AN ANALYSIS OF VISUAL POSITION DISCRIMINATION

AN ANALYSIS OF HEAD MOVEMENTS AND BINOCULAR/MONOCULAR VIEWING CONDITIONS IN VISUAL POSITION DISCRIMINATION

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The study concerns how human observers judge the relative position of successively presented points of light in an otherwise dark field. In particular, the possible role of involuntary head movements and binocular/monocular viewing conditions is considered. The data are analysed in terms of a mathematical model of the perceptual process which deals with short term memory for visual position. Contrary to previous suggestions in the literature, neither of the viewing variables proved to have a significant effect. In addition, the results provide a strong test of the theoretical model which appears to confirm the model's validity. The results of this study are shown to suggest a particular direction for future experimentation.

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Introduction

The introduction of Decision Theory into Psychology and its application in psychophysics have made it possible to obtain a measure of an observer's "sensitivity" in certain discrimination tasks which is relatively unaffected by such "non-sensory" factors as his expectancies and the costs or gains associated with the various stimulus-response contingencies. This statistical decision making approach to human signal detection and a comprehensive treatment of its application in psychophysical research is presented in a book by Green and Swets (1966). In a paper by R. A. Kinchla and F. Smyzer, A Diffusion Model of Perceptual Memory (1967), a model is presented to represent the way in which an observer compares two stimuli presented at different points in time. The model developed by Kinchla is an extension of previous detection theory in that it represents how an observer's ability to discriminate two stimuli is reduced by the temporal interval between successive stimulus presentations.

Of interest here is Kinchla and Smyzer's application of the model to data from a visual position discrimination task. The task required an observer to detect a lateral difference in position between two small points of light flashed successively in the dark with a time interval between flashes. The stimulus display, positioned at eye level with the observer seated some distance away, consisted of two circular white lights horizontally separated from each other. Each trial began with a warning tone followed by a 100 msec. illumination of the light on the right of the display. Then, after some temporal delay, either the same light or the second light, displaced to the left of the first, came on for another 100 msec. Finally, the observer had two seconds in which to indicate one of two possible decisions: "both flashes occurred in the same position" or "the second flash was displaced to the left of the first".

It is clear that in order for an observer to distinguish a difference in position between two visual stimuli separated in time he must in some sense maintain a "memory" of the first stimulus position until the occurrence of the second. The longer the delay between the two stimuli the poorer will be his memory of the first when the second is presented. Kinchla's model represents a memory decay of this sort as a type of random walk process. Kinchla and Smyzer suggest that the loss of position information represented by this theoretical random walk may to a large extent reflect overt involuntary eye movements during the interval between the two light flashes. There is evidence from another study which indicates that eye movements play a major role in this sort of discrimination (Matin, Pearce, Matin, and Kibler, 1966). Using a similar task L. Matin and his colleagues have investigated the possible role of eye movements and ocular proprioception in position or direction perception. Horizontal eye movements were measured, using a contact lens and mirror technique, while an observer gave psychophysical reports regarding the position of a point of light relative to a fixation point extinguished some time earlier. The stimulus display consisted of a horizontal array of 9 circular lights. Each trial consisted of a four second illumination of the center light followed by a fixed temporal delay of 3 seconds whereupon one of the other lights to the left or right of center came on for 6 msec. This is contrasted with the procedure used by Kinchla and Smyzer in which 100 msec. duration flashes were used and the inter-stimulus delay was varied in ½ second increments from .5 seconds to 2.0 seconds. Matin's results indicate that a large portion of the psychophysical response variability is accounted for by involuntary eye movements, primarily continuous drifts with relatively few saccadic movements. In terms of the discrimination problem, these findings indicate that it is not only the relative physical position of the stimuli on the display that determines an observer's response, but the relative point of stimulation on the retina. The relative points of retinal stimulation depend to a large extent on involuntary eye movements during the inter-stimulus interval.

In addition to the longer presentation of the initial fixation point in the Matin, et al. study, there are two other factors which make it difficult to compare their data with those of Kinchla and Smyzer. Matin, et al. used a biting block in conjunction with monocular viewing in their study whereas Kinchla-Smyzer's observers viewed binocularly with no special head stabilization. Thus in regard to head stabilization, it might be suspected that involuntary head (and body) movements could result in poorer performance by Kinchla and Smyzer's observers since such movements during the inter-stimulus interval could influence the relation of the two points of retinal stimulation in the same manner as involuntary eye movements. Kinchla and Smyzer do, in fact, suggest that stabilizing the observer's head with a biting block might reduce the magnitude of the position memory loss by as much as fifty percent. The other difficulty in comparing the Matin and Kinchla-Smyzer data is that monocular and binocular viewing may not be equivalent. For example, note that while viewing binocularly two retinal input values are available to the observer with the occurrence of each light stimulus, one in each eye. Some sort of perceptual mechanism could conceivably compare the position information available in each eye. Since it has been reported that involuntary slow drift movements, a major factor in the loss of position information, are essentially random and uncorrelated between the two eyes (Krauskopf, Cornsweet, and Riggs, 1960), the comparator might reduce the loss of position information by averaging out part of the random effect of the slow drift movements.

In another, as yet unpublished, study by Matin, Matin, and Pearce,[1] eye movements were measured in two dimensions in a similar psychophysical task. A measure of the variance of involuntary eye movements during a 3 sec. inter-stimulus interval was obtained for one observer and was on the order of .05 degrees ^{2}/sec., about ¼ the typical value obtained indirectly in the memory study. Thus according to the preceding arguments, the larger estimate of memory variance obtained from the psychophysical data in the Kinchla-Smyzer study could be due in part to uncontrolled head and body movements. Of course, it is altogether possible that the indirect psychophysical measuring technique is simply not sufficiently precise.

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[1] Matin, L., Matin, E., and Pearce, D., Columbia University (personal communication).

The present study is primarily an attempt to separate and identify some of the individual factors which may alter performance and consequently either raise or lower the rate of memory loss in this discrimination. Specifically, two factors were examined: the extent of head stabilization and monocular versus binocular viewing. It was also expected that the study would provide more information on which to evaluate the general validity of Kinchla's model and the value of the "diffusion rate" as a measure of visual position memory.

A Mathematical Model of the Perceptual Process

In this section the model developed by R. A. Kinchla (Kinchla and Smyzer, 1967) will be reviewed, notation introduced, and some measures defined which will be used later in our experimental analysis. (The reader is referred to the original paper for a more detailed development of the model.) The model applies to perceptual tasks in which the observer makes similarity judgments regarding two successively presented values of some stimulus variable. We shall denote the first value which terminates at time zero by s_0 and the second value which is introduced at time t by s_t.

The observer's performance in a discrimination task of this sort in which s_t is either equal to s_0 or equal to s_0 plus a constant denoted Δs , may be summarized by two proportions: the proportion of hits and the proportion of false-alarms. The proportion of hits equals the number of trials on which the observer correctly reported a stimulus increase divided by the total number of trials on which s_0 and s_t were in fact different. The proportion of false-alarms equals the number of trials on which the observer incorrectly reported a stimulus difference divided by the total number of trials on which s_0 and s_t were actually the same. These proportions may be treated as estimates of corresponding conditional probabilities: the probability of a hit, Pr(H), and the probability of a false-alarm, Pr(FA). For our purposes it is sufficient to note that the model accounts for changes in the hit and false-alarm proportions produced by variations in the inter-stimulus delay (t).

The basic structure of the model is shown schematically in Fig. 1. It is defined by Kinchla and Smyzer as follows:

> Each time some value of the stimulus variable initiates the input process, it evokes some value of the sensory variable X. The values of the stimulus variable at time 0 and at time t are denoted, respectively, by s_0 and s_t. Similarly, the values

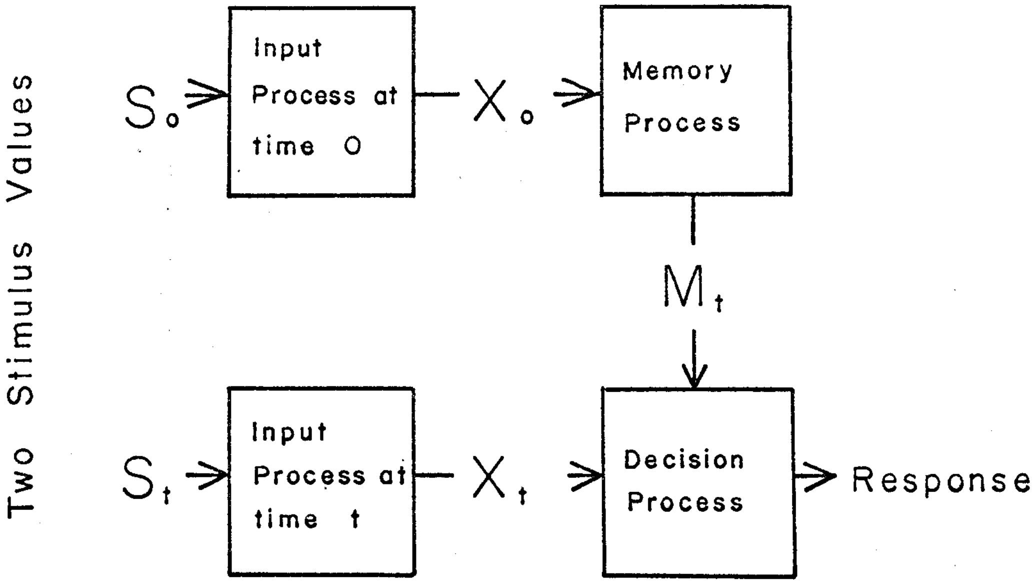

Fig. 1 Schematic of model.

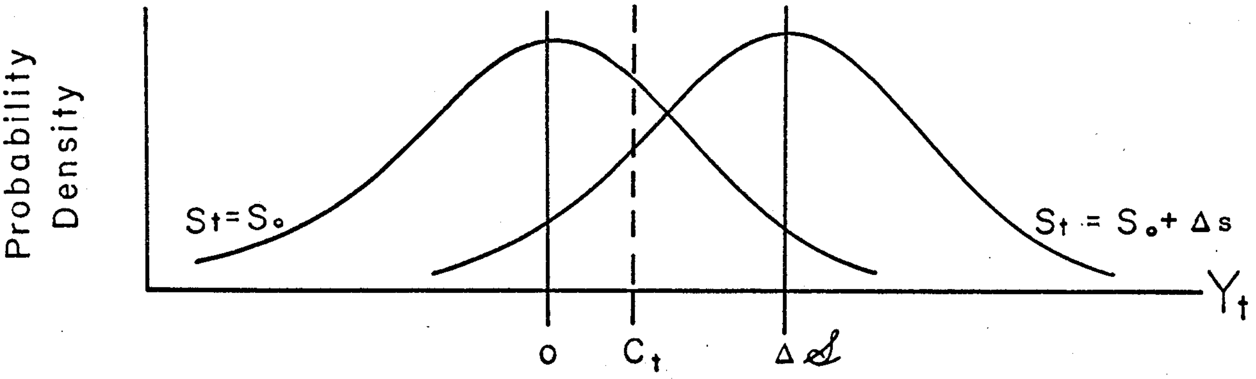

Fig. 2 Distribution of Y_t conditional on the difference between s_0 and s_t.

of the sensory variable evoked by s_0 and s_t are denoted by x_0 and x_t. Since x_t occurs later in time than x_0, the observer stores x_0 in memory until time t. He then makes a similarity decision regarding s_0 and s_t on the basis of the discrepancy between m_t, his memory of x_0 at time t, and x_t. Thus three processes interact to determine the relationship between stimulus and response: input, memory, and decision.

The Input Process

Repeated inputs of the same stimulus value, s, do not necessarily evoke the same sensory value; however, the distribution of the evoked values will be Gaussian with an expected value equal to the actual stimulus value. (Thus x can be expressed in the same units as s).

The Memory Process

Once the sensory value x_0 is stored in memory at time 0, it is diffused or modified through a random walk process until it is read into the decision process at time t as the memory m_t. One step in the random walk occurs every $1/\rho$ seconds when the value in memory is increased by the amount ω with probability p, or decreased by the same amount with probability 1-p. (We shall assume the unit parameter is chosen so that m_t is in the same units as s).

The Decision Process

The observer has some response criterion at time t, which we shall denote C_t, and only reports a stimulus difference if the discrepancy between x_t and m_t exceeds C_t.

Note that the memory of x_0 at time t (m_t) will depend upon the initial input value (x_0) plus the net effect of the random walk. Thus the apparent difference between the two stimulus events for the observer is specified in the model as the discrepancy between the actual sensory event at time t (x_t) and his <u>memory</u> of the initial sensory event (x_0) at time t (m_t). Thus it will be useful to define this discrepancy as the value y_t, where:

$$y_t = x_t - m_t. \tag{1}$$

It can be shown (Kinchla-Smyzer, 1967) that this process leads to a decision problem for the observer represented schematically in Fig. 2 by two overlapping distributions. The distributions should actually be discrete binomial functions; however, since they usually can be approximated closely by the simpler Gaussian distribution, this approximation will be used here. They represent the theoretical sampling distributions of y_t under the two possible stimulus conditions: s_t equal to s_0 and s_t equal to s_0 plus Δs . The model represents the observer as establishing some cutoff point or criterion value of y_t, denoted C_t, and reporting a stimulus difference only if the observed discrepancy exceeds C_t. Thus the hit and false-alarm probabilities will be determined by the area to the right of C_t under the appropriate curve. Furthermore, any change in the hit proportion due to a change in criterion will result in a corresponding, but generally unequal change in the proportion of false-alarms, with the sensitivity measure (δ_t) remaining constant.

It can also be shown that the observer's sensitivity can be summarized by the quantity δ_t defined as follows

$$\delta_t = \frac{\Delta s}{\sqrt{\sigma_t^2}} \qquad (2)$$

where Δs is the physical separation between the two lights and σ_t^2 is the variance of the distribution of discrepancies between m_t and x_t. It can also be shown that a consequence of the model is that

$$\sigma_t^2 = \phi t + K \qquad (3)$$

where ϕt is the variance in Y_t accrued during the inter-stimulus interval and K is the sum of the variances of x_0 and x_t (see Fig. 1). Thus we shall refer to ϕt as the "memory variance" and K as the "input variance". In the visual experiment reported by Kinchla and Smyzer the input variance was found to be negligible so that it was possible to use the model in a one parameter form with K equal to zero. Thus δ_t, the number of standard deviations separating the means of the distributions in Fig. 2, was simply a function of Δs (the stimulus difference), t (the inter-stimulus interval), and ϕ (the diffusion rate).

Estimates of δ_t can be obtained directly from the hit and false-alarm proportions by consulting a table of normal deviates (in a manner which follows obviously from a consideration of Fig. 2). This estimate of δ_t, denoted $\hat{\delta}_t$, can then be used to estimate σ_t^2 by substituting in Eq. 4 (this equation follows algebraically from Eq. 2).

$$\hat{\sigma}_t^2 = \left(\frac{\Delta s}{\hat{\delta}_t}\right)^2 \tag{4}$$

An estimate of the variance for each t value may then be plotted against time. Since σ_t^2 is theoretically a linear function of t (Eq. 3) a best fitting straight line (in the least squares sense) is then fitted to these points. The slope of this line may be considered an estimate of ϕ denoted $\hat{\phi}$; note that $\hat{\phi}$ is simply the rate at which the memory variance increases during the inter-stimulus interval. Furthermore, if we make the simplifying assumption, suggested earlier, that the input variance (K) is negligible, then by Eq. 3

$$\hat{\phi} = \frac{\sigma_t^2}{t} \tag{5}$$

In this special one parameter form of the model $\hat{\phi}$ is obtained by fitting the best linear function with intercept 0 to the plot of $\hat{\sigma}_t^2$ against t. With this overall estimate of ϕ and Eq. 3 we can obtain predicted values of σ_t^2. Then substituting these predicted values of σ_t^2 in Eq. 2 will yield predicted values of δ_t based on the overall estimate of ϕ. Finally plotting these predicted values of δ_t for each value of t indicates how sensitivity should theoretically change as a function of the delay between flashes. Later we shall consider how a comparison of these <u>predicted</u> and <u>estimated</u> values of δ_t indicates the extent to which the model is consistent with an observer's performance.

To summarize, given the hit and false-alarm rates for each t interval an overall estimate of ϕ may be obtained which reflects the rate of memory decrement during the inter-stimulus interval. Predicted values of δ_t may then be obtained using this single parameter ϕ. The degree to which the individual predictions are consistent with the estimates of δ_t for various t values is the basic test of the model.

It is of additional interest to consider the manner in which estimates of C_t, the decision criterion, can be obtained from an observer's performance. If the model were correct, the differences between the observed hit and false-alarm rates and the predicted ROC curve (i.e., the set of performances produced by changes in criterion with a fixed sensitivity) must be attributed to sampling variance. Thus the best estimate of C_t will be obtained by using that point on the predicted ROC curve nearest (in the least squares sense) the observed data point. The false-alarm rate at that point would by definition equal the area to the right of C_t under the distribution of Y_t for s_t equals s_0 (see Fig. 2). Consulting a table of normal deviates will indicate the distance between C_t and the mean of the s_t equal s_0 distribution in sigma units (denoted $\hat{C}_t'$). The criterion expressed in degrees visual angle, denoted $\hat{C}_t$, may then be obtained by multiplying $\hat{C}_t'$ (the criterion in sigma units) times the predicted values of σ_t^2 for each t delay.

Apparatus and Procedure

The stimulus display consisted of two circular white lights which were laterally separated from each other. Each light (Dialco # 39, 28V, .04 amp. operated at 20V) was .165 cm. in diameter with a luminance of 4 millilamberts. There was a 2.8 cm. separation between the midpoints of the two lights. The timing of stimulus presentations was electronically controlled to an accuracy of 1 msec. and their sequence was automatically programmed through punched paper tape. The display was placed 3.65 meters in front of the seated observer at eye level so that the distance between the two lights subtended a visual angle of .44 degrees while the diameter of each light subtended .026 degrees. The separation between the two lights remained constant during the experiment.

Each of the four observers sat in complete darkness and tried to detect a lateral difference in position between two successive presentations of light with a time interval (t) between flashes. Each of the observers had an uncorrected visual acuity of 20/20 or better in both eyes which was determined using a standard eye chart. Each trial began with a 1 second, 1000 cps, auditory warning signal. At the offset of the warning tone the light on the left of the display came on for 100 msec. and then went off. Then, after some time delay, either the same light or the light on the right of the display came on for another 100 msec. At the offset of the second light the observer had two seconds to indicate either that the two flashes had occurred in the same position ("same" response) or that the second flash was displaced to the right of the first ("different" response). He indicated his decision by pushing one of the two pushbuttons located on the arm of his chair.

In terms of the model, the stimulus variable S corresponds to the horizontal position of each light expressed in degrees visual angle from the midpoint of the light on the left of the display. Thus, the initial value of S on each trial (s_0) would always be 0 degrees while the comparison value (s_t), which occurs following the inter-stimulus delay (t), could equal 0 degrees or .44 degrees. The sequence of stimulus presentations was separately determined for each block of 50 trials. In each such sequence, s_t equaled s_0(0 degrees) on a randomly determined 25 trials, while on the remaining 25 trials s_t equaled .44 degrees. An experimental session consisted of eight such blocks with a preliminary dark adaptation period of 10 minutes and one minute rest periods (in the dark) between blocks. There were 4 values of the inter-stimulus delay: t equal .5, 1.0, 1.5, or 2.0 seconds. Each of the 8 possible combinations of t value with and without the biting block was in effect throughout one of the eight blocks of 50 trials. The sequence of conditions was randomly determined within each such session. During alternate sessions the observer viewed the display either monocularly or binocularly. In this way, each observer participated in 32 daily 50 minute sessions; the first eight of these sessions were considered practice days and were not included in the final data analysis. Thus, twelve blocks of 50 trials each were collected for each of the 16 combinations of four viewing conditions and four t values for a total of 600 trials per condition.

Each observer had his own biting block consisting of a heavy guage aluminum plate which could be fastened to a rigid stand bolted to the floor of the experimental chamber. To ensure rigid head fixation, a solid mold of each observer's teeth was formed on his biting block using dental impression compound. The head stabilizing apparatus was situated below eye level so that it offered no discernible interference in viewing the display.

The observers were informed of the physical structure of the stimulus display, the random method for generating stimulus sequences and the relative frequency of occurrence of the two stimulus events in each block of 50 trials. In addition, each observer was informed of the total number of his correct responses at the conclusion of each session in an attempt to maintain a reasonable level of motivation; however, trial by trial feedback was not included in this experimental design.

Results

Each observer's performance may be summarized by the average hit and false-alarm proportions obtained for each of the 16 combinations of four viewing conditions and four inter-stimulus delays. Each proportion is based on 300 trials so that each pair of hit and false-alarm proportions is based on 600 trials (as specified in the procedure section). These values appear in Table 1 and comprise the basic data on which the theoretical analysis is based. However, for our statistical analysis, the frequencies of the four stimulus-response contingencies were organized in a two by two matrix for each of the 16 combinations. The statistical significance of the effect of each experimental variable was evaluated by three Chi-Square homogeneity tests,[1] one for each variable. Each of the stimulus-response matrices compared in a particular test were obtained by combining all the data obtained under each value of the experimental variable being evaluated. Thus, two matrices were compared in the tests for each of the two viewing variables and four matrices were compared in the test for the inter-stimulus time (t) variable. If the null hypothesis were correct, then differences in the relative frequency of responses in the corresponding four cells of the compared matrices were produced by sampling error alone and not from systematic differences in experimental effects, i.e., the frequencies in each matrix were generated by the same stochastic process. Assuming the null hypothesis were true, the best estimate of the expected frequency in a particular cell is the average frequency in that cell among the matrices being compared. Given these expected frequencies, a Chi-Square may then be calculated in the usual manner. Table 2 presents the results of these tests for each observer. The Chi-Square for the inter-stimulus delay (t) was significant at the .001 level for each observer evaluated with 6 degrees of freedom. However, evaluated at 2 degrees of freedom neither of the two viewing variables

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[1] A detailed discussion of this type of Chi-Square test is presented in Suppes and Atkinson, 1960.

TABLE 1

Hit and False-Alarm Proportions Based on the Data from Each Combination of Viewing Condition and Time.*

		Obs.1		Obs.2		Obs.3		Obs.4	
	t	H	FA	H	FA	H	FA	H	FA
Binocular Biting Block	.5	.88	.18	.79	.17	.74	.19	.72	.17
	1.0	.75	.24	.68	.25	.58	.18	.51	.19
	1.5	.67	.25	.62	.28	.59	.26	.56	.29
	2.0	.71	.29	.62	.29	.51	.25	.57	.21
Binocular No Biting Block	.5	.81	.26	.77	.16	.71	.19	.74	.21
	1.0	.72	.25	.69	.25	.62	.24	.62	.22
	1.5	.68	.25	.62	.29	.61	.29	.61	.23
	2.0	.66	.35	.59	.29	.53	.31	.58	.35
Monocular Biting Block	.5	.84	.18	.83	.15	.77	.17	.71	.17
	1.0	.74	.21	.73	.24	.69	.25	.62	.24
	1.5	.73	.30	.63	.28	.67	.28	.62	.29
	2.0	.75	.30	.63	.31	.61	.30	.58	.31
Monocular No Biting Block	.5	.81	.26	.81	.21	.74	.21	.75	.21
	1.0	.74	.29	.68	.29	.69	.26	.67	.24
	1.5	.68	.30	.61	.29	.62	.30	.62	.32
	2.0	.66	.37	.64	.32	.61	.28	.66	.34

* Each proportion is based on 300 trials since each stimulus occurred 300 times in the 12 blocks of 50 trials under each of the 16 test conditions.

TABLE 2

Summary of Chi-Square Tests on the Effect of t
and Each of the Two Viewing Variables

Obs.	Time df = 6	Bite Block/No Bite Block df = 2	Monocular/Binocular df = 2
1	126.738**	6.288*	.046
2	182.129**	.850	.832
3	122.394**	.683	5.424
4	114.976**	2.949	2.355
Total Chi-Square	546.237**	10.770	8.657
Total df	24	8	8

* Significant at .05 level
** Significant at .001 level

showed differences statistically significant at the .01 level for any of the observers: although the effect of the biting block variable was significant at the .05 level for Observer 1. Overall Chi-Square values were computed for the effect of each experimental variable by summing the appropriate Chi-Square value from each observer. These results were evaluated at 24 degrees of freedom for the t variable and 8 degrees of freedom for each of the viewing variables. While the overall Chi-Square for the t value was significant at the .001 level of confidence, neither of the viewing variables were significant at the .05 level.

Theoretical Analysis and Discussion

As indicated in the earlier discussion of the model, estimates of each observer's sensitivity, denoted $\hat{\delta}_t$, may be obtained for each condition using the observed hit and false-alarm rates. These estimates are presented graphically as data points in Fig. 3a and 3b and numerically in Table 3. Each of the four viewing conditions for each t delay is presented. (While the Chi-Square values in Table 2 indicate no significant effects for the viewing variables, a comparison of the variables in terms of the model was conducted, since features of the data to which the statistical test was not sensitive might have become apparent.)

The extent to which the estimates of δ_t are consistent with the model requires an estimate of the diffusion rate ϕ, denoted $\hat{\phi}$, and the total input variance σ_0^2, denoted $\hat{\sigma}_0^2$, for each of the four viewing conditions. The data were examined for each observer as follows. Using Eq. 4 with the appropriate substitutions (.44 for Δs and $\hat{\delta}_t$ for δ_t), an estimate of σ_t^2 may be obtained for each t value. These estimates are plotted as points in Fig. 4a and 4b. The linear theoretical curves are based on Eq. 3 which specifies that σ_t^2 is a linear function of t with slope ϕ and intercept σ_0^2. However, upon fitting straight lines to the data points it became apparent that input variance in this discrimination is a negligible quantity. The variance of the four intercepts (one for each viewing condition) about the origin for Observer 1 through 4 were respectively, .0005, .0005, .0044 and .0037 square degrees visual angle. (This finding is in agreement with Kinchla and Smyzer, 1967.) Thus, these linear functions represent the least-squares fit for a linear function through the origin. The slope of the line in each case represents an estimate of the "diffusion rate" ($\hat{\phi}$). The linear functions provide a reasonable fit to the data for all observers under each of the four viewing conditions. The goodness of fit of the model is considered in more detail later in this section. Although no detailed comparison of the viewing conditions will be presented in terms of the diffusion rate, a visual comparison in Fig. 4a and 4b suggests that the biting block may

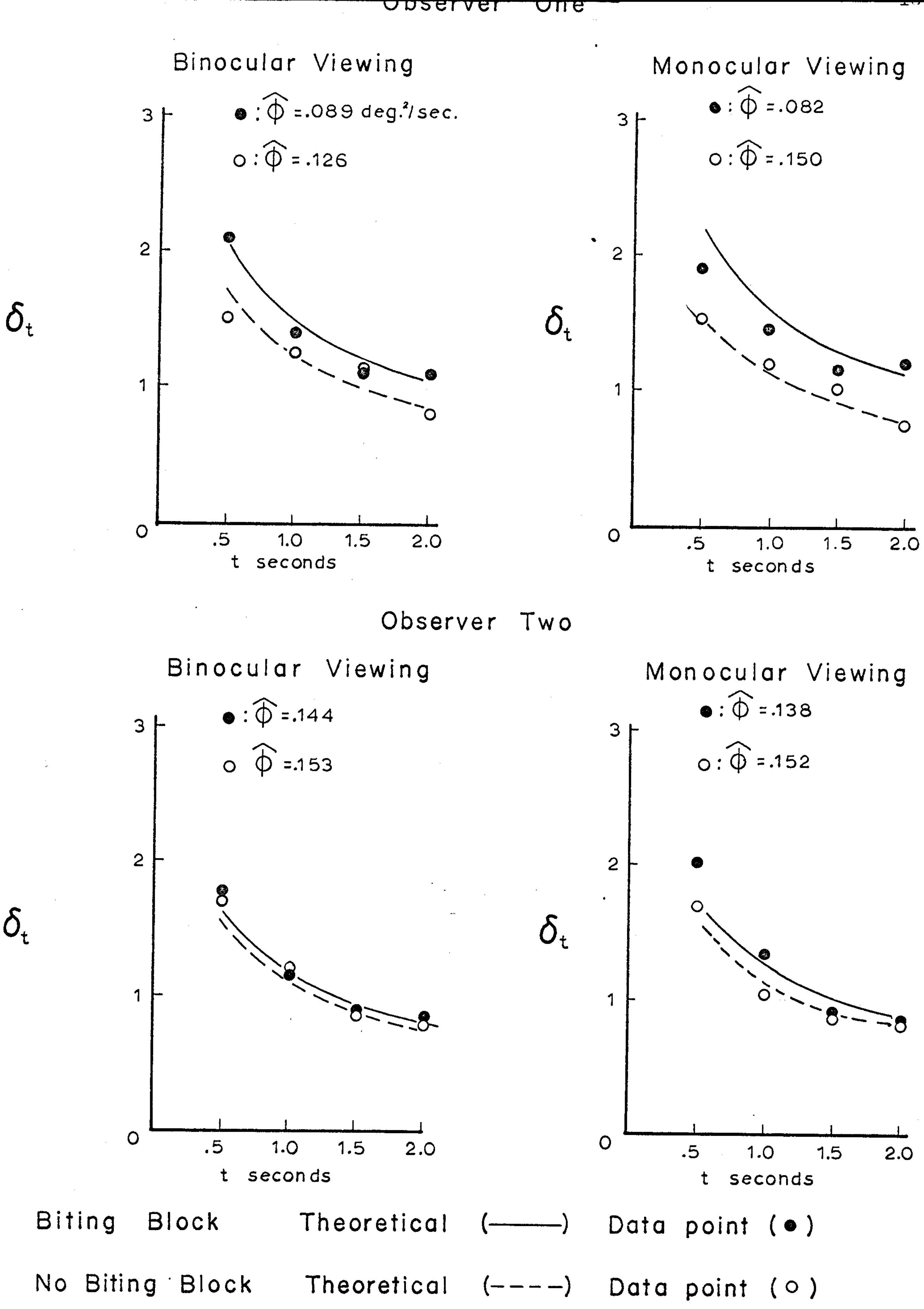
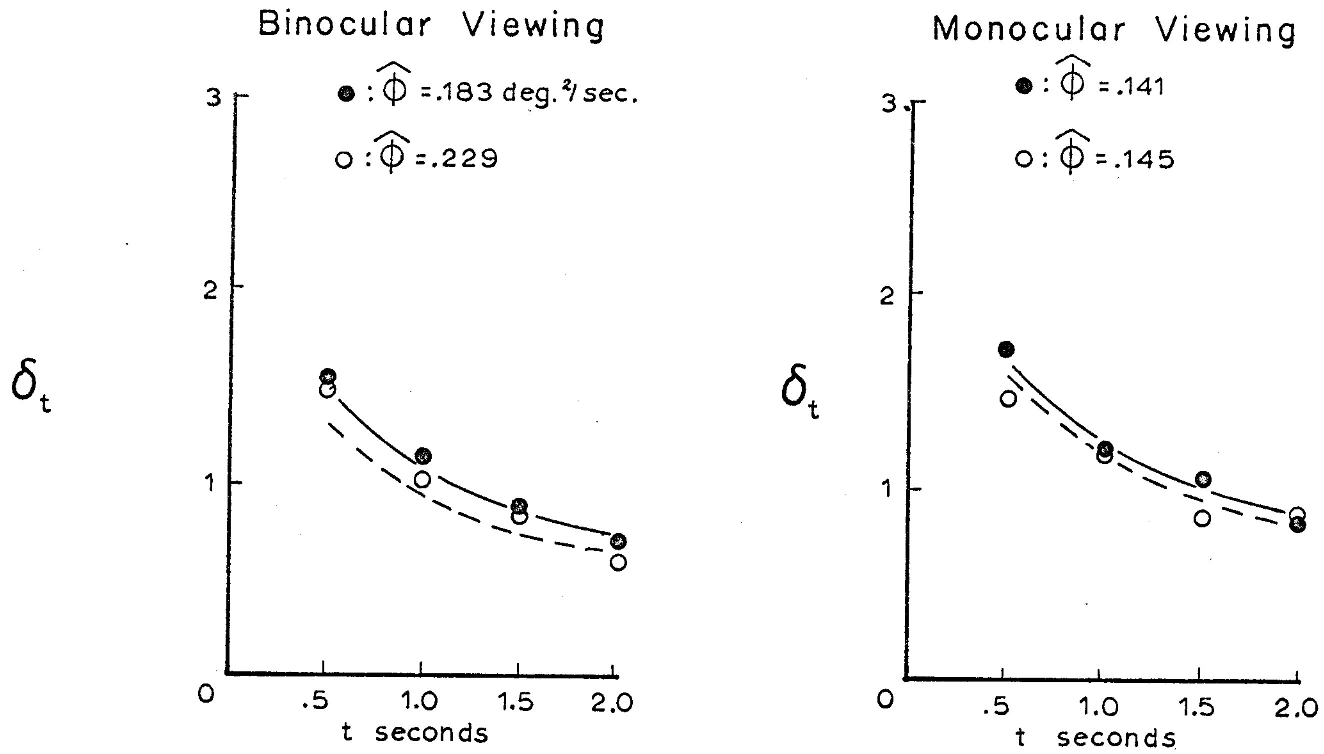

Observer One
Binocular Viewing
●: $\hat{\phi}$ =.089 deg.²/sec.
○: $\hat{\phi}$ =.126
Monocular Viewing
●: $\hat{\phi}$ =.082
○: $\hat{\phi}$ =.150
δ_t
0
1
2
3
.5
1.0
1.5
2.0
t seconds
Observer Two
Binocular Viewing
●: $\hat{\phi}$ =.144
○ $\hat{\phi}$ =.153
Monocular Viewing
●: $\hat{\phi}$ =.138
○: $\hat{\phi}$ =.152
Biting Block Theoretical (——) Data point (●)
No Biting Block Theoretical (- - - -) Data point (○)

Fig. 3a



Observer Four

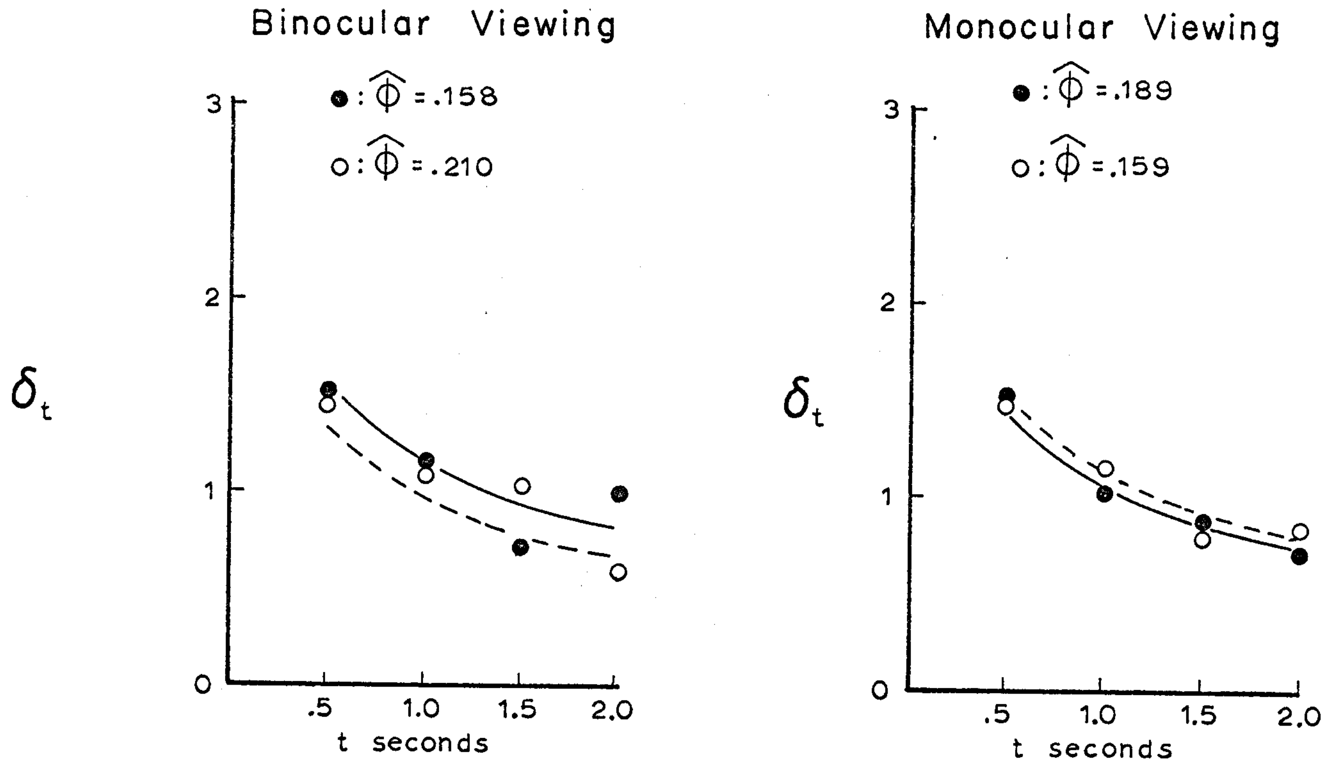


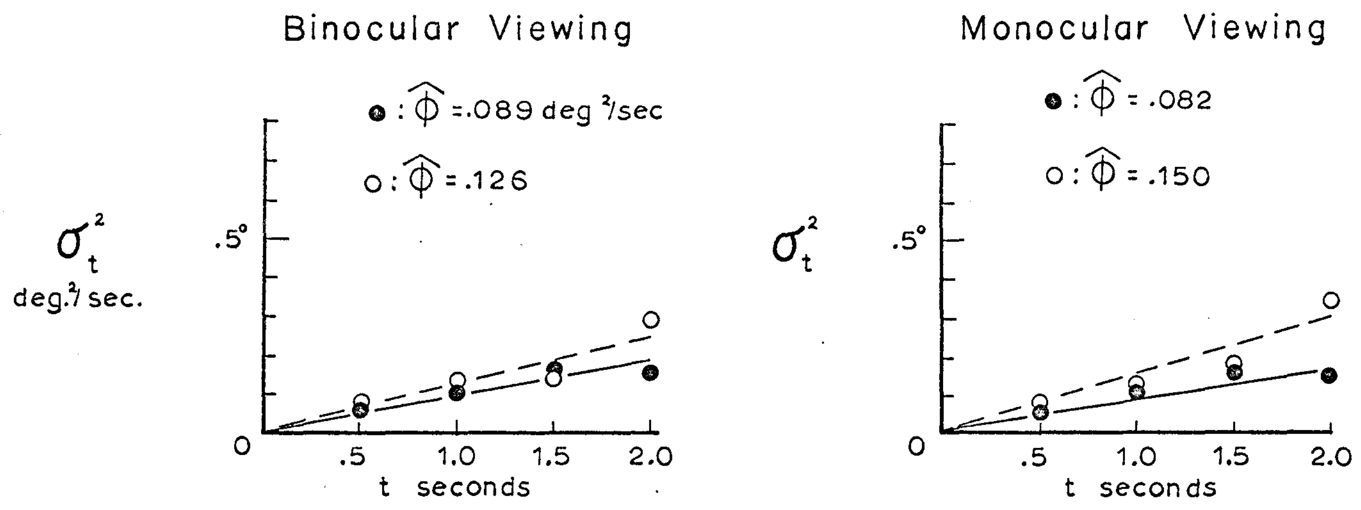
Fig. 3b

TABLE 3

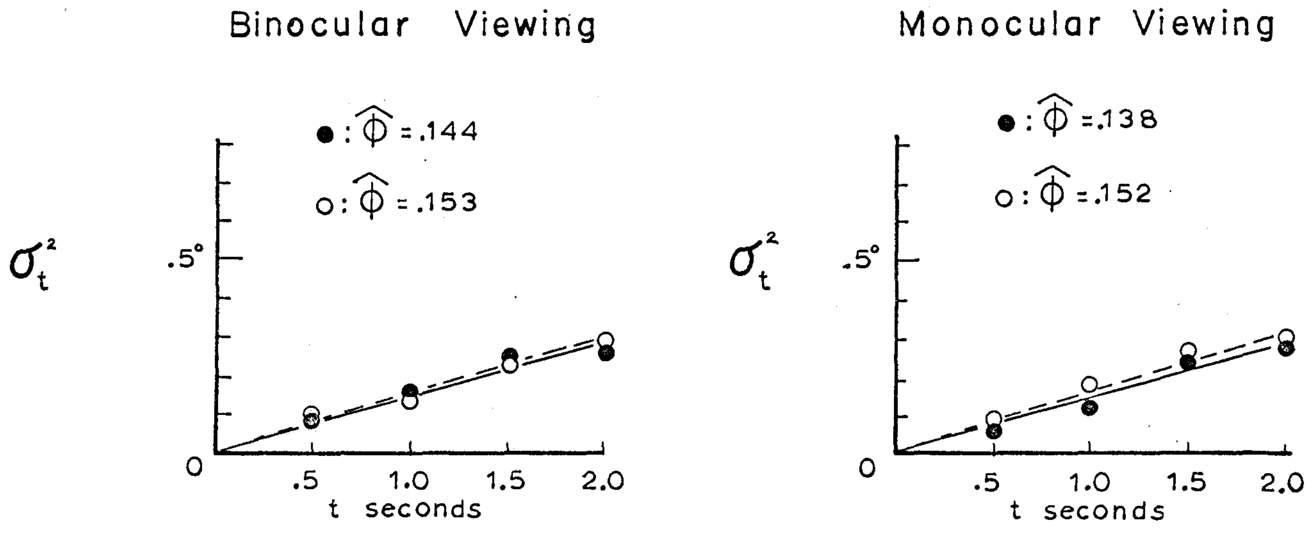
Estimated and Predicted Values of δ_t

		Obs. 1		Obs. 2		Obs. 3		Obs. 4	
		$\hat{\delta}_t$	Pred. δ_t	$\hat{\delta}_t$	Pred. δ_t	$\hat{\delta}_t$	Pred. δ_t	$\hat{\delta}_t$	Pred. δ_t
Binocular Biting Block	.5	2.09	2.08	1.76	1.64	1.52	1.45	1.53	1.57
	1.0	1.38	1.48	1.14	1.16	1.12	1.03	1.16	1.11
	1.5	1.12	1.20	.88	.95	.87	.84	.70	.90
	2.0	1.11	1.04	.86	.82	.70	.73	.98	.78
Binocular No Biting Block	.5	1.52	1.71	1.73	1.55	1.44	1.27	1.44	1.33
	1.0	1.26	1.21	1.18	1.10	1.01	.90	1.08	.94
	1.5	1.14	.99	.86	.90	.84	.73	1.02	.77
	2.0	.80	.86	.78	.78	.58	.64	.58	.66
Monocular Biting Block	.5	1.90	2.18	1.99	1.67	1.69	1.65	1.50	1.43
	1.0	1.44	1.54	1.32	1.19	1.18	1.17	1.01	1.01
	1.5	1.14	1.25	.91	.97	1.02	.96	.86	.83
	2.0	1.20	1.09	.84	.84	.80	.83	.70	.72
Monocular No Biting Block	.5	1.52	1.57	1.68	1.56	1.44	1.59	1.48	1.52
	1.0	1.20	1.11	1.02	1.10	1.14	1.13	1.14	1.08
	1.5	1.00	.91	.84	.90	.83	.92	.78	.88
	2.0	.74	.78	.83	.78	.86	.80	.82	.76

Observer One



Observer Two

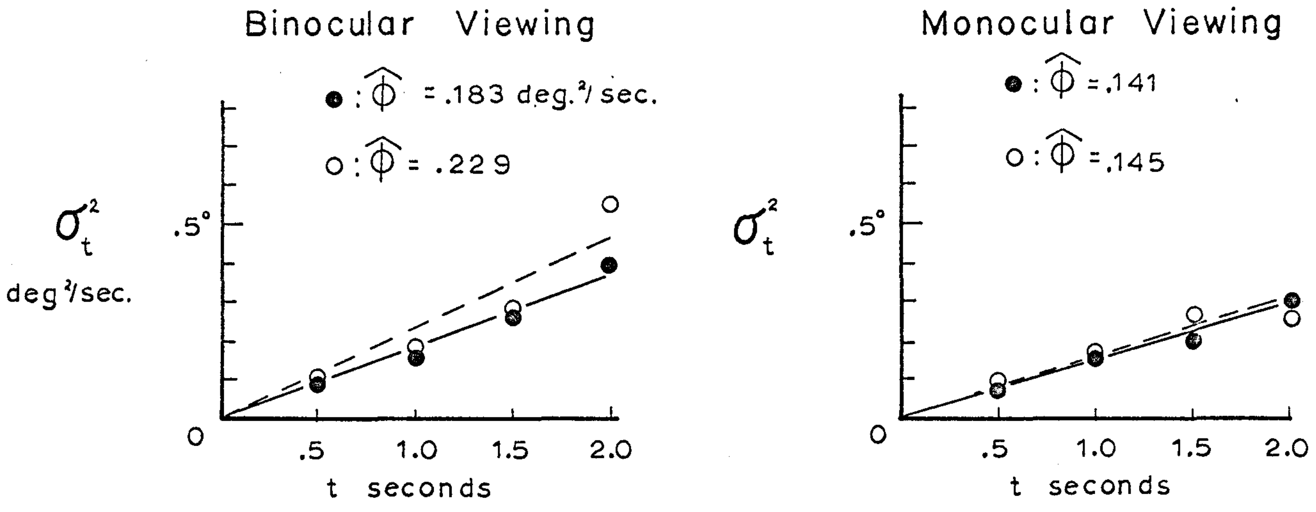


Biting Block Theoretical (——) Data point (●)

No Biting Block Theoretical (----) Data point (○)

Fig. 4a

Observer Three



Observer Four

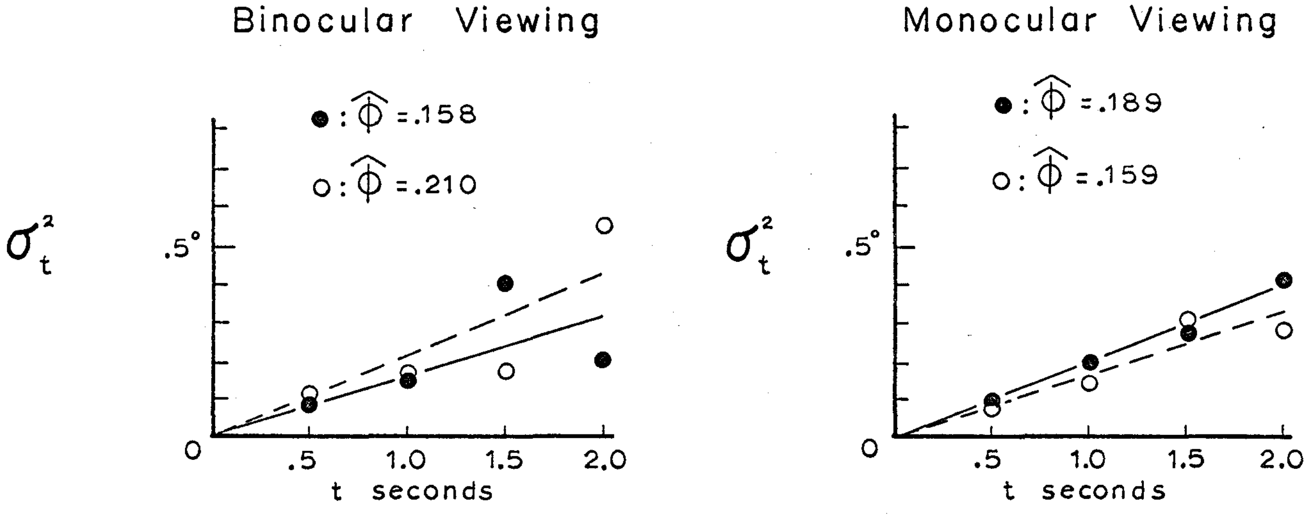


Fig. 4b

result in a small decrease in the rate of memory loss. However, the overall variability in the data points precludes any definite conclusions regarding the biting block (as indicated by the lack of significance of the Chi-Square test). At any rate, more data would be needed to establish the existence of such effects, since they must be very small if they exist at all.

The estimated values of ϕ may be used to obtain predicted values of δ_t, denoted Pred. δ_t, which may then be compared with the observed values. Substituting in Eq. 3, $\hat{\phi}$ for ϕ and assuming zero input variance, predicted values of σ_t^2 may be obtained for each t delay. Then substituting in Eq. 2, $\hat{\sigma}_t^2$ for σ_t^2 and .44 for Δs predicted values of δ_t may be obtained. These predicted values of δ_t are presented numerically in Table 2 and graphically (solid and dashed lines) in Fig. 3a and 3b. It seems clear that the single parameter form of the model provides a generally good prediction of each observer's performance.[1] However, it is also worthwhile to consider, in some more quantitative terms, how well the model accounts for changes in sensitivity over the range of inter-stimulus delays. Since the null hypothesis could not be rejected with regard to the viewing variables, it is advantageous to combine the data for each t delay over the four viewing conditions to obtain average sensitivity values at each delay based on four times as much data as employed in the individual condition estimates shown in Fig. 3a, 3b, 4a, and 4b. A convenient test of the model can then be made as follows. Taking the variance of $\hat{\delta}_t$ for the four t values around their mean as an estimate of the total variance in the dependent variable, and the variance of these same four values about their predicted values as an estimate of the unpredicted variance, one may obtain the proportion of the total variance accounted for by the model. The proportions were calculated for each observer and indicated that the model accounts on the average for about .96 of the total variance; the actual

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[1] Further support for the general applicability of the model in visual discrimination is provided in Appendix B in which additional data from Observer 2 is presented. These data are from an unpublished experiment by this author in which a greater range of inter-stimulus delays were employed than were used in the present study.

values obtained for Observers 1 through 4 were, respectively, .94, .92, .99, and .99. Thus the model accounts for a substantial part of the total variance. The hit and false-alarm proportions obtained by pooling all the data from each t value for each observer are presented in Table 4. The observed and predicted values of δ_t on which this test was based are presented numerically in Table 5 and graphically in Fig. 5 along with the average ϕ for each observer.

It is also of interest to consider the observer's decision criterion (discussed previously in the section on the model) in relation to the inter-stimulus interval. Since an initial analysis revealed no systematic differences in the observer's criterion with respect to the viewing variables, estimates based on all the data in Table 4 are presented here. It will be useful to first consider the total proportion of "different" responses made by each observer at each value of the inter-stimulus interval. These proportions, denoted P_{diff}, are presented numerically in Table 6 and graphically in Fig. 6. It is apparent that each observer maintains an approximately constant proportion of "different" responses. In fact, this proportion is very nearly .5 in each case which is reasonable since the observer knew a priori that the two stimuli would occur equally often during each block of trials. However, since sensitivity is changing as a function of the delay between the two stimuli, it must be true that the observer is changing the absolute value of his criterion in order to produce the same distribution of responses at each t delay. Estimates of the observer's criterion in degrees visual angle ($\hat{C}_t$) are presented in Table 6 and Fig. 7. These estimates may be thought of as the minimum discrepancy in degrees visual angle that must occur between the memory of the first stimulus and the position of the second stimulus at time t in order for the observer to respond "different". A stabile proportion of "different" responses implies that the criterion shifts to the right as the variance of the distribution of discrepancies between the memory for the standard and the comparison stimulus grows larger under the two possible stimulus conditions. Only if the observer's criterion is located midway between the means of the two distributions in Fig. 2, will the criterion remain constant as the variance of y_t increases during the inter-stimulus interval. If $\hat{C}_t$ is initially not at this midpoint, it must move toward it as σ_t^2 increases for the proportion of "different" responses to remain constant. Thus the variability in criterion around the midpoint (around $.5\ \delta_t$ or $.22^{\circ}$) as seen in the graphs for Observers 1 and 4 is generally consistant with this interpretation.

TABLE 4

Hit and False-Alarm Proportions Based on All the Data from Each t Value for Each Observer

	Obs.1		Obs.2		Obs.3		Obs.4	
t	H	FA	H	FA	H	FA	H	FA
.5	.84	.22	.80	.17	.74	.19	.73	.19
1.0	.74	.25	.70	.26	.65	.23	.63	.22
1.5	.69	.28	.62	.29	.62	.28	.60	.28
2.0	.70	.33	.62	.30	.57	.29	.60	.30

TABLE 5

Estimated and Predicted Values of δ_t Based on All the Data from Each t Value for Each Observer

	Obs. 1		Obs. 2		Obs. 3		Obs. 4	
t	$\hat{\delta}_t$	Pred. $\hat{\delta}_t$	$\hat{\delta}_t$	Pred. $\hat{\delta}_t$	$\hat{\delta}_t$	Pred. $\hat{\delta}_t$	$\hat{\delta}_t$	Pred. $\hat{\delta}_t$
.5	1.76	1.90	1.79	1.59	1.52	1.50	1.49	1.52
1.0	1.32	1.34	1.16	1.13	1.12	1.06	1.10	1.08
1.5	1.08	1.09	.86	.92	.88	.87	.84	.88
2.0	.96	.95	.83	.80	.74	.75	.78	.76

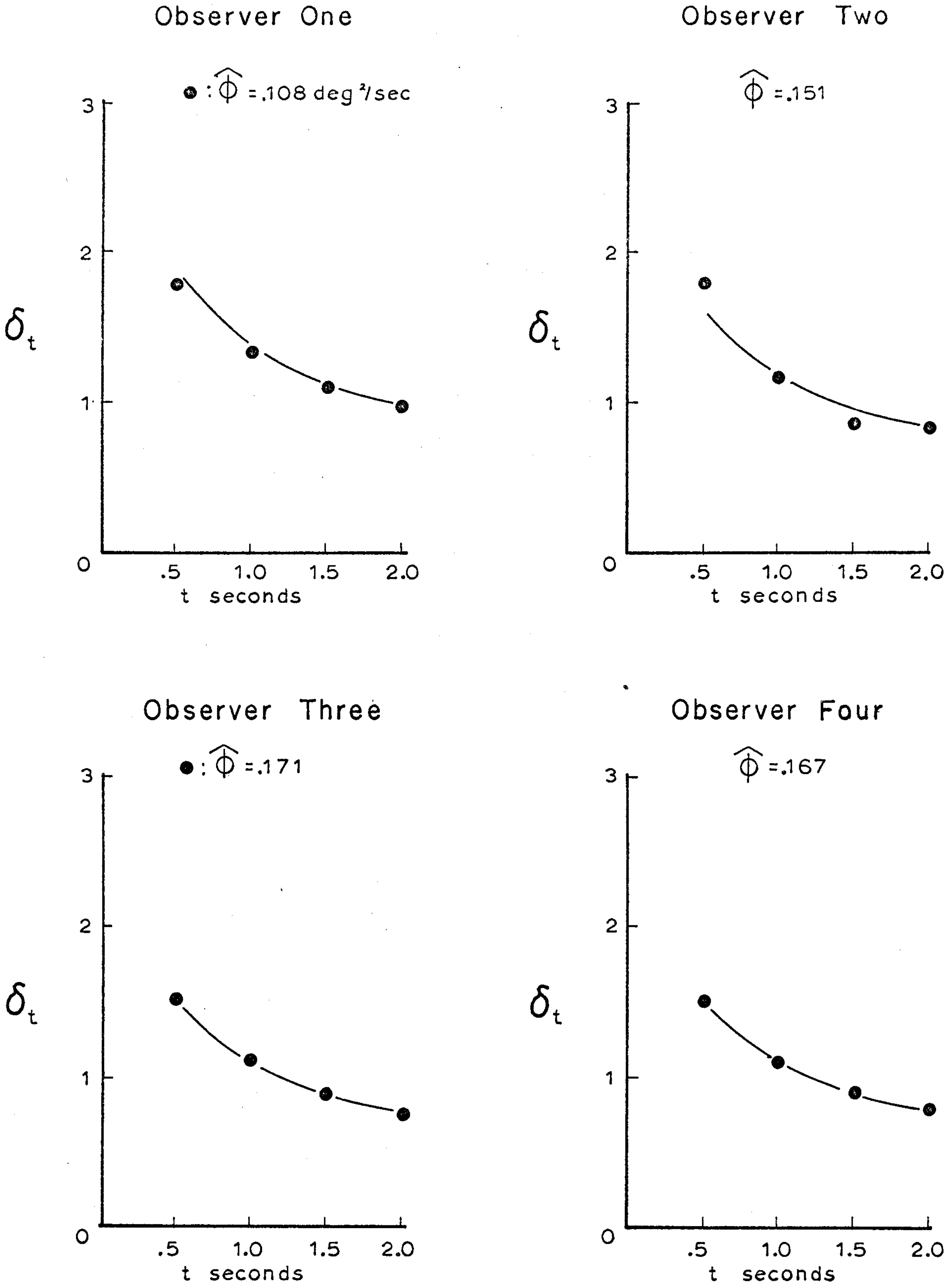
Observer One
●: $\widehat{\phi}$ = .108 deg²/sec
Observer Two
$\widehat{\phi}$ = .151
Observer Three
●: $\widehat{\phi}$ = .171
Observer Four
$\widehat{\phi}$ = .167
δ_t
0
1
2
3
.5
1.0
1.5
2.0
t seconds

Fig. 5

TABLE 6

Average Proportion of "Different" Responses (P_{diff})
and Estimated Values of the Criterion
in Degrees Visual Angle ($\hat{C}_t$)

	Obs. 1		Obs. 2		Obs. 3		Obs. 4	
t	$P_{diff.}$	$\hat{C}_t$	$P_{diff.}$	$\hat{C}_t$	$P_{diff.}$	$\hat{C}_t$	$P_{diff.}$	$\hat{C}_t$
.5	.53	.19	.49	.23	.47	.25	.46	.26
1.0	.50	.22	.48	.24	.44	.29	.43	.31
1.5	.49	.24	.46	.27	.45	.29	.44	.30
2.0	.52	.20	.46	.28	.43	.33	.45	.30

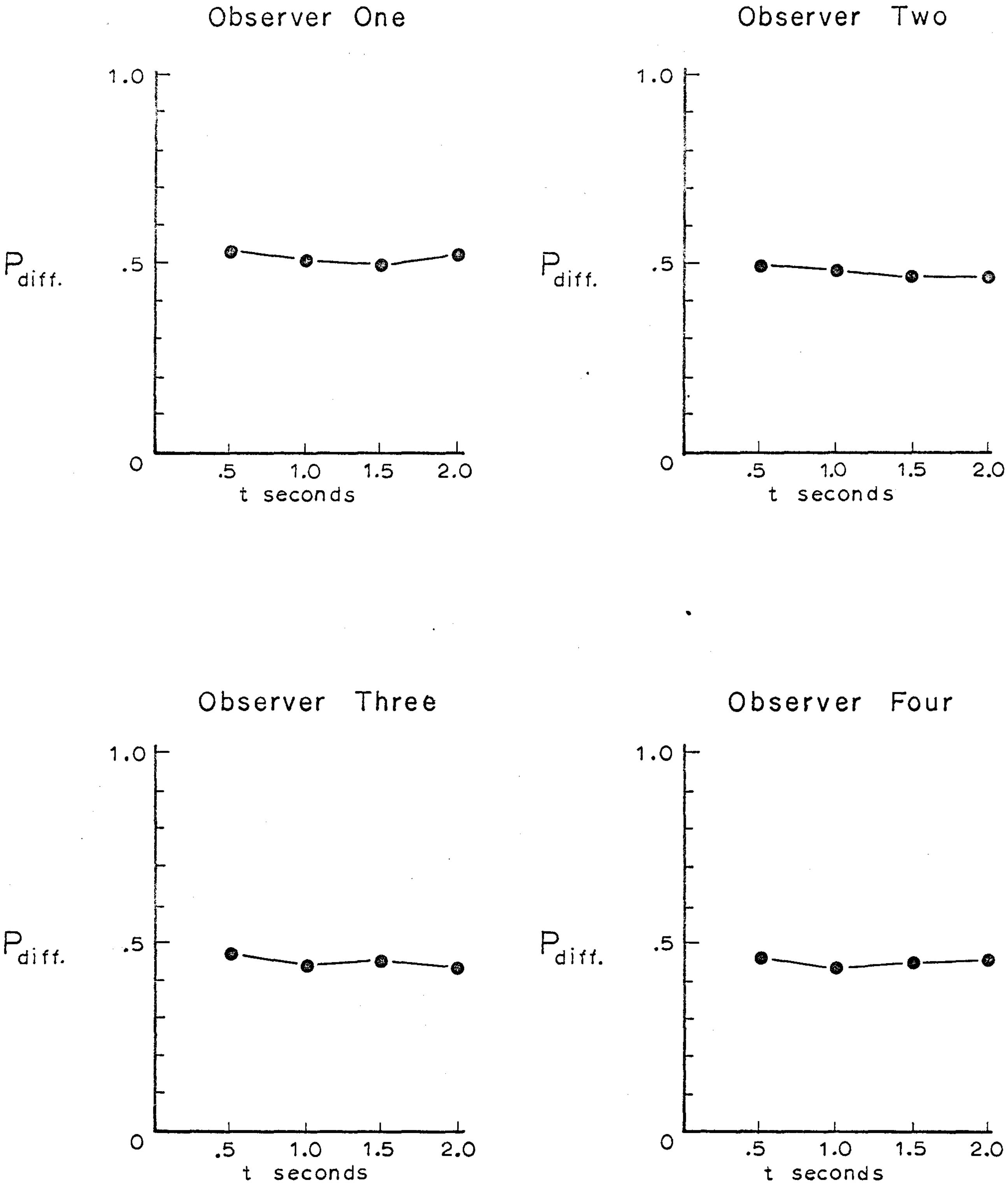
Observer One
Observer Two
Observer Three
Observer Four
$P_{diff.}$
1.0
.5
0
.5
1.0
1.5
2.0
t seconds

Fig. 6

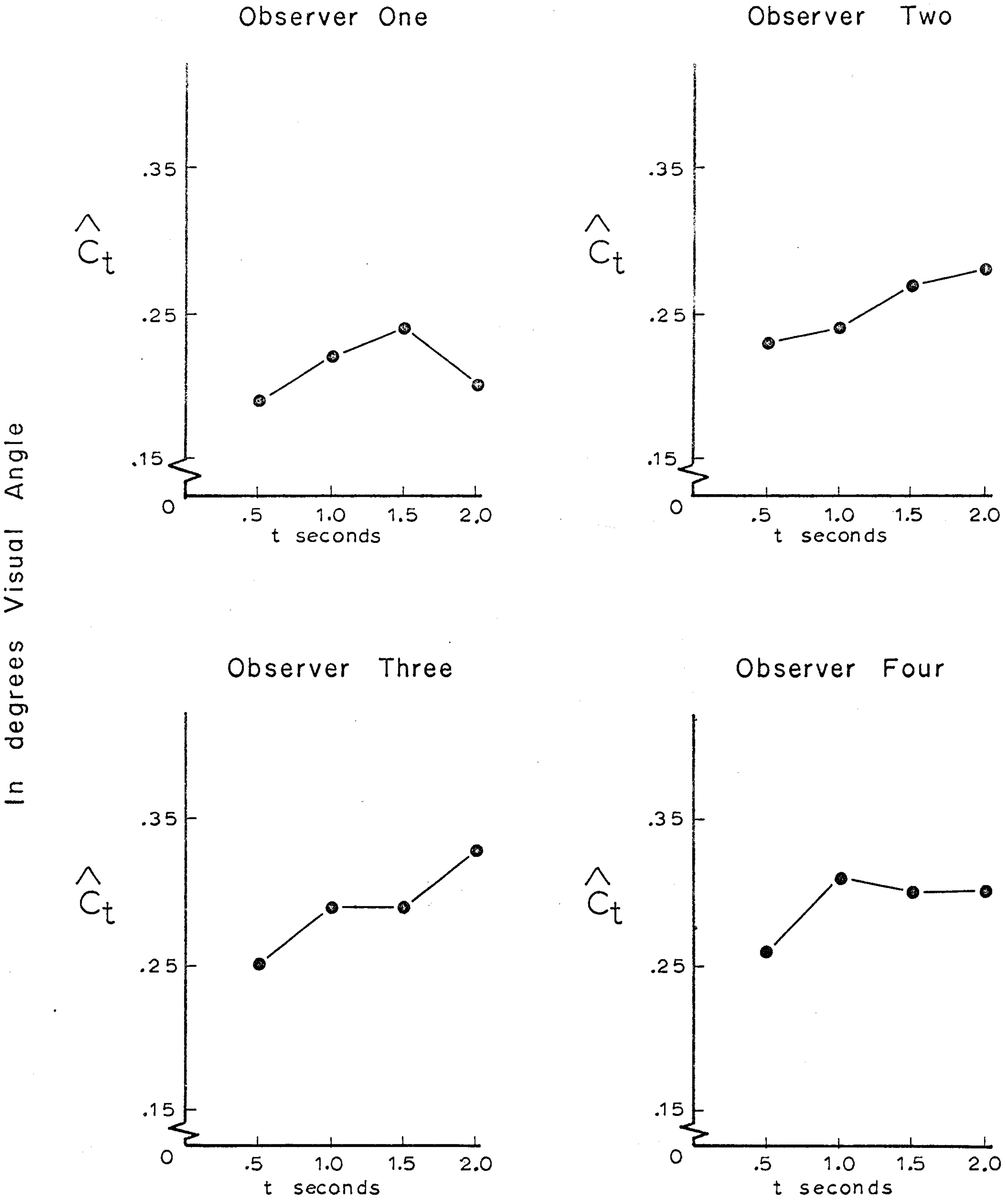
Observer One
Observer Two
Observer Three
Observer Four
$\hat{C}_t$
In degrees Visual Angle
.35
.25
.15
0
.5
1.0
1.5
2.0
t seconds

Fig. 7

Conclusion

The results of this study are consistent with the findings of Kinchla and Smýzer (1967) and provide a stronger test of the memory model because of the more extensive data collection. A goodness of fit test indicated that the stationary diffusion rate concept of this simple perceptual memory process accounted for about 96 percent of the mean changes in sensitivity produced by varying the delay between the flashes.

Given the internal consistency in the data as regards the influence of t, it seems clear that the viewing condition effects, if any, are relatively small. It would appear that although head and body movements of some magnitude must occur during the inter-stimulus interval their effect relative to other factors contributing to the loss of visual position memory is quite small. The lack of significant differences in monocular versus binocular viewing suggest that one retinal input at the time of occurrence of the light flashes is sufficient and that the additional impression available from the other eye when viewing is binocular, merely provides redundant position information. This finding is curious since the information from the second eye, given that involuntary slow drift movements are uncorrelated between the two eyes, could increment sensitivity while viewing binocularly. Some observers did report seeing two lights simultaneously when, in fact, only a single flash occurred. This might indicate that convergence error is confounded with the binocular viewing effects. Presumably, by simply increasing the duration of the light stimuli, any convergence error could be eliminated in that the viewer would have ample time to properly fixate the flash.

Prior to collecting the data in the present experiment, it was thought that our diffusion rate measure ϕ would more closely approximate the direct estimates of involuntary eye movements obtained by Matin et al. when monocular and fixed head viewing conditions were in effect as they were in their study. However, the average ϕ value obtained from the four observers was actually about three orders of magnitude larger. Thus, it would appear that either other differences in the two procedures account for the differences in the magnitudes of the two estimates or that the estimate derived from the model simply does not adequately represent the variance of involuntary eye movements. It was pointed our previously that Matin, et al. employed a 4 sec. duration initial stimulus whereas Kinchla-Smyzer used a 100 msec. duration initial stimulus. Additional unpublished data collected by this author using a single observer suggests that the duration of the initial stimulus is an important variable. The same discrimination task used in this paper was employed with longer initial stimulus durations. Four sessions were run for each of four different initial stimulus durations ranging from .5 to 2.0 sec. The average value obtained for this observer (Observer 2 in the main experiment) was .065 $deg.^2$/sec., very similar to the estimate obtained by Matin, et al. of .05 $deg.^2$/sec. Although the present estimate was based on data points representing 1600 trials each, it was obtained by combining all the data from the several durations tested, as well as from all the viewing conditions. The results are presented simply to point out a potentially fruitful direction for future research. A study in which the psychophysical procedure used by Matin, et al. was completely replicated would provide the best comparison of the two measuring techniques.

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APPENDIX A

This section presents the daily hit (H) and false-alarm (FA) frequencies for each observer under each of the four test conditions. While the actual sequence of test conditions was randomized as described in the procedure section, the data are presented here in the order in which they were collected for each test condition. Each frequency indicates the number of "different" responses the observer made to the 25 same ($s_t = s_0$) stimuli, hits, and the 25 different ($s_t = s_0 + \Delta$) stimuli, false-alarms, in each 50 trial block under a specific test condition. It can be assumed that if the observer did not respond "different" that he responded "same", since failures to respond were eliminated during preliminary training.

Daily Hit and False-Alarm Frequencies for Observer 1

Viewing Binocularly

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	8	0	18	3	9	7	13	5	17	2	7	0	15	4	11	5
2	19	4	18	5	14	10	13	7	19	4	18	7	16	8	18	10
3	22	4	17	11	20	6	20	8	18	11	22	4	20	4	19	6
4	23	9	21	7	17	12	19	12	22	8	19	4	16	10	14	14
5	21	1	18	6	17	7	19	6	21	3	18	3	19	1	16	9
6	18	3	12	1	12	3	13	8	9	0	11	4	8	0	14	5
7	21	2	20	1	12	6	16	5	18	5	16	2	15	2	15	6
8	25	3	20	3	17	4	21	6	22	5	17	8	19	6	19	7
9	21	10	21	8	19	10	22	10	22	8	19	11	18	8	13	14
10	24	4	21	11	19	9	17	13	22	10	18	8	18	9	19	14
11	23	2	16	7	16	7	18	4	21	1	15	8	16	6	14	5
12	25	2	20	7	15	8	14	7	21	8	19	6	16	10	17	10
13	17	9	18	9	18	3	15	7	21	6	19	2	17	5	11	8
14	23	6	18	5	17	2	20	7	23	10	21	7	19	9	20	7
15	23	6	21	5	18	5	17	8	21	12	23	3	16	9	18	10
16	23	7	21	8	21	12	20	7	22	11	21	14	22	11	21	11

Daily Hit and False-Alarm Frequencies for Observer 1

Viewing Monocularly with Right Eye Covered

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	18	6	17	5	16	7	14	6	22	3	17	9	16	6	16	6
2	20	5	19	5	21	4	16	10	19	1	15	6	13	9	19	6
3	21	6	20	5	18	7	19	12	22	7	19	10	19	7	17	11
4	21	3	21	3	21	5	17	9	21	8	21	7	16	7	18	8
5	19	3	17	4	15	2	15	7	15	1	14	6	12	8	13	8
6	12	0	6	1	10	4	11	2	11	2	10	1	11	4	5	4
7	19	4	17	5	15	3	18	6	19	4	17	5	17	2	20	8
8	22	5	19	3	22	9	23	7	20	4	20	7	17	9	15	12
9	21	4	18	7	18	11	17	10	23	8	17	10	14	12	17	8
10	23	6	19	8	16	10	18	12	21	6	21	7	16	11	17	11
11	24	5	20	7	24	10	20	11	23	8	16	13	19	12	16	11
12	21	6	18	3	20	7	21	4	22	9	20	3	20	10	17	8
13	24	5	19	0	15	5	22	4	22	9	21	6	20	3	20	12
14	23	2	24	8	24	9	18	6	22	10	22	7	22	3	18	10
15	23	8	23	9	16	9	23	9	22	9	21	9	18	10	20	8
16	22	6	23	7	23	11	20	12	23	7	24	14	17	6	19	10

Daily Hit and False-Alarm Frequencies for Observer 2

Viewing Binocularly

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	19	3	15	4	14	3	12	8	17	6	14	4	15	7	13	7
2	17	2	17	6	18	5	16	6	20	6	16	8	15	7	16	8
3	18	2	15	8	11	10	12	7	20	2	15	5	15	6	14	7
4	19	7	19	4	15	9	15	7	21	2	20	5	16	8	15	7
5	21	4	16	8	14	11	14	7	16	3	19	3	18	4	14	5
6	21	4	18	4	15	6	19	5	18	2	18	6	13	9	20	6
7	17	6	18	4	14	8	12	9	23	2	14	9	13	9	14	8
8	19	1	17	9	13	6	13	5	19	1	18	5	16	5	14	6
9	21	3	13	10	18	5	16	8	22	4	15	9	14	8	16	8
10	19	2	16	7	16	6	17	7	19	7	20	4	16	7	14	8
11	20	4	17	6	18	7	18	7	19	5	17	6	17	6	14	6
12	20	1	17	5	16	5	15	6	15	7	14	6	14	5	12	8
13	17	6	17	5	14	7	17	6	18	3	17	5	17	6	12	10
14	22	7	16	8	17	7	15	11	18	8	20	6	15	9	18	7
15	17	9	20	1	15	6	15	8	23	2	18	8	17	10	12	9
16	23	4	20	7	16	11	16	8	22	5	18	7	15	10	18	5

Daily Hit and False-Alarm Frequencies for Observer 2

Viewing Monocularly with Left Eye Covered

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	18	3	15	5	14	3	12	5	23	2	13	7	12	7	10	10
2	21	2	14	6	16	6	14	8	18	3	15	8	17	7	19	5
3	19	5	19	6	17	5	11	11	19	5	21	5	21	5	17	8
4	22	2	17	6	16	5	16	5	21	6	19	6	16	8	17	8
5	22	2	19	6	15	7	12	12	23	6	18	6	15	4	15	13
6	20	2	18	5	15	5	18	7	19	7	17	4	15	6	15	6
7	19	7	20	5	18	6	16	9	15	4	20	5	16	8	13	8
8	22	2	17	6	16	9	18	8	18	8	16	7	15	9	18	5
9	20	6	19	6	15	11	15	8	22	5	18	7	17	8	21	4
10	19	5	20	5	15	5	17	7	23	3	14	8	17	7	19	6
11	21	5	14	4	13	7	14	3	19	4	17	7	14	8	14	7
12	19	4	17	9	14	10	14	10	17	10	16	10	14	7	10	11
13	24	0	19	5	15	6	19	6	23	3	15	8	17	6	15	8
14	22	2	21	4	15	5	13	5	21	5	17	8	14	8	18	8
15	19	7	18	7	17	7	15	10	21	5	20	8	15	9	18	8
16	22	3	17	9	20	6	18	9	21	4	15	10	15	8	16	11

Daily Hit and False-Alarm Frequencies for Observer 3

Viewing Binocularly

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5			
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	23	8	21	6	20	7	22	18	22	3	19	5	20	7	16	8
2	24	13	16	9	22	7	19	10	21	10	22	5	16	11	18	4
3	14	12	18	14	20	10	22	14	23	10	21	8	20	18	16	10
4	22	0	17	4	18	5	18	6	21	3	22	1	16	7	18	8
5	17	1	9	1	17	8	11	4	20	0	15	0	15	6	12	7
6	21	1	22	2	13	8	14	4	22	4	19	4	16	5	15	8
7	18	5	7	1	6	0	8	1	13	1	12	3	14	5	8	14
8	18	7	16	4	20	5	16	7	17	6	20	5	13	9	11	5
9	18	6	19	5	20	5	13	6	18	7	12	10	20	7	14	12
10	18	5	18	8	14	10	17	15	18	6	19	6	14	13	18	5
11	21	4	11	2	17	7	12	3	16	3	16	8	14	5	12	8
12	17	7	10	7	9	6	13	2	20	6	12	7	16	8	12	4
13	15	5	13	6	16	7	14	9	13	7	14	10	15	7	13	9
14	22	3	15	10	17	4	14	10	19	6	17	6	17	9	12	10
15	20	5	17	2	14	9	10	4	22	3	16	7	13	5	17	8
16	18	9	17	6	14	8	12	9	15	7	13	7	16	9	15	12

Daily Hit and False-Alarm Frequencies for Observer 3

Viewing Monocularly with Left Eye Covered

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	21	6	21	13	18	13	20	12	20	3	20	6	23	17	21	18
2	24	6	22	9	19	7	25	21	19	1	21	7	22	16	12	11
3	19	3	23	9	16	9	16	11	18	2	18	6	21	6	19	6
4	19	2	20	6	19	4	15	12	21	1	14	9	18	6	19	16
5	20	1	19	7	13	5	9	7	23	1	23	9	20	4	8	5
6	19	6	14	3	8	5	15	5	17	8	16	4	16	5	17	6
7	19	8	15	6	18	8	12	7	20	4	17	8	21	12	13	6
8	20	3	15	8	15	8	18	9	19	6	16	8	19	9	17	6
9	19	7	16	7	20	6	13	8	14	9	19	6	15	4	18	7
10	21	5	17	8	15	9	15	11	16	5	20	6	15	6	17	8
11	15	7	17	7	20	9	14	10	17	6	19	4	16	13	11	5
12	21	4	18	7	18	6	12	7	18	2	8	8	10	4	15	8
13	20	4	18	7	18	6	20	7	16	9	18	7	13	8	20	5
14	18	2	20	5	19	11	17	8	17	8	13	4	14	5	17	10
15	21	2	17	6	19	5	18	7	24	1	18	8	12	10	14	9
16	19	3	21	4	17	7	20	5	21	4	20	6	14	10	15	5

Daily Hit and False-Alarm Frequencies for Observer 4

Viewing Binocularly

	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	16	6	13	10	11	8	12	7	17	7	14	10	15	6	9	12
2	17	3	13	3	15	4	8	6	22	2	15	5	18	5	12	8
3	20	4	18	5	14	7	10	10	23	4	18	3	17	9	18	11
4	19	4	18	5	17	4	16	5	21	2	16	7	13	8	15	10
5	17	6	16	7	11	9	12	7	20	3	17	4	14	6	14	9
6	17	8	14	8	15	9	15	5	19	8	18	6	17	9	14	12
7	19	6	14	6	14	8	16	5	19	8	10	9	15	4	10	9
8	19	2	12	7	16	12	10	8	18	7	18	5	16	5	18	13
9	18	3	17	6	15	9	16	6	18	3	19	2	18	7	19	6
10	18	3	19	5	13	6	16	5	20	5	19	6	18	9	14	8
11	19	3	17	6	13	5	12	8	19	3	15	6	15	5	15	6
12	17	4	14	0	9	6	17	4	18	4	13	8	16	5	16	9
13	19	4	13	5	15	5	17	3	17	6	16	5	14	1	9	6
14	19	4	14	2	15	6	14	2	19	5	14	6	13	6	11	9
15	16	4	16	2	12	5	11	3	17	3	14	3	12	4	21	8
16	19	3	18	4	19	7	16	8	19	9	12	7	15	7	13	11

Daily Hit and False-Alarm Frequencies for Observer 4

Viewing Monocularly with Right Eye Covered

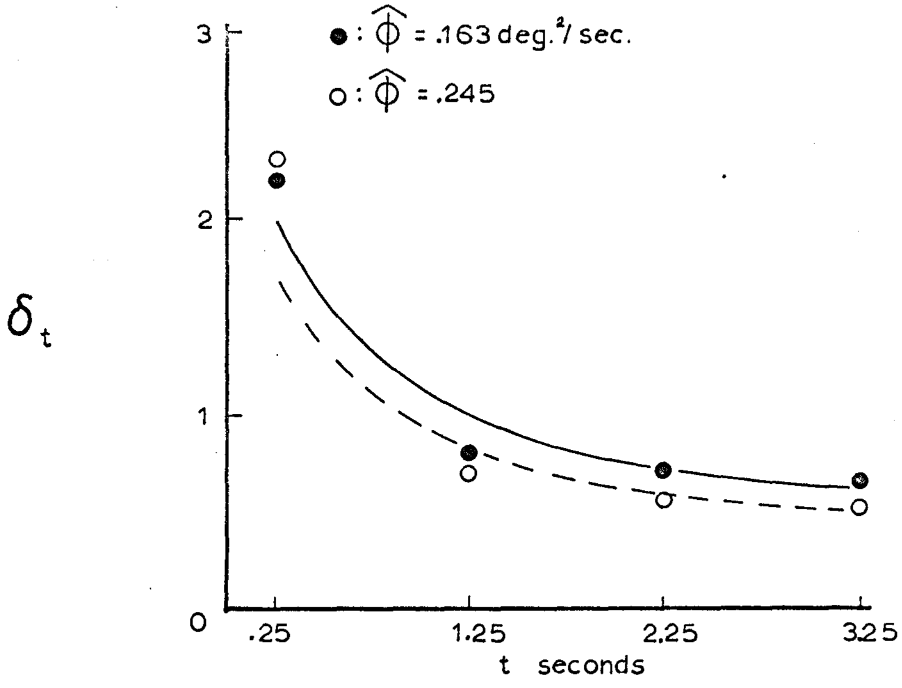
	Biting Block								No Biting Block							
	.5		1.0		1.5		2.0		.5		1.0		1.5		2.0	
Day	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA	H	FA
1	21	4	12	3	6	1	16	6	20	5	15	9	12	4	5	3
2	20	2	18	4	14	6	10	9	21	1	19	6	18	11	19	10
3	19	5	18	6	15	6	10	7	20	3	20	6	17	7	14	9
4	18	6	17	7	12	7	10	3	19	6	13	6	14	7	15	12
5	23	3	12	8	17	6	10	9	19	6	18	6	15	8	18	9
6	15	4	15	6	16	5	15	4	24	4	18	3	17	11	16	7
7	20	3	18	7	15	5	17	8	17	8	17	7	15	6	18	14
8	22	2	17	6	15	7	15	10	18	4	18	4	17	8	18	9
9	20	3	16	4	15	8	17	9	19	4	15	7	18	9	16	6
10	18	6	15	5	16	7	16	7	17	7	18	7	16	7	16	8
11	14	5	15	7	13	8	19	9	20	5	13	7	14	10	16	8
12	22	4	18	5	14	9	14	6	20	5	16	5	15	10	19	7
13	13	9	13	7	16	6	14	9	18	6	18	6	9	9	14	6
14	13	1	18	7	17	7	16	7	14	6	18	6	16	2	13	10
15	14	5	11	5	16	10	15	7	20	3	16	8	19	7	16	10
16	16	5	17	5	16	8	14	8	20	5	17	7	15	8	17	8

APPENDIX B

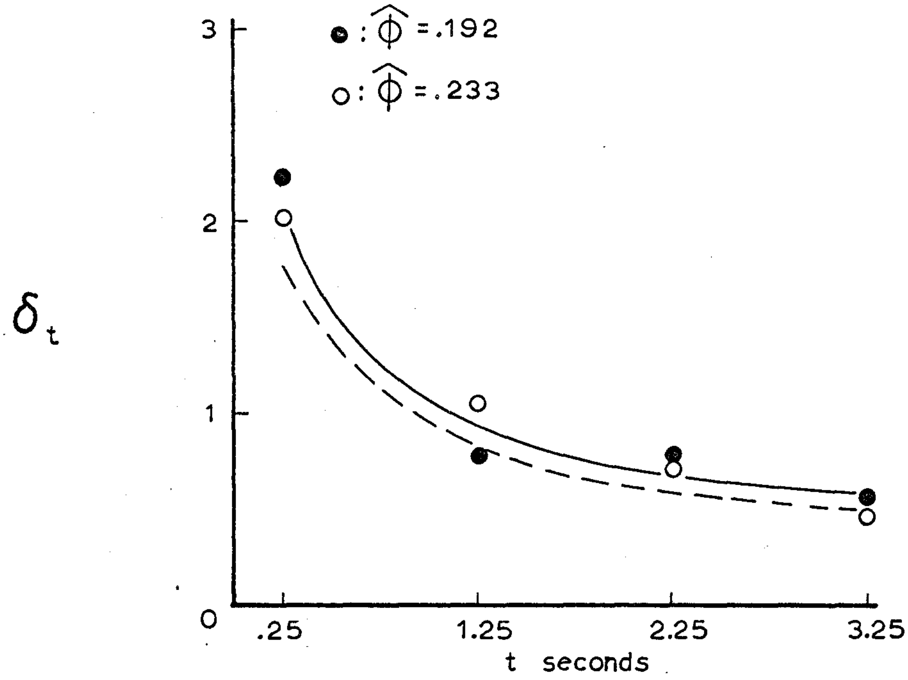
In this section data is presented which suggest that the model may be useful in predicting an observer's performance over a wider range of inter-stimulus delays than were used in the present study.

Observer 2 of the main experiment subsequently participated in 32 additional sessions in wich the inter-stimulus delays were .25, 1.25, 2.25, 3.25 sec., rather than .5, 1.0, 1.5 and 2.0 sec. as in the main experiment. In all other respects the two procedures were the same. The data was analysed in the same manner as in the main experiment and the results are summarized in Fig. B1 and B2 in Table B1. The model provides a reasonably good prediction of the observer's performance. However, note that at the shortest inter-stimulus delay the model's predictions are smaller than the estimated values. More data would be needed to decide if there is a consistent deviation from the model at the shorter inter-stimulus intervals.

Binocular Viewing



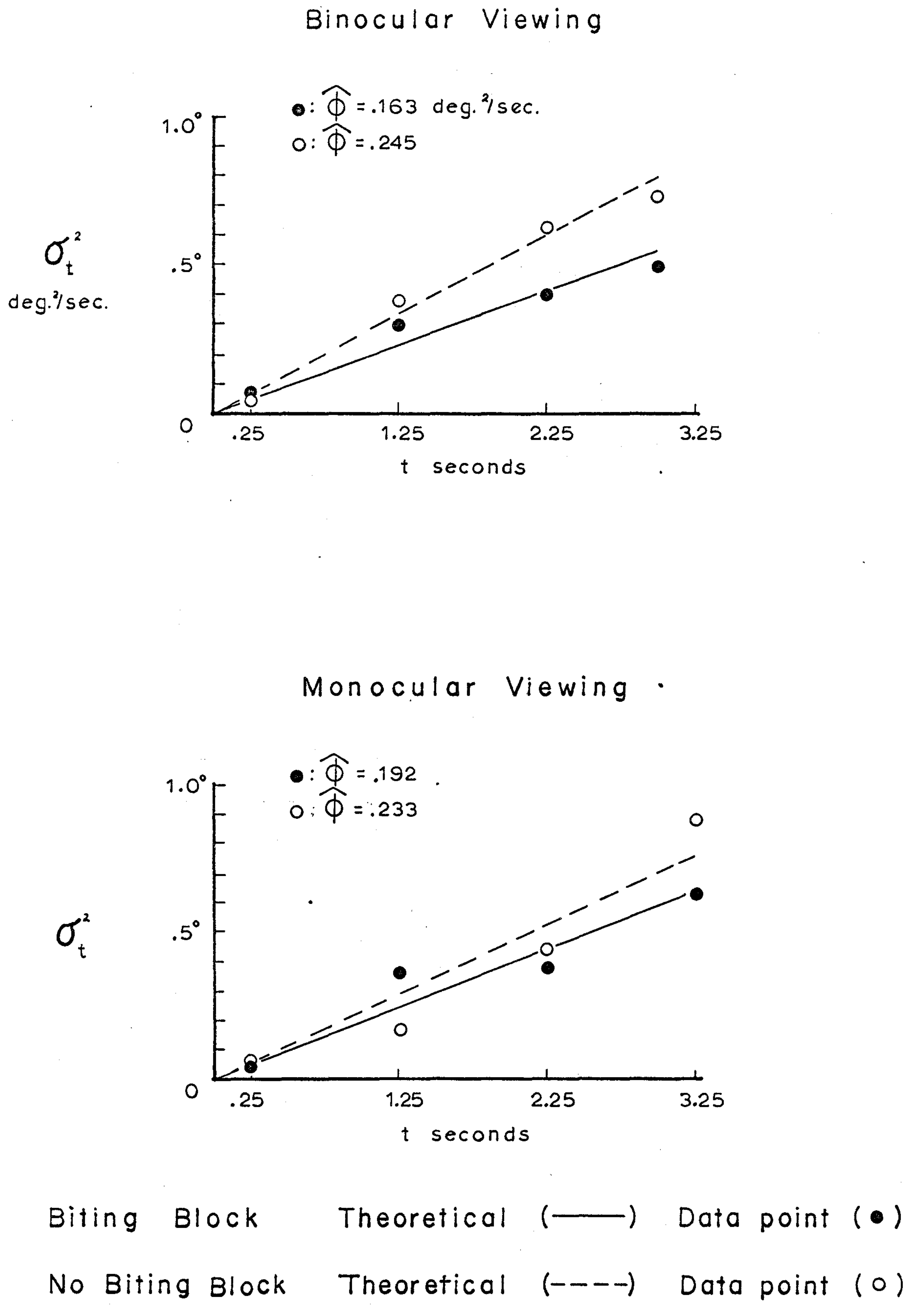
Monocular Viewing



Biting Block Theoretical (———) Data point (●)

No Biting Block Theoretical (– – – –) Data point (○)

Fig. B1



Binocular Viewing

Monocular Viewing

Fig. B2

TABLE B1

Estimated and Predicted Values of δ_t

	Binocular Biting Block		Binocular No Biting Block		Monocular Biting Block		Monocular No Biting Block	
t	δ_t	Pred. δ_t	δ_t	Pred. δ_t	δ_t	Pred. δ_t	δ_t	Pred. δ_t
.25	2.21	2.01	2.31	1.74	2.21	2.01	2.00	1.78
1.25	.81	.97	.70	.78	.74	.90	1.05	.80
2.25	.70	.73	.54	.58	.72	.67	.66	.59
3.25	.64	.60	.51	.48	.56	.56	.46	.49