EFFECTS OF FOVEAL INFORMATION PROCESSING

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INTRODUCTION

The art of oculometry has progressed a long way from the days of Jones, et.al., 1946, when they determined a pilot's lookpoint by subjectively judging motion pictures of a pilot's face frame by frame. Today, we have the ability to record a pilot's lookpoint with an accuracy of a dime's diameter on the instrument panel. These data are computer generated and recorded at a rate of 30 times a second. The technique (fig. 1) which allows this is to shine an infrared beam of light into the pilot's eye. Two reflections are returned to a video camera. The first is a broad (4 to 8 mm) reflection of the pupil, much like a cat's eye reflection from car headlights. The second is an intense pinpoint reflection from the surface of the cornea. From the video picture the computer determines the centers of each reflection and, based upon their relative positions, calculates the pilot's foveal lookpoint on the instrument panel. These lookpoint coordinates and pupil diameter are recorded for subsequent analysis. This paper will summarize the results of seven years of collecting and analyzing pilot scanning data.

SCANNING BEHAVIOR

Scanning is Subconscious

First of all, scanning by a pilot is a subconscious conditioned activity. Scanning becomes automatic for a pilot and this is the way it should be. If a pilot had to consciously think "I need altitude information, eyes look at the altimeter," the pilot would not function well in an aircraft cockpit. Since scanning is automatic for pilots, pilots are unreliable information sources concerning how they scan. Many myths have arisen as to how pilots gather information. One pilot has said, "I look between the attitude and directional gyro, defocus, and take everything in peripherally." Another has said, "I look at the instruments in a circular pattern." And some will say, "I never look at the altimeter. I get that information in my periphery." However, the data (Spady, 1978) indicates that in scanning, pilots have a home base (spending as much as 75% of their time there) — the attitude indicator. Looks at other instruments are made aperiodically as they have time to look at them for cross checks, then back to home base. There is no simple pattern to the sequence of looks at these other instruments. These looks may be dictated by several conditions such as uncertainty, need for more precise control, need to make an input to change aircraft state soon, etc.

Scanning Can Be Disrupted

If pilots are forced to "think" about something — that is, make a conscious decision — their scanning is disrupted. This causes the pilots to "stare" (Tole, 1982) at the instrument panel (generally the home base). This "staring" phenomena is worse with less experienced pilots (some "stare" as long as 10 to 15 seconds). Figure 2 shows the breakdown of the dwell histogram as cognitive tasks are forced upon the pilot. In this context a dwell is the continuous time spent looking at a particular instrument. The left figure shows a typical dwell histogram with a peak at about 0.5 seconds with a long tail out to about 2.5 seconds. The right figure no longer shows the peak at 0.5 seconds and many dwells longer than 5 seconds are plotted at the 5 seconds position at the right of the pilot. Not only do the less experienced pilots "stare" but their sequence of looking at the various instruments changes. Figure 3 shows what happens to the 10 most frequent scan sequences (a sequence in this case is the consecutive sequence of four instrument dwells) as a cognitive task is increased. Pilots 4 & 11 are the more experienced and pilot 9 is the least experienced. This disruption in scanning sequences lends credence to the hypothesis of being able to develop the ability to time share, which the more experienced pilots apparently have done. This is much like the situation of piano playing. If a person is very experienced he can play and carry on a conversation at the same time (pilots 4 and 11 have the same percentages for all mental loading conditions), but if he is a novice, he can do one or the other but not both (pilots 5, 9, and 10 decrease the percentage of the 10 most used under the no mental loading condition).

Scanning is Situation Dependent

The conditioned activity of scanning is different for each pilot. That is, the dwell percentages (percent of scanning time looking at an instrument), average dwell times (total time looking at an instrument divided by total number of looks at that instrument), and the sequences of scanning each instrument are different for each pilot. There is also a slight variation between test runs of the same conditions for each pilot. This indicates that scanning is situation-dependent. We do know, for instance, that if a pilot changes from an active controller to a system monitor his scanning behavior is different (Spady, 1978). As a controller, his percent and average dwell time on home base is increased with fewer looks at peripheral instruments. This is because his role has changed his information requirements. More information is needed to make control inputs than to monitor the position of needles (this is reflected in longer dwells). When dwells are classified (Harris, 1980) as monitoring or controlling dwells (no movement of controls or/movement of controls, respectively), the longer dwell times associated with monitoring becomes evident even when the pilot is making control inputs as needed.

The dwell histograms for monitoring and controlling are shown in figure 4. Controlling dwells can even be further classified by the number of control inputs being made during a dwell. The more the number of inputs, the longer the dwell. Figure 4 shows the histograms for 1 and 2 control inputs. The monitoring dwells are the shortest in duration and generally tend to be double peaked. This indicates that at least two processes are active in monitoring. Estimates of these two monitoring distributions are shown in figure 4 (Harris, 1980). It is believed that the shorter dwell, called glances, are what pilots are talking about when they say they are looking at instruments peripherally. They actually make a saccade to the instrument but they only want to know the orientation (o'clock position) of the needle. The longer dwells, called reads, are those dwells which are used to obtain more detailed information such as the actual position of the needle and perhaps information about rate of needle movement. As can be seen, these two curves overlap each other. This overlap prohibits us from knowing whether a dwell in the overlap region is a glance or a read. Therefore, we are forced to plot only one curve of all monitoring dwells.

Rate of Information Transfer

The relative amplitude of the glance peak (Harris, 1982 and Harris, 1981) has been found to be sensitive to the ability of the display to transfer information rapidly. For instance, figure 5 shows two monitoring dwell histograms. The solid one is the histogram for a conventional type of directional gyro. This type of display is a fixed pointer, generally the nose of an airplane outline, with a moving scale. However, the dotted line is the histogram for the same type of display with the addition of a movable index which can be placed on the movable scale at the desired aircraft heading. This gives an immediate indication of heading error and displacement of the index from the airplane's nose to the pilot. Consequently there are a lot more short dwells and fewer long dwells. Also notice that the read peak is shortened with the index present 0.4 versus 0.5 seconds.

Advanced Techniques

Finally, we have been trying to develop testing techniques and scanning analysis techniques that are sensitive to workload. One of the more promising testing and analysis techniques is one in which a side task is introduced, not to measure spare time, but to occupy or rob time from the pilot. The side task chosen is a number pattern recognition task (Tole, 1982). A series of three digits are presented aurally (0.75 seconds between digits). The pilot's task is to classify the triplet as positive or negative. A positive set would be a triplet whose first digit was lowest and last digit highest (e.g., 3-4-8) or whose first digit was highest and middle digit was lowest (e.g., 7-2-5). All other patterns are negative. The difficulty can be adjusted by varying the time interval between triplets. The reciprocal of the time interval is called the rate of presentation. The analysis of the eye scanning data is an offshoot from information theory. The entropy or randomness of the scanning is calculated. The entropy is then used with the dwell times to calculate an entropy rate.

These techniques were used to evaluate differences between two types of vertical speed indicators (Harris, 1982). One was the conventional round dial and the second was a vertical bar graph type. Pilot opinion was mixed as to which display was better. Figure 6 is a plot of the entropy rate of scanning for each display configuration plotted against the rate of presentation of the number triplet side task. As can be seen, there is only a very slight difference between the curves. This small difference corresponds to the mixed subjective evaluations. In both cases, as the rate of presentation is increased the entropy rate decreased. An exponential curve was fit to the data. As shown on the figure, the difference between the curves is a bias constant in the exponential term. This constant shifts the curve along the abscissa. The bias term was zero for the vertical vertical-speed indicator and 0.045 for the conventional vertical-speed indicator. This indicates that if the scanning workload of the two situations were to be made equal, then when flying with the vertical vertical-speed indicator the pilot would also have to be answering triplets at a rate of once every 22 seconds. This is not a very heavy workload difference and explains the reason that subjectively it was hard to discriminate. But it does show that the vertical vertical-speed indicator would be preferable in cases where workload was going to be high.

CONCLUDING REMARKS

A lot of progress has been made in the past several years in understanding the scanning behavior of pilots. However, there are still a lot of unknowns about scanning and the next several years should unravel some of these unknowns. A whole new era of display formats are forthcoming that will challenge us to unravel these unknowns so that cockpit displays can be assembled which will provide the most information accurately and quickly to the pilot so that he may perform safely all the tasks assigned to him.

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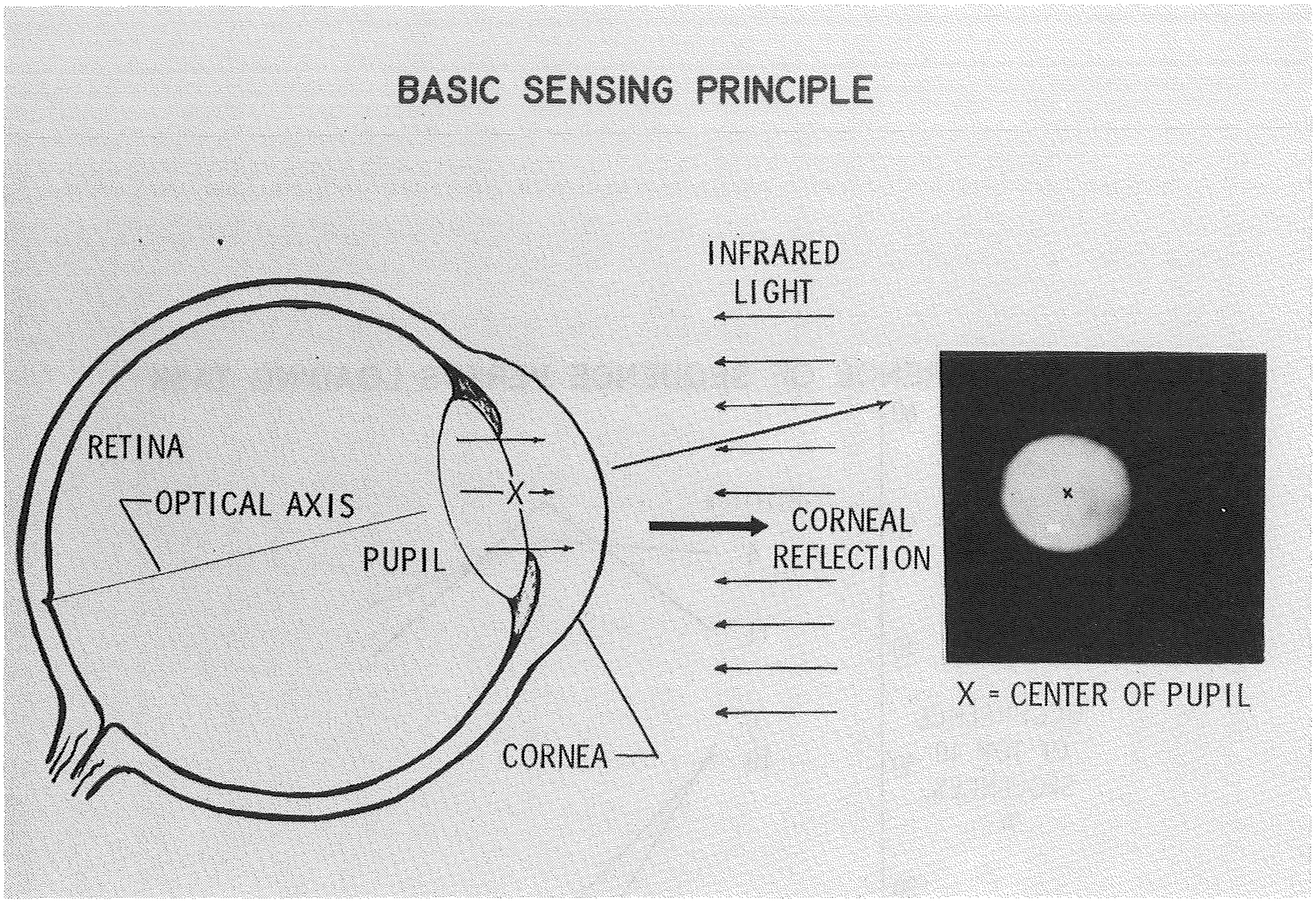


Figure 1

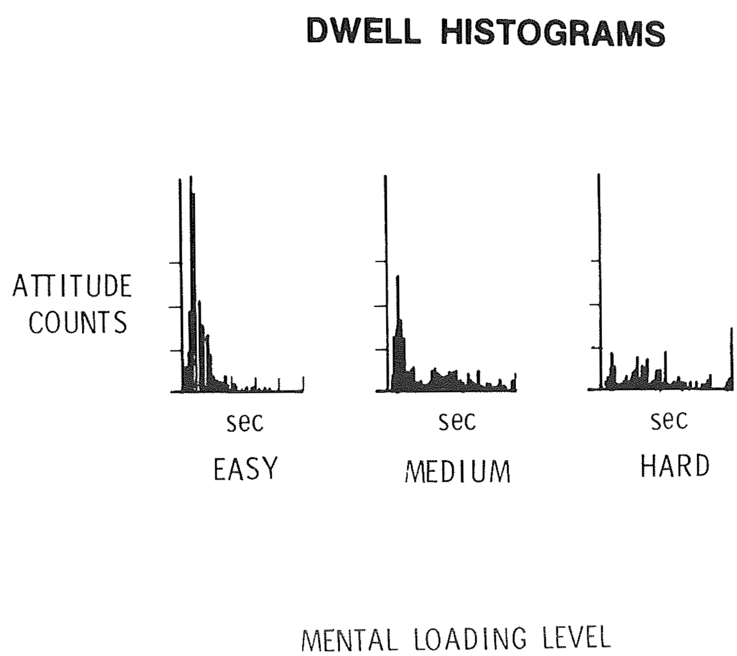


Figure 2

PERCENT OCCURRENCE OF SEQUENCE VERSUS LOADING TASK

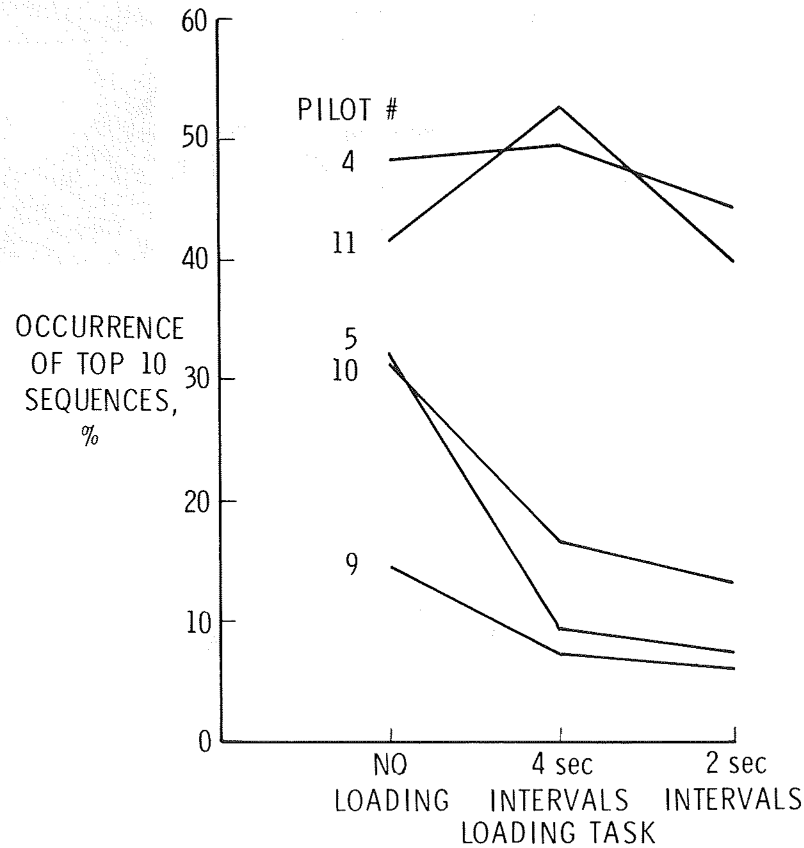


Figure 3

DWELL DISTRIBUTIONS

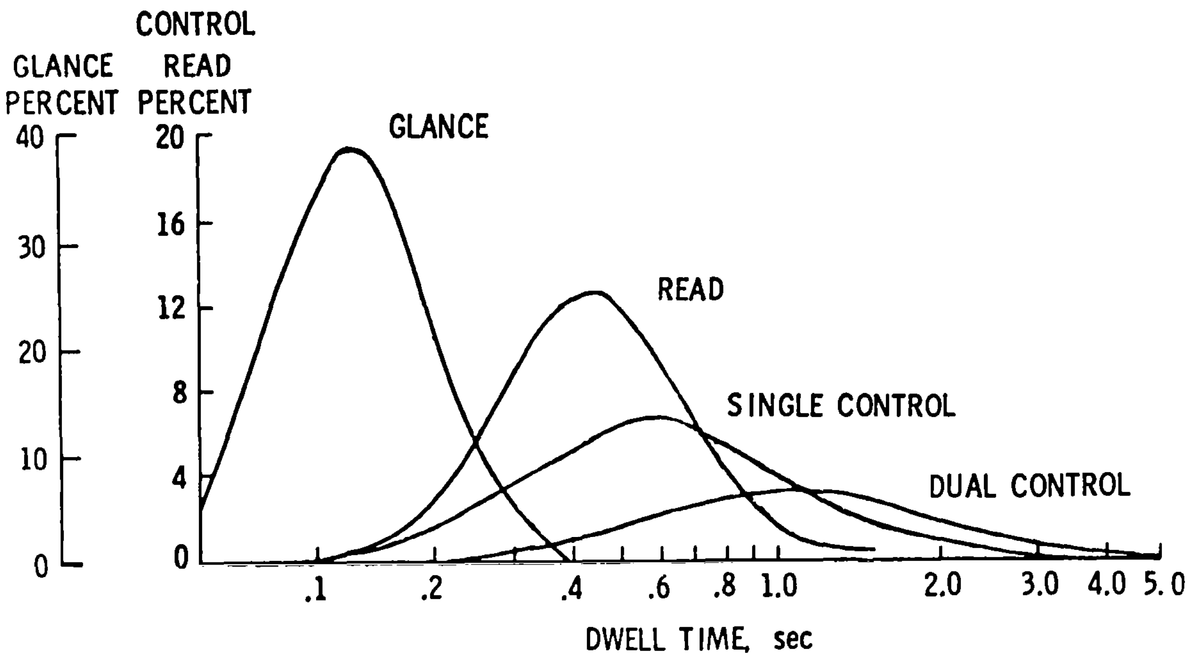


Figure 4

DIRECTIONAL GYRO MONITORING DWELL HISTOGRAM

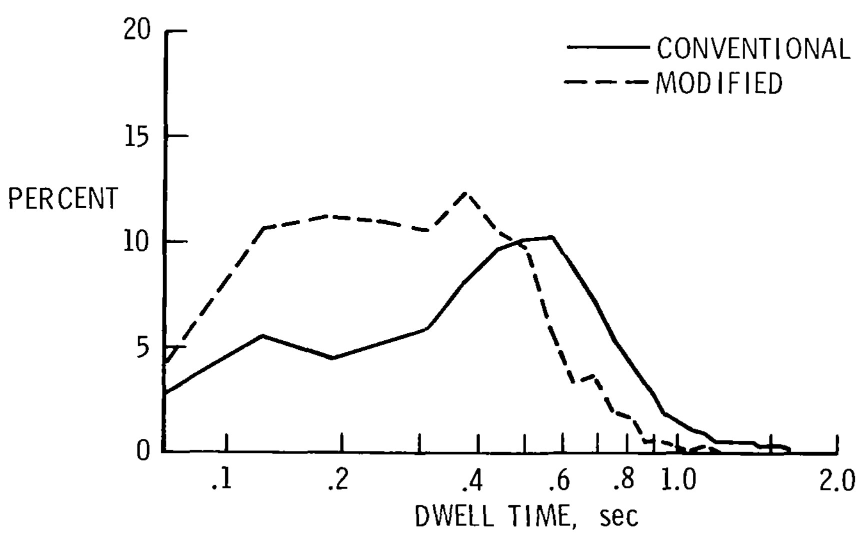
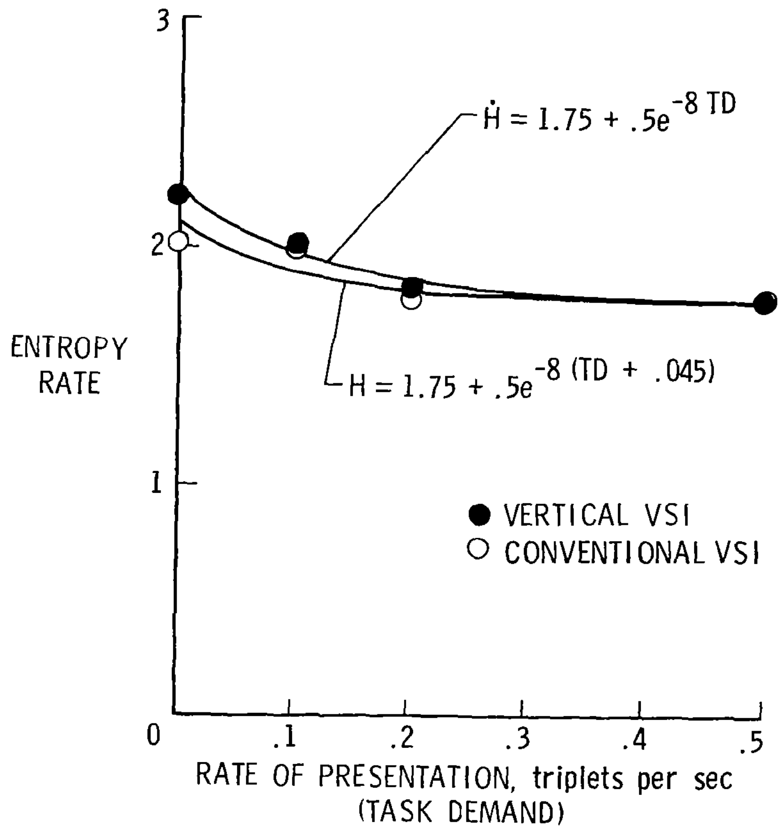


Figure 5



3
2
1
0
ENTROPY
RATE
Ḣ = 1.75 + .5e^-8 TD
H = 1.75 + .5e^-8 (TD + .045)
VERTICAL VSI
CONVENTIONAL VSI
.1
.2
.3
.4
.5
RATE OF PRESENTATION, triplets per sec
(TASK DEMAND)

Figure 6