NASA Contractor Report 3137 HUD Report 5



# The Role of Cognitive Switching in Head-Up Displays



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# The Role of Cognitive Switching in Head-Up Displays

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# PREFACE

This investigation was performed as one of the Phase II studies (2A) of the Joint FAA/NASA Head-Up Display Concept Evaluation Project conducted under Task Order DOT-FA 77 WAI-725 to Interagency Agreement NASA-NMI 1052.151, dated March 9, 1977, and under NASA Grant NSG-2269 to the San Jose State University Foundation.

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# THE ROLE OF COGNITIVE SWITCHING IN HEAD-UP DISPLAYS

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## SUMMARY

The objective of the present study was to determine pilots' ability to quickly and accurately extract information from either one or both of two superimposed sources of information: (a) static, aerial, color 35-mm slides of external runway environments and (b) slides of corresponding static head-up display (HUD) symbology. They were presented by a three-channel tachistoscope for brief exposure times, by showing either the HUD alone, the scene alone, or the two slides superimposed. Cognitive performance of pilots was assessed by determining the percentage of correct answers given to two HUD-related questions, two scene related questions, or one HUD and one scene-related question. These questions could not be answered correctly unless and until the visual information had been perceived. Twelve commercial airline pilots served as subjects. An analysis of variance indicated that: (a) the presence of the HUD symbology slide did not reduce the pilot's ability to extract required information from the external scene slides, (b) the presence of the external (background) scene reduced the pilot's ability to extract information from the HUD slides by 5%, $\underline{F}(1,11) = 51.6$, $\underline{p}<.01$, and (c) paying attention to both fields simultaneously did not significantly change performance on either the HUD slides or the external scene slides.

## INTRODUCTION

The general problem of the role of man in man-machine interfacing has been the subject of a great deal of study . One of the major areas of concern is the efficient design of the mechanical components of a system so as to take into full acount the characteristics of the human operator. Taylor (1957) described the operator in terms of a "data transmission and processing" link between the displays and controls of a machine. Gagne (1962), however, points out that just because we define the space that man occupies in the system, it does not help explain the nature of his functioning. He is still essentially a "black box" with undefined "internal functioning units" that can be activated or deactivated based on the needs of the system. Gagne further suggests that the science of psychology may be considered as having as its purpose the task of discovering and defining the functions of these "internal units."

The present study is a further effort to obtain more refined psychological data regarding certain cognitive processes involved in the system consisting of the pilot, flight instruments, and flight-related visual information. More specifically, the study is concerned with the efficiency with which attention may be switched between alternate fields of information, especially when they are superimposed. Hereafter, the term "field" will refer to the area within which information relevant to performance of the present task is located.

The ability to switch attention swiftly would appear to be generally necessary whenever there is a need to extract information from both fields in a short time. For example, it would be important for an aircraft pilot to be able to alternate efficiently betweeen his main fields of visual information in circumstances when time is of the essence.

The pilot is customarily concerned with two principal fields of information: the external forward view seen through the windshield and the instrument panel. It is possible to regard these fields as separate sources of information. (An example of each occurs when the pilot carries out the approach and landing task by reference to the external scene under VFR, i.e., Visual Flight Rules, and when the approach is made by reference to the flight instruments under IFR, i.e., Instrument Flight Rules.) However, it is usually necessary for the pilot to refer to both sources to provide himself with sufficient information needed to carry out his approach and landing tasks.

It becomes necessary, then, to ask how efficiently can this transition between information sources be accomplished. The two main areas of concern are the pilot's physiological capacity, i.e., how well can he cope with the <u>spatial separation of the fields</u>, and his mental capacity, i.e., how well can he cope with <u>shifting his frame of reference between the two fields</u>. Each of these subjects is discussed below.

## <u>Spatial Relationship of Information Sources</u>

The instrument panel and the external visual scene from which the pilot must obtain guidance and control information occupy different spatial locations.

Vertically, the two sources are separated by approximately 45 deg. The human eye is limited to 1-2 deg. of arc diameter of maximum acuity, know as foveal vision (Polyak, 1941). Therefore, the pilot is not capable of looking at both of these sources of information at the same time with the same capacity for obtaining (spatially) detailed visual information. In addition to the separate vertical locations, these two information sources are at different focal distances. The instrument panel is approximately 60 cm from the pilot's eyes. The external visual scene, on the other hand, lies at apparent optical infinity. The human eye is incapable of accommodating to d fferent focal distances at the same time.

When the pilot switches from one source of information to the other, he must change the direction of his line of sight as well as refocus his eyes. Both of these changes involve muscular action and therefore take time to accomplish. These head down to head up transitios may take as long as 2 to 5 sec (Naish, 1964; Gabriel, 1971), and reflect not only the time required to look up from the instrument panel but also the time needed to perceive and react to the visual stimulus in the external scene. During this switching process the pilot may either have to rely upon the maintenance of the ballistic trajectory of the aircraft (and assume that no external perturbing forces are acting upon the aircraft during this time), or execute a control input based on remembered or extrapolated information. This period of time, during which information could be misleading or lacking altogether, could well become critical in certain circumstances, for example, if the pilot were to attempt a transition between information fields at low altitude in certain wind shear conditions.

A solution to the problem of spatial difference between information sources is to use crew procedures that divide the job in an effective manner between the pilot and the copilot. While there are several variations of crew procedures in use, the one most often used in the United States is for one crew member to monitor the instruments, and the other the external scene. The pilot-flying receives the other pilot's information verbally and has to integrate it with his own perceived information. This procedure could conceivably give rise to human error in several ways. For example, there is only minimal redundancy in the two pilots' tasks, so it may be difficult for one pilot to recognize a mistake made by the other. Both the instrument panel information and the external scene contain essential information that is geometric in nature and cannot be expressed efficiently in words. In any case, voice relay of information tends to be slow and may be subject to various errors of interpretation and priority.

Another possible solution to the problem is to integrate the two needed sets of information into one visual field, so the pilot is able to monitor both the instrument panel-equivalent information and the external visual scene at the same time. This is the purpose of the head-up display (HUD).

Theoretically, the HUD eliminates the problems associated with the spatial differences of the two information sources by optically collimating and superimposing instrument information on the external visual scene. However, processing information from superimposed sources raises a new set of questions pertaining to the pilot's cognitive ability to critically evaluate pertinent information from both sets simultaneously.

## Cognitive Switching

Cognitive switching, in this study, is defined as:

> "alternating one's visual attention from one set of stimuli to another."

A stimulus set is in turn defined as:

> "the selection of certain items for analysis and response, on the basis of some common characteristic possessed by the desired stimuli." (Broadbent, 1971, p. 177)

The two stimulus sets used in the present study were photographic representations of the visual scene outside the cockpit and the HUD symbology, representing instrument derived information.

There are fundamental differences between the two information sets presented to the pilot. On one hand, the external scene (under clear visibility conditions) is composed of surfaces and objects that are (spatially) arrayed in three dimensions, usually possessing a wide range of color, texture and luminance. The usefulness of this set of flight-related information depends mostly on static and dynamic angular relationships, with some less reliable distance cues dependent on atmospheric perspective and texture perceptions (Gibson, 1950; Naish, 1971). On the other hand, the HUD symbology is usually composed of lines, closed geometric forms and alpha-numerics arranged in a two-dimensional field. The display is usually in one color, most often green, and has uniform luminance. The usefulness of HUD symbology is derived primarily from position matching of fixed and moving symbols and identifying alpha-numeric values. Perhaps the most important difference between the two stimulus sets is that while the external scene is directly perceived, and consists of familiar or "natural" information, the HUD array symbolizes flight information with the aid of advanced display technology and thus places an extra interpretative step between the perceiver and the perceived object.

Because the two information sets appear to be clearly different, the assumption is made here that their processing also requires different forms of logic. While a properly designed HUD system integrates the two sets optically in the same visual field, the question remains whether optical superposition results in efficient cognitive integration as well. The issue largely becomes a matter of how effectively the pilot switches his frame of reference back and forth between the two sets of superimposed stimuli.

Currently there are two views on the issue. One contention is that the pilot is capable of perceiving and processing information from both fields efficiently. This viewpoint is based mainly on the conclusions drawn from the results of a series of experiments conducted by Naish (1964). However, not everyone accepted these results as conclusive evidence for the effective utilization of superimposed fields. For example, based on a subjective investigation of the issue, Wallace (1968) expressed some concern that cognitive switching may introduce new problems in several ways: (a) The pilot may become confused as to the source of his information and perhaps misuse it. (b) The cognitive switching process may introduce a delay that could offset any time gained through the HUD by eliminating the head-down to head-up transition. (c) Tne pilot may become fascinated with and visually fixate on one of the superimposed sets to the exclusion of all cues from the other set. There is clearly a conflict between the two notions on the issue that needs to be resolved.

Existing attention theories (Broadbent, 1958; Deutsch & Deutsch, 1963) also disagree as to whetner information from superimposed sources would be processed in a parallel fashion or sequentially. In fact, there has been little basic research done on attention switching using complex, superimposed visual stimuli. Most of the research in the area has been done using simple stimuli, such as point light sources, simple geometric shapes or alpha-numerics (Broadbent, 1971; Kahneman, 1973; Moray, 1959; Treisman, 1969). While Naish (1964) used both simple and complex stimuli, his series of experiments basically were applied studies. There is a need to look at the efficiency of information transfer from complex superimposed visual fields in a fundamental and closely controlled manner. The present study attempts to fill this need.

## Objective of the Study

The objective of this study is to determine pilots' ability to quickly and accurately extract information from either one or both of two superimposed sources of information. The two specific issues are:

1. The effect of superimposed information fields.
   a. What is the effect of the presence of a HUD symbology on extracting information from the external scene also present in the visual field?
   b. What is the effect of the presence of an external scene on extracting information from a HUD symbology also present in the visual field?
2. The effect of divided attention.
   a. What is the effect of divided attention on extracting information from the external scene?
   b. What is the effect of divided attention on extracting information from HUD symbology?

# METHOD

## Subjects

The 12 subjects (hereafter referred to as pilots) were five captains, four first officers and three flight-engineers currently employed by five major airlines. Their ages ranged from 33 to 59 years, with a mean of 42 years, and they had an average of 5200 flight hours in multiengine jets. Each pilot was administered a battery of vision tests to ensure that all subjects had 20/20 distant acuity, normal color perception, full visual field sensitivity, and no visual dysfunctions that might adversely effect the performance of these tasks.

## Apparatus and Stimuli

The study was conducted in an 8 x 8 ft. (2.4 m x 2.4 m) sound attenuating experimental chamber, using a three-channel Iconix T-scope described elsewhere (Haines, 1978). Briefly, the total field of view in the T-scope was 7.9 deg. (137.8 mrad) high x 8.9 deg. (155.3 mrad) wide. Two Kodak Ektagraphic RA-960 projectors with Ektanar 4 to 6 in., f/3.5 zoom lenses and ANSI-CBA, 500 watt, 120 volt bulbs were used to project the stimuli. A third projector with an ELH, 300 watt, 120 volt lamp was used to keep the intertrial screen luminance constant. All three projectors were equiped with mechanical shutters (opening time 3 msec, closing time 1 msec).

The stimuli consisted of two sets of 35 mm, high fidelity colored slides: 24 external scenes and 24 displays of corresponding symbology as described below.

<u>External scenes</u>. The external scenes were aerial photographs of runways taken at four airports with the aircraft on a 3-deg. (52 mrad) glide-slope. All photographs were taken in daylight with excellent visibility, and with altitudes ranging from 1500 ft. (457.2 m) to field level. An example of the external scenes is shown in Figure 1. Six of the 24 scenes had a clearly visible aircraft located somewhere in the sky. This effect was achieved by superimposing artist-rendered images of aircraft within the sky background of the external scenes.

<u>HUD symbology</u>. These slides were prepared so as to correspond to each of the external scenes in terms of indicated altitude, localizer, and horizon. The specific symbology set for this study was selected because the same symbology elements were used in a parallel experiment (Hodges, 1978), thus allowing possible comparison between studies. It is assumed, however, that similar results would have been achieved for other (comparable) symbologies than the one used here. While all stimuli were static (since all were produced by 35-mm slides), certain flight parameter elements changed position or value from slide to slide. They are called "dynamic elements" here. An example of a typical symbology slide (with explanatory captions added) is shown in Figure 2. The altitude scale changed values in increments of 25 ft. (7.6 m) between 0-100 ft. (0-30.5 m), 50 ft. (15.2 m) between 100-1000 ft. (30.5-305 m), and 100 ft. (30.5 m) above 1000 ft. (305 m). There were 18 different height values represented by the 24 slides, the center value being the actual altitude of its corresponding external scene. The localizer and glide-slope indicator scales were also dynamic elements. The horizon line and the depressed 3-deg. glide-slope line always remained parallel and moved together by the same amount of roll and pitch. The horizon line conformed to the position of the real horizon. The velocity vector symbol always stayed on the vertical center line of the display and moved up and down independently of the horizon line. In an actual flight situation the point where this symbol overlays the external scene is where the aircraft would land if it continued on its current path.

The symbology slides were projected through a light-green gelatin filter, which approximated a CRT P1 phosphor. The pilot saw them as green lines against the background which was either an external visual scene (Figure 3), or an


Figure 1. Example of an external scene.

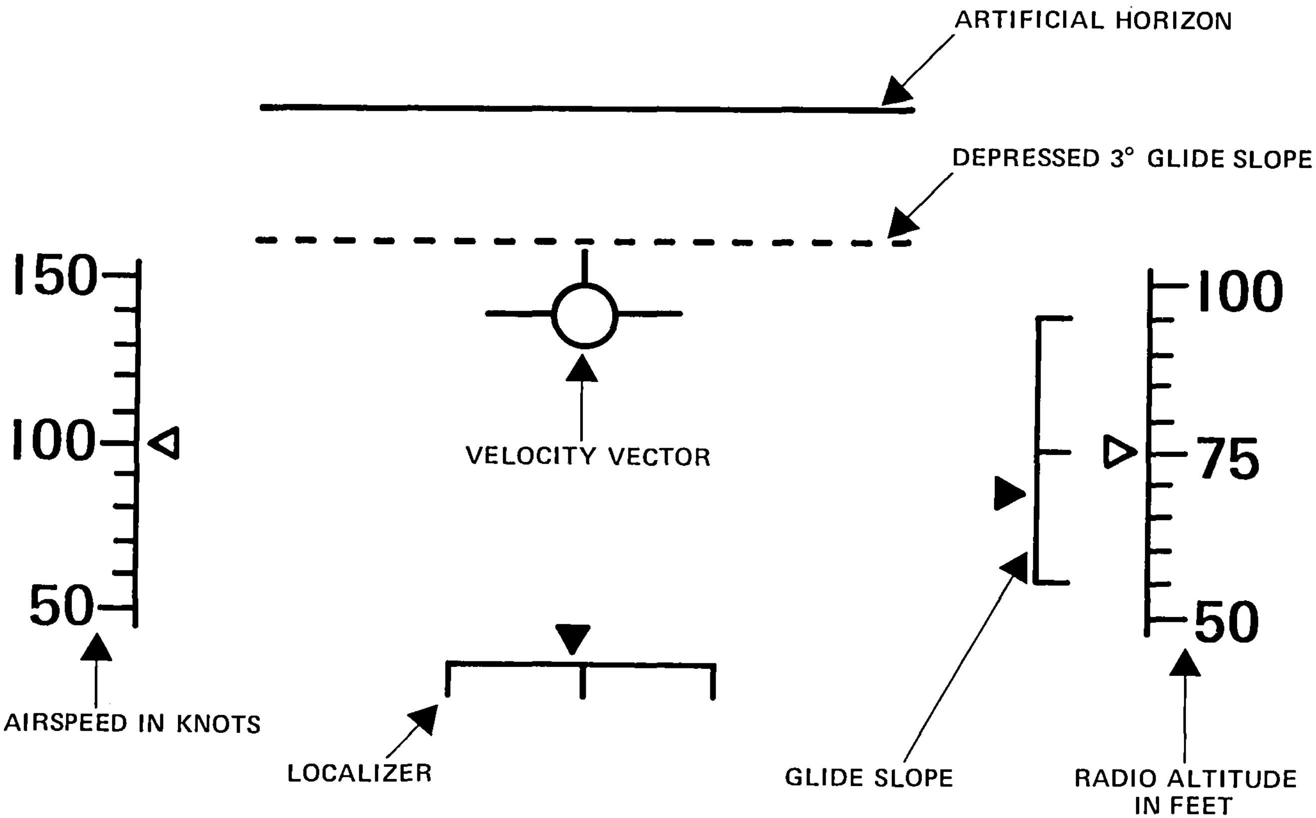


Figure 2. Example of a HUD symbology slide (with captions added).


Figure 3. Example of HUD symbology superimposed on the external scene.

homogeneous blue-gray "cloud" scene. The symbology luminance was held constant for all conditions, and the symbology was always readily visible against the background scenes.

## Procedure

The study was conducted in two parts. Experiment 1 determined the effect of superimposed information sources on processing information from (or paying attention to) only one of the sources. Experiment 2 examined the effect of dividing attention between (or paying attention to) two superimposed information sources. Attention was divided by asking the subject to extract information from both fields, thus motivating him to divide his attention between the HUD and the scene. All 12 pilots were tested in all conditions.

In order to determine the pilot's ability to process information under the various conditions, he was exposed to a slide for a brief period of time, and he was instructed to respond to two questions asked by the experimenter, pertaining to the specific slide. The pilot always knew ahead of time what the questios are going to be. These questions could only be answered correctly if the information was present and perceived correctly. Pilot's responses in all conditions were quantified by the percentage of correct answers.

Experiment 1. The first experiment may best be described in two parts. Part A addressed the question: What is the effect of the presence of the HUD symbology on extracting information from the external scene? In order to determine the pilot's ability to extract information from the external scene alone (without any possible interference from the symbology), he was shown the scene slides only and was asked the following two scene-related questions: Which airport are you at (V1)? Do you see any air-traffic (V2)? The proper response was the name of one of the four airports for the first question, and "yes" or "no" for the second question. Data collected under this (and any other) single-field condition will be referred to as "base-line" data.

In order to assess the effect of the presence of symbology on the external scene, data were collected by exposing the pilot to the superimposed HUD and scene, and he was to respond to the two visual questions above. Data collected under this (and any other) superimposed fields condition will be referred to as experimental data.

Part B addressed the question: What is the effect of the presence of the background scene on extracting information from the HUD symbology? Here, the pilot was first exposed to the HUD symbology alone, then to the HUD superimposed on the scene. In both cases the task was to answer the following two HUD symbology-related questions: What is your altitude (H1)? Are you on the 3-deg. glide-slope (H2)? For the altitude question the pilot was to report the exact number in the middle position of the HUD altitude scale. For the glide-slope question he was to report whether any part of the circle portion of the velocity vector symbol crossed the dashed line. If the circle was below the line the answer should have been "no;" if it was crossing this line, the pilot should have said "yes." (The velocity vector was never above the glide-slope line because all scenes were taken on a descending slope during the approach).

<u>Exposure Times</u>. Since performance was measured by the percentage of correct answers, and the ability to perform depended on exposure time (given enough time, all pilots could have answered all questions with 100% accuracy), it was necessary to find an exposure time that would keep performance below 100%. For this study, the target performance level was arbitrarily set at about 80%. Based on an exploratory study which used nine college students as subjects, it was found that the exposure time for the desired performance level for the two specific visual questions used in Part A was 25 msec. For the two HUD questions used in Part B the desired exposure time was 200 msec. The difference between exposure times in the two parts is irrelevant, since performance between Part A and Part B, i.e., external scene vs. HUD, was not compared. All statistical comparisons were made across conditions, i.e., single vs. superimposed fields in Part A using 25 msec exposure time, and single vs. superimposed fields in Part B using 200 msec exposure time.

<u>Sequence of procedural events</u>. Before the experimental session began, the subject was thoroughly familiarized with the stimuli by showing him 8 x 10 color prints of the external scenes, and prints of the HUD symbology. He learned to identify the four airports with 100% accuracy, and became familiar with the "dynamic elements" of the symbology set. The subject was then tested as to his knowledge of these stimuli using long exposure times (1000 msec) in the T-scope. This also introduced him to the use of the apparatus. Once the experimenter was satisfied that the subject was ready (i.e., he responded to a set of 24 slides with 90% accuracy), base-line data collection began.

During the experiment the subject looked into the T-scope, and when he was ready he pushed a response button, exposing the slide for the preset exposure time. After the stimulus was extinguished, the pilot answered the two appropriate questions for that slide. The experimenter, also sitting in the experimental chamber, entered the answers into a PDP-12 computer via a data-entry terminal.

The experimental design for Experiment 1 included two conditions: single field and superimposed fields. Both conditions were repeated with attention directed to the HUD and to the scene, resulting in the following four combinations: (a) HUD slides only, two HUD-related questions asked (H1 and H2), (b) External scene slides only, two scene-related questions asked (V1 and V2), (c) Superimposed HUD and scene slides, two HUD-related questions asked (H1 and H2), and (d) Superimposed HUD and scene slides, two scene-related questions asked (V1 and V2). As may be seen, (a) and (b) were the single field conditions where the base-line data were collected (Part A), and (c) and (d) were the superimposed conditions where the experimental data were collected (Part B).

For each subject in each condition, the appropriate set of 24 slides (24 scene slides alone, 24 HUD slides alone, or 24 superimposed slides) was shown 12 times in six random orders, resulting in 288 trials per subject. Each series of 24 slides was designated as a trial block. Before each block of trials was presented, the pilot was informed regarding what type of slides he would see, and what the questions for the block of slides would be as well as the order in which to answer them. He was also advised to fixate his line of sight in the general direction on tne screen where the first piece of information was expected to appear, and pick up the second information peripherally. For example, if the task was to report the altitude and the position of the velocity vector symbol, the subject was to look at the right hand side of the screen during the inter-trial period, because that is where the altitude scale was located. The questions in a set were always asked in the same order for all subjects. Half of the subjects were randomly assigned to start with the HUD-alone condition and the other half with the external scene-alone condition. If a subject started with HUD alone the next condition would be the external scene alone, then the superimposed stimuli with HUD questions only, and finally, the superimposed stimuli with the scene questions only.

As may be seen, the base line data for both Parts A and B were collected before the experimental data collection for either part. The reason for this was that the subject had to be thoroughly familiar with both sets of stimuli before being exposed to the superimposed set in order to compensate for the novelty of the stimuli which would likely be a biasing factor in performance.

The total data collection for Experiment 1 took about 4 hours per subject. This time period included short, 5-minute breaks after the first six blocks of trials in each condition, and a 10-, 30- and 10-minute break between each succeeding condition, respectively. Before data collection began for the superimposed sets, each subject was given a practice session to bring his performance up to his base-line performance, as determined by the last three data points on his base-line data.

Experiment 2. The second experiment dealt with the matter of having to pay attention to both the external scene and the HUD symbology at the same time (i.e., within the viewing duration). It was conducted the day following Experiment I for each subject using the same general procedures, stimuli, and questions as just described. Before data collection began, each subject was given a short practice session viewing superimposed sets, responding to either the HUD or the external scene, until he performed at his previous level of accuracy.

During the experimental session the subject was motivated to perceive both information sources simultaneously by having him view the superimposed HUD and scene for a brief period, then requiring him to answer one of the HUD and one of the scene-related questions in the following combinations: (a) H1 and V1, (b) H1 and V2, (c) H2 and V1, and (d) H2 and V2.

Each combination of questions was repeated for a total of 144 trials per subject. Thus, each subject repeated the task 576 times. The order in which the four question sets were asked was randomized between subjects, but the HUD question was always asked first. The rationale for this was that since the HUD questions were harder, i.e., took longer to answer, putting them in second position would only increase the over-all error rate or the exposure time but would not likely influence the effect of the condition.

Exposure times. Exposure times for all trials in Experiment 2 was 112 msec. This duration was arrived at by the following reasoning. The exposure time for the two HUD questions (H1 and H2) in Experiment I was 200 msec, and the two scene questions (Vl and V2) required 25 msec, a total of 225 msec for the four questions. It was assumed that one of the HUD questions and one of the scene questions would require on the average half of that total time, or about 112 msec. This assumption was based on the preliminary pilot study which indicated that responding to one question took about half the time than to two questions of the same type. By asking the questions in the four combinations, the possible differences in difficulty level of the two HUD questions and of the two visual questions were compensated for.

## RESULTS

### Experiment 1

Each pilot's performance was measured by the mean percentage of correct answers given (for both questions) for each block of 24 trials. These data points, averaged across subjects, were used as the dependent variable in the data analysis. There were three areas of interest for analysis: (a) learning effects, as evidenced in the baseline data, (b) the initial effect of superimposed fields, and, (c) the more permanent effect of superimposed fields. Figure 4 presents the mean data for the visual questions. Figure 5 shows the mean data for the HUD questions.

Learning effects. It was expected that an initial learning period would be required before performance would level off under the single field conditions (HUD slide only, HUD questions; scene slide only, scene questions). While no special statistical analysis was performed on these data, it may be seen in the early (left hand) sections of Figures 4 and 5, that performance indeed increased over time. This was more pronounced for the HUD symbology than for the scene slides. The data also show that most of the improvement in performance occurred by the end of the sixth trial block for both the HUD and the scene; after that performance leveled off. Since the end of the sixth block of trials also coincided with the first rest period, it seemed reasonable to designate the first six trial blocks (for both the HUD and the scene) as learning data, and the second six trial blocks as the actual base-line data against which the experimental data would be compared. For the remainder of this report, base-line data will refer only to the last six trial blocks of the experimental data.

Initial effect of HUD on extracting information from the scene. The effect of the presence of HUD symbology on information extraction from the scene was determined by comparing the responses to the visual questions under single and superimposed field conditions. As may be seen in the right hand side of Figure 4, most of the change in performance under the superimposed field condition also was complete by the sixth trial block (which corresponded to a

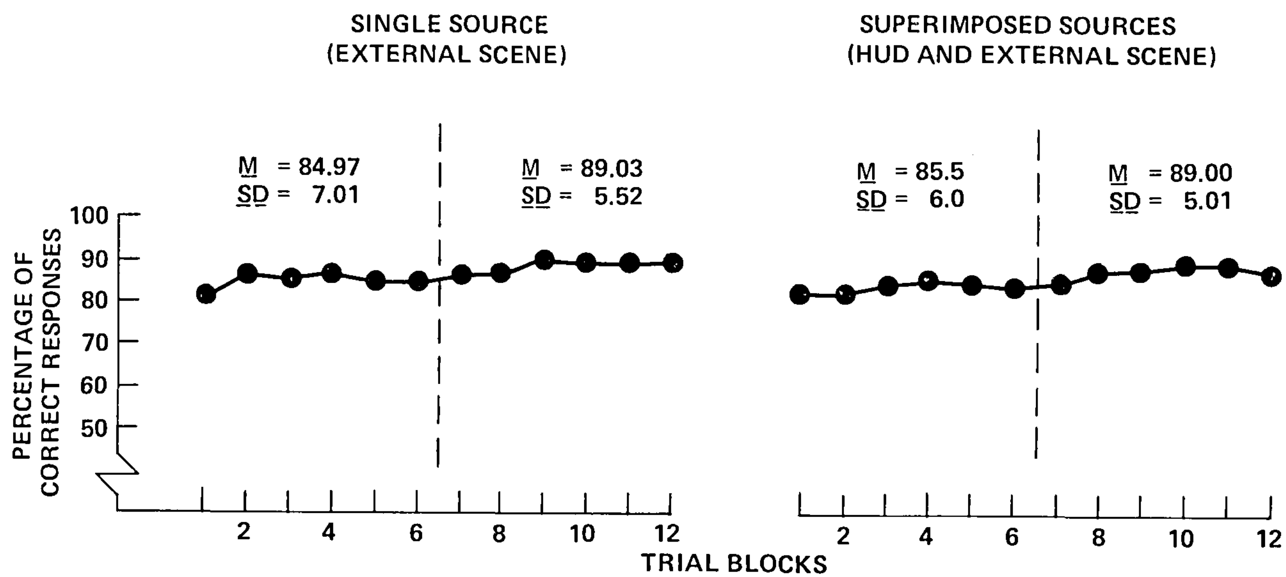


Figure 4. The effect of HUD on the external scene. Mean percentage of correct responses to visual questions under single and superimposed field conditions. N = 12 pilots.

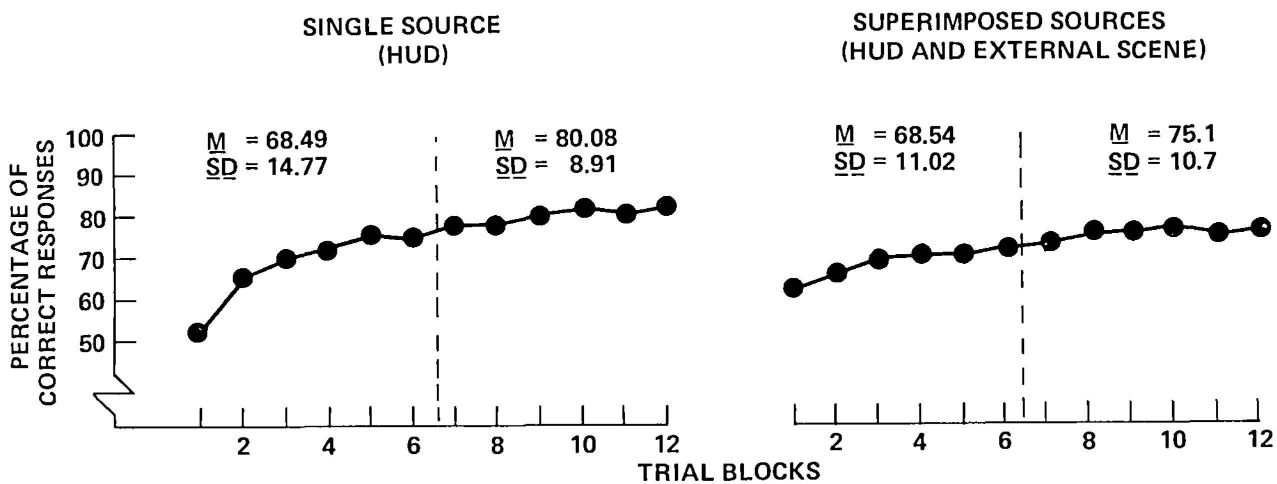


Figure 5. The effect of the external scene on HUD. Mean percentage of correct responses to HUD questions under single and superimposed field conditions. N = 12 pilots.

rest period). Thus, as before, the data were divided in the middle (between the sixth and seventh trial blocks), and the first six trial blocks were interpreted as showing the initial effect of the presence of HUD symbology on information extraction from the external scene. The right-hand side (trial blocks 7 to 12) of Figure 4 shows that when pilots were first exposed to superimposed fields, response accuracy to the scene questions ($\underline{M}$ = 85.50, $\underline{SD}$ = 6.0) decreased, compared to the base-line data ($\underline{M}$ = 89.03, $\underline{SD}$ = 5.5). In order to test the statistical significance of the decrease in performance, a nested, 3-way repeated measures analysis of variance (Keppel,1973) was conducted with: 2 conditions (single field, superimposed fields) x 6 trial blocks (nested within conditions) x 12 subjects. The analysis (cf. Table 1) showed that the difference due to condition was statistically significant, $\underline{F}(1,11) = 16.85$, $\underline{p} < .01$ .

Table 1
Analysis of Variance Summary: Initial Effect of HUD on External Scene

| Source | df | MS | Error | F |
|---|---|---|---|---|
| Subjects (S) | 11 | 217.8 | -- | -- |
| Condition (C) | 1 | 548.3 | SxC | 16.85** |
| Trial(Cond) T(C) | 10 | 38.9 | SxT(C) | 2.76** |
| SxC | 11 | 32.5 | -- | -- |
| SxT(C) | 110 | 14.1 | -- | -- |

**$\underline{p}<.01$

<u>The stabilized effect of HUD on external scene</u>. As may be seen in Figure 4, by the 7th trial block performance reached an approximate plateau, therefore trial blocks 7-12 were accepted as representing the experimental data showing the effect of the presence of HUD on extracting information from the external scene. It may also be seen that mean performance ($\underline{M}$ = 89.00, $\underline{SD}$ = 5.0) was almost identical to the base-line performance ($\underline{M}$ = 89.03, $\underline{SD}$ = 5.5) indicating that the presence of the HUD slide did not reduce these pilots' ability to extract needed information from the external scene slides. The analysis of variance summary in Table 2 verifies that there was no significant difference in performance due to condition.

Table 2
Analysis of Variance Summary: The Stabilized Effect of HUD on External Scene

| Source | _df_ | _MS_ | _Error_ | _F_ |
|---|---|---|---|---|
| Subjects (S) | 11 | 185.3 | -- | -- |
| Condition (C) | 1 | 2.5 | SxC | .04 |
| Trial(Cond) T(C) | 10 | 19.9 | SxT(C) | 1.71 |
| SxC | 11 | 27.1 | -- | -- |
| SxT(C) | 110 | 11.7 | -- | -- |

_Initial effect of external scene on information extraction from HUD_. The effect of the presence of the visual background on information extraction from the HUD slides was determined from a comparison of the responses to the HUD questions under single and superimposed field conditions. Comparing the mean base-line data ($M$ = 80.08, $SD$ = 8.9) to the mean of the first six trial blocks under superimposed condition ($M$ = 68.54, $SD$ = 11.0) in Figure 5, it may be seen that there was a sizable reduction in performance, when the subjects were first introduced to superimposed fields. Another 2 x 6 x 12 analysis of variance (as before) shows that the difference due to condition was statistically significant $F(1,11) = 51.6$, $p < .01$ (Table 3).

Table 3
Analysis of Variance Summary: Initial Effect of External Scene on HUD

| Source | _df_ | _MS_ | _Error_ | _F_ |
|---|---|---|---|---|
| Subjects (S) | 11 | 754.8 | -- | -- |
| Condition (C) | 1 | 4726.6 | SxC | 51.61** |
| Trial(Cond) T(C) | 10 | 96.4 | SxT(C) | 2.44* |
| SxC | 11 | 91.6 | -- | -- |
| SxT(C) | 110 | 34.4 | -- | -- |

*$p < .05$
**$p < .01$

*The stabilized effect of external scene on HUD*. Figure 5 shows that although mean performance improved over time for the superimposed condition, it did not reach the performance level ($M$ = 80.1, $SD$ = 8.9) of the base-line data. Comparing the last six data points ($M$ = 75.1, $SD$ = 10.7) of the experimental data to base-line performance, the analysis of variance (cf. Table 4) shows a statistically significant difference due to condition, $F(1,11) = 11.58$, $p < .01$.

Table 4
Analysis of Variance Summary: The Stabilized Effect of External Scene on HUD

| Source | df | MS | Error | F |
|---|---|---|---|---|
| Subjects (S) | 11 | 833.6 | -- | -- |
| Condition (C) | 1 | 860.4 | SxC | 11.58** |
| Trial(Cond) T(C) | 10 | 28.1 | SxT(C) | .81 |
| SxC | 11 | 74.3 | -- | -- |
| SxT(C) | 110 | 34.4 | -- | -- |

**$p < .01$

## Experiment 2

As in Experiment 1, performance was indicated by the mean percentage of correct answers per block of 24 trials. Data points for each block were obtained by averaging data across subjects as well as the four types of question groups. Since it was of interest to look at the effect of divided attention on the overall performance, as well as on the specific performance in each of the two superimposed fields, three sets of six data points were calculated: (a) mean data for the two questions together, (b) for the HUD questions only, and (c) for the external scene questions only. These three sets of data points comprised the experimental data for Experiment 2 and they were compared with the last six data points of the experimental data in Experiment 1 for both the HUD and the scene as these data was used as the base-line data for Experiment 2.

The HUD and the external visual scene data were independent in Experiment 1, but dependent in Experiment 2, therefore statistical comparison of the two types of data is not justified. For this reason, comparison is made only by visual inspection of the graphed data.

Overall performance under divided attention. Figure 6 compares overall performance under divided attention (1 HUD and 1 scene question) to performance under undivided attention (2 HUD or 2 scene questions), while viewing superimposed fields. It shows that when pilots had to pay attention to both fields in order to answer the questions correctly, their overall performance ($\underline{M}$ = 85, $\underline{SD}$ = 7.9) was between their earlier performance of paying attention to either the HUD ($\underline{M}$ = 75.1, $\underline{SD}$ = 10.7), or the scene ($\underline{M}$ = 89.4, $\underline{SD}$ = 6.1) alone.

In order to find out how dividing one's attention affected performance on each of the two superimposed fields, the experimental data were separated into a HUD component (responses to the HUD questions), an external and a scene component (responses to the scene questions).

The effect of divided atttention on HUD. The mean percentage of correct responses to the HUD component of Experiment 2 were compared to the experimental HUD data in Experiment 1. Figure 7 shows that when pilots had to pay attention to the HUD component part of superimposed fields only, they performed at $\underline{M}$ = 75.1, $\underline{SD}$ = 10.7, but when they had to respond to both the scene and the HUD, their performance on the HUD portion increased to $\underline{M}$ = 81, $\underline{SD}$ = 8.9. Thus, divided attention did not have any noticeably adverse effect on these pilots' ability to extract information from the HUD slides.

The effect of divided attention on external scene. Figure 8 shows that the pilots' mean performance on the scene questions were almost identical in both conditions: $\underline{M}$ = 89.0, $\underline{SD}$ = 5.1 when they had to respond to questions related to the external scene portion of superimposed fields only, and $\underline{M}$ = 89.4, $\underline{SD}$ = 6.1 when they had to respond to both sets of information sources. Divided attention did not effect the pilots' ability to extract information from the external scene slides.

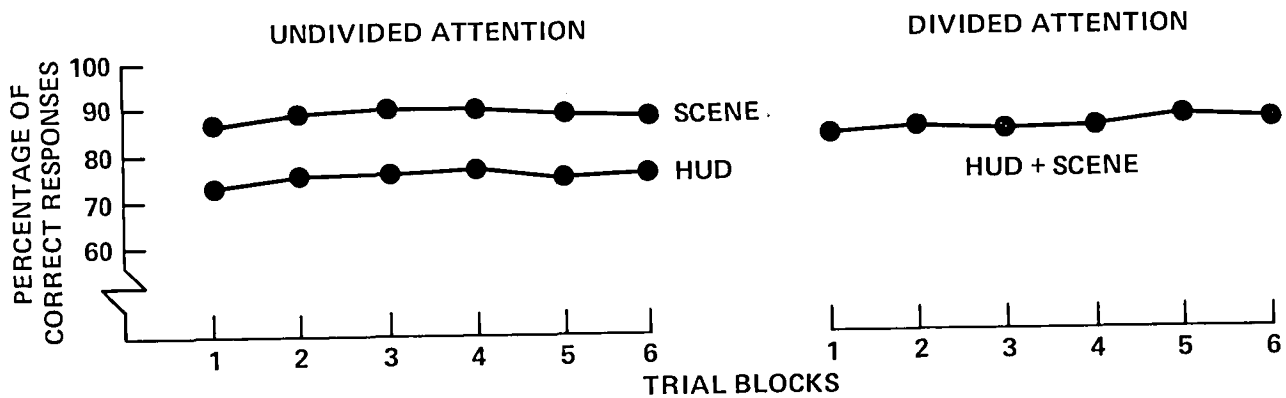


Figure 6. The effect of divided attention on overall performance. Mean percentage of correct responses under undivided and divided attention, viewing superimposed fields. N = 12 pilots.

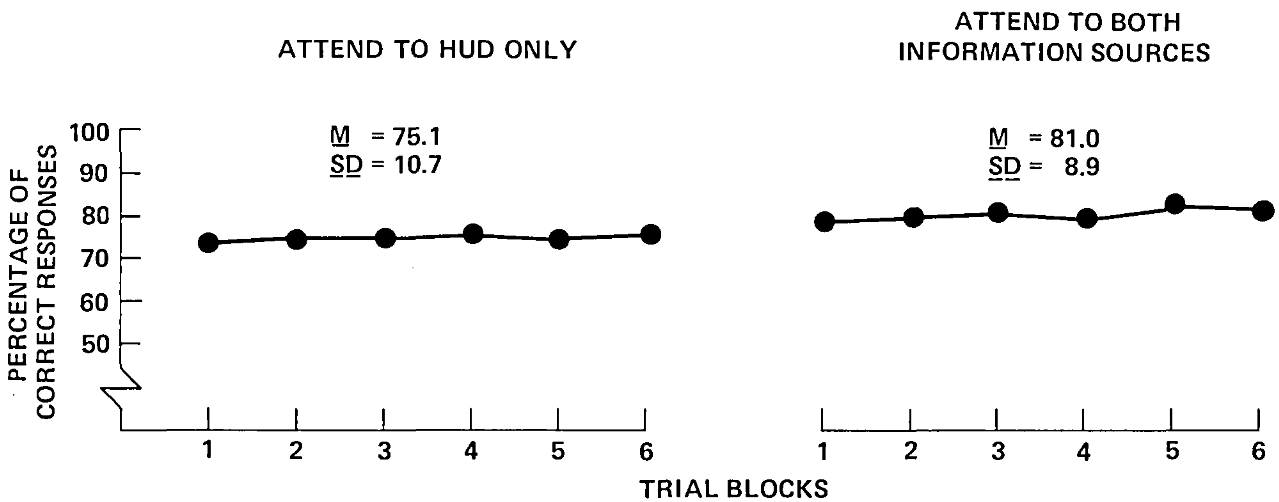


Figure 7. The effect of divided attention on HUD. Mean percentage of correct responses to HUD questions under undivided and divided attention. N = 12 pilots.

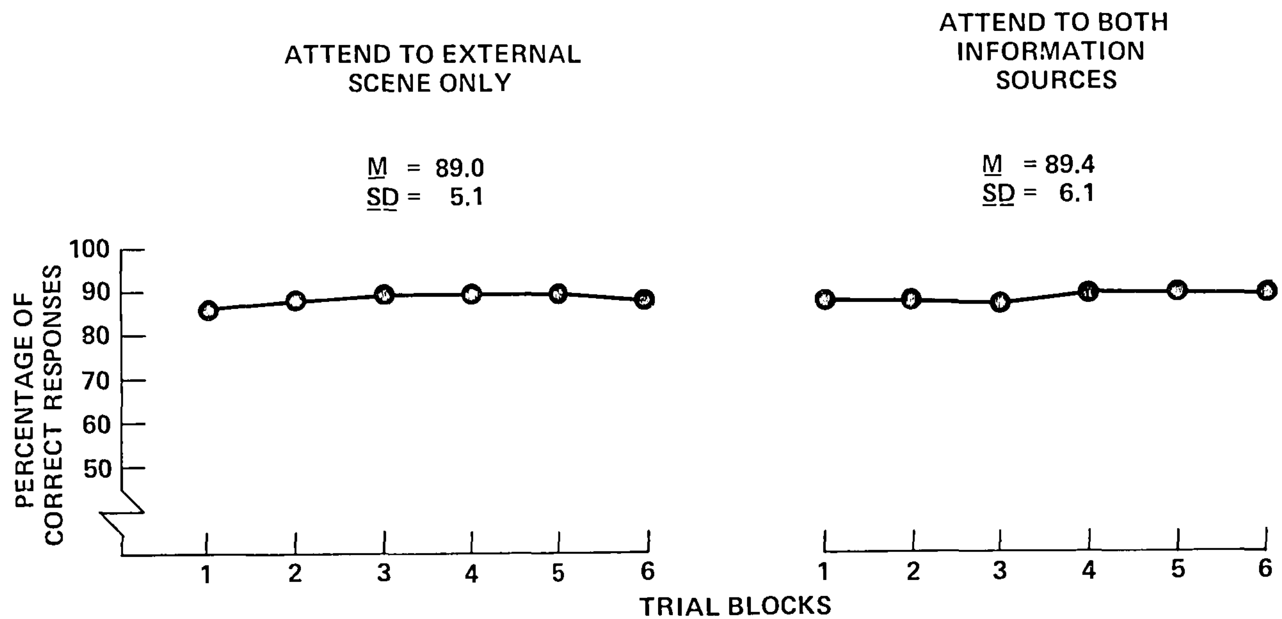


Figure 8. The effect of divided attention on scene. Mean percentage of correct responses to visual scene questions under undivided and divided attention. N = 12 pilots.

# DISCUSSION

The results of the present study support the experimental conclusion of Naish (1964) that pilots are able to extract information from superimposed visual fields efficiently. Specific findings from the present study are discussed below.

## The Effect of Superimposed Fields.

The presence of the HUD symbology did not reduce pilots' ability to extract information from the external visual scene. It is interesting to note that the extremely brief, 25-msec exposure time used to view the external scene is shorter than any found in the literature by the investigator, especially for complex stimuli. Yet, the pilots performed at or near their final level of response accuracy almost immediately, being able to identify the airport and the presence or absence of air-traffic with a high rate of accuracy. Superimposing the HUD symbology on the visual scene did not change their performance. In fact, most pilots reported after the experimental session that since they were not required to pay attention to it, sometimes they were not even aware of the HUD symbology being present.

Extracting information from the HUD symbology under undivided attention was more difficult with the external scene backgrounds than with a homogeneous blue-gray background. This finding was expected. Since the symbology was green and a high proportion of the external scenes tested was also different shades of green, part or all of a symbol or a numeral sometimes appeared "washed out." By increasing the luminance of the symbology the less visible parts would have become more visible, but then the brightness of the symbols would have annoyed the pilots' eyes (as was found in the preliminary study). This points out the importance of determining the optimum symbol luminance for different operational environments.

It should be noted that surveying the data for the individual questions reveals that the decrease in performance on the HUD was due almost entirely to decreased performance on the altitude question. All subjects consistently (and in all conditions) found it more difficult to report numbers (in spite of the fact that they felt that the numbers were large, sharp and bright enough to be clearly visible) than the position of the velocity vector symbol. The fact that longer exposure time was needed for the HUD questions than for the visual questions is also attributed to the altitude question. Responses to the velocity vector question were just as fast and accurate as responses to the scene questions. This suggests that lines and shapes may be easier to recognize than alpha-numeric characters. Naish (1961) also found that minimizing and optimally locating digital information improved the "flyability" of his HUD.

The Effect of Divided Attention.

Paying attention to both the HUD symbology and the external scene slides simultaneously did not reduce the efficiency with which pilots extracted information from either field. The previous two conclusions regarding the effect of superimposed fields indicate that there was no interference between the superimposed fields, i.e., just because the pilot was presented with two superimposed sets of information, he did not have to perceive them together. He was able to very efficiently attend to the set he needed information from at the time and ignore the other set. The conclusion regarding the effect of divided attention indicates that pilots did not become fascinated with and visually fixate on one of the superimposed sets of information to the exclusion of the other set. When they needed to get information from both sets, the pilots were able to pay attention to both fields just as efficiently as they did to only one of the fields. None of the pilots had any difficulty extracting one item of information from the HUD symbology such as the altitude and one from the scene such as the presence or absence of airtraffic, both in only 112 msec. In fact, often the subject voluntarily offered the other two items of information as well (position of velocity vector, identity of airport), indicating that he was able to pick up more information than he was required to do. This may be an indication that the task of perceiving two items of information in 112 msec was too easy. Clearly, another study should be performed using several exposure times to quantify the presentation duration/content/accuracy trade off.

It is also important to note that pilots were able to extract information from the HUD symbology more efficiently under divided attention (when they also had to pay attention to the external scene), than they did under undivided attention (whether they viewed the HUD with a homogeneous background, or with the external scene, but were asked to pay attention to the HUD only). This was true even for those pilots who verbally expressed doubt as to their ability to "see" both sets efficiently. This phenomenon of performing slightly better (although not statistically significant) under divided attention was also found in Mackworth's study (1962c), where subjects named more colors correctly when this task was coupled with calling numbers, than when the task was performed alone, and in Naish's (1964) second experiment where subjects reacted to the appearance of a light faster when they also had to perform a tracking task than when they had to respond to the light alone. Since in all three studies the two stimuli were unrelated, the increase in performance cannot be attributed to better defined or more information due to redundancy. This suggests that perhaps the integration of information sources into the same visual field may have some facilitating effect on performance, i.e., perceiving two items from superimposed sources may take less time than perceiving two equivalent items from a single source. The reason may be that dealing with superimposed fields is more interesting and demanding than dealing with one type of information, therefore it may increase vigilance. Davies and Tune (1969) in their review of the vigilance related literature found that presenting signals simultaneously to two modalities (such as visual and auditory) often results in a higher level of overall performance than in single modality conditions. Storoh (1971) in his review of the vigilance literature shows that increasing the complexity of simple visual tasks increases performance. For example, when subjects had to monitor two or three clocks and respond to "double jumps" of the pointer, they performed better than when they only monitored one clock. The suggested explanation was that increased complexity initially results in greater alertness, and thus improves performance. However, performance was better on two clocks tham on three clocks, indicating that there is a delicate balance between alertness and workload. The present study, as well as the above mentioned studies by Mackworth (1962c) and Naish (1964) limited attention to only two stimuli. With higher workloads superimposed fields may or may not be as facilitating.

Theoretical Considerations.

The results of the present study do not conform precisely to either of the attention theories reported earlier. The fact that two (and sometimes more) items of information were successfully extracted during one fixation period could be interpreted to mean that information was processed in parallel, as Deutsch and Deutsch (1963) would predict. However, if we consider the duration of the afterimage which may occur under certain viewing conditions, it is possible that the second item of information was picked up from the afterimage in a serial fashion, as Broadbent's (1958) theory would indicate.

Surveying the raw data indicates that responses to the second question were often less accurate than responses to the first question. This again may indicate sequential processing. However, it is also possible that this reduction in performance was due to the angular separation of the stimuli. Since the two items of information were always separated by 3 to 5-deg. (which is larger than the 1 to 2-deg. sharp foveal vision), and by instruction the pilot always should have looked at one of the target stimuli, the other stimulus may have been perceived simultaneously with the first, but would not be focused as sharply on his retina. Indeed, the raw data suggested that the closer two target stimuli were to each other the higher the percentage of correct answers to the second question. This again suggests a parallel processing model.

While the data do not clearly specify the attention mechanisms involved in processing simultaneously presented visual stimuli, the results clearly indicate that there was no significant time delay in the processing. Performance did not decrease when one question pertained to the HUD and one to the scene compared to performance involving two external scene or two HUD questions.

One interpretation may be that the reason pilots did not need any time to switch attention, or "frame of reference" was that they did not use two reference frames for the superimposed information sets. Perhaps the classification of information into sets based on their physical and logistic characteristics is not the proper one. Weinberg (1975), a system theorist, points out that where a human operator is part of the system, the observation can not be looked at without also looking at the observer. For example, it may not be enough to look at the physical differences of sets, because the differentiation of sets may have come from within the observer, i.e., each set presupposes a whole group of other sets that were derived from personal experience, therefore may be different for each person. A set may be also defined solely by the intent or goal of the operator, rather than by the physical similarities of its components. For example, when a pilot is flying an approach with a HUD, and his immediate intent is to determine the vertical position of his aircraft in relationship to the runway touchdown point, his set may include the glide-slope and altitude information from the HUD, and the apparent size and shape of the runway and other known visual "guideposts" (such as tall buildings) visible in the external scene. In other words, his chosen set of information will include all of the visual cues available that would aid him in attaining his goal, regardless of the source of the information. The components of the set of information that establishes vertical position will likely be somewhat different from pilot to pilot, based on their previous training and experience.

As the intent of the pilot changes, so will his attention set change. If there is any cognitive switching going on it may be between two sets each of which is defined by different goals, e.g., changing attention from vertical position to lateral alignment to airspeed. Clearly then, the usefulness of the HUD symbology would depend on whether the needed information was present and how easily it could be perceived and understood. The question then should be changed from whether superimposing the HUD on the external scene will cause interference to: what kind of information, how much of it, and in what form should be presented on the HUD to enable the pilot to fly most efficiently?

Suggestions for Further Research.

It must be pointed out that the present study was conducted under static, laboratory conditions, and the results and conclusions may not be applicable to real flight situations. One of the purposes of this study, as of other studies (Haines, 1978; Haines & Guercio, 1978; Hodges, 1978) in the joint FAA/NASA HUD Concept Evaluation Project was to critically evaluate the adequacy of laboratory techniques for use in head-up display assessment studies. In order to evaluate the validity of both the present laboratory technique and the results of this study on a more general basis, i.e., whether the results would be the same when the cognitive task was coupled with manual tasks, it is necessary to repeat it in a dynamic, flight-simulator in which the HUD symbology and background scene are constantly in coordinated motion and in which a more realistic pilot workload is involved.

To investigate some of the theoretical questions posed by the present study, an experiment is proposed using dynamic superimposed stimuli to find out how the pilot clusters (perhaps by means of reducing the extent of his eye scan and/or focusing his attention) the visual information available to him in his forward line of sight into functional sets. The specific questions that should be addressed are: Does the pilot in fact mix information from the two fields? How many items of information can he handle at any one time? How does the spatial relationship of successive attention sets affect performance, i.e., is there in fact some cognitive switching going on from set to set? Performance would be assessed by recording eye movements, objective flight performance data such as glideslope tracking, and by subjective reports from the pilots.

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# APPENDIX

## *SURVEY OF RELATED LITERATURE*

"One of the chief advantages claimed for the HUD is that it permits placement of display information in the same line of view as the outside world information, thus enabling the pilot to combine the two reference sources. The validity of this assertion is subject to challenge, however, and it has become one of the most important controversies surrounding the head-up display." (Jenney, Malone & Schweickert, 1971, p. VII-29)

The controversy centers around man's ability to attend to, i.e., perceive and make effective use of two complex sets of information presented simultaneously in the same visual field. The literature reflects three basic types of theories: (a) Man has a single channel capacity, therefore he processes information sequentially (Broadbent, 1958). (b) Man has multichannel capacity, and is quite capable of parallel information processing (Deutsch & Deutsch, 1963). (c) Both sequential and parallel processing may occur during the different segments of acquisition (Treisman, 1960; Reynolds, 1964; Neisser, 1967).

Although all of these attention theories are based on auditory experiments, they will be presented briefly, because they have often been generalized to account for visual sensory data processing. In fact, <u>there is no specific attention-switching theory for visual attention to date in the psychology literature</u>.

In addition to the theories of attention mentioned above, this appendix presents reviews of several specific studies focusing on visual attention, and the attention-switching related studies of Naish (1964) that were performed in connection with the development of HUD.

### <u>Theories of Attention</u>

<u>Sequential processing</u>. The sequential processing, or single channel theory of attention was originally developed by Broadbent (1958). The model is based on an extensive series of experiments, but the crucial one is the so called "split-span" experiment (Broadbent, 1954), in which subjects were presented three pairs of digits, one member of the pair being presented to one ear at the same time the other member of the pair is presented to the other ear. Subjects tended to report the digits according to which ear

they were heard through rather than by pairs. This finding indicated to Broadbent that processing takes place sequentially rather than simultaneously, and must involve several stages. He analyzed the human function in terms of the flow of information within the organism, and presented the summary of his conclusions about human attention in a flow diagram model (Figure 9), which came to be known as the filter theory of attention.

According to the model, information enters the system through the senses in many parallel channels, and often simultaneously. If more than one stimulus arrives at the same time, they are temporarily stored in a buffer or short term memory. From here the messages enter into a filter that is predisposed to select a particular input by means of focused attention, and forward its message to a limited capacity channel (limited meaning that only one message can enter it at a time) for perceptual analysis. This multiplexing mechanism has access to the long term memory as well. Processed information enters the effectors (output mechanisms such as hands, vocal cords, etc.) and a particular response results as an outcome. In the meantime the other messages are held in short term storage in the form of echos or images, for 2 to 3 sec. During this time they may be accessed and processed by the system in a serial fashion, thus preventing overload of the system. The processing of simultaneously entered complex messages fails when the processing of the first message selected takes longer than the decay time in the storage system.

Filter theory implies that attention can not be divided, because the mechanisms of consciousness are such that only one input can be processed at a time. There have been numerous experiments supporting this theory. For example, studies prompted by the overload problem of the air-traffic controller indicated that the listeners either completely failed to deal with simultaneous auditory messages, or at best, handled them successively (Broadbent, 1952; 1954; Mowbray, 1953, 1954; Poulton, 1953; Spieth, Curtis & Webster, 1954; Webster & Solomon, 1955). Subjects also failed to process information simultaneously when an auditory and a visual item were paired together (Broadbent & Gregory, 1961; Madsen, Rollins & Senf, 1970). However, it was found that the tendency to report items by channel can be overcome by other grouping factors, such as content (Broadbent & Gregory, 1964; Yntema & Trask, 1963).

In summary, the split-span experiments showed that in auditory studies, subjects prefer to organise their responses by the perceived origin of the input. These results, however, should not be regarded as evidence that subjects have to respond in this manner, or that they can not and do not perceive simultaneous inputs in parallel

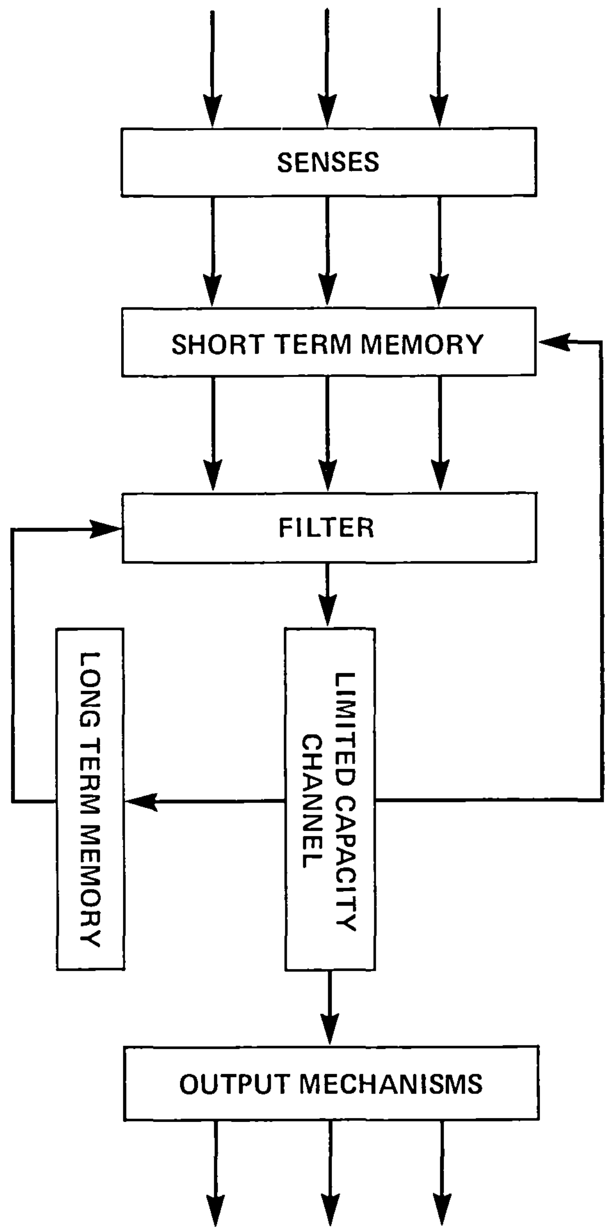


Figure 9. Broadbent's filter theory (after Broadbent, 1958).

(Kahneman, 1973).

<u>Modified sequential processing</u>. A modified sequential processing model was proposed by Treisman (1960). She modified Broadbent's filter theory by proposing that filtering is a two stage process. At the first stage messages are analyzed and assigned channels on such properties as loudness, pitch, and position of sound. Each property is also given weight based on the degree to which attention is focused on it. From here the messages pass through a network of what Treisman calls pattern recognizers or dictionary units where the strongest message triggers a unit and it gets recognized.

Treisman based her theory on a series of "speech shadowing" experiments (Moray, 1959; Treisman, 1960, 1964a, 1964b, 1964c) where the subject was presented with separate messages in each ear, and was asked to repeat (shadow) one of the messages while he was hearing it. In a later experiment (Treisman, 1969) target words were added to the stimulus words, to which the subject had to respond by tapping, in addition to shadowing. It was found that when the target words where given in a different voice than the stimulus words, subjects had no trouble at all responding to them whether they came in the shadowed ear or the ignored ear (99% accuracy for both conditions). However, when the target words were spoken by the same voice as the rest of the words, the response for the attended ear was 70% correct, and the ignored ear only 38%. Treisman proposed that parallel processing of two simultaneous inputs is possible if they do not reach the same analyzer, but serial processing is neccessary when the same analyzer must operate on both inputs.

<u>Parallel processing</u>. The parallel processing model is attributed to Deutsch and Deutsch (1963). They went one step further than Treisman and postulated that all incoming stimuli are perceived and analyzed in parallel at a preattentive level, regardless of whether attention was paid to it or not. However, a response is triggered only by the most important stimulus at the moment with responses to all other stimuli being prohibited. This implies that while perceptual analysis of incoming stimuli is parallel, responses to them are serial.

As support for their theory that conscious attention does not depend on focused attention, but the importance of the message, Deutsch and Deutsch (1963) site several studies. In one experiment by Moray (1959) the subjects were required to listen to the message in one ear, ignoring a different message in the other ear. But when the subject's name was called on the unattended ear, he responded to it. This result is supported by a later study by Horvath and Ellis (1961), who showed that subjects respond to their own name much more readily than to other names. Treisman (1960) found that even during sleep, subjects tend to respond to their name. However, in another study Treisman (1969) pointed out that responses to unexpected target words on the unattended ear are relatively rare, ranging from 6% to 50%, and that they seem to depend on the emotion attached to the stimulus. Emotionally neutral or irrelevant messages, even those with a change in the language, are not detected when not attended to (Cherry, 1953).

To sum up the existing attention theories then, there seems to be a general uncertainty about the mechanisms of attention, and the processes of attention switching. This confusion becomes even more pronounced, if one attempts to apply these attention theories derived from auditory studies to visual attention. Kahneman (1973) expressed this feeling aptly. He compared auditory attention where one has to pick one message out of a medley, to visual attention to one dancer in an ensemble. He writes:

> "It is tempting to speculate that the modern theory of attention could have taken a different course if Broadbent (1958) had been concerned with how one sees dancers rather than with how one hears messages. Since it is surely possible to see many dancers while attending to one, the concept of a filter that allows inputs into perception in single file might not been proposed. Deutsch and Deutsch (1963), on the other hand, might not have argued that attention does not alter perceptual analysis, because the difference between the perception of the prima ballerina and of lesser dancers is too obvious to be ignored." (p. 135)

## Studies in Visual Attention

Sampson and Spong (1961) and Sampson (1964) performed the exact visual analog of Broadbent's auditory split-span experiment, using the two eyes rather than the two ears. As Broadbent (1971) himself pointed out,

> "The results are markedly different. If in a set of six digits each pair is delivered simultaneously, one to one eye and one to the other, the typical order of response will be pair-by-pair rather than "eye-by-eye.". (p. 168)

This suggests that the two sets of information were processed in parallel, or in rapid succession. However, exposure times in the above experiment were too long (1100 msec) to shed light on how rapid the attention switching might have been.

Mackworth (1962a, 1962b, 1962c) presented rows of digits for short exposure times (63-2000 msec) and found that simultaneous presentation of all items was better than serial presentation of each digit successively, as measured by the time per recalled digit. For example, when a series of 12 digits was presented one-by-one for 63 msec each, and the subjects had to record the digit after each presentation, they recalled on the average two of the digits correctly, but when all 12 digits were presented simultaneously for 63 msec, they recalled over four of the digits correctly. On the average, a single digit had to be displayed approximately twice as long as a group of four digits in order that the same amount may be recalled. It was also found that exposure duration had an effect; up to about 1000 msec there was an additional correct answer for about every 300 msec. Since the subjects were able to recognize about three digits even at the lowest exposure time (63 msec), this resulted in about six correct answers for the 1000-msec exposure time. Longer exposure increased performance very little, for example, at 8 sec the subjects still recognized only 7.4 correct digits. Mackworth interprets these results in terms of the visual afterimage, which lasts about 1 sec, and the memory trace, which, in her estimation, should last at least 8 sec. She concludes that

> "The duration of the visual image is the limiting factor up to stimulus durations of one second, while at stimulus durations of longer than four seconds the limiting factor is the memory capacity." (Mackworth, 1962c, p. 59)

In further experiments Mackworth (1963) tachistoscopically presented rows of digits alone, rows of color patches alone, and digits superimposed on colors, for exposure durations of 27-2000 msec. The subject's task was to recall as many of the stimuli as he could. It was found that digits alone were easier to recall than colors alone. For example, the 100 msec exposure time produced 4.35 correct digits and 2.67 correct colors out of eight of each. Another important finding was that when subjects were presented with superimposed information sets (four digits over four colors), the total number of recalled items was more (4.34 digits and colors combined), than the mean of the recalled number of digits alone and the number of colors alone (3.35). Mackworth suggests that "each digit-color combination is recognized as a unitary figure-ground display, though it has to be described successively as a digit and a color. (p. 77)

Gould and Schaffer (1966) investigated the effect of divided attention on monitoring multichannel displays. In this study subjects had to monitor a display containing 4-16 channels, each channel represented by a digit. Two or more of the digits changed simultaneously and at different rates in different trials (6 or 12 per minute). The task was to compare the configuration of digits in the display to a criterion set on a smaller display, indicate whether it was the same or different, and tell whether the display changed. Attention was divided by giving the subjects a secondary task, such as permutation of alphabetic characters. Performance was measured by the number of changing signals detected and the error rate. It was found that, while performance was affected by the number of channels and the rate of change in the displays, it did not differ significantly when attention was divided by a secondary task compared to when full attention was paid to the display only.

Dick (1972) performed two experiments using tachistoscopic recognition in order to find the effects of visual masking on a parallel mechanism and those of postexposure cueing on a serial mechanism. Subjects were presented three rows of four letters of which one or two of the rows may have been masked by a grid of lines. The letters were exposed for 50 msec and the masking grid for 75 msec. Three different tone cues were used to indicate to the subject which row to report. The tone cue was presented either directly after the termination of the stimuli or 200 msec later. It was found that the results of the masking and those of the cueing indicate different types of processing. On the one hand, the greater the amount of display that was masked, the higher the performance on the unmasked rows. This suggests parallel processing, the reason being that the subjects were paying attention to the entire set of information, not just the row indicated by the cue. On the other hand, the delay of the tone cue reduced the accuracy of reporting, suggesting sequential processing, the reason being that the subjects were paying attention to the indicated line first and then the rest of the display. Dick concluded that since both the masking and reporting-cue manipulations were effective in the same experiment, both the parallel and the sequential processing mechanisms must have been operative. He suggests that simultaneously received visual information is not only stored in iconic memory, but visual analysis such as spatial position, shape, orientation, or the presence of mask is performed here, and probably at the preattentive stage. This parallel system is connected to a sequential system in which verbal labels are attached. The order of transfer from one system to the other may be either self-induced (e.g., reading habits and biases) or by instruction (such as the reporting tone cue). If the instruction arrives late, the subject begins to transfer items according to his own criteria. These may be different from the incoming instruction, in which case he has to switch attention and alter the order of transfer, resulting in loss of accuracy and/or increased performance time.

In summary, the above studies of visual attention show that visual attention may be successfully divided between inputs, and that this is probably an indication that processing is taking place either in parallel, or in a coupled parallel and sequential mode.

### The Naish Studies

In the early developmental stage of the HUD Naish (1964, 1970) addressed the attention switching problem in a series of experiments. In the first experiment he looked at the effect of the relative positions of simple visual fields on performance. The external visual scene was represented by a continuous stream of numerals presented at rates of .6 to 1 per sec and situated 240 in. from the subject's eyes in the forward, head-up position, for all conditions. The display was represented by a rotating black and white helix which was presented in three positions: superimposed on the forward view, at the same distance (as if collimated), superimposed on the forward view, but only about 25 in. from the eyes (as if on the windshield), and at a head-down (instrument panel) position. Five linear display speeds from .47 to 4.78 in./sec were tested. The task was to eliminate apparent left and right movements of the helix while calling out the numbers with an accuracy of at least 95%. Tracking errors were compared for the three relative positions and the five linear speeds, but no significant differences were found. Naish noted that this may have been due to the simplicity of the stimuli and tasks, i.e., pilots had enough time to perform well in all conditions.

In the second experiment more complex visual fields were used. The external scene was represented by a 30 deg. field in which a dim light would appear at random positions and at random time intervals. The display information was represented by a two-dimensional command signal, displayed in two positions: collimated and superimposed on the external scene (head-up position), or in the head-down (instrument panel) position. The subject's task was to track the signals and respond to the appearance of a light in the external scene. In a balanced experimental design the two tasks were performed separately and in parallel, in both the head-up and head-down modes. This study shed light on two important issues: (a) The relative position of the two information fields had a significant effect on performing two tasks at the same time. It was found that both display tracking and reacting to the external light source were performed more efficiently in the head-up (superimposed) position than when the two fields were separated. Mean response time to the appearance of the light was .88 sec in the superimposed condition and 3.86 sec in the head-down (separate fields) mode. Naish inferred that 3 sec were needed for the head-down to head-up transition. (b) Superimposing the two fields did not have a detrimental effect on each other. In the head-up position, tracking accuracy on the display was the same when performed alone or concurrently with the external scene. Mean aquisition times for the external task were 1.23 sec when performed alone, and .88 sec when performed concurrently in the head-up, superimposed condition. This shows that there was no deterioration of performance due to divided attention.

In a third experiment critical observation of complex superimposed fields was tested in a flight simulator. The external visual field was represented by a simulated airfield, and command information was presented to the pilot on a collimated combiner glass. The task was to "fly the aircraft" through a set of maneuvers in the vicinity of the simulated airfield following the HUD information. On the 10th trial a small 3-deg. error was introduced unexpectedly into the HUD at the last leg of the maneuver, resulting in misalignment with the runway. The hypothesis was that if the pilots did not pay critical attention to the external scene, they would follow the HUD command. All pilots, however, ignored the divergent information, and flew visually along the runway. Naish (1970) concluded that

> "a head-up display might help eliminate or modify the transition in real flight, since the external field was observed critically while occupied (continuously) with the display field in a representative manner." (p. 10)

This assumption was tested in a follow-up flight test (Naish, 1964). After adequate training with the use of the HUD information, pilots were instructed to execute low-altitude, terrain-following maneuvers, guided by the HUD information. The efficiency with which the HUD was used was measured by deviation from the glide path, and it was found that performance was satisfactory. To assess how well the pilots observed the outside world while flying with the HUD, two methods were used. One was to insert a false command into the HUD, telling the pilot to "fly down" when it was not appropriate. Not all the 50 pilots participating in this test were given this command, but all who did receive it ignored it and switched to flying visually. Naish (1970) points out that "The false command technique was not used in all cases because adequate experience could not always be assumed." The other method was to ask the pilot to give a continuous verbal description of the visual scene while flying with the HUD. Only one of the subjects was given this task, and he spent about 50% of the time describing the outside scene correctly while executing an accurate approach. While the results of the flight test did not prove "continuous and complete awareness of both fields," they indicated to Naish that pilots got adequate information from both fields to enable them to fly the aircraft safely and efficiently, and that the results from the laboratory experiments could be transfered to real-life situations.

Regardless whether information processing takes place sequentially or in parallel, both the theoretical and the applied studies in visual attention indicate that man is capable of processing more than one item of information from the same visual field within a very short time. However, all of the studies cited in the section entitled Studies in Visual Attention used simple stimuli, such as digits or letters, and with the exception of Mackworth's (1962c) study, all used only one set of information, and investigated the subject's ability to perceive the various members of that one set. Naish used two sets of information sources that were more complex, but they were also presented dynamically, and required the subject to give two types of responses: a manual tracking response that is in itself a complex task, and a verbal response. The dual task may have influenced the cognitive processes involved in processing the two sets of information.

The aim of the present study was to look only at the cognitive effects of superimposed fields that may be encountered by pilots flying with a HUD. This was accomplished by using complex stimuli that were actual photographic representations of the real world and actual HUD equivalent symbology displays, in a static presentation that requires the subject to give only verbal response. The results should aid in evaluating the information transfer effectiveness of complex visual fields, and serve as a stepping stone to further studies integrating several responses.

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16. Abstract

"The objective of the present study was to determine pilot's ability to quickly and accurately extract information from either one or both of two superimposed sources of information: (a) static, aerial, color 35-mm slides of external runway environments and (b) slides of corresponding static head-up display (HUD) symbology. They were presented by a three-channel tachistoscope for brief exposure times, by showing either the HUD alone, the scene alone, or the two slides superimposed. Cognitive performance of pilots was assessed by determining the percentage of correct answers given to two HUD-related questions, two scene related questions, or one HUD and one scene-related question. These questions could not be answered correctly unless and until the visual information had been perceived. Twelve commercial airline pilots served as subjects. An analysis of variance indicated that: (a) the presence of the HUD symbology slide did not reduce the pilot's ability to extract required information from the external scene slides, (b) the presence of the external (background) scene reduced the pilot's ability to extract information from the HUD slides by 5%, $F(1,11) = 51.6$, $p > 0.01$, and (c) paying attention to both fields simultaneously did not significantly change performance on either the HUD slides or the external scene slides.

17. Key Words (Suggested by Author(s))

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