EVALUATION OF THE HELMET-MOUNTED LASER PROJECTOR FOR AIR TO GROUND WEAPONS DELIVERY AND TARGET ACQUISITION TASKS

Dennis C. Wightman
Naval Training Systems Center
Orlando, Florida

Lawrence J. Hettinger
Monterey Technologies
Carmel, California

Sherrie A. Jones
Daniel J. Sheppard
Naval Training Systems Center
Orlando, Florida

Daniel P. Westra
Allen Corporation of America
Little Rock, Arkansas

ABSTRACT

Two experiments were conducted at the Navy's Visual Technology Research Simulator (VTRS) to evaluate the influence of the Helmet Mounted Laser Projector (HMLP) on pilot performance. The HMLP is a proof-of-concept visual display systems for use in flight simulators which employs optics mounted on the pilot's helmet to project visual imagery onto a screen. The HMLP provides a wide-angle, low-resolution background display and a high-resolution inset or Area of Interest (AOI). The system is capable of using either head-tracking to reposition the entire display or combined head-and-eye tracking to reposition the AOI within the display as a function of eye movement. This provides an unlimited field of regard with high resolution at a lower cost than conventional systems. Both experiments reported here were conducted to assess how the HMLP affects pilot performance in the simulator on two different tasks. The results of the first experiment indicated that there were no operationally relevent differences between HMLP and fixed projection, nor were there any differences between head versus head-and-eye tracking on the air-to-ground weapons delivery task. The results of the second experiment indicated no significant differences between head tracking and head-and-eye tracking in the speed and accuracy of target identification. There were also no significant effects of altering the size of the blend region or length of delay in the eye-tracking mechanism.

INTRODUCTION

This report reviews two human performance experiments conducted at the U.S. Navy's Visual Technology Research Simulator (VTRS) to assess the utility of the Helmet Mounted Laser Projector (HMLP) for application in flight simulation.

Since its inception, one of the principal goals of the research program at VTRS has been to evaluate the utility of simulator design features through empirical assessment of performance on flight tasks in the simulator and subsequent transfer of acquired flight skills to the operational environment [1].

HELMET MOUNTED LASER PROJECTOR

The Advanced Simulation Concepts Laboratory of the Naval Training Systems Center developed the HMLP visual display system for use in flight simulation [2]. The HMLP was designed to provide an alternative to fixed-projection displays of out-of-the-cockpit visual imagery which have traditionally been used in flight simulation. The HMLP employs optics mounted on the pilot's helmet to project visual imagery onto a retroreflecting domed screen. It is driven by two visual display channels, one providing a wide-angle, low-resolution background display, the other providing a smaller, high-resolution inset.

The high-resolution inset, or Area of Interest (AOI), presented foveally, consists of an area 27 degrees horizontal and 24 degrees vertical and provides an area of high resolution and observable detail. The peripheral field, or Instantaneous Field of View (IFOV), is an area of lower resolution 140 degrees horizontal and 100 degrees vertical. The AOI is located in the center of the IFOV, and the two areas can be blended by means of a variable width border area surrounding the AOI within which the two display channels are mixed to provide a smooth transition. The system is capable of employing either head or combined head-and-eye tracking to reposition the entire display, and can, provide in effect, an unlimited field of regard with high resolution.

The advantage of the HMLP, compared to fixed projection display systems, is that it presents the area of greatest resolution in the central (foveal) area of the pilot's gaze, thereby eliminating the need to provide high resolution throughout the entire display. The cost of wide field of view visual systems which provide large areas of high resolution is proportional to the number of high resolution channels provided. Therefore, the logic behind the development of the HMLP and other AOI systems has been to match the resolution characteristics of the display to the resolving power of the pilot's eye and provide the necessary mobility to present the display in the area of the pilot's gaze. The eye cannot resolve fine detail in the periphery so there is little need to provide it there. However, since foveal vision is characterized by high resolution capabilities, system designers have worked toward developing a display which concentrates the area of highest resolution in that region. The HMLP system is described in more detail by Breglia, Spooner, and Lobb [2].

HMLP AIR-TO-GROUND WEAPONS DELIVERY EXPERIMENT

The HMLP air-to-ground weapons delivery experiment was designed to assess the differential performance effects of fixed projection versus the use of head and head-and-eye tracked imagery using the HMLP. Differential effects were also assessed within the HMLP system itself by contrasting performance under conditions of head and head-and-eye tracking. Under the head-and-eye tracked condition only, performance comparisons were made between two types of eye-tracker calibration: individual calibration to each subject's right eye versus a "generic" calibration in which a previously calibrated routine was used.

Experimental Plan

The HMLP experiment constituted a partial replication of an earlier air-to-ground weapons delivery experiment conducted by Westra [4] which employed the same simulator used in the current experiment, but with the out-of-the-cockpit imagery displayed using a fixed projection system. The data from the two experiments were later combined to yield a comparison of the two projection types on the air-to-ground weapons delivery task. Two of the visual data bases used in the fixed projection experiment, the Twin Towns and Gila Bend scenes, were used in the HMLP experiment. The manipulation of scene types allowed for a performance comparison between scenes within the two tracking modes of HMLP (head versus head-and-eye), and with regard to projection type (HMLP versus fixed projection).

The Twin Towns database consisted of a flat terrain with multicolored fields, two clusters of buildings, a number of roads and one isolated building designated as the target. The Gila Bend database was a replica of the gunnery range at Gila Bend, Arizona. The scene consisted of a large diamond-shaped gaming area with a target consisting of different colored concentric circles embedded in a corner of the diamond. The scene also contained several explicit orientation lines including a run-in line leading directly to the target. Figures 1 and 2 are schematics of the two data bases.

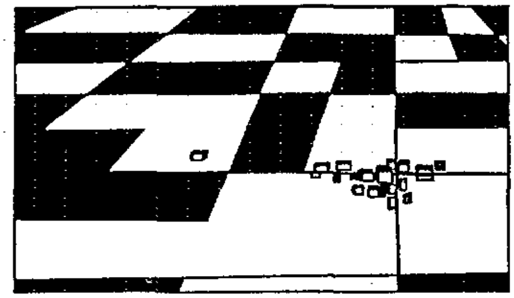

Figure 1. Schematic of Twin Towns scene and target: View at 6000 feet altitude in a 30° dive.

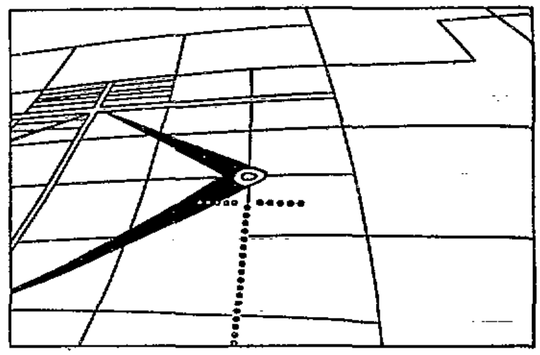

Figure 2. Schematic of Gunnery Range scene and target: View at 6000 feet altitude in a 30° dive.

The simulated air-to-ground weapons delivery task consisted of: 1) flying a curved and level path towards the run-in line, 2) turning into the target approximately 30 degrees short of the run-in line, 3) rolling over to pull the nose down to a 30-degree dive as the run-in line closes in, 4) rolling out in a 30-degree dive and heading towards the target, 5) diving toward the target to release bombs at 3,000 feet altitude and 350 knots indicated airspeed (IAS) and 6) pulling out of the dive to establish a positive rate of climb. The task was identical for both the HMLP and fixed projection experiments. Figures 3 and 4 show the task from both a side and top view.

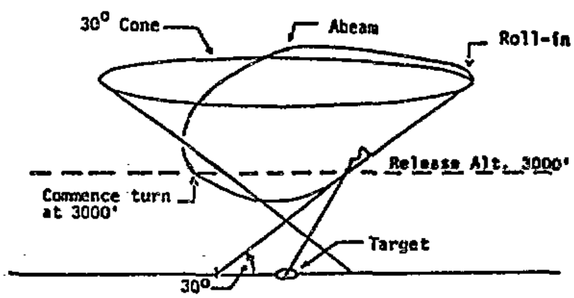

Figure 3. 30° cone pattern, side view.

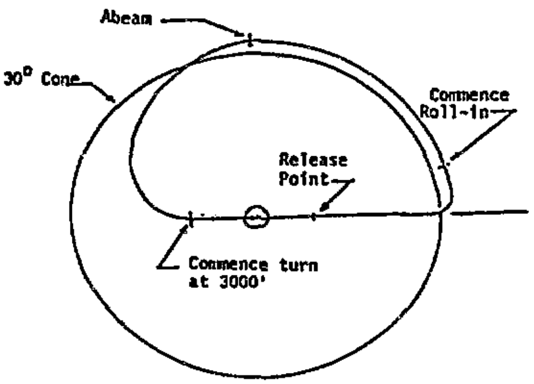

Figure 4. 30° cone pattern, top view.

Nine experienced Navy F-18 and A-6 pilots completed 32 bombing trials using the HMLP system in each scene type. The tracking (head tracking versus head-and-eye tracking) and scene type (Twin Towns versus Gila Bend) manipulations were counterbalanced across eight eight-trial blocks. The selection of pilots for the HMLP experiment was intended to match, as closely as possible, the level of experience of the eight pilots tested by Westra [2].

Only the data for the Twin Towns and Gila Bend scene types were used from the Westra [2] fixed projection experiment.

Results

A summary of results from the current experiment are reported in this section. A more detailed presentation appears in Hettinger, et al [3].

Projection Type. The only significant effect involving the contrast between fixed projection and HMLP appeared in the bomb impact measures. The HMLP resulted in a significantly lower longitudinal error at bomb impact ($F(1,15\ df)=16.47$, $p<.01$). On the average, the use of the HMLP resulted in a longitudinal miss distance of 38.91 feet closer to the target than performance under the fixed projection condition. This difference is well within the effective destructive radius of the weapon and the corresponding bomb tracking error scores are not indicative of pilot skill differences. Therefore, the longitudinal bomb impact differences should not be considered substantial, and are probably not operationally significant.

No significant differences were observed between fixed projection and HMLP on performance measures in the dive segment or at bomb release.

Comparisons Within HMLP. Under the HMLP condition, the scene type manipulation resulted in significant differences on average lineup error in the dive ($F(1,8\ df)=6.78$, $p<.05$) and also on the corresponding bomb drop heading measure ($F(1,8\ df)=8.48$, $p<.05$). Although lineup performance on both scene types was consistently biased to the right, lineup on the Twin Towns scene was 91.63 feet closer to the run-in line than lineup on the Gila Bend scene. The mean difference between scenes on the bomb drop heading measure was 1.85 degrees. However, since the significant lineup bias did not carry over to significant differences on either RMS lineup error or lateral bomb impact, and hence no task outcome differences, the lineup bias and bomb drop heading effects may not be operationally significant.

Within the head-and-eye tracking data, there were no significant performance differences as a result of type of eye calibration (individual versus generic). The lack of a significant calibration effect should not be considered conclusive because of the limited number of subjects available for this between-groups comparison (four versus five pilots). Large subject variability due to pilot differences resulted in significant pilot-by-tracking and pilot-by-scene type interactions on many of the measures.

Summary

Performance differences as a result of the scene type manipulation were not surprising, as each scene constituted a somewhat different task. Performance was not consistently better in either scene, suggesting that certain types of optical information were present in each scene to support effective performance in some control dimensions, but not in others. Of greater interest is the comparison between projection types, and between tracking conditions using the HMLP. These results indicated that there were essentially no operationally relevant differences between HMLP versus fixed projection, nor were there meaningful differences between head versus head-and-eye tracking on the air-to-ground weapons delivery task. These results were not disappointing, as equivalent performance in the simulator was obtained using the less expensive HMLP system. Likewise, head-tracking produced performance equivalent to that under the combined head-and-eye tracking, again, at less cost and with greater pilot acceptance.

These results indicated that the design and operation of the HMLP is sufficient to support performance of the air-to-ground weapons delivery task in the simulator. However, in the head-and-eye tracked mode a majority of pilots reported inconsistencies in the manner in which the AOI tracked their eye movements (i.e., noticeable lags between eye movement and AOI movement, jitteriness of the AOI, or momentary loss of eye-tracking). The eye-tracking mechanism tended to lose track of the eye during instrument scans, and may not be suitable for simulated tasks requiring frequent scanning within the cockpit. Since the weapons delivery task required pilots to perform extensive cross-checking between the out-of-cockpit display and the simulator's instrument panel, further evaluations of the system were recommended to determine its utility in the performance of tasks which require pilots to maintain their visual scan primarily outside the cockpit. Therefore, a subsequent experiment was performed which employed an air-to-air target acquisition task to further evaluate the differential effectiveness of head versus head-and-eye tracking.

HMLP TARGET ACQUISITION EXPERIMENT

The target acquisition experiment utilized a dual task paradigm to evaluate the degree to which pilots' ability to detect and subsequently identify a target was facilitated by head or head-and-eye tracking. At the same time, the pilots also performed an operationally meaningful flight task. The primary hypothesis tested was that if head-and-eye tracked projection allows more rapid and accurate localization of gaze than head-tracked projection, performance in a target acquisition task should be superior in the former condition.

The experimental task required the pilot to pursue a simulated F-18 lead aircraft as it executed alternating 30 degree bank turns to the left and right every 10 seconds while, at the same time, scanning the local airspace to detect and identify a total of 14 targets that appeared one at a time during each experimental trial. The pilot's primary objective in this scenario was to identify the targets as quickly as possible but not at the expense of accuracy. Thus, speed and accuracy of detection were of equal importance. The secondary objective was to maintain the same altitude and airspeed as, and a specified distance directly behind, the lead aircraft throughout the trial.

Experimental Plan

The primary interest was to determine if any performance differences (i.e., speed or accuracy of target acquisition) were attributable to the use of the HMLP *in the head versus head-and-eye tracked* modes of projection. Data were also collected using two different size blend regions between the high-resolution inset and low-resolution background, and using two different delays between registration of eye-movements by the eye-tracker mechanism and subsequent repositioning of the high-resolution inset. These comparisons were made in order to provide information about the differential effects of potential HMLP system configurations.

Blend Region

The AOI and the IFOV are generated through two separate channels. In order to alleviate a sharp contrast between the high resolution inset and the low resolution background, a "blend region" can be implemented to successively transition the AOI into the IFOV. Two levels of blend region were manipulated in the target acquisition experiment, two degrees and five degrees. The five degree blend region provided a smoother transition, but resulted in a smaller AOI (14 degrees vertical by 17.4 degrees horizontal). The two degree blend region resulted in a sharper contrast between the AOI and IFOV, but also provided a larger AOI (20 degrees vertical by 23.4 degrees horizontal).

Eye Tracker Delay

The eye tracker samples the position of the right eye at a 60 Hertz iteration rate, that is, at a rate of 60 samples or "frames" per second. Each frame, therefore, equals 16.66 msec. Delays in repositioning the AOI following eye movements are a function of the number of frames necessary to calculate the gaze angle and reposition the AOI based on that calculation (4.5 frames $\pm$ 0.5 frames). The one-half frame variability in the eye tracker system is attributable to the *scanning phase, that is, the least* possible transport delay attainable at VTRS is 117 msec, or seven frames, although eye movements during the scanning of the eye can cause a delay variability of up to eight frames. Two levels of eye tracker transport delay were manipulated in the present experiment: 142 $\pm$ 8.33 msec (referred to as the "nominal" delay) versus 192 $\pm$ 8.33 msec. Three additional frames were introduced into the SEL 32/27 to make up the longer delay.

Targets

The targets to be identified were either circles or squares and were designed so that they could be detected in the low resolution IFOV, but could only be accurately identified if they were positioned by the pilot in the high resolution AOI. The target disappeared either when the pilot responded to the target, *or when four seconds had elapsed,* in which case the pilot had failed to detect the target. Pilots were instructed to press the trigger button on the control stick if the target was a circle, and the pickle button if the target was a square. The targets appeared randomly in any of 14 locations (Figure 5), and each target (square and circle) was presented at each location four times in each hop of eight trials. The time interval between target presentations varied between five and ten seconds. Each trial lasted approximately two and a half minutes.

Eight Naval pilots from NAS Cecil Field, Florida, participated as subjects in the experiment. All were experienced F-18, A-7, S-3, and TA-4J pilots averaging 1148.75 total flight hours ranging from 290 to 2500 hours. Each pilot executed a total of 32 trials in sessions (hops) of eight trials each.

A large number of summary measures were computed on-line immediately following each trial for the primary objective (target detection and

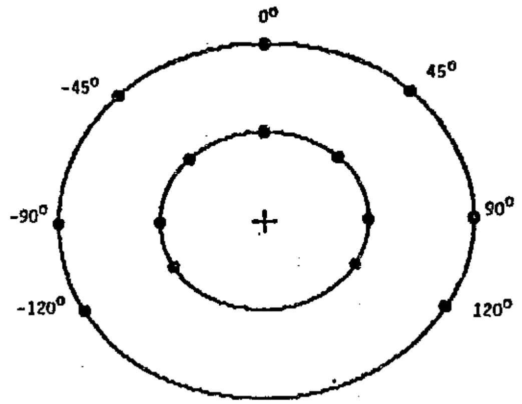

Figure 5. Locations of target presentation.

identification) and secondary objective (pursuing the lead aircraft). Reaction time and target identification accuracy were the criterion referenced quality indicators for the target detection and identification task. Reaction time was measured in milliseconds, only for correctly identified targets.

Results

Within the head-and-eye tracking condition only, the eye tracker delay manipulation did not result in significant performance differences on any of the measures. Therefore data were summed across the eye tracker delay conditions within the head-and-eye tracking condition, prior to making head versus head-and-eye tracking comparisons, and no data are presented for the eye tracker delay manipulation. None of the experimental manipulations resulted in significant time-on-tolerance main effects for any of the measures.

The results indicate that speed and accuracy in identifying targets that were lower in the visual field relative to the lead aircraft ($\pm$ 90 and $\pm$120 degrees, Figure 5) were better under head tracked conditions. Conversely, speed and accuracy in identifying targets that were higher in the visual field (0 degrees and $\pm$ 45 degrees) were superior under head-and-eye tracked conditions. Under the conditions of this experiment, therefore, there is no indication that head-and-eye tracking provides an overall advantage in visual scan performance over head tracking alone.

Summary

The results of the HMLP target acquisition experiment indicated no significant differences between head tracking and head-and-eye tracking in the speed and accuracy of target identification. There were also no significant effects of altering the size of the blend region or length of delay in the eye tracking mechanism.

The only result from the current experiment which appears to bear on the distinction between the two modes of tracking was the significant tracking by target elevation interaction observed for the reaction time and accuracy measures. There was a clear indication that both measures of performance were superior for targets in the lower half of the visual field with head tracking, and for the upper half of the visual field with head-and-eye tracking. This effect may be due to excessive oscillation of the AOI which could have been accentuated in the lower portion of the visual field. In general, pilots, comments indicated that it was far more difficult to stabilize the AOI on a target in the head-and-eye tracked condition. Furthermore, several pilots reported difficulty in making head movements to look down and to the left or right. Given this difficulty with head movement in the lower visual field, pilots may have attempted to minimize head movements in those directions under head-and-eye tracked conditions. Therefore, in order to localize a target in the lower visual field, pilots would necessarily have to make more extensive eye movements, resulting in greater oscillation of the AOI in those areas and, as a result, poorer target identification performance.

In terms of differences in performance between the two modes of tracking, the results of the present experiment are essentially identical to those of the air-to-ground weapons delivery experiment in indicating no meaningful difference between the two modes of tracking. Pilots were, in general, far more favorably disposed to the concept of head tracking and identified numerous difficulties with the execution of the eye tracking capability. These primarily involved the erratic movement of the AOI and the excessive AOI oscillation while attempting to fixate an object.

While these results hold somewhat discouraging implications for the prospects of eye-tracked projection in flight simulation, the use of such a technology should by no means be ruled out as of yet. An essential function of behavioral evaluations of emerging technologies is to illuminate those features which require modification to optimize the value of the technology to the user. The two HMLP evaluations have provided a large database of information on the capabilities of this system, and strongly suggest that improvements in eye-tracking technology may make it a superior technology for the simulation of flight tasks that require rapid and accurate visual scanning.

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ABOUT THE AUTHORS

Dennis C. Wightman is an Engineering Research Psychologist with the Human Factors Division of the Naval Training Systems Center in Orlando, Florida. He was responsible for the behavioral research program at the Navy's Visual Technology Research Simulator. He received the Ph.D. in Psychology from the University of South Florida in 1983. He currently conducts research and consults on various training systems acquisition programs at the Naval Training Systems Center.

Lawrence J. Hettinger is a Senior Research Scientist with Monterey Technologies at the NASA-Ames Research Center. He previously was employed with the Essex Corporation as a Senior Research Scientist at the Visual Technology Research Simulator in Orlando, Florida. He received the Ph.D. in Psychology from The Ohio State University in 1987. His primary research interests are in visual perception, visual vestibular interactions, and the perception of real and simulated self-motion.

Sherrie A. Jones is a Psychologist with the Training Systems Evaluation Division of the Naval Training Systems Center in Orlando, Florida. She received the M.S. degree from the University of Central Florida in 1986. She was previously employed as a Research Associate with the Essex Corporation at the Visual Technology Research Simulator.

Daniel J. Sheppard is a Psychologist with the Special Projects Division of the Naval Training Systems Center in Orlando, Florida. He was previously employed as a Research Psychologist with the Essex Corporation at the Visual Technology Research Simulator. He received his M.S. degree from the University of Central Florida in 1983. His principal research activities have been in aviation training.

Daniel P. Westra is a Research Psychologist with the Allen Corporation of America in Little Rock, Arkansas. He was the Essex Corporation's Program Manager at the Visual Technology Research Simulator in Orlando, Florida. He received the Ph.D. degree in Human Factors Psychology from the University of South Dakota in 1978.