sony Glasstron sessions resulted in mild symptom occurrence only. Eyestrain was raised, indicating that people did find the glasses strenuous to some extent. Drowsiness was also increased, not so much as a side effect of nausea (there were no reports of nausea), but probably more as a result of the relaxing influence of immersive video watching. There was no evidence for increased burning eyes overall, although some individuals did experience watering and burning eyes.

Evaluating the Sony Glasstron, we could find no indicators for vergence lock. Given that other researchers did find vergence lock for Sony's eyeglass displays, we speculate that this might be due to the fact our subjects were encouraged to divert their gaze outside of the virtual environment.

The evaluation of the prototype showed, that they too produce few symptoms. Itchy eyes, but not Eyestrain (as was the case with Sony glasses), was raised significantly but the increase was only mild. However there were very strong indicators that the prototype causes vergence lock. At this point, I will discuss the results of the dissociated phoria and fixation disparity measures in more detail.

Dissociated Phorias. The dissociated phorias were measured three times at each of two different distances (50cm and 100cm). The graph below (figure 5) shows the (prototype) results for the 50 cm distance. The three trials, trial 1, trial 2 and trial 3, are along the X-axis. The Y-axis shows the mean responses across the eleven subjects. A positive number indicates exo-phoria and a negative number indicates eso-phoria.

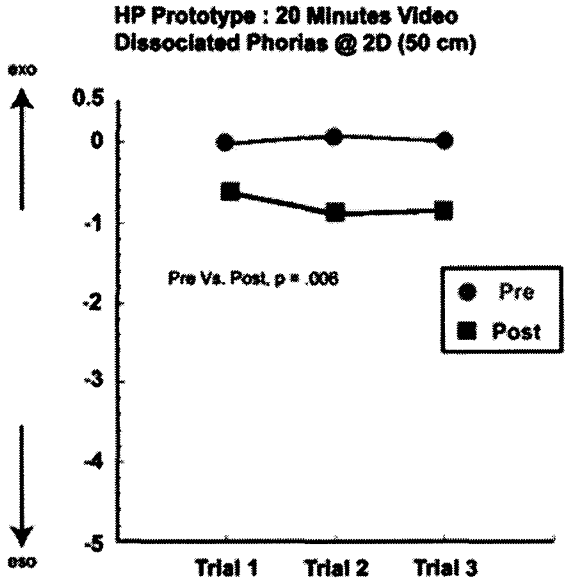

Fig. 5. Mean dissociated phorias at 50 cm

The grey line with round markers signifies the mean dissociated phorias (for the three trials) before testing, and since we had a good mix of exo-phoric and eso-phoric subjects, the mean for the pre-testing measures is close to zero. The darker line with square markers shows the mean dissociated phorias after testing. It is clear from the graph that the means are closer to -1, indicating an overall shift into an eso-phoric direction.

Evaluating the effects of pre-post measurement and trials per distance showed the pre post effects for the 50 cm and also 100 cm (not shown here) distances to be highly significant. For 50 cm this level of significance was $p = .006$ (and for 100 cm this was $p = .022$). The correlation between before and after phoria scores for 50 cm was highly significant, $r = .969$, $df = 10$, $p = .000$. This indicates that by and large all subjects showed a similar change.

User Issues. For both eyeglass displays, prototype and Sony, most people found the experience highly enjoyable and they could see themselves using glasses for watching films or playing games, in situations where people are not required to be social. Some people thought that they could be good to use with a notebook while on the road. But the glasses are not for every one, some people would not want to use them and found them uncomfortable. Although most people were very much immersed in the film, they expressed the wish for a more occluded eyeglass display for that bit of extra immersion. They mentioned that they were highly aware of people walking by in the corridors and they actually found this annoying. They were also pleasantly surprised by the quality of the prototype and the Glasstron display and overall rate it as good as a computer screen and better than a TV screen.

During the sessions all subjects without exception sat very still, hardly changed position. This included an overall lack of head movement. From peoples' comments we deduce that this is not as a result from peoples' unease with the combination of a non-moving image with a moving head, but is more likely to be a consequence of participant's immersion in the film.

3.3. Experiment 3 : Feature Length Video Watching

Going through a similar procedure, seven subjects watched 90 minutes of video on the prototype. Again we found a highly significant eso-shift of dissociated phorias and fixation disparities. Compared to the 20 minute video watching experiment, the magnitudes of the effects were not greater. We also found a mild but significant worsening of accommodation. Interestingly, one subject, who had been ill the previous day, reported a relatively high number of symptoms before testing, which after the video watching were markedly reduced. We mention this, because there have been subjects whose symptoms exacerbated after wearing the glasses.

4. Discussion

Our experiments indicate that eyeglass displays do not produce nausea. However, vergence lock, as a consequence of staring at the same focal distance for a prolonged period of time, can be a serious problem. This problem can be attenuated by providing enough peripheral vision and encouraging people to look away from the virtual environment regularly. We found indications that watching a video on a eyeglass display in a light, distractive environment with good peripheral vision might counteract vergence lock. However, participants expressed a preference for a more immersive, occluded appliance. For (mobile) computer tasks, the opposite, a strong desire to remain aware of what is happening around you, might be true.

The comparison of reading and video watching tasks showed that video watching is more likely to result in itchy and burning eyes and people are likely to become more drowsy as a result of the relaxing nature of the experience. In contrast, reading really forces the eyes to work hard, covering all corners of the screen. One must bear in mind here, that if we do not look through the centre of a lens we effectively look through a prism, which is strenuous for the eyes. Reading might result in not always looking through the centre of the lens. One consequence is, that the different tasks require different optics. For video watching it might be sufficient to have good central vision with less need for clear edges, whereas for every day computer tasks, the whole of the screen including the edges must be absolutely sharp and clear.

Both the prototype and the Sony Glasstron are very well suited for watching video and this is, for most people, very enjoyable. People also judge the virtual displays to be very good, as good as computer monitors and better than TV's. They could see themselves using the glasses in situations where they do not need to be social.

Both eyeglass displays produced few symptoms, although our results confirmed that the eyes feel a bit hot and burning, resulting in tearing.

The prototype needed some further refinements. Whereas the Sony glasses produced no significant effects on the visual system, for the prototype we found a pronounced esophoric shift both for the dissociated phoria and fixation disparity measures.

The prototype is characterised by a one meter apparent viewing distance. The small form factor of the prototype allows a clearly visible peripheral field. However, this necessitates a narrow exit pupil requiring adjustment to suit individuals' inter pupillary distance. Together, with the slight canting of the optics block this resulted in a vergence demand of somewhere between 85 and 95 cm, "shoe-horning" as it were subjects into an eso-response. The Sony Glasstron similarly has a 1.2m apparent viewing distance. It differs from the prototype in that the peripheral field is less visible (only from the corners of the eyes), there is a wide exit pupil.

To resolve these conflicts we suggest that the focal distance should be set at 300 cm with the optics block perpendicular to the frame of the glasses. Hereby we overcome the current optical conflicts. Three meters has been suggested by our optometry experts as a comfortable distance for most people. There is a further advantage to setting accommodative and vergence demand to three meters: It is less problematic for presbyopic subjects: almost anyone over the age of about 50 years won't be able to accommodate to the currently required one meter without their spectacles.

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