NAG 1- 1425

IN-61- CR

159390

P.37

Final Report

Perceptual Factors that Influence Use of Computer Enhanced Visual Displays

Professor David Littman, Principle Investigator
Department of Computer Science

Professor Debbie Boehm-Davis, Co-Principal Investigator
Department of Psychology

George Mason University
Fairfax, VA 22030-4444

3/31/93

Final Report

Perceptual Factors that Influence Use of Computer Enhanced Visual Displays

Professor David Littman, Principle Investigator
Department of Computer Science

Professor Debbie Boehm-Davis, Co-Principal Investigator
Department of Psychology

George Mason University
Fairfax, VA 22030-4444

3/31/93

1. Introduction

This document is the final report for the NASA/Langley contract entitled "Perceptual Factors that Influence Use of Computer Enhanced Visual Displays," performed for Mr. James Burley.

The document consists of two parts. The first part contains a discussion of the problem to which the grant was addressed, a brief discussion of work performed under the grant, and several issues suggested for follow-on work.

The second part, presented as Appendix I, contains the annual report produced by Dr. Ann Fulop, the Postdoctoral Research Associate who worked on-site in this project.

The main focus of this project was to investigate perceptual factors that might affect a pilot's ability to use computer generated information that is projected into the same visual space that contains information about real world objects. For example, computer generated visual information can identify the type of an attacking aircraft, or its likely trajectory.

Such computer generated information must not be so bright that it adversely affects a pilot's ability to perceive other potential threats in the same volume of space. Or, perceptual attributes of computer generated and real display components should not contradict each other in ways that lead to problems of accommodation and, thus, distance judgments. The purpose of the research carried out under this contract was to begin to explore the perceptual factors that contribute to effective use of these displays.

2. Work Performed Under the Contract

The initial year of this project focused on two primary topics, which are described in detail in the Annual Report, included as Appendix I.

First, the post-doctoral research associate (Ann Fulop) and the domain expert (Joseph Clark) performed a task analysis of a one-on-one air combat engagement. The purposes of the study were to 1) explore types of information required by pilots in one-on-one combat situations in thrust-vectored aircraft and 2) identify potential representations of information that display designers might use to construct effective displays.

Second, a study was carried out to determine the relative effects of size, distance, and field position of a virtual target on detection of those targets in a dual-task human performance study.

The results of both of these activities are described in Appendix I.

3. Recommendations for Future Work

This section contains recommendations for follow-on work. Two categories of follow-on work are recommended. The first category continues the work begun during the first year. This work would continue to focus on perceptual effects of attributes of computer generated displays that are overlaid with real-world information.

The second category of suggested future work addresses the effects of cognitive factors such as training and task compatibility on the ability to make use of computer generated information that is overlaid with real world information in the same virtual space. A subsection which discusses previous, relate work performed by the Principal Investigator attempts to provide justification for the recommendations.

3.1. Perceptual Factors

The annual report prepared by Ann Fulop describes several key areas of importance for follow-on work, in particular, the effects of availability of various cues on distance and size judgments The primary topics identified in the report were the effects of 1) various patterns of interposition, 2) field of view, and 3) long term exposure

to head mounted displays, especially as this variable affects convergence. Two cognitive factors were identified in the recommendations, namely the effects of various representations of abstract concepts associated with (referred to as conformal displays in Appendix I.)

In addition to the factors suggested in the annual report, there are other perceptual factors that may be useful to address in follow-on work. First, both rapid and slow changes in ambient light may affect all the variables identified by Ann Fulop in Appendix I.

If real-world information is transmitted as part of the display, rapid changes in ambient light -- such as the changes generated by an explosion of an aircraft or target, or a burst of reflected sunlight -- may affect the pilot's ability make use of computer generated information. As well, slow changes due to e. g., daybreak or nightfall may also affect the ability of pilots to use displays that combine real information with computer generated information.

One potentially useful outcome of this line of research might be the specification of equations that can determine how to automatically adjust display intensities to offset illumination changes so that both the real information and the computer generated information maintain constant apparent (relative) brightness.

Second, the effects of rapid deceleration and acceleration may also affect the ability of pilots to use computer generated information. The effects of acceleration and deceleration may create disorientations that are harder to overcome with computer generated displays. Conversely, there may be computer generated displays that could offset the effects on real world information of rapid acceleration and deceleration. If it were possible to identify such offsetting computer generated information, its presentation could be triggered under rapid acceleration and deceleration.

3.2. Cognitive Factors

Several cognitive factors may be of importance to performance with displays that integrate computer generated information with real world information. These suggested studies would address the problem of practiced behavior in multi-task settings which combine computer generated and real world information.

This is a potentially useful area of research because expert, multi-task behavior may produce effects that differ substantially from novice behavior, especially when both groups of subjects are not already trained in an existing paradigm. That is, it may be important to contrast the effects of various perceptual and cognitive factors on performance of 1) skilled pilots who are trained in the new paradigm as well as 2) novice pilots who are not highly practiced in the existing paradigm. Because new pilots will be increasingly trained in the new paradigm, it seems important to understand the effects of practice, task compatibility, and so forth on them as well as on already-trained pilots.

3.2.1. Background & Justification of Cognitive Factors

Beginning in 1973, David Littman and Robert Becklen performed a series of experiments under the direction of Ulric Neisser with the intention of determining the factors that influence the ability of humans to respond effectively to *two different, meaningful events that occur in the same virtual space.*

The impetus for this series of studies was the demonstration by Paul Kolers in 1971 that it was difficult, if not impossible, to follow two *separate, meaningful,* events in the same virtual space. Koler's demonstration was performed with an apparatus that consisted of a pilot's helmet with the visor replaced with a half-silvered mirror. The half-silvered mirror performed two functions.

• First, the half-silvered mirror permitted the subject to view the world in front of him or her.

• Second, the half-silvered mirror projected a reflection of the world *behind* the observer into the same virtual space by means of full-silvered mirrors placed at various locations on the side of the helmet.

The observer thus had available at all times the information needed to see what was going on in front at any depth, behind at any depth, or both. Koler's initial studies with the modified pilot's helmet apparatus produced two main findings.

First, under any reasonable conditions of lighting, including night conditions, subjects were able to follow without difficulty either the events occurring in front of them or the events occurring behind them with essentially no interference.

Second, novice subjects were utterly unable to follow both the events occurring in front of them and the events occurring behind them regardless of how hard they tried, how much they were paid, or any reasonable manipulations of relative illuminations of the two events.

That is, as long as the meanings and contents of the events in front of and behind the subjects were different, subjects were easily able to follow either event without confusion. But they were not able to follow both at the same time. Rather, they were forced to "switch" back and forth between events whenever they wanted to or were instructed to. This suggested that visual attention during meaningful tasks may follow many of the same laws as auditory attention during meaningful tasks.

Littman [1] and Littman & Becklen [2] performed a series of experiments to determine some of the basic laws that govern the abilities of subjects to 1) follow *either* one or the other of the two events, 2) *switch* from one event to the other, or 3) "see" two events at the same time. The results of this research generally agreed with the results of Koler's initial studies and, therefore, with models of selective auditory attention. Two effects discovered during this research may be relevant for the NASA research project.

First, subjects got much better at tracking two target events with practice. It appeared that, in the initial stages of practice, subjects switched back and forth between events, often getting lost when they tried to switch back.[1] and often missing targets that were "right in front of their noses." With practice, however, subjects seemed to abandon their switching strategy and were able to identify target events in both events simultaneously. The expertise the subjects acquired appeared to consist at least in part of identifying predictable patterns of activity *across the two events* that followed natural laws of physics. Thus, subjects seemed to be able to learn best when the events did not "appear out of nowhere" and where patterns of appearance and disappearance became familiar to the subjects. In essence, with extensive practice, the subjects appeared able to learn to combine two separate events into a single perceptual experience.

Second, subjects also got better at detecting low-probability or even *totally unexpected* events as they acquired expertise in the primary task of tracking the visual events.[2]

These two findings together suggest three points:

• Studies of perceptual ability in certain simple dual task settings may yield results that are not completely generalizable to complex tasks that are performed under heavy attention loads when subjects have had extensive training..

• The ability of subjects to identify, categorize, and respond to unexpected meaningful events increases significantly with practice.

---

[1] The two events subjects were asked to monitor were, in some cases, distinguished by low level perceptual features, such as the colors of the objects or the speed at which they moved.

[2] Again, these totally unexpected events conformed to natural laws of physics. Pilot evidence suggested that when unexpected events did not conform to the laws of physics (e.g., they appeared out of nowhere) they were much harder to detect.

- Events that violate natural laws of physics (e.g., they just pop into existence) may take longer to learn to detect than events that come into existence under natural laws.

Taken together, these findings from early multi-event tracking studies suggest two points that may be of relevance for the problem of designing displays that incorporate real and computer generated information.

First, significant aspects of skilled performance of subjects can be accounted for by 1) practice and 2) the cognitive compatibility of the elements of the displays vis-a-vis the identification, classification, and decision making tasks being performed. Thus, perceptual factors may have their most significant impact for unpracticed subjects in essentially performing largely meaningless tasks.

Second, the acquisition of the ability to identify "unexpected events" appears to follow a step function. Once a subject attains a certain level of skill in a primary task, the secondary task e.g., detection of unexpected events, becomes very easy.

4. Final Comments

The study of the integration of real world and computer generated information is a fascinating topic which has implications for many domains. Real time decision support systems for battlefield use; decision support systems for architects, which, for example, overlay computer generated buildings on real terrain; diagnostic systems for doctors that permit the diagnostician or surgeon to "look through" various layers of a person's body and so forth all will rely on the integration of computer generated and real world information.

The results of studies being carried out at NASA Langley on the integration real world and computer generated displays thus have a very real chance to be an important subject of technology transfer activities.

5. Citations

[1] Littman, D. The stimulus determinants of selective looking. Doctoral Dissertation, Department of Psychology, Cornell University, 1976.

[2] Littman, D. & Becklen, R. "Selective looking with minimal eye movements." *Perception and Psychophysics*, 1976, 26, 77-79.

6. Appendix I

Visual Perception of
Stereo Helmet-Mounted Displays
Annual Report for NASA Grant 5-26955
February, 1993
George Mason University

by Ann C. Fulop

TABLE OF CONTENTS PAGE

TASK ANALYSIS
Purposes

A task analysis of a one versus one air combat situation in which the pilot is in a thrust-vectored aircraft was completed. Purposes of the task analysis include:

1) Determine new problems that pilots will have when maneuvering a thrust-vectored aircraft.

2) Determine how pilots' information requirements will change in a thrust-vectored aircraft.

3) Inform the display designer of the information requirements and how information relates to each other.

4) Help display designers create performance measures to evaluate display concepts.

5) Help the display designer exploit the stereo capability of the display medium, or the helmet.

In addition, the information based on the task analysis can be used to:

1) Acquire a general understanding of air combat.

2) Facilitate interviews and discussions with pilots.

3) Facilitate communication among the display designers.

4) Design displays.

5) Evaluate display concepts before empirical testing.

6) Create experimental tasks to test display concepts.

Method

A naval aviator, Joseph Clark, was the subject matter expert (SME) for the analysis. The SME is a former F-14 pilot with over 100 hours and 300 carrier landings. The subject matter expert has spent 100 hours experience in a thrust-vectored flight simulator.

To begin the analysis, the phases of air combat were described and the goals of each phase defined. Table 1 lists the phases and goals of air combat.

Once the goals of air combat were determined, the tasks the pilots must accomplish to achieve each of the goals were listed. This list includes the information pilot's currently use to perform tasks and accomplish goals. In addition, mistakes pilots make were included in the task analysis. The information was then grouped into 6 information groups. The groups included information concerning weaponeering, spatial awareness, air and surface threats, friendly aircraft, target aircraft, and own aircraft.

A chart was then created to show the relationships among the pieces of information and the various tasks involved in air combat. The chart shows all of the information requirements on the y-axis and the phases of flight on the x-axis. Looking across the chart the display designer knows which information is needed by that pilot during which phases of flight. Furthermore, colored boxes indicate which goals pertain to the information. The second column

Table 1.
Phases and goals of air combat.

I. Pre-merge phase.

      Goal 1: To choose a plan of action to target the highest threat to the completion of the mission assigned.

      Goal 2: To choose a plan of action to prevent threat from interfering with mission.

      Goal 3: To choose a plan of action to prevent threat from accomplishing his mission.

II. Merge Phase.

      Goal 4: To anticipate or predict target's behavior.

III. & IV. Initial turn and Second merge.

      Goal 5: To gain an offensive.

      Goal 6: To maintain an offensive

V. Leave or bug-out.

      Goal 7: Avoid being shot.

VI. All phases of mission.

      Goal 8: Enable safe recovery of aircraft.

   Goal 9: Avoid external threat missile envelopes.

of the chart shows other information that is related to the information in that row. Figure 1. shows the chart.

      Once the task was completed, 9 pilots reviewed the analysis. The nine pilots included 5 Navy pilots, 3 Air Force pilots, and 1 NASA test pilot. As a group, the pilots have experience in all modern fighter aircraft. The pilots have spent an average of 10 hours in a thrust-vectored simulator. The task analysis was updated to include inputs from the pilots.

Results

      The task analysis defined the information requirements of a one versus one air combat situation and illustrated how information relates to each other. The task analysis also showed display designers how pilots visualize and mentally depict concepts. The task analysis created a taxonomy of display concepts and information that pilots use during air combat

      The task analysis and chart are available from Joseph Clark, Lockheed Engineering and Sciences, Hampton, VA. Any future grantees have this information available for future reference.

goals 1,2,3 ■ goal 5 ■ goals 6,7 □ goal 10 ▨ goal 11

Information	Shape	Relate	Takeoff	Enroute	Intercept	Engaged	Leave
Airspeed a	(rate)	b, c, d	□	▨	▨ ▨	■ ▨	▨
Turn rate b	(rate)	a, e				■	
Turn radius c	⊢→ (distance)	a, e				■	
Alpha d	∡ (angle)	c, e	□	▨	▨	■	▨
Load factor e	▮ (amount)	a, c, d				■	

(rate) ⊢→ distance ▮ amount ∡ angle

Figure 1. Energy Management Portion of Task Analysis Chart

A TARGET DETECTION STUDY FOR DETECTING VIRTUAL OBJECTS PRESENTED AT VARYING DEPTHS AND LOCATIONS WHILE MONITORING THE PHYSICAL ENVIRONMENT

ABSTRACT

The objectives of the present research were to determine whether it was possible for participants to monitor simultaneously stimuli in both the virtual world and physical world, and to determine the appropriate depth and location to present static virtual objects. Participants were required to monitor an arrow projected onto a wall approximately 60 feet in front of them. When they detected a change in the direction of the arrow, they responded as quickly as they could by pressing a mouse button. At the same time that participants were monitoring the arrow, they were looking for a virtual target presented via a helmet-mounted display. Various virtual shapes would "pop up" at one of 5 locations and one of 3 depths. When they detected the target stimulus, they responded as quickly as they could by pressing a mouse button. Results suggested that it was possible for humans to monitor stimuli in both worlds, however reaction times were slower than typically reported when monitoring only the physical world. Results also showed that virtual objects presented at the same depth as the physical object were detected faster than virtual objects presented 3 feet in front of the participants. Virtual stimuli presented in the center of the field of view were responded to faster than stimuli presented at the edges of the field of view.

INTRODUCTION

If helmet-mounted displays (HMD) are to have practical applications, it is necessary to understand the visual perception problems of intermixing virtual objects presented via the binocular HMD with physical objects located in the "real world". HMD's were developed and designed to allow pilots to view symbology at optical infinity. It was believed that virtual imaging devices would enable pilots to simultaneously view displayed symbology and targets without needing to change accommodation. However, traditional two-dimensional and biocular virtual image displays do not cause the eye to focus at optical infinity (Hull, Gill, & Roscoe, 1982; Iavecchia, Iavecchia, & Roscoe, 1988; Normal & Erlich, 1986). With the use of these displays, focus shifts from the far point inward toward the dark focus, or the resting accommodation. Accommodation depends on the acuity demand of a task. A demanding task will pull the eye farther toward the far point than will a less demanding task. Currently, it is unknown whether a shift toward the resting accommodation occurs with binocular or stereo three-dimensional virtual image displays. The stereo display creates a three-dimensional image by presenting a slightly different view to each eye. The brain fuses the disparate images to create a single image perceived in depth. Stereo images make it possible to model the physical environment and, thus, present images within the display at real world depths.

Convergence is necessary to fuse the image in a stereo display. However, convergence and accommodation are decoupled when viewing objects through an HMD. It is assumed that accommodation is fixed for all objects regardless of the distance at which objects are presented through the helmet. For example, when two objects exist at two depths in the virtual display the

observer will see double images of the unattended object because both objects are in focus simultaneously. The observer cannot converge both objects simultaneously unless they are in close range. Thus, when the observer is required to attend to both physical and virtual objects, it is unknown how the eyes accommodate and converge. It seems reasonable to assume that when the observer is attending to a physical object the eyes are accommodated to that object's distance. Thus, virtual objects presented at the physical object's distance will also be accommodated to that distance and should be responded to faster. However, accommodation to virtual objects is assumed to be fixed near the dark focus (Iavecchia et al, 1988) thus, virtual objects presented at the dark focus distance may be responded to more quickly than other objects.

It was hypothesized that virtual stimuli presented at the same distance as the physical stimuli would be reacted to faster than other stimuli because participants should be accommodated at that distance. It was hypothesized that larger stimuli would be responded to faster than the smaller stimuli.

METHOD

Subjects.

A total of 14 participants, 11 males and 3 females, between the ages of 23 years and 34 years volunteered to participate in the study. Participants had normal color vision, acuity, and stereoacuity.

Helmet-mounted display (HMD).

The HMD used was a variable overlap, binocular system with 30 degree vertical by 40 degree horizontal field-of-view transmissive oculars. The oculars were turned to diverge 5 degrees horizontally producing a total field-of-view of 45 degrees. The helmet used two 1 inch displays (image sources) with a 1280(h) x 1024(v) picture element resolution. The helmet weighed 6.5 lbs.

Task.

Participants were required to monitor simultaneously a 4 foot arrow projected onto a far wall 57 feet directly in front of them and virtual objects presented through the helmet mounted display. The arrow pointed to the left or right. When the arrow changed direction, the participants were required to press the left mouse button as quickly as they could. The arrow changed direction 3 times per minute. Participants were told that they received 3 points for every change in direction that they detected. Six different virtual missile shapes were presented to participants via the helmet at approximately the rate of one shape per second. The missile shapes are shown in Figure 1. When they detected the target missile shape, they were required to press the right mouse button as quickly as they could. The target was presented 3 times per minute. Participants were told that they received one point for every target that they detected. To motivate participants to remain focused on the arrow, they received 3 points for detecting a change in the arrow direction, but only 1 point for correctly detecting the target.

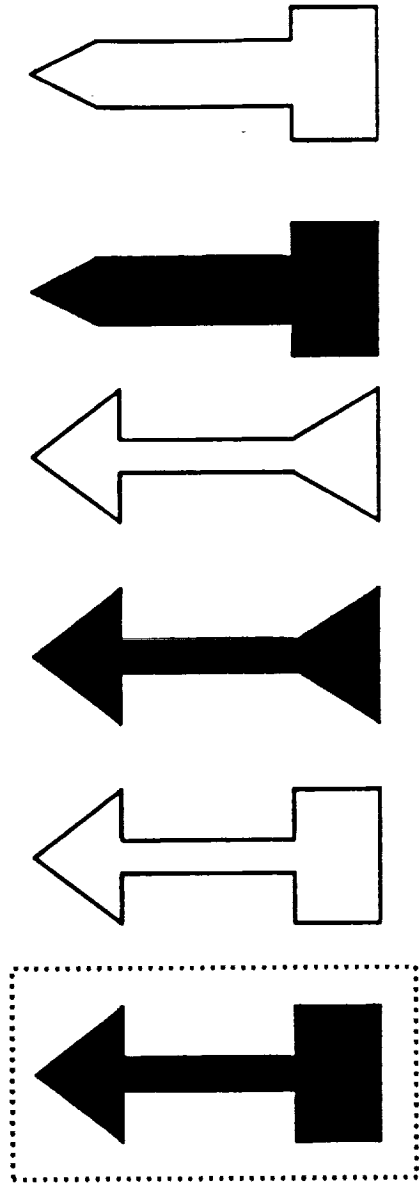Independent variables and experimental design.

Figure 1. Target and Distractors. Target is signified by dotted box.

The three independent variables; distance, location, and size of stimuli were within subjects in nature. Virtual stimuli were presented at three different distances, 3.128 feet, 18 feet, and 57 feet from the participant. The distance of 3.128 feet is approximately the dark focus distance, and 18 feet is approximately the point at which the convergence angle is 0. Virtual stimuli were presented at five locations, upper left, upper right, center, lower left, and lower right. Thus, stimuli were presented at each of the 5 locations at each of the 3 depths, or 15 places. The target stimulus was presented in each place 3 times. Virtual stimuli subtended either 2.5 degrees of arc or 1 degree of arc. The design was a repeated measures design.

Procedure.

Participants were read instructions. Then, the helmet was fitted on the participant's head for physical comfort. A standard display (see Figure 2) was used to ensure that participants had identical images in both the right and left eyes, and that they were seeing a stereo image. After the display was aligned, participants then performed a 5 minute practice task to familiarize themselves with the helmet display and the responses. After the practice trial, participants performed two 15 minute experimental sessions. In one session, the size of the virtual stimuli were 2.5 degrees of arc, in the other session, the virtual stimuli subtended 1 degree of arc. Assignment of participants to size condition was counterbalanced. Reaction time data to the target stimuli and arrow changes were collected. The experiment was performed in the dark.

RESULTS

Mean reaction time (M = 1.095 sec., sd = 2.67) to the change in the arrow suggests that participants were primarily attending to the virtual stimuli rather than the arrow change. To test the hypotheses, a repeated measures analysis of variance was performed on the reaction time data to the target stimulus. Table 1 shows significant main effects for distance, location, and size. Significant interaction effects for distance by location, and size by location were found. The main effect of distance supports the hypothesis that virtual stimuli presented at the same distance as the physical stimulus would be responded to faster. The virtual stimuli presented at 57 feet (M = 751 ms, sd = 168 ms) were responded to significantly faster than stimuli presented at 3.128 feet (M = 790 ms, sd = 184 ms).

The main effect of location shows that virtual stimuli presented in the center of the display were responded to faster than stimuli presented in the periphery. Table 2 displays the means and standard deviations for reaction time at the five locations.

The main effect of size shows that the large stimuli (M = 727 ms, sd = 160 ms) were responded to faster than the small stimuli (M = 819 ms, sd = 184 ms). This supports the hypothesis that larger stimuli would be responded to faster than smaller stimuli.
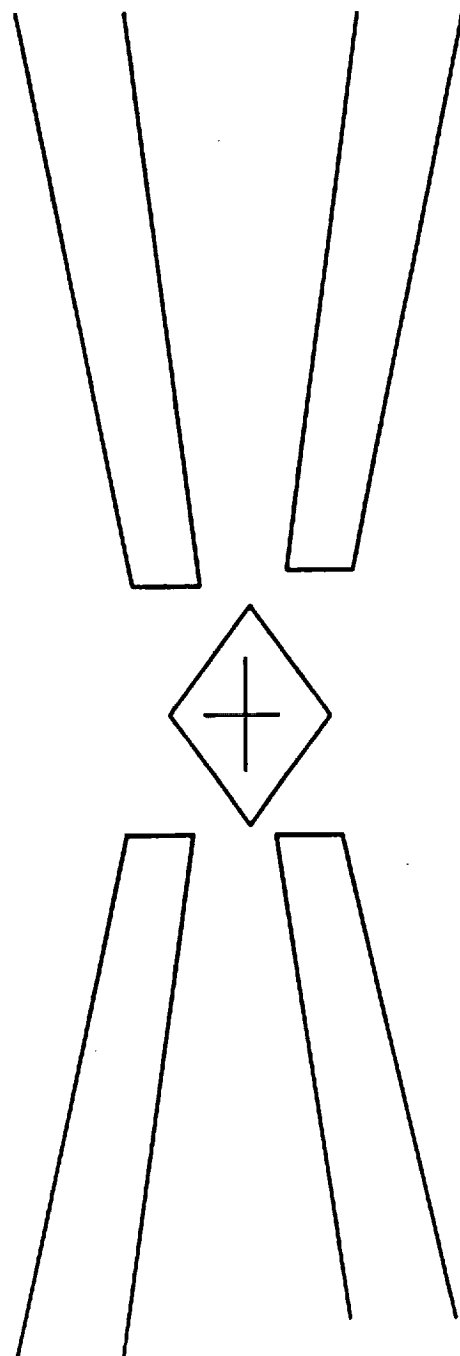
Figure 2. Alignment Display

Table 1. Summary table for repeated measures ANOVA on reaction time to target stimuli.
* Significant at alpha .05.

SOURCE	DF	F	eta2
Distance	2	6.03*	.02
Location	4	7.66*	.04
Distance by Location	8	2.56*	.03
Size	1	97.45*	.12
Size by Distance	2	.77	
Size by Location	4	2.64*	.02
Size by Distance by Loc.	8	.41	
Subject	13	15.79*	.23

Table 2. Mean reaction time of detecting target stimuli at five locations.

	Upper Left	Upper Right	Center	Lower Left	Lower Right
Mean	788 ms	766 ms	723 ms	794 ms	781 ms
Standard deviation	197 ms	165 ms	152 ms	179 ms	183 ms

The interaction effect of distance by location reveals that stimuli located in the center of the display were responded to faster at distances of 16 feet and 57 feet than stimuli in the periphery (see Figure 3). However, stimuli located at the center 3 foot distance were not responded to faster than stimuli in the periphery.

The interaction effect of size by location shows that small stimuli presented in the center of the display were responded to as quickly as the large stimuli (see Figure 4).

DISCUSSION

It was hypothesized that virtual stimuli presented at the same distance as a physical stimulus would be reacted to more quickly than virtual stimuli presented at closer distances. Results from the present study supported this hypothesis. Thus, the display designer should model the physical world within the display so that important virtual objects are presented at the same distance as the physical world target. Furthermore, these results show that displaying virtual objects at the dark focus distance results in slower reaction times when the observer is attending to a physical objects at a further distance. The increase in reaction time is probably due to the need for the eyes to converge and to see objects presented at the dark focus distance.

It was hypothesized that larger stimuli would be responded to more quickly than smaller

Rxn Time

800 ms
700 ms
600ms

UL   UR   Cnt   LL   LR
Location

●3.128 ft   ■18 ft   O57 ft
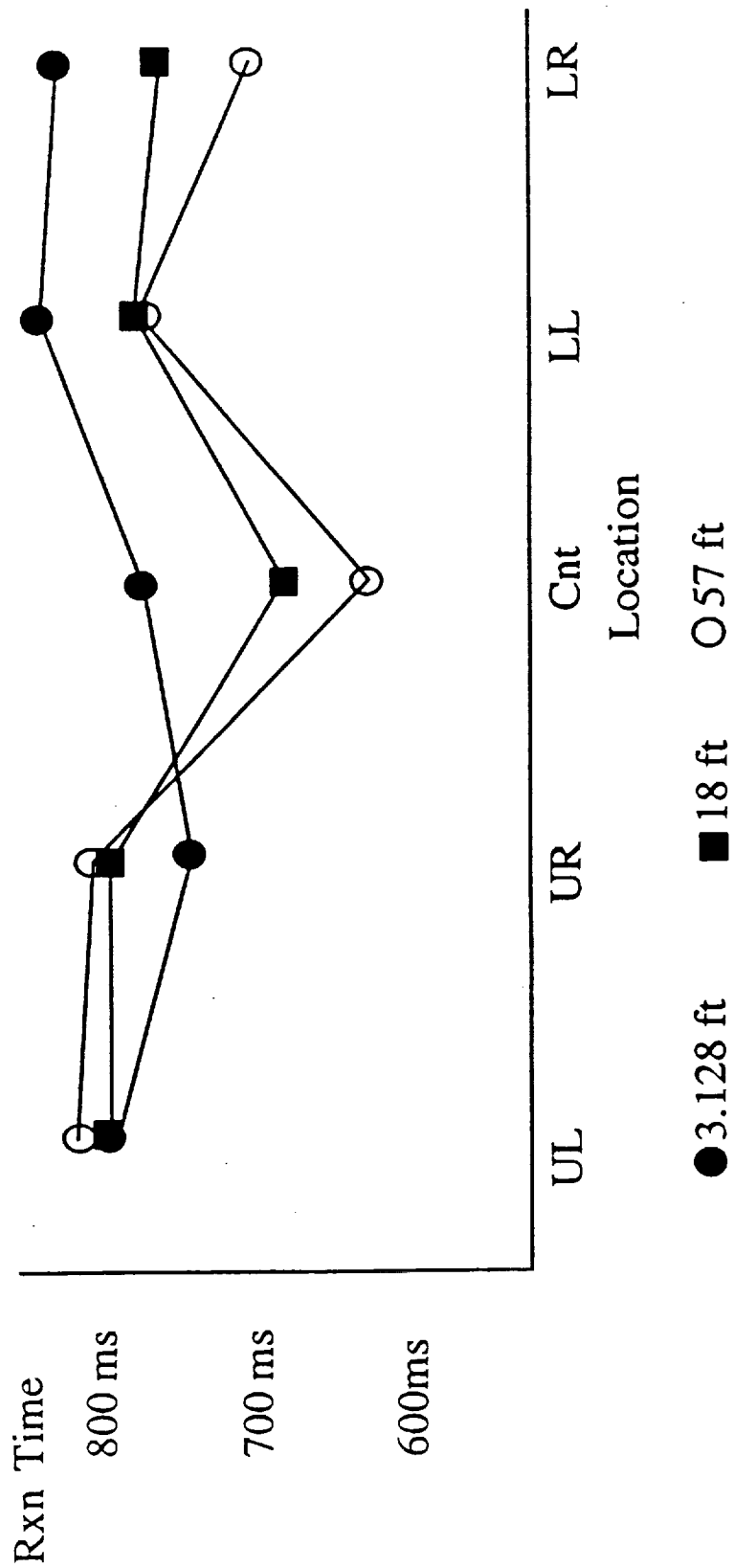
Figure 3.--Interaction Effect of Distance by Location for Reaction Time to Target Stimuli

Rxn Time

850 ms
800 ms
750 ms
700 ms

UL   UR   Cnt   LL   LR

Location

● large   ■ small
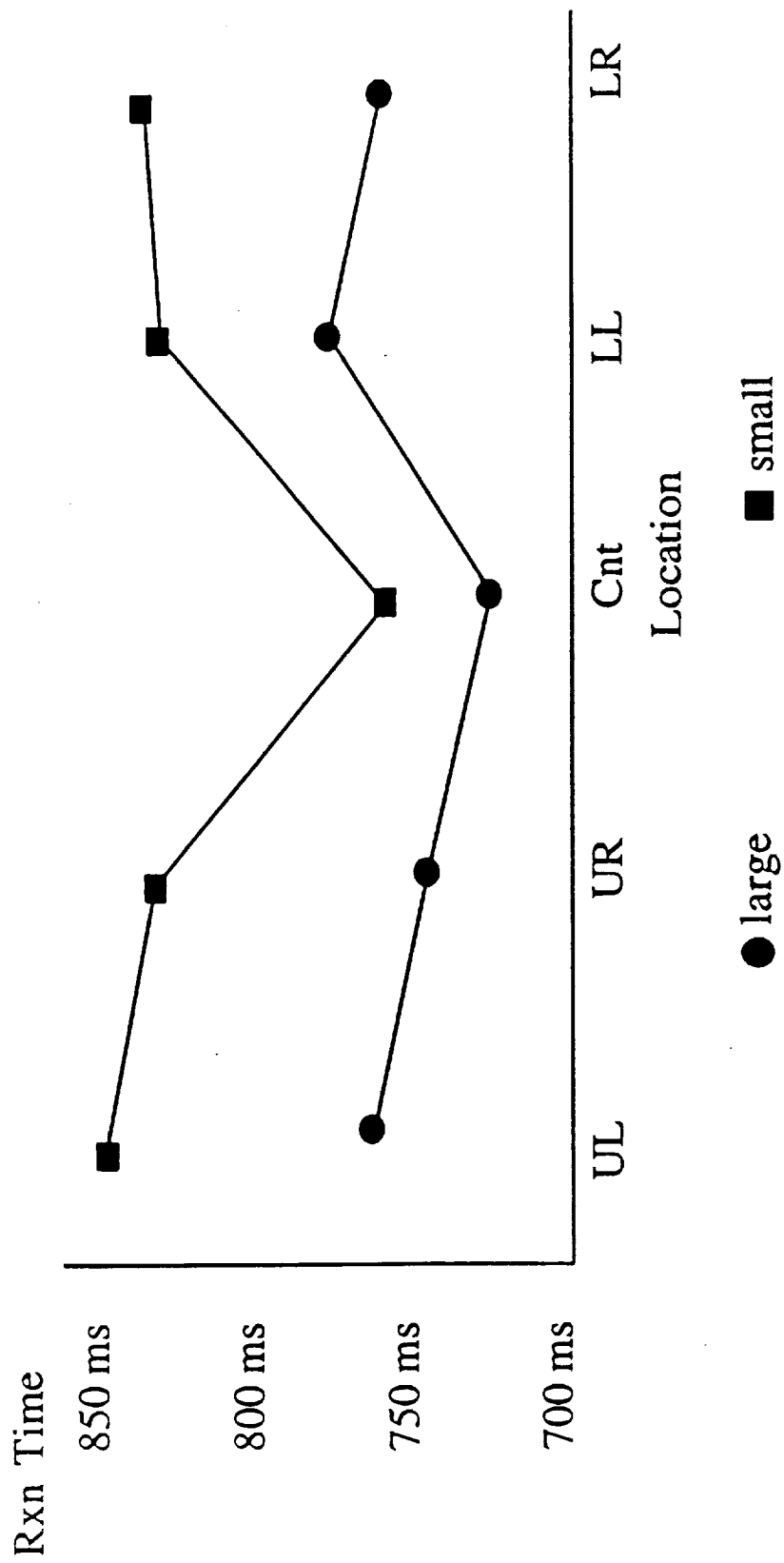
Figure 4. Interaction Effect of Size by Location for Reaction Time to Target Stimuli

stimuli. Results from the present study showed that stimuli presented in the center of the display are responded to faster regardless of the size of the stimulus. This suggests that smaller information such as, alphanumerics should be presented in the center of the screen when the observer is attending simultaneously to the physical world and virtual world.

Response times to both the arrow and the virtual missiles were slow. This finding suggests that attending to the physical world and the virtual world simultaneously is a difficult task. Thus, pilots may have a difficult time switching attention from the virtual scene to the physical scene even though they
simultaneously see both scenes. The problem of cognitively switching from the virtual world to the physical world warrants further research. Some participants reported that they did not perceive three distances in the display. However, they reported seeing some objects become larger or smaller. The only cues to distance in the display were accommodation, convergence, and lateral disparity. With HMD's, accommodation and convergence are decoupled. Thus, distance cues need to be included in virtual displays so that observers can accurately determine distance and size changes. Future research will explore the effect that pictorial depth cues have on distance perception of virtual stimuli.

REFERENCES

Hull, J.C., Gill, R.T., & Roscoe, S.N. (1982). Locus of the stimulus to visual accommodation: Where in the world, or where in the eye? Human Factors, 24, 311-319.

Iavecchia, J., Iavecchia, H., & Roscoe, S.N. (1988). Eye accommodation to head-up virtual images. Human Factors, 30, 689-702.

Norman, J. and Ehrlich, S. (1986). Visual accommodation and virtual image displays: Target detection and recognition. Human Factors, 28, 135-151.

VISION SOFTWARE INTERFACE

An in-house software package , VISION, was created in order to facilitate display design for the helmet and testing of displays in the Differential Maneuvering Simulator (DMS). The software package allows designers to connect to the DMS, record and playback data runs of pilots in the lab, simulate flight while in the lab, and interactively configure helmet displays while in the lab. In addition, the software allows the researcher to monitor from a bird's-eye perspective or from an inside the cockpit perspective a pilot's behavior during an experiment.

The grantee designed a Motif interface for the software package. The prototype for the interface, a User's Group Description Document, a Task Description Document, an Object Description Document, and a Systems Objectives Document were delivered to the software developer, Alan Dare.

CONSULTATION

Grantee performed experimental method and data analysis service to the cockpit technology branch at NASA Langley. Grantee has critiqued and reviewed experimental design and helped to design future experiments. In addition, the grantee conducted colloquia to help other display designers acquire knowledge and skills in experimental methodology, quantitative analysis, and SAS programming. In addition, the grantee provided critiques of various display designs and when appropriate made suggestions according to human engineering principles. Any future grantee will need to continue these efforts.

WORK PLANNED
DISTANCE STUDY

INTRODUCTION

Virtual image displays, or head-up combining glass displays (HUD) and helmet-mounted projections of computer generated images (HMD), were developed and designed to allow pilots to view symbology at optical infinity. This enables pilots to simultaneously view displayed symbology and targets without needing to refocus. However, traditional two-dimensional and biocular virtual image displays, such as HUDs and HMDs, do not cause the eye to focus at optical infinity (Hull, Gill, & Roscoe, 1982; Iavecchia, Iavecchia, & Roscoe, 1988; Norman & Erlich, 1986;Roscoe, 1985) With the use of these displays, focus shifts from the far point inward toward the dark focus, or the resting accommodation. Consequently, accommodation micropsia, "or a reduction in the apparent size of an object of given retinal angle"(Smith, Meehan, & Day, 1992, pp. 289), causes objects in the physical world to appear smaller and farther away than they actually are physically. The micropsia induced by the virtual image causes poor judgments of apparent distance and size. This explains why pilots flying with virtual images make fast approaches, round out high, and land long and hard (Roscoe, 1987). Controlled crashes into terrain during low level flights have also been attributed to the accommodation micropsia induced by HUDs. That is, mountain tops seem farther away and lower to the horizon than they actually are, the pilot flies at an altitude too low and crashes into the top of the mountain. Furthermore, the effect is more pronounced when an observer needs to identify a target on a textured terrain than when the terrain is unimportant (Iavecchia et al, 1988). Therefore, adequate distance and size judgments are difficult to make with traditional virtual image displays.

Currently, it is unknown whether accommodation micropsia occurs with binocular or stereo three-dimensional virtual image displays. The stereo display creates a three-dimensional image by presenting a slightly different view to each eye. The brain fuses the disparate images to create a single image perceived in depth. Stereo images make it possible to model the physical environment thus present depth cues within the display that model "real world" depth. Presenting strong depth cues in the display may eliminate or attenuate the lapse toward resting accommodation because objects can be displayed at the same depth as physical "real world" objects. Thus, accommodation may shift outward from the dark focus in order to view the virtual object at a further distance. Furthermore, the added pictorial cues in the display provide a richer textural content in which to make distance and size judgments. As the virtual world begins to resemble the physical world size and distance judgments will become more accurate.

The Zoom-lens hypothesis attempts to explain the accommodation micropsia problem with virtual image displays (Roscoe, 1985). The hypothesis states the function of the eye is analogous to the zoom-lens of a camera. That is, changes in lens curvature cause changes in the size of the retinal image. Inward accommodation from the dark focus produces large changes in

refraction that bring near objects into sharp focus at the expense of depth of field. These inward shifts in accommodation are accompanied by reductions in apparent size. Outward accommodation from the dark focus produces small changes in refraction. Image clarity is maintained with increasing depth of field, therefore apparent size of objects increases. Zoom-lens hypothesis suggests that an outward shift in accommodation also magnifies the retinal image. Consequently, more photoreceptors on the retina are stimulated resulting in finer discriminations and an increase in apparent size. This hypothesis is supported by the work of Iavecchia et al (1988), they showed with increasing acuity demand of a task, accommodation shifted outward. The accommodation of the eye is a result of the pull of the dark focus and the pull of the visual task. A visually demanding task results in a shift in accommodation away from the dark focus. Thus, the apparent size of targets increases with outward accommodation. However, with the use of a virtual image accommodation shifts inward toward the dark focus causing a decrease in retinal image size thus, apparent size or accommodation micropsia. The Zoom-lens hypothesis implies that changes in retinal image size are not necessarily related to focal distance. This raises the question of how size constancy is mediated with virtual image displays.

Other researchers (Marsh & Temme, 1990; Smith, Meehan,& Day, 1992) argue that the reduction in apparent size of objects can not be attributed to a change in retinal image size caused by accommodation. Equations, derived from studies utilizing a schematic eye, show that retinal image size decreases about 2% with 10D accommodation, or 0.3% at 1.5D, the approximate dark focus of accommodation. These changes are not large enough to explain the minification of objects (Roscoe, 1984) viewed through a virtual image display. In normal viewing circumstances, accommodation and convergence are linked to present a single fused and focused image on the retina. Convergence stimulates accommodation. Accommodation also stimulates convergence. This is accommodative convergence. Smith et al (1992) suggest that accommodation micropsia is a result of accommodative convergence. An increase in convergence can decreased the perceived size of an object (Heinemann, Tulving, & Nachmias, 1959) particularly when the vergence is induced by viewing through a prism. However, the increase in convergence necessary to induce the size change may also produce diplopia or double vision. It is plausible that accommodation micropsia can result due to an increase in accommodative convergence.

Convergence is necessary to fuse the images in a stereo display. However, convergence and accommodation cues may be decoupled when viewing objects in the virtual display. It is assumed that accommodation is fixed for all objects regardless of the distance at which objects are presented through the helmet. For example, when two objects exist at two depths in the virtual display the observer will see double images of the unattended object because both objects are in focus simultaneously. The observer cannot converge on both objects simultaneously unless they are in close range. Thus, the feedback loops between accommodation and convergence are interrupted with the stereo virtual image display. Fusional convergence does not

influence accommodation, likewise accommodative convergence is not an influence because accommodation does not change. Numerous studies have shown that when accommodation is not possible, size judgments made with the convergence cue are underestimated. Consequently, distance judgments are also inaccurate. It is possible, that using stereo virtual displays may result in inaccurate size and distance judgments because accommodation is fixed and size judgments are based on the convergence cue. The display will not eliminate the accommodation micrposia problem.

Size Constancy

The presentation of pictorial depth cues in the display may facilitate the accuracy of distance and size judgments. In normal viewing conditions, as the distance between the eye and a target increases the size of the retinal image decreases. However, the perception of size does not change as retinal image size changes. This phenomenon is size constancy. Thus, changes in the perception of apparent distance should alter judgments in apparent size. Therefore, the observer's ability to make veridical size judgments depends on the accuracy of the observer's distance judgments. The law of size constancy implies that the observer makes size judgments based on the size and distance of a physical object, or the distal stimulus, rather than retinal image size, or the proximal stimulus. When adequate distance cues such as, linear perspective, texture gradient, optical flow patterns, convergence, accommodation, binocular disparity and head movement parallax are present and in agreement the observer relies on the distal stimulus to make size judgments. However, when these cues are diminished or unavailable, the observer relies on the proximal stimulus or visual angle to judge size.

For example, a classic experiment by Holway and Boring (1941) showed size judgments were based on the distal stimulus when distance cues were available. That is, as a target stimuli changed in distance, the observers changed the physical size of a stimulus to match the size of the target stimulus. In a dark room with reduced distance cues, observers made size judgments based on visual angle or retinal image size. That is, observers did not perceive a change in size of the stimulus because it always subtended the same visual angle.

Previous research (Meehan & Triggs, 1992) has also shown visual scenes with plentiful depth cues result in more accurate judgments of size. Meehan and Triggs (1992) argue that apparent size and apparent distance are determined separately and independently by the visual system. They showed that estimated size was close to actual size when multiple cues to depth were available. However, perceived distance was not influenced by the absence of depth cues in a scene. They concluded distance cues facilitate size judgments more than distance cues facilitate distance judgments. Likewise, size is an important cue for distance. Therefore, including depth cues such as, linear perspective, texture gradient, and interposition within the virtual image display may result in more veridical size judgments, thus more accurate distance judgments. Modeling the physical world's dimensions in a display and providing appropriate depth cues

within the display should produce more accurate size and distance judgments. This is a unique advantage of stereo virtual images.

Meehan and Triggs (1992) concluded that different cues or sets of cues may influence differentially perceptions of size and distance. For example, Thouless (1968) suggests that binocular disparity influences distance judgments more than it influences size judgments, and monocular viewing influences size judgments more than distance judgments. Furthermore, the importance of different cues will vary based on viewing conditions. Iavecchia et al. (1988) have shown that the background texture and acuity demand of a task can affect size and distance judgments. Therefore, the conditions which facilitate or hinder size and distance judgments need to be examined and understood. Display designers of virtual image displays need to consider the visual task requirements, the scene or terrain content, ambient lighting, viewing distance, color, the mode of viewing; monocular, biocular, or binocular modes, and other factors that define viewing conditions. If stereo virtual image displays eliminate the accommodation micropsia problem or mediate size constancy, then they have a performance advantage over traditional biocular and two-dimensional virtual image displays.

This research was done to examine the effects that various viewing conditions have on distance judgments and size judgments with the hope of determining the performance advantages of stereo virtual image displays. These studies attempted to answer the following questions: (1) Will accommodation micropsia occur when viewing an object through a three-dimensional stereo helmet mounted display? (2) Does presentation of distance cues with and without size cues in the virtual image display influence the accuracy of size and distance judgments? (3) Which distance cues or combinations of cues are more important when judging distance and size? (4) Does the type of background of the physical world interact to influence the accuracy of size and distance judgments? (5) Will size constancy be mediated similarly inside the range of convergence, less than 20 feet, and outside the range of convergence?

Participants were required to move virtual image objects to match the depth and size of physical objects. Participants will perform the judgments viewing a biocular display, then viewing a binocular display. Half the participants will have a size cue when making distance judgments; the visual angle of the virtual object will change according to the distance moved. The other participants will not have a size cue; the virtual image will subtend the same visual angle as it is moved in depth. Participants will make judgments in situations which vary the number of distance cues from one cue, accommodation, to a full cue condition including accommodation, retinal disparity, convergence, linear and texture perspectives, and occlusion. However, a target detection study (Fulop & Williams, 1993) suggested that accurate perception of distance in the helmet is not possible with accommodation, retinal disparity, and convergence alone. Pictorial cues are needed. Distance and size judgments will be made against two types of backgrounds, textured and untextured.

Hypotheses

Accommodation will be fixed near or at the dark focus when accommodation is the only cue present in the display. Participants viewing a physical textured background will be accommodated closer to the dark focus than participants not viewing a physical textured background. Thus, participants viewing a textured background should underestimate size and overestimate distance compared to non-textured background participants. Furthermore, judgments of apparent size should not be affected by the distance of the target. There should be no difference in size judgments between those participants who receive a distance cue and those who do not. Distance judgments will be based on the change in visual angle of the object. Therefore, distance judgments will be impossible to make for those participants who do not receive a size cue.

Because accommodation and convergence are decoupled with the display, size judgments should be underestimated for all participants. Therefore, distance judgments should be inaccurate. However, the binocular disparity cue may interact with the convergence cue to influence distance judgments so that the judgments are more accurate.

Adding linear perspective and texture gradient to the display should result in more accurate size and distance judgments for all participants.

METHOD

Participants

Thirty-two participants between the ages of 20 years and 40 years will volunteer to participate in the study. Participants will be tested for visual acuity with an orthorater and tested for stereoacuity with a random dot stereogram test. Participants' interpupillary distances (IPD) will be measured. All participants will need IPD's greater than 56 mm.

Procedure

After the helmet is properly fit on participants, the instructions will be read to them. Then, they will make distance and size judgments in both biocular and binocular display conditions. The order for distance-size judgments and biocular-binocular displays will be counterbalanced. When making judgments cues will be presented in an additive or subtractive manner. This will also be counterbalanced. That is, in the additive condition participants will begin with the accommodation cue, make the distance judgments then will be presented with accommodation and retinal disparity cues, and eventually followed by the full cue conditions of accommodation, retinal disparity, convergence, linear perspective, texture gradient. and interposition. In the subtractive condition, participants will begin with the full cue condition, then cues will be eliminated one by one until accommodation will be the last cue.

Participants will make 4 distance judgments with each set of cues, then the next set of cues will be presented. Each participant will make 24 distance judgments in the binocular display conditions and 20 distance judgments in the biocular display condition. Participants will make 4 size judgments with each set of cues. Again, cues will be presented in an additive or subtractive

manner. Each participant will make 24 size judgments in the binocular display condition and 20 size judgments in the biocular display conditions. A participant will receive the same order, additive or subtractive, of cue presentation for both the distance and size judgments.

Independent Variables and Experimental Design

The six independent variables in the study include size cue presentation, depth cue presentation, type of physical background, distance of physical stimuli from observer, the size of physical stimuli, and the mode of display presentation. Size cue presentation will be manipulated as a between subjects variable when participants make distance judgments. Half the participants will receive a size cue when making distance judgments. The size of the virtual object will be adjusted as the object moves through space, therefore size constancy will be maintained. The remaining participants will not receive a size cue when making distance judgments. The visual angle subtended of the virtual stimulus will remain constant, therefore size constancy will not be maintained.

When making distance judgments, the physical stimuli will be placed at four distances _____ feet and _____ feet, outside of the range of convergence, and ____ feet and _____ feet, inside the range of convergence. The farthest physical stimulus will be placed at the same depth as the physical background.

Depth cue will be manipulated as a between subjects variable when participants make size judgments. The physical and virtual stimuli will be placed at the same depth,_____, for half the participants. The remaining participants will be presented with the physical and virtual stimuli placed ____ feet apart with the virtual stimulus displayed at _____ feet and the physical stimulus placed at _____ feet.

When making size judgments, the 4 visual angle sizes of the physical stimuli will be ___, ___, ___, ___.

Mode of presentation will be manipulated as a within subjects variable with 2 levels. Participants will first make their distance and size judgments viewing a biocular display. Identical images of the virtual image will be presented to each eye. Then, participants will repeat the judgments viewing a binocular display, in which two slightly different images will be presented to the observer. The observer will need to fuse the images into a single image.

Distance Cues

The six depth cues included in the study include: accommodation(A);retinal disparity(RD) and A; convergence(C), RD and A; linear perspective(LP), C, RD, and A; texture gradient (TG), LP, C, RD, and A; occlusion(O), TG, LP, C, RD, and A. The binocular mode of presentation includes all of the above cues. The biocular mode of presentation eliminates the convergence cue in all cases. It is not necessary to manipulate independently accommodation, retinal disparity, and convergence. A previous study (Fulop & Williams, 1993) has shown that distance is not accurately perceived with these cues alone.

Linear perspective will be presented as a stereo display in the binocular condition and as a three-dimensional non stereo display in the biocular condition. Texture gradient will be presented as a stereo display in the binocular condition and as a three-dimensional display in the biocular condition. Occlusion or interposition will be presented as a stereo display in the binocular condition and as a three-dimensional non stereo display in the biocular condition.

Performance Measures

Performance measures for distance judgments will be the distance traversed for the virtual image and the difference in distance between the physical stimulus and the virtual stimulus. Distance should be measured in feet, pixels displaced, and change in retinal disparity. Several measures are needed because it is unknown whether the stereo equations generating the stereo images are correct. Electronic measures of distance in the helmet have to be related to physical measures of distance.

Performance measures for size judgments will be the size change in the virtual image and the difference in size between the physical stimulus and the virtual stimulus. Size should be measured in inches and pixels displaced.

REFERENCES

Heinemann, E.G., Tulving, E., & Nachmias, J. (1959). The effect of oculomotor judgments on apparent size. American Journal of Psychology, 74, 440-445.

Holway, A.H., & Boring, E.G. (1941). Determinants of apparent visual size. American Journal of Psychology, 54, 21-37.

Hull, J.C., Gill, R.T., & Roscoe, S.N. (1982). Locus of the stimulus to visual accommodation: Where in the world, or where in the eye? Human Factors, 24, 311-319.

Iavecchia, J., Iavecchia, H. & Roscoe, S.N. (1988). Eye accommodation to head-up virtual images. Human Factors, 30, 689-702.

Marsh, J.S., & Temme, L.A. (1990). Optical factors in judgment of size through an aperture. Human Factors, 32, 109-118.

Meehan. J.W., & Triggs, T.J. (1992). Apparent size and distance in and imaging display. Human Factors, 34, 303-312.

Norman, J. & Ehrlich, S. (1986). Visual accommodation and virtual image displays: Target detection and recognition. Human Factors, 28, 135-151.

Roscoe, S.N. (1984). Judgments of size and distance with imaging displays. Human Factors, 26, 617-629.

Roscoe, S.N. (1985). Bigness in in the eye of the beholder. Human Factors, 27, 615-636.

Roscoe, S.N. (1987). The trouble with HUDs and HMDs. Human Factors Society Bulletin, 30, 1-2.

Smith, G., Meehan, J.W., & Day R.H. (1992). The effect of accommodation on retinal image

size. Human Factors, 34, 289-302.

Thouless, R.H. (1968). Apparent size and distance in vision through a magnifying system.
British Journal of Psychology, 59, 111-118.

NOTES

The distance study will need to be done outside. It should be completed as soon as the helmet is operational and weather permits. This research should tell researcher whether the stereo equations used to generate the images are correct. It will also tell the researcher the available volume of the display. If the volume is less than 1000 feet, the helmet will not be sufficient for air combat. The displays are programmed. They are available from Steve Williams, NASA-Langely Research Center, Hampton VA.

FUTURE RESEARCH

Interposition problem

Interposition cues between the virtual objects and physical objects are not predictable. Virtual objects do not behave like physical objects. Virtual objects can pass through physical objects or be superimposed on objects. This problem needs to be explored to determine the factors that influence perceptions of placement or location of virtual objects, and to determine types of errors made from misperceptions. Solutions to this problem should be evaluated.

Field-of-View Studies

Research determining the minimum acceptable field-of-view for helmet displays for various tasks needs to be determined. The tasks should include pursuit tracking, compensatory tracking, target detection, and spatial awareness tasks. It is assumed that the acceptable field-of-view will varying depending upon the stereo viewing volume of the display. For example, if virtual objects are going to be presented between 1000 - 3000 feet the field-of-view may be different than when the volume is 50 - 500 feet. However, the helmet has a maximum field-of-view of 60 degrees, therefore not all the research can be done with the helmet. Some of the research can be done in a University laboratory.

References

Barnes, W.J. (1989). Tactical applications of the helmet display in fighter aircraft. Proceedings from the SPIE Helmet-Mounted Displays Conference, Orlando FL., 1116, 149-161.

Dixon, K.W., Krueger, G.M., & Rojas, V.A. (1989). Effect of instantaneous field of view size on the acquisition of low level flight and 30 degree manual dive bombing tasks. Proceedings from the SPIE Helmet-Mounted Displays Conference, Orlando FL., 1116, 110-121.

Lippert, T.M. (1990). Fundamental monocular/binocular HMD human factors. Proceedings from the SPIE Helmet-Mounted Displays Conference, Orlando FL., 1290, 185-191.

Wells, M.J., and Venturino, M. (1989). Effects of field-of-view size on performance at a simple simulated air-to-air mission. Proceedings from the SPIE Helmet-Mounted Displays Conference, Orlando FL., 1116, 126-137.

Long term exposure study

The long term effects of viewing the stereo helmet mounted display on stereoacuity or depth perception is unknown. It is foreseeable that pilots will be wearing these helmets on a daily basis for hours at a time. The long term effects of decoupling convergence and accommodation should be explored.

Conformal Displays

At NASA-Langley we have defined a conformal display to be a representation of a concept presented in a location either relative to the earth, air, pilot's aircraft, or opponent's aircraft. Conformal displays make an abstract concept concrete by providing a visual representation of the concept to the pilot. Therefore, the pilot does not have to mentally map a display into a 3-D space or infer system states from several alphanumeric values. The pilot can "see" this information in a conformal display, thus cognitive workload should be reduced. Disadvantage of a conformal display is that the pilot must look in the correct location for information thus, information is not always in the center of the field of view. Research needs to be done in this area to answer the following questions.

A) Which type of display is better for navigating a safe path through air space a 2-D bird's eye view or a 3-D conformal display?

B) Which type of display is better for troubleshooting and monitoring aircraft systems, such as fuel consumption, traditional cockpit gauges or gauges conformal to the aircraft? For example, the pilot would look over the shoulder at fuel tank to "see" quantity of fuel in tank.

C) Does a 3-D conformal display prevent pilots from becoming disoriented or help them recover from unusual attitudes more quickly because the helmet can account for head position and adjust display accordingly?

Attention Study

The target detection study (Fulop & Williams, 1993) suggested that it may be difficult for pilots to switch attention between the physical world and the helmet world. Research addressing this issue needs to be completed. The following questions needs to be addressed.

(1) Is it difficult for pilots to switch attention from the virtual world to the physical world? OR, from the helmet world to head down displays?

(2) As the virtual world begins to look more like the physical world, will switching attention become more difficult or less difficult? Or, will the task change. That is, everything may look physical, so pilots would have to only switch attention form one object in the "real world" to another object in the real world.

All research should result in information that can be used to write display guidelines for display designers.