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VISUAL BEHAVIOR IN THE F-15 SIMULATOR FOR AIR-TO-AIR COMBAT

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Flight simulators have evolved into complex systems capable of providing training for a number of operational tasks. These systems must make optimal use of the available technology to ensure cost and training effectiveness. Particular emphasis is placed on the requirements for field of view (FOV). The current research effort investigated the visual behavior of pilots performing air-to-air maneuvers in an F-15 simulator. The subject's eye position was recorded and window usage analyzed to determine what portion of the FOV the pilots used during the task and to obtain data on how pilots use their visual system during flight. The results infer that significant differences exist between window usage and task performed. In general, offensive set-ups displayed showed a greater usage of the front windows; defensive set-ups displayed more usage of peripheral windows; neutral set-ups required little peripheral information; and the mutual support set-ups displayed a mix of all trends. The data from this effort can now serve as a baseline for more extensive investigations and comparisons between different aircraft, pilots, and experience levels.

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SUMMARY

This research effort was conducted to determine visual strategies of F-15 pilots during air-to-air combat through the use of an eye tracking system. This type of work helps simulator designers define field-of-view requirements for simulators. While an increase in field of view size produces a more realistic scenario for the pilots, it results in a decrease in brightness and resolution levels, and increases the cost.

Six F-15 pilots flew offensive, defensive, neutral, and mutual support set-ups in the Simulator for Air-to-Air Combat (SAAC) at three different altitudes. Analyses show that the visual strategies and window usage vary greatly among the four set-ups. Before final conclusions are made concerning field-of-view requirements during air-to-air tasks, this experiment should be partially replicated using electronic masking.

PREFACE

This research and development effort was conducted by the Operations Training Division of the Air Force Human Resources Laboratory, AFSC, at Williams Air Force Base, Arizona, under Work Unit 1123-32-04, Simulator Field-of-View Requirements. The principal investigator was Capt. Kevin W. Dixon, assisted by Lt. Gretchen M. Krueger, Lt. Victoria A. Rojas, and Dr. Elizabeth L. Martin. The research and development was supported by the 58th Tactical Fighter Training Squadron (TFTS) and Logicon Inc. at Luke Air Force Base, AZ. This paper was written in order to document work completed for field-of-view requirements in air-to-air combat tasks. This work was done in order to support requirements of the Training Technology Objective of the Air Force Human Resources Laboratory Research and Technology Plan, by development of cost-effective flight simulator visual display technology.

The authors would like to express their sincere appreciation to the members of the 58th TFTS for their cooperation throughout this effort. A special thanks to Major "Pepper" McBride, Bart Raspotnik, and Ed Hayes for their efforts in coordinating this work.

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I. INTRODUCTION

Traditionally, field-of-view (FOV) requirements have been investigated by pilot opinion questionnaires and/or direct pilot performance measures with limited emphasis on the requirements for tactical maneuvers. An experiment by Weikhorst and Vaccaro (1987) investigated the FOV used to perform certain tactical maneuvers. Experienced fighter pilots performed specific portions of air-to-air and air-to-ground maneuvers in the Simulator for Air-to-Air Combat (SAAC) and the Advanced Simulator for Pilot Training (ASPT). Target migration plots were generated based on the two aircraft's positions and standard pilot eye-point. The results indicated that the FOV requirements for air-to-air and air-to-ground maneuvers are different and vary from task to task. This implies that FOV configurations can be multipurpose and able to train a variety of tactical maneuvers. The determinations of a multipurpose field of view size are difficult and interact with cost, training effectiveness and visual system performance (level of scene detail required, resolution, brightness).

This difficulty is somewhat overcome when the pilot's visual behavior is determined for a number of tasks. The characteristics of visual behavior can be plotted and various plots compared to enhance field of view determinations. In an experiment performed by Dixon, Martin, Rojas and Hubbard (1989), an eye tracker was employed to test the use of such a device for FOV determinations. In addition to visual data, direct performance measures and questionnaire data were collected for comparison. The eye tracking system was head-mounted and worn by the pilot while performing the simulator mission. Experienced C- 130 pilots flew low level missions with an airdrop on two routes, using two different FOV conditions, 160° H X 35° V and 102° H X 35° V). Performance data showed no strong or consistent effects due to FOV manipulations. However, eye position data revealed an increased use of the front windows and instruments in the limited FOV condition and a decreased use of the window to the left of the pilot. The authors concluded that the peripheral windows may not be required for experienced pilots, but if present, are used, and if absent, alter visual behavior. The change in visual behavior would not have been detected using traditional performance measurement techniques. FOV recommendations using visual behavior data may have important training considerations if the pilots are transitioning into the aircraft.

The two experiments outlined above imply that important field-of-view determinations can be made by examining the visual behavior of pilots. Further research using visual data should prove useful in evaluating simulator designs and understanding eye movements in both the aircraft and simulator.

II. Background

Basic fighter maneuvers comprise the tactics involved in visual range fighter combat. Initial training is accomplished in Fighter Lead-in School from various set-ups using a high performance jet aircraft. Further training is done at Replacement Training Units for the specified aircraft. These basic maneuvers are taught by increasing the level of difficulty on the initial set-ups. The training of these maneuvers is done on tactical ranges. If pilots can receive effective training for these maneuvers in the simulator, valuable flight time may be spent on accomplishing more complex tasks. The reason for studying eye movement is to describe pilot visual behavior in the simulator and provide recommendations for simulator visual systems for different tasks.

Research Hypothesis

The specific hypothesis for this effort was that there would be significant differences in the percent of time spent in each window, number of glances to each window, average time per glance, and percent glance per window for a given task. It is expected that the forward windows will receive the most visual behavior for offensive and neutral engagements, and the peripheral windows will be used on defensive and mutual support tasks.

III. Method

Subjects. Six F-15 instructor pilots, assigned to the 58th Tactical Training Wing, Luke AFB, Arizona, served as subjects. The average total number of hours for these subjects was 1550 with a range of 750-2500.

Apparatus. This research effort was conducted in the SAAC, located at the 57th Fighter Weapon Wing/Operating Location, at Luke AFB, Arizona. The SAAC is used primarily by experienced pilots in the air-to-air combat environment and has two fully interactive F-15 cockpits with full instrumentation and weapon systems indicators. The visual system of the SAAC includes eight pentagonal display windows combined with infinity optics within a 16-foot dodecahedron (See Figure 1).

A hardware image generation system provides a "checkerboard" ground, sun, sky, and a low altitude haze layer. The aircraft target image is provided by four closed-circuit television pictures of gimballed model aircraft displayed on the earth/sky background by means of a small raster inset. The high resolution image allows the target to be seen as far away as three miles. At one mile, the pilot can make out details such as direction, speed, altitude, and wing geometry. Simulator realism includes on-line firing and hit cues, aural effects, g-cues, and weapon sounds.

The SAAC provides an ideal system for FOV evaluations because of its large FOV visual system and tactical aircraft capabilities. This research investigated a number of tasks that directly relate to the air superiority mission.

Task Description. Each pilot performed basic fighter maneuvers from four set-ups. Fifteen trials were completed for both offensive and defensive set-ups and 10 trials for mutual support and neutral set-up. The total number of trials per subject was 50. All trials ended with a kill, role reversal, or at the maximum time limit (two minutes). The only weapons available for deployment were aircraft guns in order to better simulate a close-in fighting environment.

The offensive and defensive set-ups were performed at the same initial altitudes and initial airspeeds, except the subjects' cockpits were switched. An example of these set-ups with separation distances, altitudes and initial airspeeds is depicted in Figure 2. Five trials were performed from each separation point.

The neutral set-ups were performed at an altitude of 19000 feet above ground level and an airspeed of 350 knots (See Figure 3). Pilots were instructed to perform five trials of being cleared to maneuver at turn and five trials being cleared to maneuver at pass.

Mutual support set-ups added a third aircraft that was chased by the subjects for five trials (Offensive mutual support) and evaded for five trials (Defensive mutual support) (See Figure 4).

Procedure. Pilots received an initial briefing on the purpose of the experiment, simulator familiarization, and task guidelines. The experiment was performed over a four-day period in which the subjects received one set-up condition per day. Subjects were instructed to perform in as realistic a manner as possible with the objective being "to kill or be killed."

Data Analysis. Eye position data was collected using an eye-tracking system consisting of a Model 210 eye movement monitor from Applied Science Laboratories, a video recorder, a time code generator and a computer software analysis program. The monitor employs a photoelectric sensing and processing technique to determine magnitude and direction of eye movements. Infrared illumination is used for eye illumination and sensing with minimal distraction to the subject. The device is attached to a head-band mounted camera which provides a video fixation point capability. The video fixation point capabilities of the device present either cross hairs or a cursor superimposed over a television monitor image of the scene being viewed by the pilot. The image is captured with a video recorder and time coded to complete the data collection procedure. A software program called Tapemaster was used to analyze the data by coding eye-position relative to previously defined areas of the visual scene. This analysis procedure results in information on the time spent in each window, number of glances per window, percentage of time spent in each window, percentage of glances per window, and percent time per glance. This data was encoded into a statistical program for analysis. Analysis of variance techniques indicated those variables significant at alpha < .05. For those significant variables, a Student-Newman-Keuls pairwise comparison test was used to isolate task differences.

IV. Results

The results of the eye position data are depicted graphically in Figures 5 thru 8. The percent or average number of glances is shown within each of the respective windows. The black bars within the windows represent those tasks that are not significantly different at alpha = .05 using the Student-Newman-Keuls post-hoc multiple comparison test for the various figures.

Figure 5 depicts the average number of glances per window and significant multiple comparisons between the tasks. The average number of glances per window varies significantly between the tasks and between the windows. For example, the defensive set-ups were significantly different from the other tasks in the left peripheral windows, but were not significantly different for the heads-up display (HUD). In addition, there were no significant differences found for windows 1 and 8 for the number of glances per window.

Figure 6 shows the percent of glances per window and has significant task differences for all windows except window 8. There is wide variation in the percent of glances showing that the majority of the glances occurred in window 1 for all tasks. Percent of total glances for the neutral and offensive set-ups were centered in the forward windows (1, 5, 6, HUD), which accounted for 78.2% and 79.5%, respectively. The defensive and mutual support set-ups were more evenly distributed with respect to percent of glances per window with windows 2, 4, 5, 6, 7, and 8 accounting for 62.5% and 62.1%, respectively.

The percent of total time spent in each window is represented by Figure 7. No statistical differences between tasks were found for windows 6 and 8. In general, a grouping of three tasks was found not statistically different, with one task being significantly different depending on the window and set-up. For instance, windows 2 and 4 have no statistical difference for mutual support, neutral, and offensive set-ups, but the defensive set-up is significantly different. Window 1 had the highest percent of total time for all tasks except the offensive set-up, which displayed a 40.78% for the heads-up display.

The average amount of total time spent on each glance is presented in Figure 8. Window 1 is the only window displaying any significance for the various tasks. For window 1, offensive and mutual support tasks are not statistically different, mutual support and neutral tasks are not significantly different, and neutral and defensive tasks are not statistically different, but offensive tasks are significantly different than defensive tasks.

V. Discussion

This experiment was conducted to investigate the visual behavior of pilots performing air-to-air maneuvers in the F-15 simulator. The objective was to determine what portion of the FOV pilots used during the task and to obtain data on how pilots use their visual system during flight.

The graphical information presented above reflects the overall dependence of information in the forward window (window 1). This finding is not surprising since in many of the set-up conditions, window 1 provides information about the environment directly in front of the pilot. There was a general trend in the windows used in specific set-up conditions. It appears that windows 1, 5, and 6 were used most often in the offensive and neutral set-up conditions. This is the front, upper left and upper right window positions, respectively, which is to be expected since a pilot's task in the neutral and offensive set-ups is to maneuver into a position which requires use of visual information directly in front and to his upper right and left. The defensive set-up displayed more use of the peripheral windows (windows 2 and 4) as evidenced by the differences between tasks for the time and glance data. The mutual support set-ups demonstrated aspects from all set-ups, as expected due to the nature of the mutual support set-up, which contains various areas of the different tasks.

One important finding from this data is that pilots spend about the same amount of time per glance for all windows except heads-up display. This implies that the time needed to gain information from the environment does not vary significantly with the tasks being performed. However, there were some significant differences associated with glances to the heads-up display. The implication here is that there are different information needs, and the amount of time needed to process this information varies.

VI. Conclusions

This experiment was a preliminary investigation to obtain a general indication of the portion of the FOV being used during specific air-to-air tasks. The data will serve as a baseline for follow-on investigations which will consist of a more detailed analysis of pilots' visual behavior, comparisons with trainees' performance, and compared with performance when selected windows are not available.

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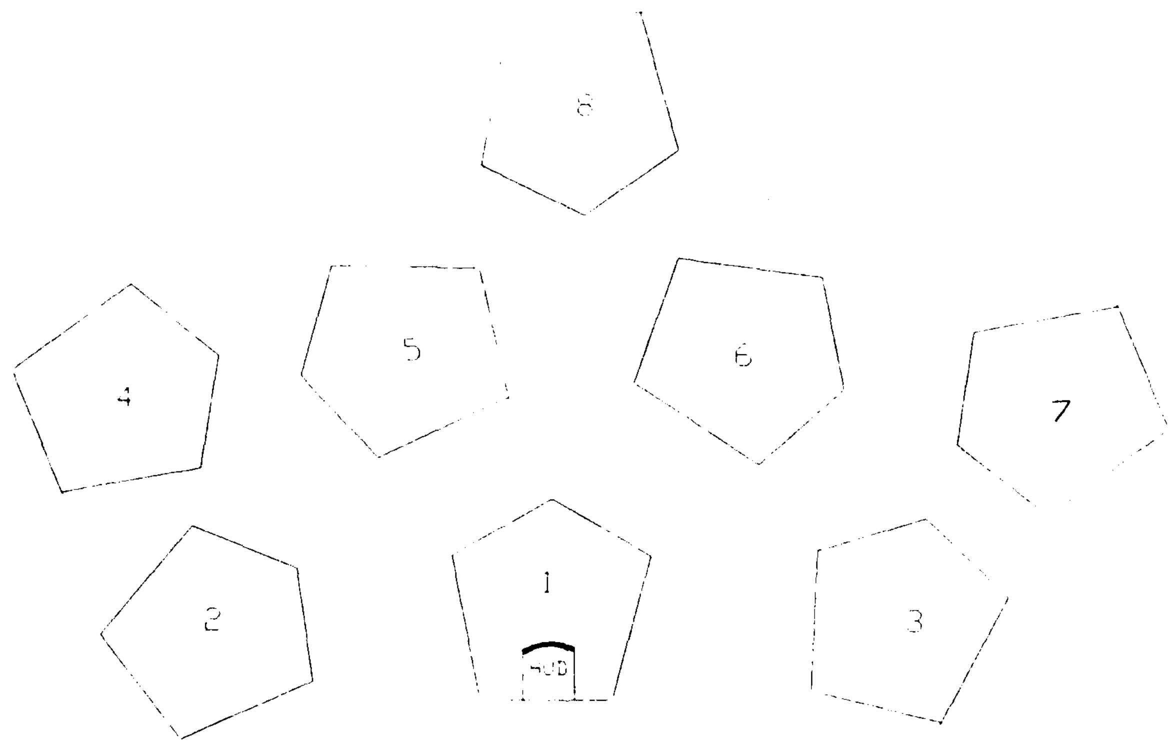

Figure 1. Simulator for Air-to-Air Combat Window Configuration

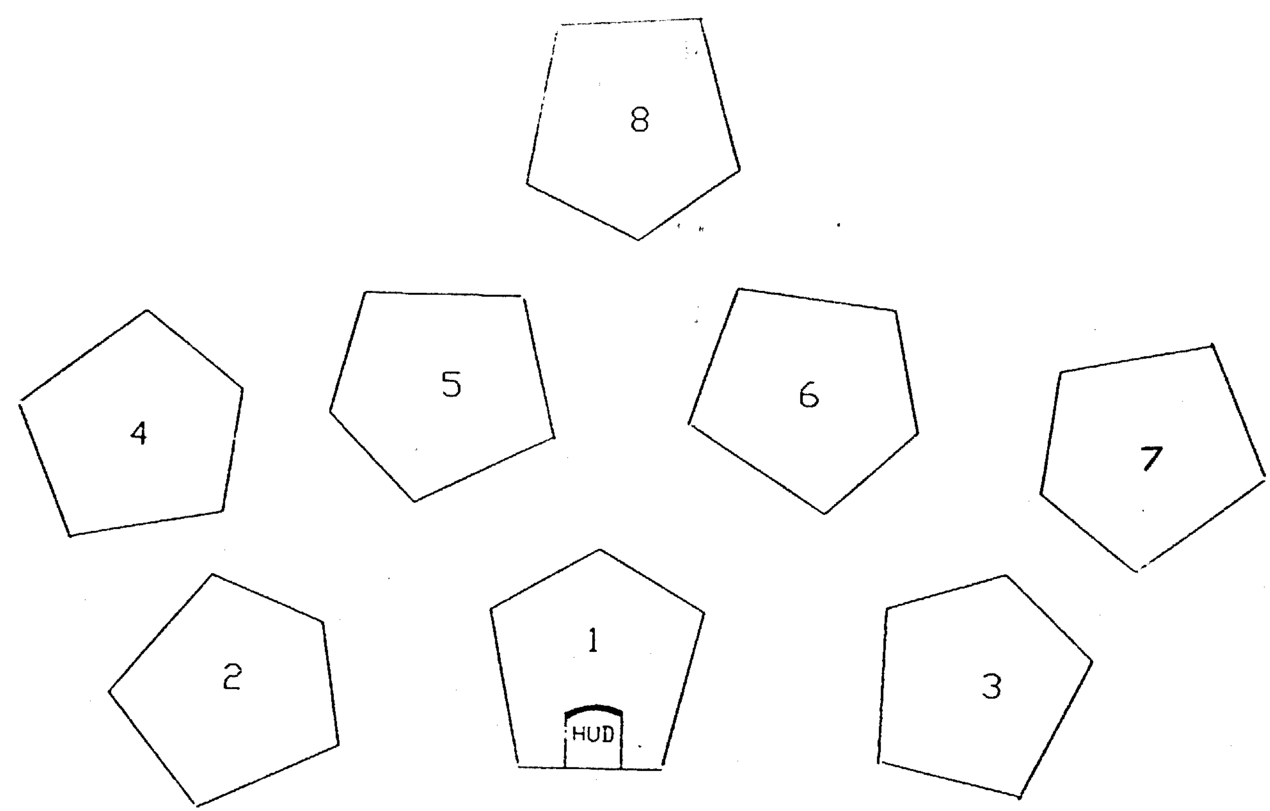

Figure 1. Simulator for Air-to-Air Combat Window Configuration.

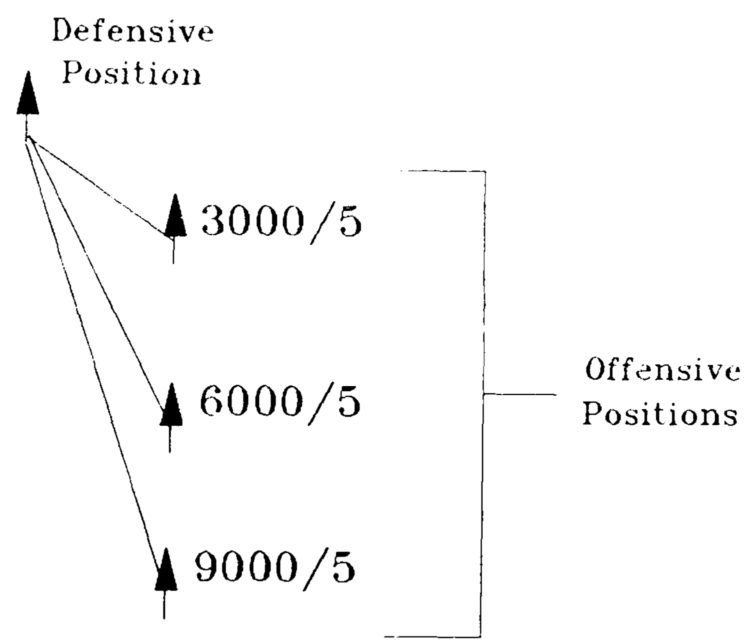

Figure 2. Offensive/Defensive Initial Set-ups.

* NOTE: 3000/5 = 3000 FT Separation
5 O'Clock Position

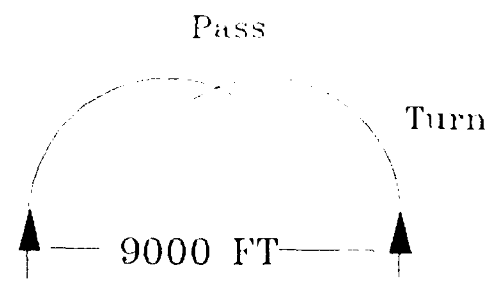

Figure 3. Neutral Initial Set-up.

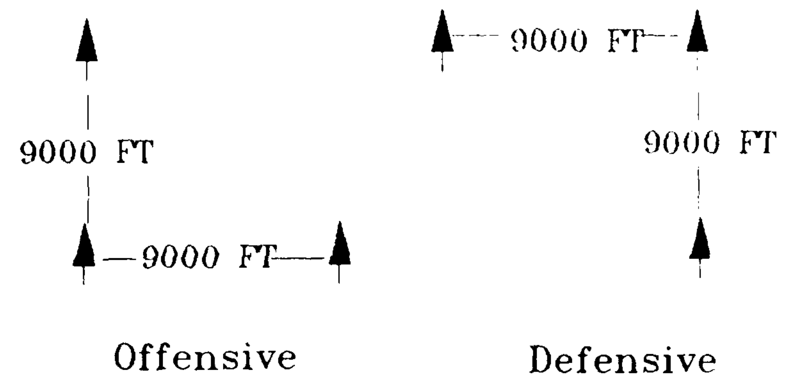

Figure 4. Mutual Support Operations Initial Set-ups.

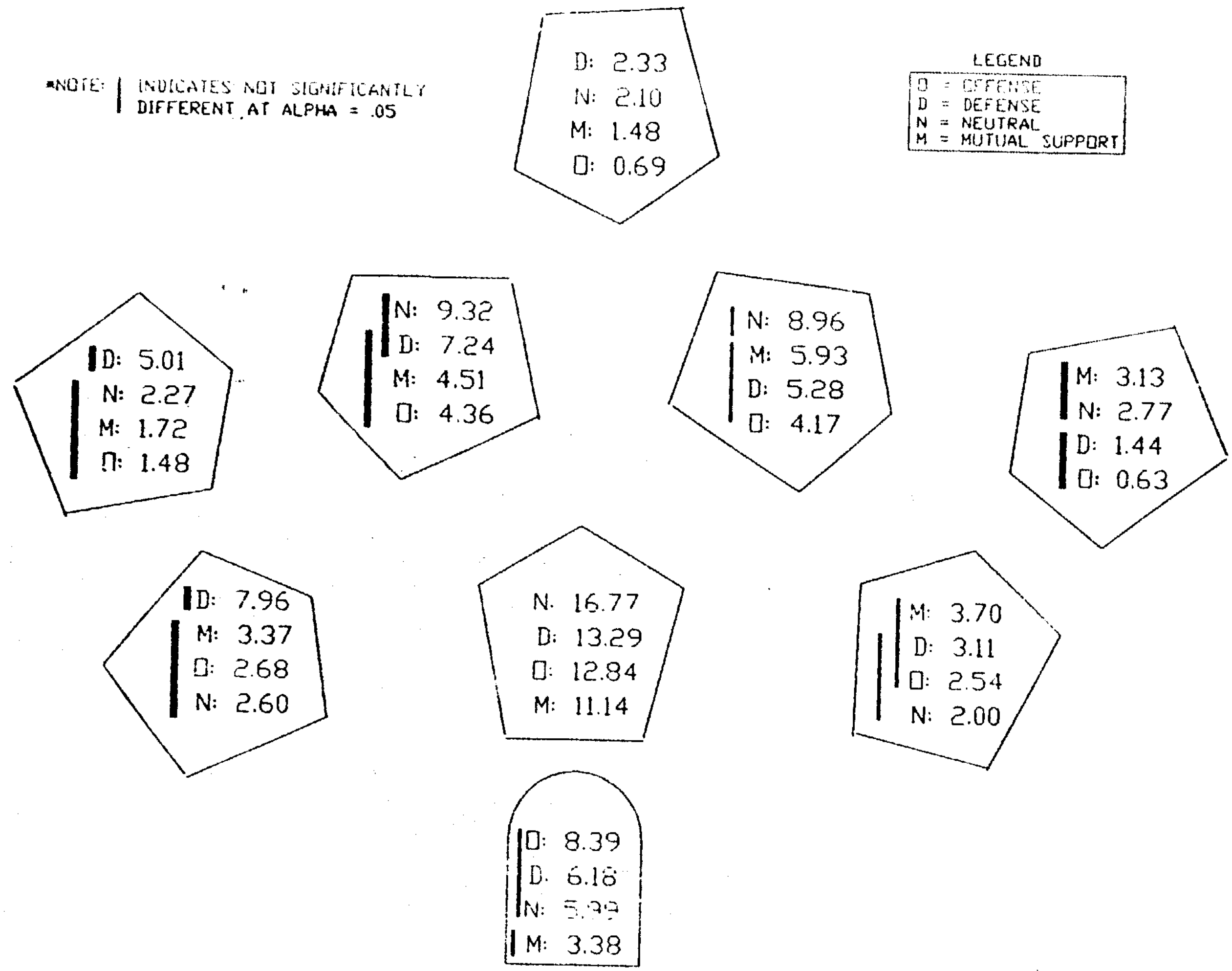

Figure 5. Average Number of Glances per Window.

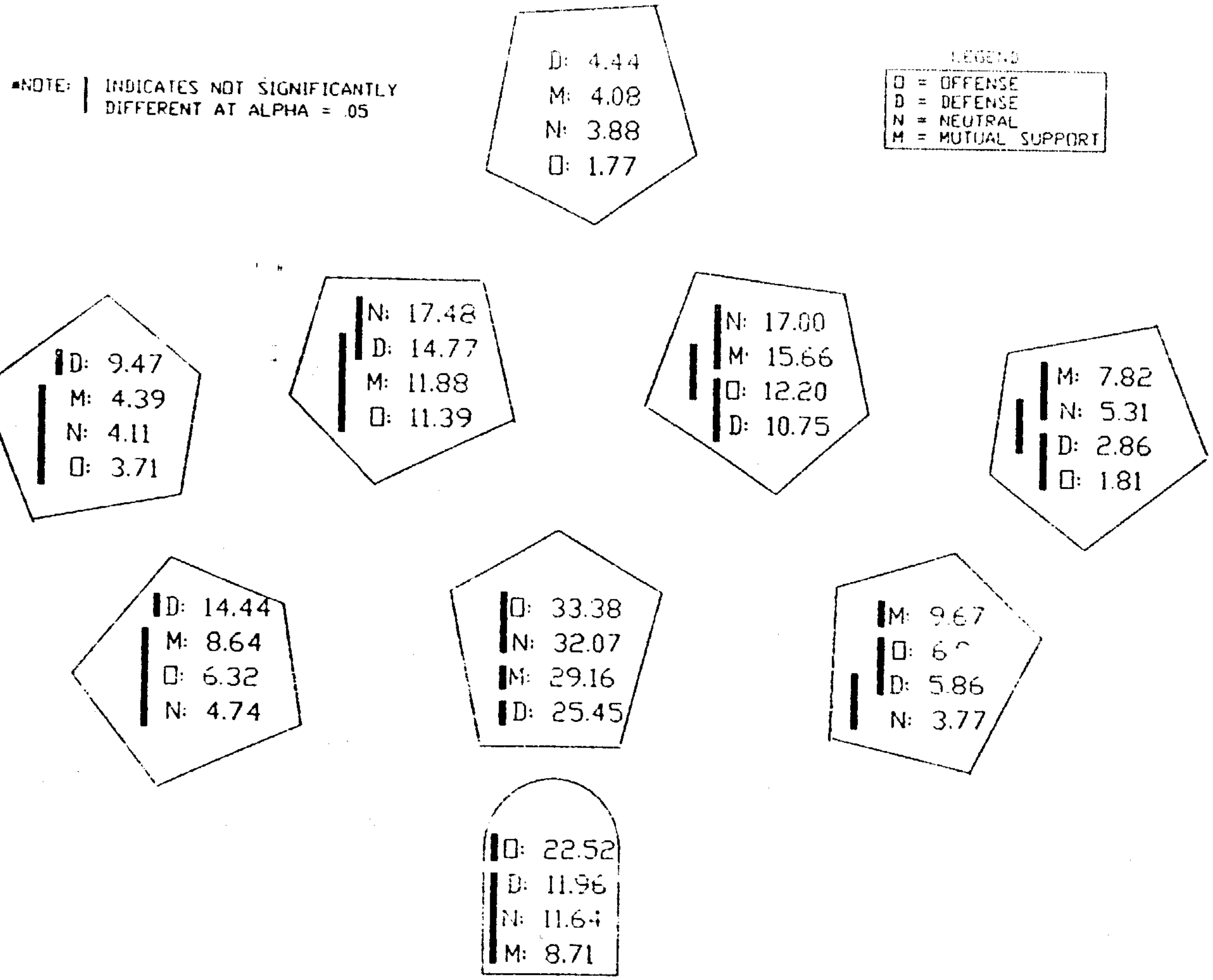

Figure 6. Percent Glances per Window.

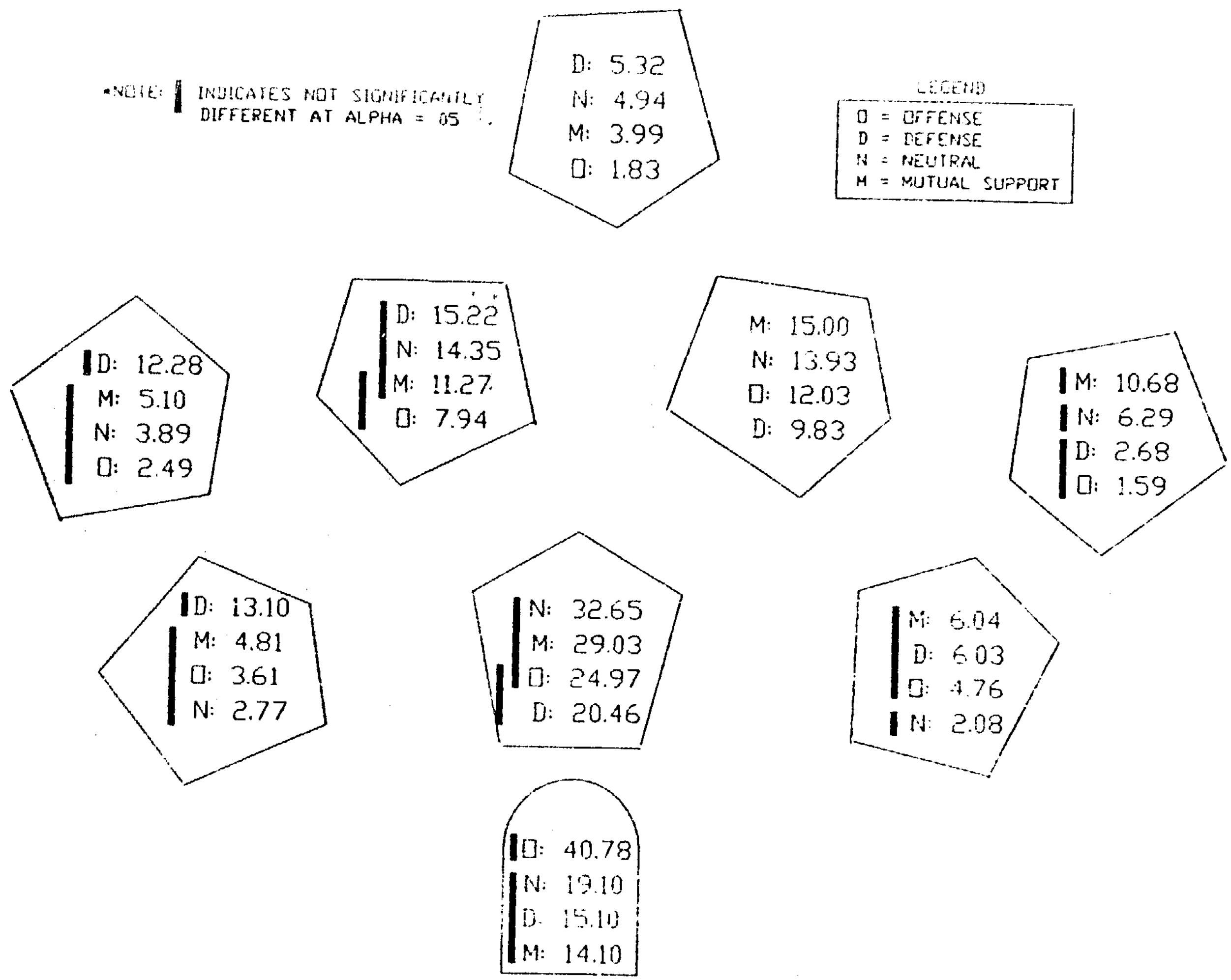

Figure 7. Percent Time (Seconds) per Window.

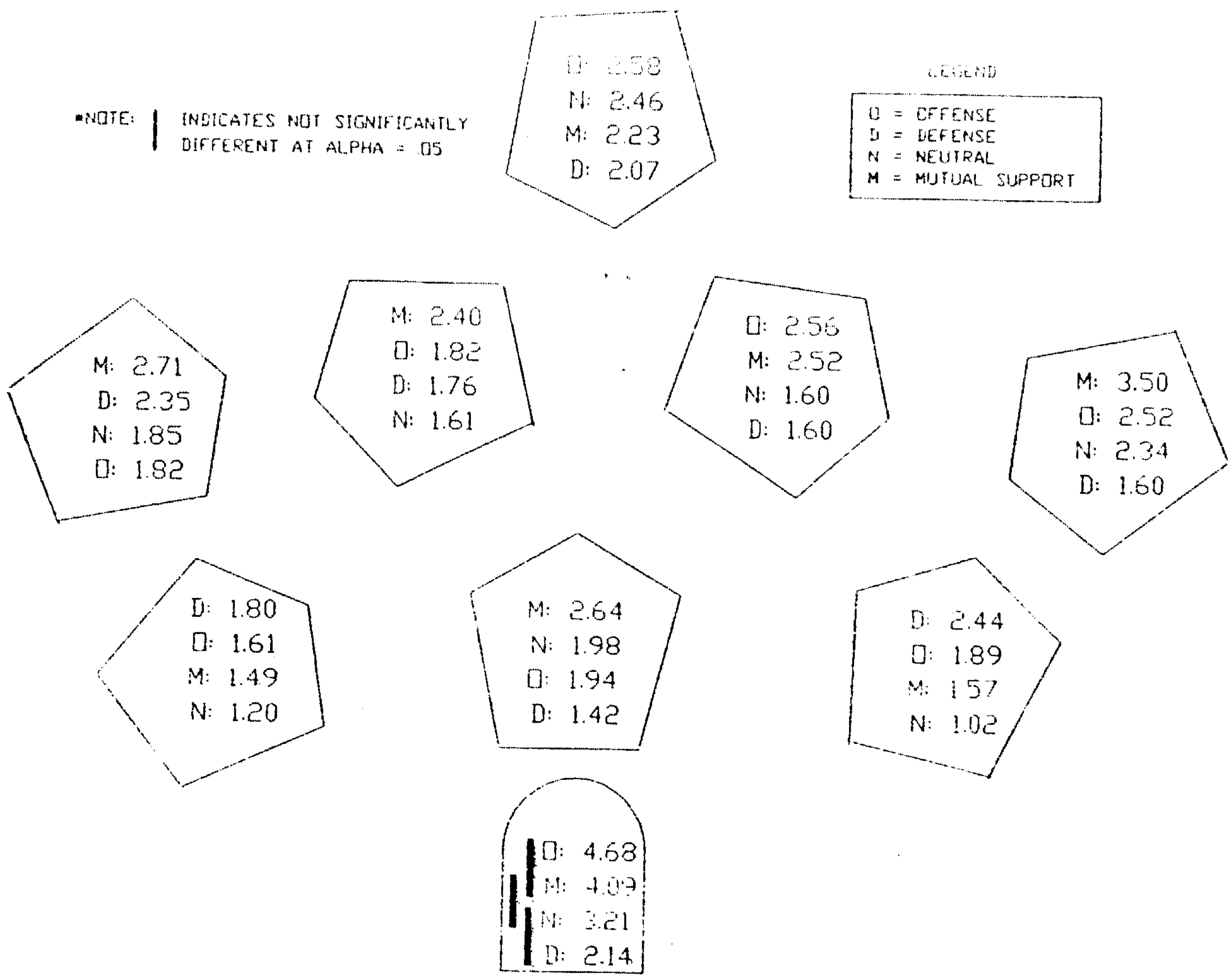

Figure 8. Average Time per Glance (Seconds).