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Pilot Scanning Patterns while Viewing Cockpit Displays of Traffic Information

By Stephen R. Ellis and Lawrence Stark

NASA Ames Research Center &
U.C. Berkeley Department of Physiological Optics

ABSTRACT

Scanning eye movements of airline pilots were recorded while they judged air traffic situations displayed on cockpit displays of traffic information (CDTI). The observed 1st order transition patterns between points of interest on the display showed reliable deviations from those patterns predicted by the assumption of statistical independence. However, both patterns of transitions correlated quite well with each other. Accordingly, the assumption of independence provided a surprisingly good model of the results. Never the less, the deviation between the observed patterns of transition and that based on the assumption of independence was for all subjects in the direction of increased determinism. Thus, the results provide objective evidence consistent with the existence of "scanpaths" in the data.

INTRODUCTION

In the following experiment we examine the spatio-temporal structure of scanning eye movements made by airline pilots while viewing a cockpit display of traffic information (CDTI) previously studied by Palmer, Jago, et. al. (2, see also ref. 6). While viewing the displays, the pilots had to determine if intruding aircraft would pass in front or behind their ownship. In particular we wished to examine the specific sequencing of fixations made with the goal of determining an information processing model of the in front/behind decisions the pilots made. Other aspects of the scanning will be discussed in future more detailed papers(see ref 5).

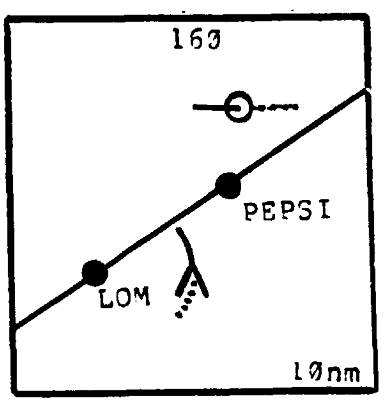
METHODS

Display conditions

A series of 24 track-up CDTI displays was generated on a calligraphic computer graphics system in the manner of Palmer et. al. (2,3). Each display depicted an encounter between two aircraft at the same altitude. (see inset of figure 2). The miss distances for all encounters were set at 6000 feet while ownship position was updated every 0.1 second and and the intruder was updated every 4 seconds. Map range was set at 18.5 km (10 nm). Each encounter consisted of 7 4-second updates; 2 before the intruder appeared, and 5 afterwards. The display was blanked in such a way that after the last update, there remained 44 seconds before the fight paths of the aircraft crossed. After the display was blanked, the subject was prompted to decide if the intruder would pass in front or behind ownship.

The encounters represented both straight and turning horizontal encounter geometries. Turn rate was constant at 1.5 degrees/second. All aircraft had 32 seconds of previously tracked positions displayed as 8 dots of trail, one for each update, and had a 32 second predictor (see insert of figure 1 for sample display)

Figure 1



Two sets of identical encounters were prepared: in one all aircraft had "straight" predictors which were based on extrapolation of current ground speed, in the other "curved" predictors were used which were based on current ground speed and turn rate. In addition to ownship and the intruder the display contained two geographical locations (LOM and PEPSI) and a route shown as a solid line. All trajectories crossed near LOM, a fact neither pointed out to the subjects nor discovered by them during the course of the experiment.

Direction of gaze data were recorded with a Gulf and Western 1994 pupilometer-based eye monitor which was calibrated by recording fixations at 25 reference points in a 5 X 5 array, 14 degrees/side, centered in the subject's forward field of view. The display itself subtended a rectangle 12 by 10 degrees at the viewing distance of 75 cm. The eye monitor output (x,y direction of gaze and pupil diameter), the subjects signals, and the time markers from the videotape were all digitally recorded. The sample rate was 33 hz, the maximum allowable by the eye monitor.

Subjects

Eight airline pilots were subjects in the experiment. All had had at least 3 hours experience in previous experiments using similar CDTI displays and requiring similar in front behind judgements. All had at least average performance in these previous studies.

Procedure

During an orientation session before each experiment, the subjects were told that the purpose of the experiment was to determine if pupilary changes could be used to predict their in front/behind judgements. Lengthly briefing was unnecessary due to their extensive familiarity with the CDTI project in general and the display format in particular; the meaning of all parts of the symbology was, however, reviewed and each subject was given about 20 minutes practice making in front/behind judgements before their scanning patterns were recorded. After the initial practice, the eye monitor was adjusted to track the left eye An initial 25 point calibration was taken by having the subject signal when he had fixated each of the reference points. The median x,y position taken during each of these fixations provided the basis for subsequent linearization and removal of cross-talk. Interspersed between data gathered during the encounters were reset calibrations taken to correct for drift by having the subject refixate a position corresponding to the center of the calibration grid. A reset calibration was taken whenever the signal was observed to drift more than about 1.0 degree.

Data Processing

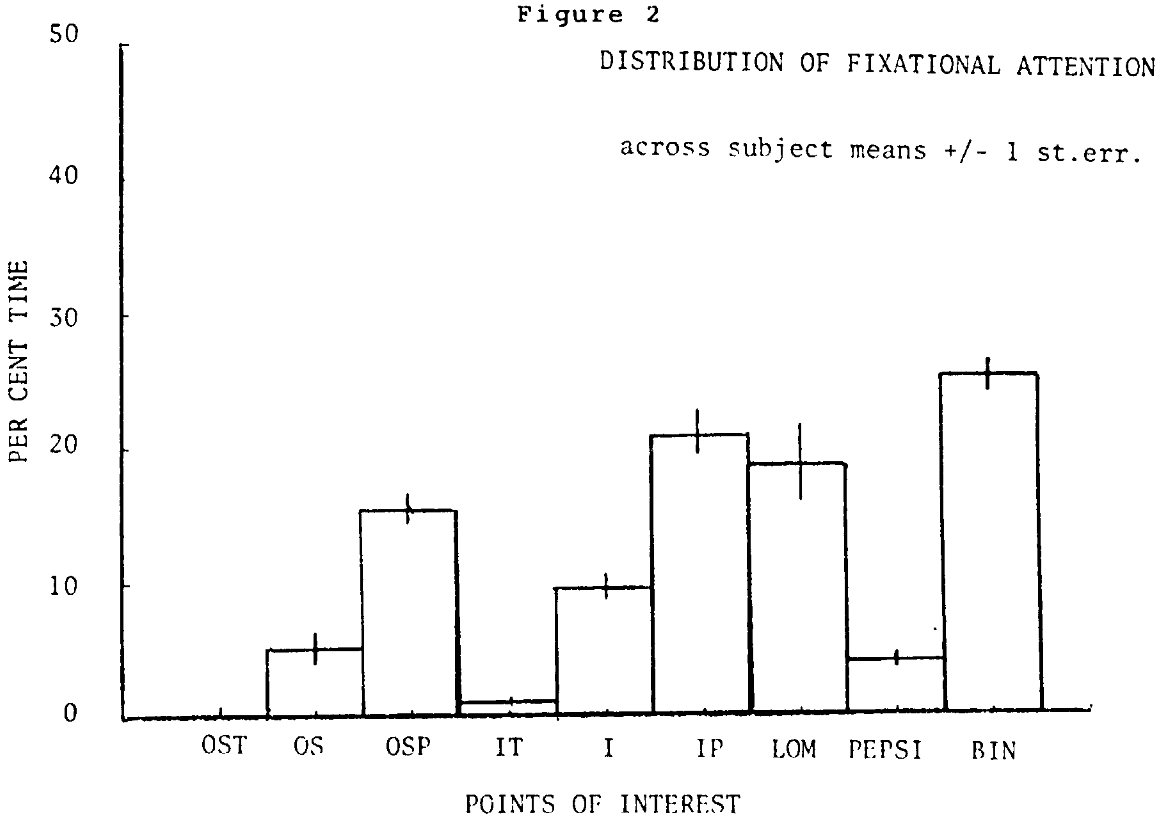
After the experiment, the data were transferred to a PDP-11/70 computer where it was linearized according to a piecewise-linear approximation derived from the calibration fixations. Fixation locations were determined by passing a space-time window through the data and identifying fixations as those clusters of temporally contiguous datapoints representing at least 90 msec (3 samples) falling within a square region 0.82 degrees(side, approximately the resolution of the eye monitor. If a cluster of data points potentially considered a fixation were interrupted by less than 90 msec of saturated values, they were considered as a single fixation. This protected fixations from being interrupted by blinks. Longer interruptions resulted in their being considered as two separate fixations.

After identifying the positions, duration, and onset time of all fixations, the data were correlated with records of the positions of all points of interest as a function of time after the beginning of each encounter. Thus, each fixation could be assigned to one of eight possible points of interest: the end of ownship's trail (OST), ownship present position (OS), the end of ownship's predictor (OSP), the end of intruder's trail (IT), intruder's current position (I), the end of the intruder's predictor (IP), location PEPSI (PEP), and location LOM (LOM). (see figures 1 and 2) All fixations not within 2 degrees of any of the above points of interest were assigned to the BIN. The data were then tabulated to determine overall distribution of fixation duration as well as separate distributions for each point of interest. Per cent of time spent at each point of interest was determined.

RESULTS

The pilots distributed their fixational attention across the the eight points of interest in a highly stereotyped manner as indicated in figure 2.

Figure 2



Their distributions of attention reflect the differential usefulness of the spatial information at each point of interest for the in front/behind judgement that they were required to make. Earlier studies of this particular display had shown, for example, that the presense or absence of the trail had no effect on accuracy of the pilots judgements, whereas the presense and typê of predictor was very important (2). The higher proportion of viewing time on the location LOM probably occured because it was the point of intersection of the flight paths for all the encounters.

The differential probability of viewing the various points of interest leads to a constraint on the scanning sequences that could produce the impression of sequential scanning, namely that transitions between high probability points of interest are likely simply due to the zero order probability of viewing the respective points. Accordingly, any claim for the observation of repetitive sequences in the the transition patterns among points of interest must first show that the extent of the "sequenciness" exceeds that which could be produced by the zero order probabilities.

We have examined this possibility by using a method described by Senders <u>et</u>. <u>al</u>, (4). They note that the joint assumption of 1) statistical independence of the transitions and 2) the existence of unobserved transitions from each point of interest to itself provides a means of calculating p(a to b), probability of a transition between any two points of interest, provided p(a), p(b), the zero order probabilities of the two points are known.

$$p(a\ to\ b) = \frac{p(a)p(b)}{1 - \sum_{i}^{n} p(i)^2}$$

We have used these calculated probabilities to determine expected frequencies of 1st order transitions between points of interest to compare with observed transition frequencies. This comparison was made on a subject by subject basis with a chi-square goodness of fit test on the entire distribution of observed transitions with that of expected transitions. The very low probability of viewing the end of the aircraft's trails, resulted, however, in very low expected frequencies for some of the transitions. Thus, it was necessary to collapse some of the transitions with expected frequencies less than 4.0 in order to insure that not more than 20% of the terms in the chi-square calculation had expected frequencies less than 5.

Table 1

Subj	X-sqr(df)	Number of transitions	Corr	Corr(df) log	H(matrix) observed bits	H(matrix) expected bits
1	35.[illegible]9(12)p<.01	154	.965	.844(39)	1.606	1.785
2	152.55(21)p<.001	417	.962	.785(51)	1.940	1.980
3	134.78(27) " "	409	.943	.719(43)	1.846	2.115
4	97.28(19) " "	348	.955	.747(49)	1.838	1.978
5	85.80(25) " "	270	.935	.794(43)	2.003	2.197
6	84.54(30) " "	431	.970	.843(57)	2.282	2.509
7	173.81(24) " "	429	.962	.821(48)	1.885	2.104
8	78.26(22) " "	275	.945	.721([illegible]3)	2.002	2.183

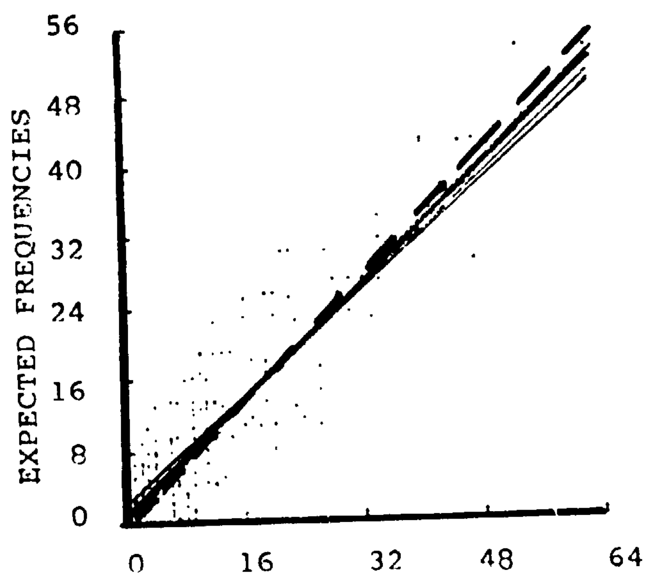
The chi-square test showed for every subject a highly reliable difference between the observed and expected transition frequencies. The reliability of this difference was partly due to the very great statistical power of the test since the total number of transitions analyzed for each subject ranged between 154 and 431. Furthermore, the test neither addresses the magnitude nor the direction of the deviation.

Accordingly, in order to assess the extent of the deviation each subject's expected transition frequencies were ploted against his corresponding observed frequencies. In a such a plot a perfect prediction corresponds to a linear regression with a slope of 1.0 and correlation of 1.0. As is clear from figure 3, the slope of the regressions for each subject are quite close to 1.0 (dashed line) and there is a strong linear relation between the observed and expected frequencies.

Figure 3

FREQUENCIES OF TRANSITION 0TH ORDER MODEL

(ALL SUBJECTS)



Two correlations between observed and expected frequencies are shown in table 1 for each subject. The first is the pearson correlation corresponding to the regresssions shown in figure 3. The second is a pearson correlation based on log transforms of both expected and observed frequencies which corrects for the skew in the marginal distributions of observed and expected frequencies.

Though there exists a reliable deviation between the observed and expected frequencies, the independence model provides a surprisingly good prediction of the actual 1st order transition pattern. However, the chi-square test comparing observed and expected transition frequencies provides no indication of the direction of the deviation. The observed distribution could, for example, be more rectangular than that predicted, i.e. the transition frequencies in any row of the 1st order matrix are more equal to each other. Such a deviation would be in the direction of less determinism. Conversely, the observed distribution could be less even with higher peaks and lower valleys; such a deviation would be in the direction of more determinism. The most deterministic case being that with only one type of transition occuring on each row of the 1st order matrix.

We assessed the direction of the actual deviation on a subject by subject basis by treating each ith row of the 1st order transition matrix as a probability vector and calculating H(i), the "information" in bits contained in it. The total "information" in the matrix, H(matrix), was calculated as a weighted average of the rows where n(i), the total number of transitions in each row, providing the relative weights and p(i,j) was the probability of a transition to point j given a previous point of interest i.

$$H(\text{matrix}) = \frac{n(i)\left[-\sum_{j=1}^{n} p(i,j)\log_2 p(i,j)\right]}{N}, \quad N = \sum_{1}^{n} n(i).$$

This measure of uncertainty when applied to each subject's observed and expected transition matrices consistently indicated that the observed transition matrices were more deterministic than the expected matrices (two-tailed sign test $p < .008$). thus establishing the direction of the statistically significant chi-square previously discussed.

DISCUSSION

The above results show that a surprisingly unstructured model of the transition pattern of fixational eye movements can provide an approximation of the actual pattern of transition among points of interest on a simple display. To the extent this approximation is correct the results are consistent with Senders visual sampling model. It predicts the number of looks at a point of interest as a function of the bandpass of the signal presented there. (4). The collection of the eye movement data over an extended period of time and across different display conditions, however, raises the possibility that the data reflect the mixing of a variety of scanning strategies and that the transition pattern of the subjects was statistically nonstationary. This procedure would bias the results against evidence of deterministic 1st order transition patterns. Thus, the observation that all the subjects transition patterns deviated from that calculated from the independence model in the direction of more determinism is particularly significant and provides some support for the hypothesis of Noton and Stark (1) that visual scanning is characterized by nonrandom repetitive sequences of fixations which they called scanpaths.

Clearly, the way to more explicitly demonstrate these patterns is to study situations in which the covert switching of information processing strategies can be externalized and used to separate the eye movement data corresponding to different strategies. Indeed, the extent of the deviation of the scanning pattern from that expected by statistical independence may reflect different information loads on the pilot. Simple monitoring may be well modeled by a independence model as used above, while more difficult procedure-following may produce more deterministic scanpaths.

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