2005

An Evaluation of Head-Mounted Displays in an Airborne Command and Control Simulation Environment

Scott M. Galster

Rebecca D. Brown

Brent T. Miller

Alison M. Tollner

AN EVALUATION OF HEAD-MOUNTED DISPLAYS IN AN AIRBORNE COMMAND AND CONTROL SIMULATION ENVIRONMENT

Scott M. Galster[1], **Rebecca D. Brown**[2], **Brent T. Miller**[1], **Alison M.Tollner**[3]

[1]Air Force Research Lab
WPAFB, OH, USA

[2]General Dynamics, AIS.
Dayton, OH USA

[3]University of Cincinnati
Cincinnati, OH, USA

An examination of HMDs to ameliorate the problems associated with display clutter in an Air Battle Management environment was conducted. Information to complete tasks was given via two HMDs, on the primary display, or via paper. The results indicated that the paper condition engendered a higher percent of correct responses and faster response times in several of the tasks performed. The specific experimental results are presented and future experimental design propositions are discussed.

Introduction

Air Battle Management (ABM) is a complex and demanding task that requires operators to direct the implementation of a dynamic air tasking order (ATO) and control the tactical execution of air-to-air and air-to-ground operations specified by that ATO. In order to do so, they typically monitor and manipulate a situation display (SD) comprising a map overlaid with landmarks, geographical features, and moving tracks representing the air and ground assets of coalition and enemy forces, as well as neutral tracks and those tracks for which positive identification is lacking. In addition to this surveillance component, ABMs perform a myriad of secondary tasks, such as associating coalition assets with targets, coordinating air-to-air refueling, and responding to alarms and alerts. Those secondary tasks often require a portion of the visual display that is occupied by the SD, and typically occlude part or all of the SD, which can potentially lead to decreased performance on one or more of the concurrent tasks.

One solution that addresses the problem of display occlusion and clutter is to increase the size of the display area by adding additional or larger monitors. Although this solution does not require the SD to be occluded, it does require overt shifts of visual attention, potentially involving head or eye movements. In this design scenario, information would be placed further away from the center of the workstation not only resulting in time spent looking away from the SD, it would also require additional time to reacquire the situation once the off-axis task has been dealt with. Furthermore, this solution is not practical in many ABM environments, especially those sited on airborne platforms, due to space limitations.

Most modern ABM workstations are transitioning to electronic documentation of information and abandoning traditional paper manuals therefore creating an ever increasing need for the display of battle space information. The need for increased screen space in command and control environments has been expressed (St. John, Manes, Oonk, & Ko, 1999). The increasing need for the display of information along with space limitations bring about questions of how information can be displayed in a manner that is space efficient, useful and least disruptive to other tasks.

Technological advancements in processing speed and the miniaturization of technology have led to several possible alternative solutions. One potential solution for improving the problem of display occlusion is to use a head-mounted display (HMD) to provide additional screen space. HMDs have received considerable attention and investigation due to their ability to enhance human perception and performance in certain complex work environments. HMDs have been used successfully in various environments including surgery, entertainment, manufacturing, military applications, training, and education. For instance, HMDs have been proven to enhance the operational effectiveness of Apache AH-64 helicopter pilots (Stelle, Reynolds, Rash, Peterson, & Leduc, 2003) as well as provide a safe and controlled environment for surgeons to practice and rehearse surgical procedures (Liu, Tendick, Cleary, & Kaufmann, 2003).

Despite the potential for HMDs to enhance perception and performance in complex work environments, HMDs are confronted by many technical and ergonomic challenges, including optical distortion, suboptimal resolution, FOV limitations, time delays, and helmet fit and discomfort. While these technical and ergonomic limitations have been shown to adversely affect performance and operator workload, HMDs can also cause simulator sickness

(Stanney, Hale, Nahmens, & Kennedy, 2003; Stanney et al., 1998). Simulator sickness is a significant problem in synthetic environments because in some cases the symptoms are severe enough for users to discontinue use (Stanney et al., 2003; Stanney, Lanham, Kennedy, & Breaux, 1999) and for some users the symptoms may linger for a period of time after use, potentially compromising operator safety and acceptance (Stanney & Kennedy, 1998; Stanney, Kingdon, & Kennedy, 2002).

Although there are problems inherent with the use of HMDs, they may serve as a promising solution to the problem of display occlusion in ABM work domains. The utility of HMDs in multi-task environments remains uncertain therefore it is important to identify operationally relevant task environments for which HMDs are best suited. The purpose of the present investigation was to evaluate various display technologies for reducing the effects of occlusion on task performance in ABM work domains during simulated air-battle scenarios.

Method

Participants

Six males and six females between the ages of 18 and 34 (M = 23.83) participated in the experiment. All participants reported normal or corrected-to-normal vision in both eyes. Individuals were paid for their participation.

Apparatus

The study was conducted in a medium-fidelity simulated AWACS environment. A stereo headset was required to hear audio tones and radio calls. A calculator was provided for use by the participants for time and distance calculations.

Two commercial-off-the–shelf HMDs were evaluated during the experiment. A monocular HMD, the MicroOptical Instrument Viewer (SV-9), was tested (MicroOptics). This HMD was a VGA clip-on (glasses) display with a color LCD that presented a full-size image right in front of the eye (either right or left eye). It provided a 20 degree field of view with a resolution of 640 × 480. In addition, the Sony Personal LCD binocular HMD was tested (Glasstron). This HMD was a small, lightweight (5.3 oz) VGA head-wearable display with two 1.55 million dot LCDs and a resolution of 640 × 480. It provided a television viewing experience comparable to watching a 30-inch screen from a distance of approximately 4 feet.

Primary Task

Participants were asked to control an air battle involving the re-targeting of strike aircraft. The participants were required to perform distance measurements and calculations to determine if strike aircraft could be re-directed to various targets and/or an air refueler using information provided on a re-targeting form. Participants were required to look up strike aircraft call signs, preplanned air refuelers, and planned refueling times on the re-targeting form. They also needed to determine distances using the on-screen measuring features. Worksheets and a calculator were provided for use by the participants.

Secondary Tasks

At random times throughout each mission, 4 radio frequency calls occurred (2 via audio and 2 via a displayed text message) requiring the participants to look up and enter a new radio frequency from a form.

During each trial, participants also received 4 authentication tasks requiring the participants to search for and enter an authentication code found on an authentication form.

The presentation of the 3 forms (re-tasking, radio frequency change, authentication) for each mission was accomplished using one of the possible display technologies (paper forms, forms displayed electronically on the monitor, forms displayed with the monocular HMD and forms displayed with the binocular HMD). The three forms were available in Excel format.

All participants received a training protocol that was divided into three functional areas: 1) operator workstation and tactical display control; 2) measuring and calculation training without the secondary tasks; and 3) measuring and calculation training with the secondary tasks.

During training it was explained to the participants that all of the tasks were important and to complete them quickly and accurately. The participants were instructed to develop strategies to aid them in the completion of all the tasks in the allotted 10 minute mission time.

Experimental Design

A within-subjects design was employed. Display technology (paper forms, forms displayed electronically on the monitor, forms displayed with the monocular HMD, and forms displayed with the binocular HMD) was the manipulated variable**.** Each participant completed 3 missions (trials) for each display technology for a total of 12 trials. The maximum duration of each mission was 10 minutes. After completion of each mission, the participants were asked to rate their subjective impressions of mental workload and situational awareness (SA). The entire experiment, including training, lasted approximately 5-6 hrs for each participant.

Subjective Measures

The NASA-TLX (Hart & Staveland, 1988) sub-scales were used for ratings of mental workload. The Measures of Situation Awareness (3-D SART) questionnaire (Taylor, 1990), with an additional question asking the participant to rate their overall SA, was also administered. Both scales were rated by the participants following each mission.

Results

Primary Task Performance

The data collected during the trials was analyzed using a 4 (display technology) factor Analysis of Variance (ANOVA) for both percentage of correct responses and the response times. The results of the ANOVA conducted for the primary task indicated that there was a significant difference in the percent of correctly re-tasked strike aircraft, $F(3, 33) = 5.25$, $p < .01$. This analysis, depicted in Figure 1, indicates that participants responded correctly more often when the information about the re-tasking was available via paper. This was followed by the screen condition, the Glasstron HMD condition, and finally the MicroOptics condition. The response times for this task failed to reach a significant difference for the four display technologies available.

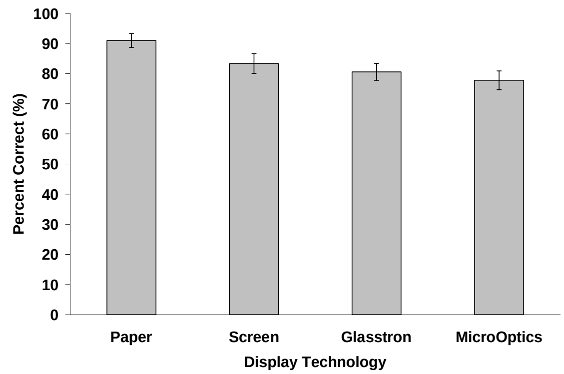

Figure 1. *Percent of correct responses for the re-tasking evaluation as a function of display technology.*

Secondary Task Performance

A similar statistical strategy was employed for the percent correct and response times for the secondary tasks. The results indicated that there was a significant difference for the percent of correct responses for the radio frequency change task, $F(3, 33) = 19.30$, $p < .01$. This result, depicted in Figure 2, suggests that participants responded correctly in a similar manner to that of the primary task; more often when the information was available via paper, followed by the screen, the Glasstron HMD, and finally the MicroOtics HMD.

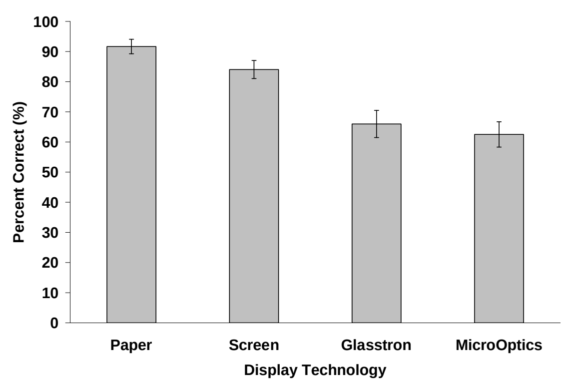

Figure 2. *Percent of correct responses for the radio frequency change task as a function of display technology.*

The results of the ANOVA conducted on the response times for the radio frequency change task was also significantly different for the different display technologies available, $F(3, 33) = 23.53$, $p < .01$. The response times for this task, illustrated in Figure 3, are inversely related to the percentage of correct responses. That is, the response times for the radio frequency task were fastest when that information was available in the paper condition. Response times lengthened in the screen condition, followed by the Glasstron HMD and the MicroOptics HMD.

The ANOVA conducted for the authentication task revealed that there was not a significant difference for the percentage of correct responses but the response times did espouse a significant difference for this task, $F(3, 33) = 41.28$, $p < .01$. This difference is virtually the same as the result found for the radio frequency change task. The shortest response times were those that were obtained when the participants had the information available via paper (M = 18.38s, SE = 0.87s), followed by the screen condition (M = 23.41s, SE = 0.91s), the Glasstron HMD (M = 33.66s, SE = 1.75s), and the MicroOptics HMD (M = 34.40s, SE = 1.56s).

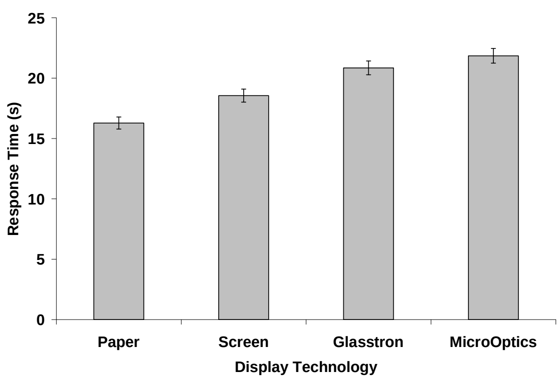

Figure 3. *Response times for the radio frequency task as a function of display technology*.

Subjective Measures

The NASA-TLX sub-scale scores were averaged to yield one workload score for each trial. This score was used in an ANOVA analogous to that described previously. The results indicated that there was a significant effect for the display technology on the workload ratings, $F(3,33) = 5.72$, $p < .01$. This effect, illustrated in Figure 4, indicates that participants rated their workload highest while using the MicroOptics HMD, followed by the Glasstron HMD, the screen condition, and lowest when the information was available via paper. Participant ratings of Situation Awareness failed to differ significantly for the display technology utilized.

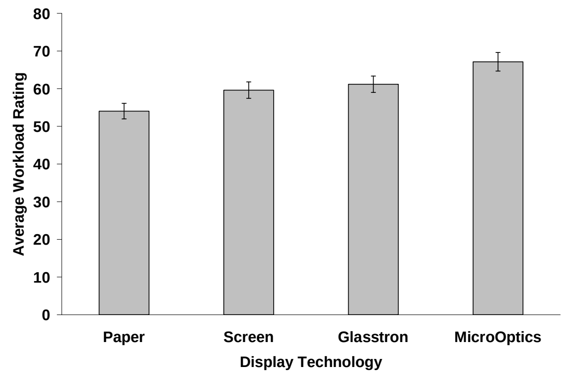

Figure 4. *Average participant workload ratings as a function of display technology.*

Discussion

This is the first in a series of studies examining the utility of HMDs in an Air Battle Management environment. The results indicate that the HMDs selected did not produce a significant performance benefit. Further, the workload reported by the participants suggests that they experienced the lowest workload when the information was available via the paper medium. Upon examination of the results, it was posited that the reason for the lack of a performance benefit may be due to the nature of the tasks the participants were required to perform. Namely, these results may be significantly influenced by the lack of complexity in the required tasks. All of the forms that were used in the information retrieval were one page or less in length. It was suggested that this one page length may not be representative of the types of tasks that may be amenable to the utilization of HMDs. Further, it was suggested that the information operators typically need to access is often found in sources that are comprised of several, if not several hundred pages. The next experiment in this series will utilize more complex tasks to examine the potential benefit HMDs may provide.

References

Conn, E.S. (2003). *JAVA-BASED performance oriented visualization system* (Tech. Rep. No. AFRL-IF-RS-TR-2003-87). Wright-Patterson Air Force Base, OH: Air Force Research Laboratory.

Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In P.A. Hancock and N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam: Elsevier Science/North Holland.

Liu, A., Tendick, F., Cleary, K., & Kaufmann, C. (2003). A survey of surgical simulation: Applications, technology, and education. *Presence, 12,* 599–614.

ModSAF 5.0, Advanced Distributed Simulation Technology (1999). *ADST-II-CDRL-MODSAF5.0-9800324*.

St. John, M., Manes, D. I., Oonk, H. M., & Ko, H. (1999). Workspace control diagrams and head-mounted displays as alternatives to multiple monitors in information-rich environments. *Proceeding from the Human Factors and Ergonomics Society 43rd Annual Meeting,* 438-442.

Stanney, K. M., Hale, K. S., Nahmens, I., & Kennedy, R. S. (2003). What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience. *Human Factors, 45,* 504-520.

Stanney, K. M. & Kennedy, R. S. (1998). Aftereffects from virtual environment exposure: How long do they last? *Proceeding from the Human Factors and Ergonomics Society 42nd Annual Meeting*, 1476-1480.

Stanney, K. M., Kingdon, K. S., & Kennedy, R. S. (2002). Dropouts and aftereffects: Examining general accessibility to virtual environment technology. *Proceeding from the Human Factors and Ergonomics Society 46th Annual Meeting*, 2114-2118.

Stanney, K. M., Lanham, D. S., Kennedy, R. S., & Breaux, R. (1999). Virtual environment exposure drop-out thresholds. *Proceeding from the Human Factors and Ergonomics Society 43rd Annual Meeting*, 1223-1227.

Stanney, K., Salvendy, G., Deisinger, J., DiZio, P., Ellis, S., Ellison, J., Fogleman, G., Gallimore, J., Singer, M., Hettinger, L, Kennedy, R., Lackner, J., Lawson, B., Maida, J., Mead, A., Mon-Williams, M., Newman, D., Piantanida, T., Reeves, L., Riedel, O., Stoffregen, T., Wann, J., Welch, R., Wilson, J., & Witmer, B. (1998). Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda (Report sponsored by the Life Sciences Division at NASA Headquarters). *International Journal of Human-Computer Interaction, 10,* 135-187.

Stelle, J. A., Reynolds, B. S., Rash, C. E., Peterson, R. D., & Leduc, P. A. (2003). The role of the pilot's night vision system (pnvs) and the integrated helmet and display sighting system (ihadss) in ah-64 apache accidents. *Proceedings of Helmet- and Head-Mounted Displays VIII: Technologies and Applications, SPIE Vol. 5079,* 31-40.

Taylor, R.M. (1990). Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In Situational Awareness in Aerospace Operations (AGARD-CP-478, pp. 3-1 and 3-17). Neuilly Sur Seine, France: NATO-AGARD.