



AFRL-HE-AZ-TP-2007-06

**BINOCULAR RIVALRY AND ATTENTION
IN HELMET-MOUNTED DISPLAY
APPLICATIONS**

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February 2007

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**Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Readiness Research Division**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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|---|------------------------------------|--|-----------------------------------|--|--|
| 1. REPORT DATE (DD-MM-YYYY) October 2006 | | 2. REPORT TYPE Technical Paper | | 3. DATES COVERED (From - To) Mar 2006– Oct 2006 | |
| 4. TITLE AND SUBTITLE BINOCULAR RIVALRY AND ATTENTION IN HELMET-MOUNTED DISPLAY APPLICATIONS Presented at the 2006 Human Factors and Ergonomics Conference | | | | 5a. CONTRACT NUMBER FA8650-05-D6502 | |
| | | | | 5b. GRANT NUMBER | |
| | | | | 5c. PROGRAM ELEMENT NUMBER 62202F | |
| 6. AUTHOR(S) Marc D. Winterbottom, Robert Patterson, Byron J. Pierce, Christine Covas, & Jason Rogers | | | | 5d. PROJECT NUMBER 1123 | |
| | | | | 5e. TASK NUMBER B1 | |
| | | | | 5f. WORK UNIT NUMBER 23 | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Link Simulation and Training 6030 South Kent Mesa, AZ 85212 | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory Human Effectiveness Directorate Warfighter Readiness Research Division 6030 South Kent Street Mesa AZ 85212-6061 | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) AFRL; AFRL/HEA | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-HE-AZ-TP-2007-06 | |
| 12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. | | | | | |
| 13. SUPPLEMENTARY NOTES This paper was originally published in the 2006 Proceedings of the Human Factors and Ergonomics Society conference. | | | | | |
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| 15. SUBJECT TERMS Head-mounted displays, HMD, binocular rivalry, flight simulation | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT UNCLASSIFIED | b. ABSTRACT UNCLASSIFIED | c. THIS PAGE UNCLASSIFIED | | | Byron J. Pierce |
| | | | UNLIMITED | 5 | 19b. TELEPHONE NUMBER (include area code) 480-988-6561 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

BINOCULAR RIVALRY AND ATTENTION IN HELMET-MOUNTED DISPLAY APPLICATIONS

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ABSTRACT

As monocular head-mounted displays (HMDs) are introduced into existing flight simulators for training and mission rehearsal it will be important to determine whether binocular rivalry affects the visibility of HMD presented symbology or the out-the-window (OTW) flight simulator display imagery. In the present study, we examined whether rivalry suppression could be objectively measured under conditions that simulated a monocular HMD and OTW display, and whether voluntary attention and moving imagery influenced the strength of rivalry suppression. The results indicated that strength of suppression under these conditions was less than that found under classic dichoptic viewing conditions, and that attention had little influence on performance.

INTRODUCTION

Over the past several years, one important technological advance has been the development of wearable head-mounted displays (HMDs) for military and commercial applications (e.g., Melzer & Moffitt, 1997; Patterson, Winterbottom & Pierce, in press; Velger, 1998). An HMD presents information to one eye (monocular HMD) or both eyes (binocular HMD) using one or two miniature visual displays mounted on the head. HMDs can offer advantages over traditional displays, such as increased situational awareness (Velger, 1998).

Despite these potential advantages, there can be problems with the use of HMDs. For example, Wenzel, Castillo and Baker (2002) found that aircraft maintenance workers reported problems such as eye strain, headache, nausea, and dizziness when a HMD was used. Morphey, Shively, & Casey (2004) found that nausea, disorientation, and oculomotor strain were greater with an HMD compared to a standard computer monitor when performing an Unmanned Aerial Vehicle control task. Hakkinen (2004) reported similar problems when a monocular HMD was used for a text-editing task. Finally, simulator sickness can occur when HMDs are worn (e.g., Draper, Virre, Furness, & Gawron, 2001; Draper, Virre, Furness, & Parker, 1997). Thus, Keller and Colucci (1998) concluded that many real-world users have been disappointed with HMDs.

These and other problems arise because HMDs present an unnatural viewing situation (see e.g., Patterson et al., in press). For example, in the case of a semi-transparent monocular HMD, images from the HMD symbology are presented to one eye while both eyes view a real-world scene. In the eye that receives the symbology, those images overlap the images from the real-world scene and could conflict with the images in the other eye. When the two eyes receive different stimulation, a condition exists for creating binocular rivalry.

Binocular rivalry refers to a state of competition between the eyes, such that one eye suppresses the visual processing of the other eye. The visibility of the images in the two eyes alternates over time, with one eye's view becoming visible while the other eye's view becomes suppressed, which reverses over time. During binocular rivalry, portions of stimulation in one eye, but not the other eye, may gain access to higher levels of visual processing (Howard, 2002). As pointed out by Patterson et al., binocular rivalry is an important topic to study because it represents a condition by which visual information could go unprocessed while using an HMD.

There are a number of stimulus factors that affect binocular rivalry, such as contour density (Levelt, 1965), luminance (Fox & Rasche, 1969), contrast (e.g., Hollins, 1980), size (O'Shea et al, 1997), and velocity (e.g., Breese, 1899). Another factor may be voluntary attention. Breese (1899) believed that he could influence the rivalry process by exerting attentional control, and Lack (1978) reported the existence of attentional control over rivalry when viewing through artificial pupils or after paralysis of accommodation, which ruled out peripheral effects. Ooi and He (1999) reported that suppression was less when individuals attended to a rivalrous stimulus relative to a non-rivalrous stimulus. According to Blake (2001), attentional effort may bias the predominance of one eye's stimulus over the other eye's stimulus.

The purpose of the present study was to investigate factors that may affect binocular rivalry when semi-transparent monocular HMDs are worn. Suppression of HMD presented symbology, or suppression of the out-the-window (OTW) view due to HMD symbology, would pose problems for the integration of monocular HMDs into existing flight simulator display systems. We therefore sought to determine whether rivalry suppression could be objectively measured and whether voluntary attention or simulated flight motion influenced the strength of rivalry suppression.

METHODS

Observers

Eight observers served in the study. All observers had normal or corrected-to-normal acuity and normal binocular vision (tested with an Optec 2000P, Stereo Optical, Inc.).

Stimuli and Apparatus

Two visual displays were used: an Eizo Flexscan 985 EX LCD flat panel display and a VDC Sim 1600 LCoS projector. The LCD flat panel displayed a photorealistic depiction of a desert scene and was referred to as the out-the-window (OTW) display. The LCoS display rear-projected an image of HMD symbology onto a small DA-Lite DASS screen (see Figures 2 and 3). Both the LCD flat panel and LCoS projection displays were viewed through a beam splitter to allow the OTW display and symbology (see Figure 1) to be optically combined. (The combination of the LCoS display and beam splitter was referred to as the simulated-HMD display.) The viewing distance to each display was 36 in., matching the viewing distance in many Air Force flight simulators. A chin rest stabilized observer head position, and PCs were used to present the imagery and record responses. MetaVR VRSG was used to generate both the static and dynamic scenery.

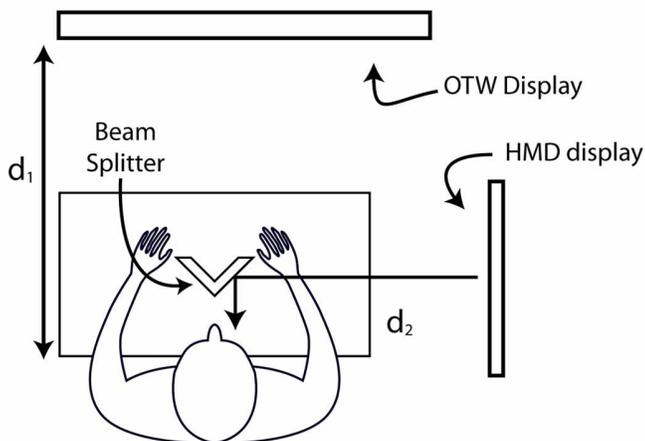


Figure 1. Display configuration and beam splitter.

A white block letter 'E' served as a probe stimulus for indexing the occurrence of rivalry suppression. The contrast of the probe stimulus ranged from about 0.05 to 0.3 and was 0.7 degrees in size. The probe was briefly presented to the left or right of a fixation cross, on one display or the other, and could be oriented either rightward or leftward for each trial. The contrast varied due to variation in brightness of the flight database. For the no-motion condition, the contrast of the probe was selected to match the average contrast of the probe in the flight motion condition (approximately 0.15).

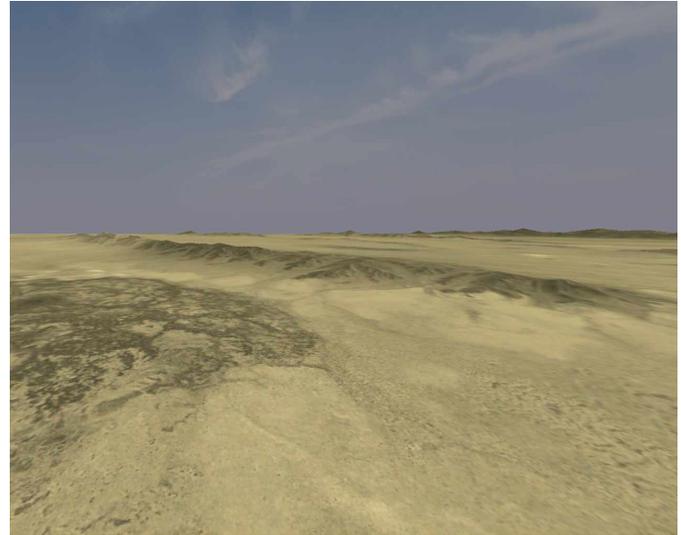


Figure 2. Desert scene/OTW view.

Preliminary Experiment

We performed a preliminary experiment in order to determine the precise methods to be used in the main experiment, described below. In the preliminary experiment, the exposure duration of the probe (ranging from approximately 67 to 251 msec.) was adjusted for each observer individually, so that performance yielded an 85-percent correct recognition level under the control condition (neutral attention). This duration was then used as the exposure duration of the probe in the remaining conditions (thirty trials collected under each condition). The OTW scene was static. Reaction time and percentage correct were obtained under nine combinations of conditions. There were 3 viewing conditions (control, fused, and dichoptic) \times 3 attention conditions (neutral, background, symbology). The probe could appear on either the OTW display or the HMD display.

We found that, overall, percentage correct responding declined by about 23% under the dichoptic condition relative to the control condition, and recognition performance declined by about half that amount under the fused condition relative to control. We also found that, overall, reaction time to the probe was lengthened by about 34% under the dichoptic condition relative to the control condition, and reaction time was lengthened by about one-fifth that amount under the fused condition relative to control. Thus, there appeared to be some evidence for rivalry suppression under the fused condition (and more so under the dichoptic condition, as expected). However, the effect of attentional instructions on either recognition performance or reaction time seemed haphazard and difficult to interpret.

In this preliminary experiment, the probe could be presented on either display even though the observer was instructed to shift attention to one or the other display. Thus, it is possible that the 50% probability that the probe would occur on one or the other display on any given trial overrode the attentional instructions. In this case, the observers may have split their attention across the two displays in a complex

way in order to maximize performance on one or the other dependent variable, which varied across observers (thereby inflating within group variability).

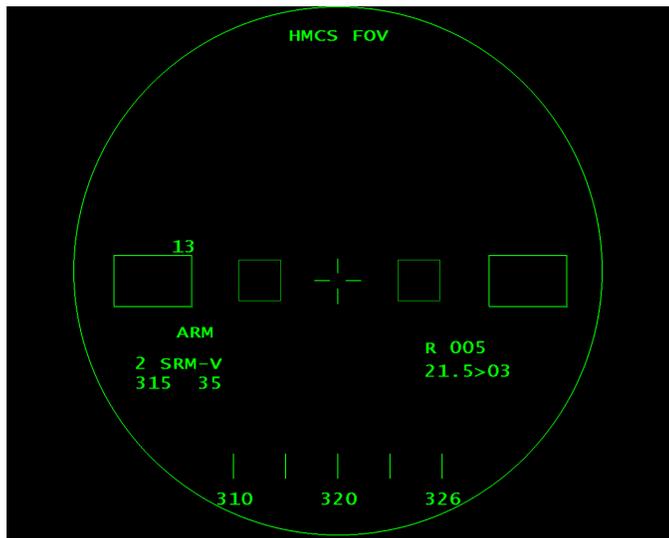


Figure 3. Simulated HMD symbology optically combined with the desert scene shown in Figure 2. The targets appeared within the small boxes on either side of the fixation cross/aiming reticle.

Procedure

In this study, observers simultaneously viewed either static or dynamic background scenes and HMD symbology while performing a probe recognition task. The static condition was similar to the dynamic condition except flight speed was set to zero. In the dynamic condition flight speed was 600 knots. Each was at an altitude of 1000 meters. The probe was presented to the left eye, right eye, or both, via either the OTW display or the HMD display. There were three viewing conditions: 1) The simulated HMD condition, which will be referred to as the fused condition, where the background scene was fused (viewed by both eyes), while the HMD symbology was seen by the right eye; 2) dichoptic condition, the background scene was viewed by the left eye, while the HMD symbology was seen by the right eye; 3) control condition, both background scene and symbology were viewed by both eyes. These three conditions were performed under three sets of attentional instructions: 1) background condition, the observers were instructed to strongly attend to the background scene during the trials and ignore the HMD symbology; 2) symbology condition, the observers were instructed to strongly attend to the HMD symbology during the trials and ignore the background scene; 3) neutral condition, the observers were given no attentional instructions. The probe was always presented on the display to which the observers were instructed to shift their attention, thus reinforcing the attentional shift instructions.

The probe duration was staircased so performance converged to a threshold value of 70.7% (2-down/1-up rule; Levitt, 1971). Each staircase took 8 reversals to complete with the last 4 being averaged together. Exposure duration

therefore varied from approximately 17 msec. to 250 msec. This was a two alternative forced choice (2 AFC) task, thus observers were forced to respond following each target presentation.

RESULTS

The results were analyzed in four steps: (1) thresholds obtained from each observer under the dichoptic and fused viewing conditions were normalized by subtracting each threshold obtained under those conditions from the thresholds obtained under the control condition, and dividing the differences by the control condition (thus producing a measure reflecting proportional change in threshold duration); (2) an analysis of variance (ANOVA) was computed to test for a significant overall difference between the dichoptic and fused viewing conditions (without regard to effect of attention or motion, our interest being in effect of attention and motion in the simulated HMD, or fused condition); (3) a two-way ANOVA was computed on the data obtained from the fused viewing condition; (4) individual t-tests were computed on the data from the fused viewing condition to test for significant differences of group means from an expected value of zero.

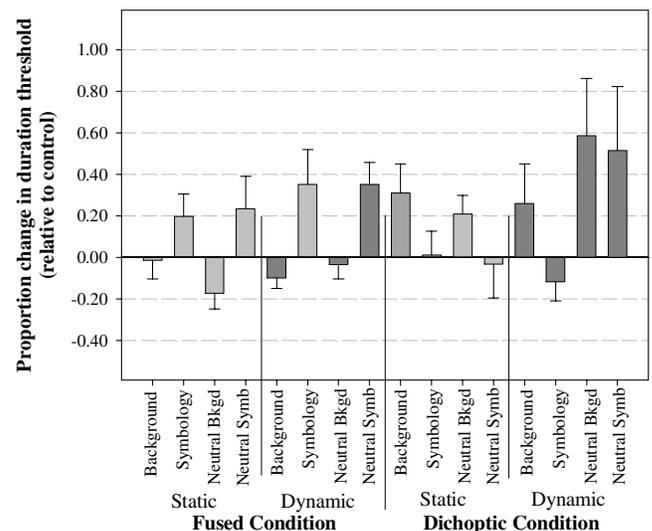


Figure 4. Proportional change in threshold duration for HMD and Dichoptic viewing conditions.

With respect to the OTW display, the ANOVA revealed that there was a significant overall difference between the dichoptic and fused viewing conditions, $F(1,7) = 11.1, p < 0.02$, indicating that the dichoptic viewing condition produced a greater overall increase in duration threshold than the fused viewing condition (see Figure 4). Here, the OTW display in the dichoptic viewing condition was seen by only one eye and it was therefore susceptible to rivalry suppression, while the OTW display in the fused condition was seen by both eyes thus resulting in partial fusion. With regard to the HMD display, there was no significant overall difference between the dichoptic and fused viewing conditions, $F(1,7) = 2.1, p > 0.05$, indicating that both viewing

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conditions produced increases in duration threshold over the control condition. In this case, the HMD display in both dichoptic and fused viewing conditions was seen by only one eye and thus it was susceptible to suppression.

Singling out the fused viewing condition, an ANOVA showed that there were no significant main effects or interactions among the various conditions for the OTW display or for the HMD display. However, individual one-tailed t-tests showed that for the HMD display, the directed attention condition and the neutral attention condition (both in the dynamic condition) were significantly greater than zero, $t(7) = 2.1$ and 3.3 , respectively, $p < 0.05$ (the same conditions with static background approached significance), thus the lack of significant main effects and interactions across conditions with the ANOVA was due to the fact that those conditions produced similar amounts of threshold increase (Figure 4). For the OTW display, the directed attention and neutral attention conditions, with a moving background or with a static background, were not significantly greater than zero.

DISCUSSION

The results for the fused (simulated monocular HMD) viewing condition showed that threshold duration increased for the HMD display (with a moving or static background) but not for the OTW display. This is likely due to the fact that the OTW display was seen by both eyes and was therefore fused while the HMD display was seen by only one eye and it was therefore susceptible to rivalry suppression. Thus, it seems that binocular fusion of the OTW scene does mitigate against the effects of binocular rivalry suppression on the symbology presented on the HMD, but does not eliminate it. This is counter to findings by Blake and Boothroyd (1985) where results indicated that rivalry was eliminated when two eyes viewed a pattern of one orientation, and one eye viewed a pattern in a different orientation. The study by Blake and Boothroyd employed simple sine wave grating stimuli while the present investigation used more realistic, and complex, imagery, which may account for the difference in results between the two studies.

There was no effect of directed versus neutral attentional set on threshold duration in the fused viewing condition. This result is inconsistent with reports by Breese (1899), Lack (1978), and Ooi and He (1999), who suggested that rivalry suppression can be affected by attentional control. It may be that attentional control of rivalry suppression requires extended practice, particularly with the complex imagery used in this study, which is a topic worthy of future research. According to Blake (2001), the evidence suggests that observers cannot control the occurrence of rivalry suppression through attentional effort, but may be able to bias the rate of alternation of dominance. The occurrence of rivalry is likely driven much more strongly by low-level stimulus attributes (e.g. contrast, motion, orientation). The results of the current study support this notion.

Although there is an increase in threshold duration in the fused viewing condition for the HMD display, this

impairment in performance was less than that reported in a previous investigation (Winterbottom, Patterson, Pierce, & Taylor, 2006). This previous investigation involved the use of probe stimuli whose contrast was significantly lower than that used in the present study (5 versus 15%, respectively). It may be that higher contrast briefly-presented probes create transients which break through the rivalry suppression more easily. This was noted by observers who stated that the probe was sometimes clearly visible within a zone of suppression. Subjectively, observers in both studies reported that the symbology in the fused condition appeared to periodically fade or disappear from view. This further indicates that rivalry suppression was occurring, but that the transient high contrast target tended to break through this suppression.

The lack of an overall effect of static versus moving background in the HMD viewing condition in the present study is surprising. This is because moving stimuli have been shown to dominate stationary stimuli during rivalry (Breese, 1899; Fox & Check, 1972), and rivalry involving moving stimuli shows a greater depth of suppression (Norman et al., 2000). The lack of an effect of background motion may be due, in part, to the low contrast, low resolution flight database that was used in this experiment.

In summary, the present results show that binocular rivalry suppression affects the visibility of HMD symbology when semi-transparent monocular head-mounted displays are used for augmented-reality applications. However, the suppressive effect on the HMD symbology may be small, particularly for high contrast symbology.

ACKNOWLEDGEMENTS

This work was supported by U.S. Air Force contract FA8650-05-D6502 to Link Simulation and Training (a division of L3 Communications Corp.). We would like to thank Mike Slater for developing the code that was used to carry out these experiments.

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