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TACHISTOSCOPIC RECOGNITION OF LETTERS AND TRIANGULAR  
ORIENTATION IN THE VISUAL HALF-FIELDS

by

GARRY A. NELSON

A dissertation submitted to the Graduate Faculty in  
Psychology in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy, The City  
University of New York.

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## Abstract

### TACHISTOSCOPIC RECOGNITION OF LETTERS AND TRIANGULAR ORIENTATION IN THE VISUAL HALF-FIELDS

by

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Advisor: Professor William S. Battersby

Psychophysical thresholds (50% correct recognition) for both letters and triangular orientation were measured in the left and right visual half-fields of either or both eyes. Four Os were tested, employing a method of constant stimuli. Monocular viewing of both types of stimulus material produced lower duration thresholds in the nasal half-fields of either viewing eye, while binocular viewing produced no half-field differences in recognition. The results were interpreted in terms of differential hemi-retinal visual acuity, which manifests itself monocularly, but which balances out upon binocular testing.

## ACKNOWLEDGEMENTS

I would first like to thank my mentor and advisor, Dr. William S. Battersby, whose patience, wisdom, and understanding guided every phase of this research. I am most grateful to Drs. Mitchell Kietzman and Jack Orbach, whose advice and support aided and enhanced both the completion and understanding of this work. In addition, my sincerest thanks are extended to Drs. Ruth Rutschmann and Thomas Frumkes for their invaluable and timely criticism. I also wish to thank Mr. Russell Speer for his photographic work. Finally, I wish to dedicate this manuscript to my wife, Joanne, and my son, Dagan, who by understanding the experimental data less, appreciate the personal commitment more.

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## INTRODUCTION

In recent years, a considerable amount of research has been devoted to the study of asymmetries between the left and right visual half-fields in tachistoscopic recognition. Initially, Mishkin and Forgays (1952) exposed English and Yiddish words tachistoscopically to either the left or right of a central fixation point. Subjects were bilingual and presentation was binocular. English words were better recognized when presented in the right visual field (RVF), while Yiddish words were slightly better recognized in the left visual field (LVF). As a logical extension of this study, Heron (1957) exposed letters or geometric forms binocularly on both sides of fixation simultaneously and found a differential recognition accuracy for letters (not forms) favoring material in the LVF. Since these two studies, a large number of task, stimulus, and subject variables have been studied and an abundance of theoretical interpretations have been advanced to account for half-field differences in tachistoscopic recognition.

Despite specific differences among experiments, two presentation paradigms have been consistently employed in the study of tachistoscopic recognition. In paradigm 1 (e.g. used by Mishkin and Forgays), stimulus material is presented on a single exposure to either the LVF or RVF. This manner of presentation may be labelled successive. In

paradigm 2 (e.g. used by Heron), stimulus material is presented simultaneously to both the LVF and RVF per exposure. This type of presentation may be labelled simultaneous. For both paradigms, the viewing may be binocular or monocular, but in general, binocular viewing in conjunction with a successive paradigm has been most frequently employed. Typically, this combination has produced differential recognition scores favoring the RVF for English words (Bryden, 1970; 1973; Bryden & Rainey, 1963; Orbach, 1952; 1967; Terrace, 1959), letters (Bryden, 1965; Hayashi & Bryden, 1967), and familiar figures (Wyke & Ettlenger, 1961), while the simultaneous paradigm has generally yielded binocular recognition scores which favor the LVF for English letters and words (Hines, 1972; Neill, Sampson & Gribben, 1971; White, 1969; 1972).

Mishkin and Forgays (1952) interpreted the superiority for English words in the RVF and Yiddish words in the LVF in terms of a presumed differential training of the left or right cerebral hemisphere due to previously acquired reading habits underlying the reading of either English or Yiddish. In brief, learning to read English in a left to right direction and Yiddish in the reverse direction, selectively trains the left or right hemiretinae respectively, thus producing a "more effective neural organization" (Mishkin & Forgays, 1952; p. 47) in the corresponding hemisphere. A follow-up study by Forgays (1952) demonstrated that half-field differences in recognition of

English words developed gradually, with superior recognition in the RVF becoming pronounced only after the seventh grade of school. Orbach (1952) replicated the original findings of Mishkin and Forgays and demonstrated that only those subjects who had learned Yiddish as their first language showed a LVF superiority in the recognition of Yiddish words. Both studies offer supportive evidence for the original Mishkin and Forgay's theory of asymmetrical cerebral organization based upon presumed differences in visual training.

In contrast to a cerebral training hypothesis, Heron (1957) accounted for half-field asymmetries in recognition (using both presentation paradigms), in terms of a directional "post-exposure scanning process" (Heron, 1957; p. 46) based on the two types of eye movements that underlie the reading of English or Yiddish. During the reading of English, the short saccades shift the eyes from left to right, while the preliminary shift (from right to left) returns fixation to the beginning of each successive line. In Heron's concept, post-exposural neural processes mimic the actual eye movements found during reading. Therefore, when English words are presented successively, a RVF is found since the two neural processes representing the two types of eye movements are complementary (both left to right) in this half-field. With simultaneous stimulation, however, these two neural tendencies conflict and the stronger tendency, presumably moving the eyes to the

beginning of the next line, dominates, producing a LVF superiority. Supportive evidence for this concept has been offered by Terrace (1959). In addition, Crovitz & Daves (1962) recorded the actual eye movements made following tachistoscopic exposure of single numbers simultaneously under both binocular and monocular viewing. Using the initial post-exposure eye movement as an index of neural "tendency", a strong congruence was found between the direction of initial horizontal eye movements and the side of the visual field showing superior recognition. Further, under monocular testing more eye movements were made in the direction of the temporal half-fields of either eye (i.e., RVF for the right eye, LVF for the left eye). According to these authors, using short exposure durations (i.e., below the latency of initial post-exposure eye movements of approximately 150 msec.) does not eliminate the possible effects of differential "tendencies" to eye movement" (Crovitz & Daves, 1962; p. 498) upon the subsequent reporting of stimuli.

While earlier studies focused most extensively on paradigm differences in an attempt to account for half-field differences in tachistoscopic recognition, a large number of studies since 1960 have directed attention toward certain factors that may be called stimulus and subject variables. Bryden (1964; 1965) attempted to account for recognition asymmetries in terms of handedness and inferred hemispheric dominance. The successive presentation of

single letter material to right-handed subjects (presumably left hemisphere dominant) produced superior recognition in the RVF, while familial left handers (presumably right hemisphere dominant) showed superior recognition in the LVF. However, when multiple letter stimuli were used, highly learned directional reading habits supposedly overpowered the effects of cerebral dominance and produced superior recognition in the RVF for both left and right-handed subject.

Kimura (1966; 1969; 1973) and Kimura and Durnford (1973) have advanced a hemispheric specialization hypothesis and have claimed that half-field differences in recognition depend heavily upon the nature of the stimulus material and the cerebral hemisphere stimulated. Using binocular viewing with successive presentation, "verbal" tasks (i.e., letter and word recognition) produced differential recognition scores which favored the RVF (projected to the left hemisphere), while "spatial" tasks (i.e., dot enumeration and localization) were more accurately performed when material was exposed in the LVF (projected to the right hemisphere). Data such as these seem to imply that the two hemispheres of the human brain manifest a "dual functional asymmetry" (Kimura, 1966; p. 275) in visual perception. McKeever and Huling (1970a & b) have given additional support to such a hypothesis by substantiating the typical RVF superiority for binocular word recognition,

and by further showing that the reproduction of dot figures is more accurate following stimulation in the LVF. Other "spatial" tasks, such as the recognition of random shapes (Dee & Fontenot, 1973) and line orientation (Fontenot & Benton, 1972) have also been more accurately performed when stimulus material was exposed in the LVF. Thus, various researchers have advanced the concept that the left hemisphere may be specialized for a linear, sequential, linguistic mode of processing, while the right hemisphere may favor a holistic, simultaneous, visuo-spatial mode (Bogen, 1969; Galin, 1974; 1975; Ornstein, 1972; Semmes, 1968).

Kershner and Gwan-Rong Jeng (1972) supported a hemispheric specialization hypothesis by showing that English and Chinese words were better recognized (by Chinese subjects) when binocularly exposed in the RVF (i.e., projected to the left hemisphere), while geometric forms were better recognized when exposed in the LVF (i.e., projected to the right hemisphere). In addition, these authors emphasize the factor of ocular dominance (i.e., ocular sighting preference). Subjects with right eye sighting dominance showed superior recognition of letters, while those with left eye sighting dominance showed superior recognition for forms. Since the crossed fibers of the optic nerve are considered the numerically dominant projection to visual cortex (Polyak, 1957),

ocular sighting dominance presumably interacts with anatomical fiber superiority to enhance either a LVF or RVF recognition superiority. In brief, the combination of right eye dominance and crossed fiber superiority produces better word recognition in the RVF (projections to the left "verbal" hemisphere), while left eye dominance in conjunction with crossed fiber superiority enhances form recognition in the LVF (projections to the right "visuo-spatial" hemisphere).

A variant concept of hemispheric specialization has been proposed by Kinsbourne (1970), who postulates an "attentional" factor which can bias the favoring of left or right visual space, depending upon which cerebral hemisphere is more activated. According to this concept, unilateral hemispheric activation is accompanied by orientation to contralateral half-space; in other words, activation of the left hemisphere shifts attention to right visual space, while activation of the right hemisphere shifts attention to left visual space. In support of this concept, Kinsbourne has shown that the ability to detect a gap in a square figure is initially performed equally well on both sides of fixation. However, when subjects were told to repeat a group of words before, during, and after tachistoscopic exposure, gap detection was performed more accurately following exposure in the RVF. Apparently, "concurrent verbal activity" (Kinsbourne, 1970; p. 199),

mediated by the left hemisphere, can bias attention to right visual space, producing an enhancement of visual functioning. Implicit in this concept is the prediction that "spatial" activity, presumably mediated by the right hemisphere, should bias attention to left visual space.

While the bulk of research on half-field differences in tachistoscopic recognition has utilized only binocular viewing, a number of monocular studies have been performed in an attempt to measure sensory factors, such as acuity and hemiretinal differences and effects due to optic fiber asymmetries in the visual system. Thus, Overton and Wiener (1966), employing a successive paradigm in conjunction with monocular viewing, found recognition of English words to be superior in the RVF, but only for the left eye (i.e., the left temporal hemiretina). Furthermore, left eye hemifield differences were found to be significant only at a retinal eccentricity of  $2^{\circ}6'$  and not at  $1^{\circ}3'$ . Markowitz and Weitzman (1969), McKeever and Huling (1970a), Neill et al. (1971), and Shai, Goodglass, and Barton (1972) have reported a similar favoring of the left temporal hemiretina for the monocular viewing of successively presented letters, nonsense syllables, and words. Also, Neill et al. (1971) have shown that both temporal hemiretinae, relative to the nasal hemiretinae, are more efficient in the overall recognition of letters. In addition, Markowitz and Weitzman (1969) have found that

the visual acuity of either eye, as measured with the Landolt C, is superior for the temporal hemiretinae. In comparison, however, Crovitz and Lipscomb (1963) reported that the monocular recognition of successively presented single numbers is more accurate following stimulation of the nasal hemiretinae of either eye. Accordingly, "sensory" factors, such as differential ocular or hemiretinal sensitivity, may be influencing half-field asymmetries in some tachistoscopic tasks, even when only binocular viewing is employed.

In summary, the number of variables typically considered in the study of half-field recognition differences has become large. Measurable differences in presentation paradigms, stimulus materials, viewing conditions, subject characteristics (i.e., first learned language, handedness, and ocular dominance), anatomical asymmetries (i.e., crossed vs. uncrossed fibers), hemiretinal acuity, and type of experimental tasks, as well as inferred differences in hemispheric specialization and processing have all been considered as variables affecting tachistoscopic recognition.

Despite differences in many task, stimulus, and subject variables, however, almost all researchers have inevitably used one experimental method. The typical procedure consists of using a modified psychophysical method of limits (usually ascending only) as a preliminary

assessment of the region of duration threshold and then choosing one or two exposure durations (in msec.) that hopefully produce recognition that exceeds 50%. The selected stimulus material is then randomly presented a specific number of times successively in either the LVF or RVF, or simultaneously in both half-fields, at each of the chosen durations. In many previous studies, large samples of subjects were used, usually with a small number of observation (i.e., 20 to 40) in each half-field. Typically, recognition scores for each half-field have been averaged across both subjects and stimulus materials. Thus, in many cases, significant half-field differences may be found for group scores, while individual subject differences may not achieve significance. Furthermore, many researchers have reported or discussed only the typical group differences and have neglected to comment on obvious individual deviations. White (1971), for example, exposed four different single letters successively in either the LVF or RVF and found a significant RVF superiority for only the letter V. Yet, the claim is made that letters were significantly better recognized in the RVF. While the use of group "tachistoscopic thresholds" may be a relatively simple and quick technique (Dember, 1960), the possibility of obfuscating significant and instructive differences in both subjects and stimulus materials is ever present.

In an attempt to correct for this possibility and to explore half-field recognition differences in greater depth, a psychophysical method which allowed for the production of individual psychometric functions was employed in the present study. Such a psychophysical approach has not been used in any previous study of half-field recognition differences. In addition, both binocular and monocular observations were made and stimulus material of presumed "verbal" and "spatial" character was utilized.

## METHOD

### Observers

Four college students were used as observers (Os) in the study. Two of the Os, FC, a 19 year old male, and MD, a 20 year old male, both undergraduates, had uncorrected 20/20 or better visual acuity. The third O, DL, a 21 year old female undergraduate, had corrected 20/30 visual acuity. The fourth O, HC, a 28 year old male graduate student had corrected 20/30 visual acuity and was the only O aware of the design and purpose of the study. Excepting MD, who was left eye dominant, all Os were right eye dominant as measured with a sighting test designed by Crovitz and Zener (1962). All Os were right handed as measured with the Edinburgh Inventory (Oldfield, 1971) and were paid \$2.00 per hour. FC and HC received extensive tachistoscopic practice and were used in each of the three main experiments. MD and DL served only in Experiments II and III.

### Apparatus

A three-channel tachistoscope (Scientific Prototype, model GA) was employed. An adjustable chin rest and viewing hood were provided to maximize stable viewing. Adapting field and fixation targets were presented through the blank channel, which went off when stimuli were delivered through channel 2. Luminance in the adapting field (fix-

ation) was set at 27.4 mL, while that of the stimulus channel was set at 28.4 mL, as measured with a MacBeth illuminometer at the eye. All fixation targets and stimuli were hand drawn with black India ink on 5 x 7 inch white cards. A standard viewing distance of 48 inches produced a visual field of 7°45' horizontally by 5°22' vertically.

### General Procedure

All experiments were performed in a darkened room, with Q seated, head comfortably in the chin rest. A 7 watt bulb was affixed to the side of the tachistoscope to provide the necessary lighting for E's tasks. A wooden screen was attached to the front of the tachistoscope to prevent Q from observing the stimuli and to reduce the ambient light from the 7 watt bulb. All triggering and changing of stimulus material, as well as the recording of Q's verbal report were performed manually by E. Both monocular and binocular observations were required. An eyepatch was worn during monocular testing.

In all experiments, a successive paradigm was employed; i.e., stimulus material was presented on a single exposure in either the left or right visual half-field of either or both eyes using a Gellerman (1933) series. Throughout the experiments, Q was reminded to maintain fixation and to report "ready" only when he/she felt that fixation was being adequately maintained. The typical

trial began with a ready signal from E, and following O's ready response, a stimulus was presented at one of several exposure durations. After the stimulus exposure, E recorded the response, changed the stimulus card, varied the exposure duration, and again said "ready" to begin the next trial. The intertrial interval was approximately 10 seconds and the interval between O's ready response and stimulus onset was approximately one second.

Detailed procedures for each experiment are given below. Regardless of the specific stimuli or viewing conditions employed, 10 minute rest periods were given half-way through each session. Os were generally tested two to three times a week at regularly scheduled hours.

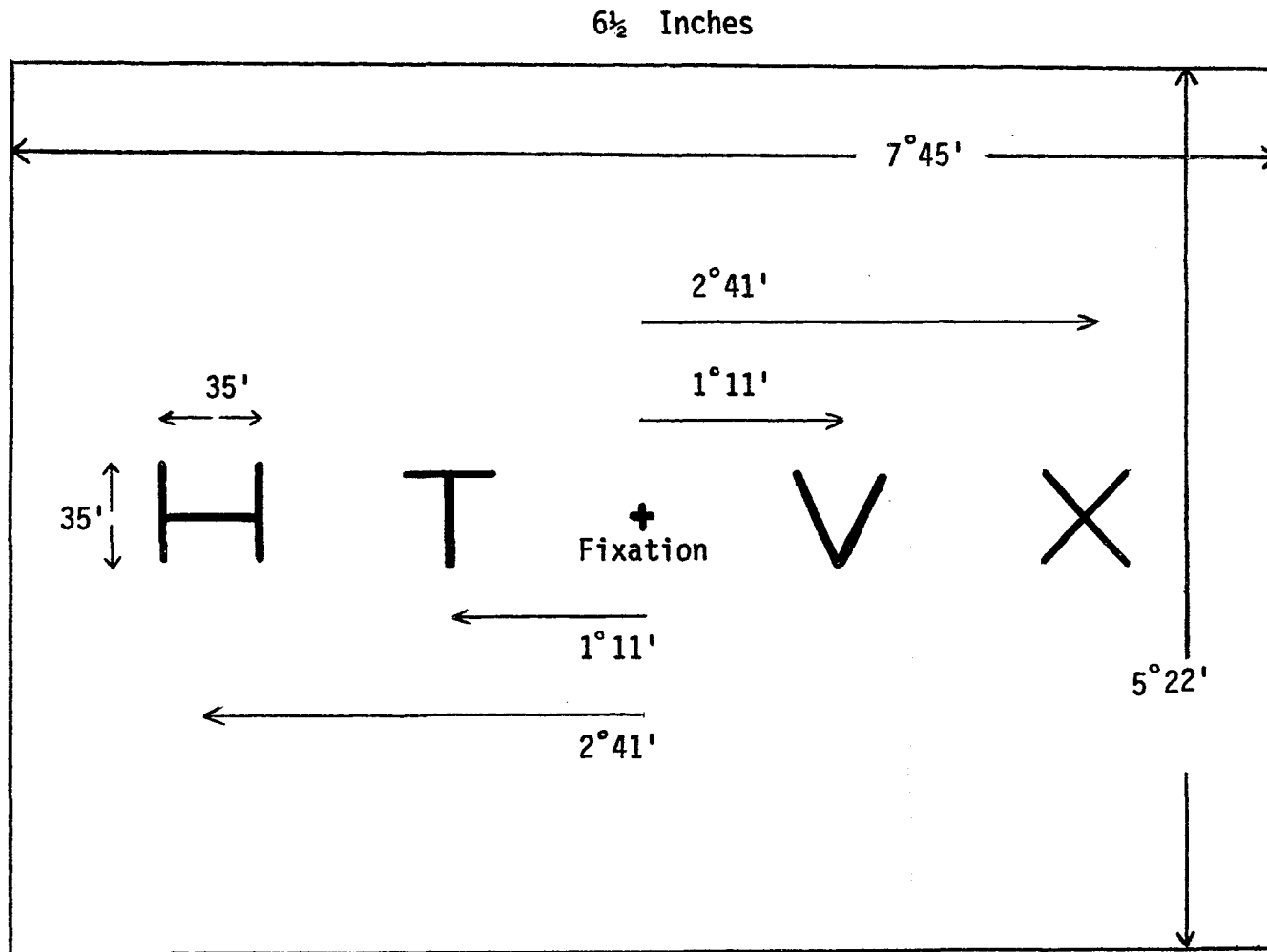
## EXPERIMENT I

### Stimulus Material and Conditions

The stimulus material consisted of four letters: H, T, X or V, only one of which was exposed on any one trial, but each was presented an equal number of times at each retinal eccentricity. Figure 1 shows the size and retinal eccentricity of these stimuli in degrees of visual angle. Each letter subtended a visual angle of 35' in horizontal and vertical extent and was presented at two retinal eccentricities ( $1^{\circ}11'$  or  $2^{\circ}41'$ ) in the LVF or RVF as measured from fixation.

Figure 1. Diagram of stimulus material employed in Experiments I and II. Dimensions of full visual field indicated in inches and degrees of visual angle; size and retinal eccentricities of stimuli indicated in degrees of visual angle. In Experiment II, only the retinal eccentricity of  $2^{\circ}41'$  was used.

4½  
Inches



## Procedure

An ascending method of limits was used initially to estimate the dynamic range of correct recognition. Based on pilot work, a subthreshold exposure duration was chosen and increased in one msec. steps until O correctly recognized a letter three times in succession. Using approximately 30 such preliminary trials, five exposure durations were then chosen that would ideally generate psychometric functions ranging from 20% to 80% correct recognition. A method of constant stimuli was then employed for the main body of the experiment, each letter being exposed an equal number of times in random order at each pre-selected duration, using a pre-determined order chosen from a table of random numbers. In this way, in a single session, each of the four letters was exposed five times at each of five durations in each visual half-field, for a sub-total of 200 stimulus exposures. In addition, a total of 40 blank trials, consisting of blank white cards, were interpolated into each session for a grand total of 240 exposures. Each session was sub-divided into 10 blocks of 24 trials each. Two to three minute rest periods were given between blocks to allow E to reorder the stimulus cards. The total session time was approximately two hours. Only monocular observations were made, and in any one session, only one eye and retinal eccentricity were tested. The order of testing eyes and retinal

eccentricities was counter balanced across the two Os: FC and HC. One experimental session was required for each combination of eye and retinal eccentricity.

Throughout the experiment, O was aware of the stimulus choices and was advised to adopt a strict response criterion by reporting the presence of a letter only when quite certain of its exposure. As a result, three classes of report were given by O: (1) reports of seeing "nothing"; (2) reports of seeing something in the correct half-field; and (3) reports of seeing a specific letter in the correct half-field. Only the third class of report, if accurate, was considered a correct response.

## EXPERIMENT II

### Stimulus Material and Conditions

The stimulus material was identical to that used in Experiment I, but was presented at only a retinal eccentricity of  $2^{\circ}41'$ .

### Procedure

The procedure was identical to that employed in Experiment I. However, four Os were tested and binocular viewing, as well as monocular viewing, were employed.

## EXPERIMENT III

### Stimulus Material and Conditions

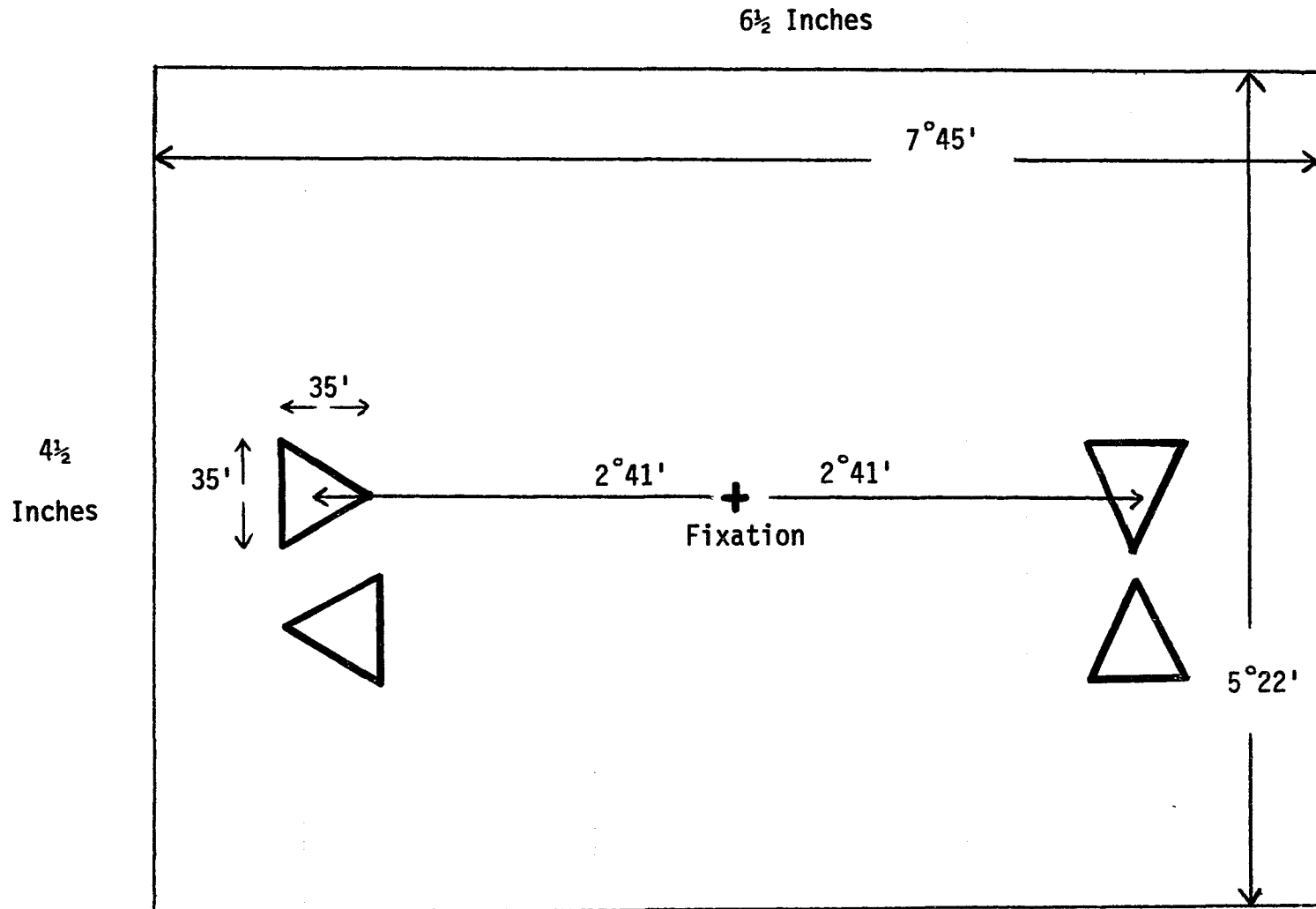
The stimulus material consisted of equilateral triangles whose apexes were oriented in one of four posit-

ions: up, down, left or right. Only one triangle was exposed on any one trial, but each was presented an equal number of times in each half-field. Figure 2 shows the size and retinal eccentricity of these stimuli in degrees of visual angle. Each triangle subtended 35' of visual angle in horizontal and vertical extent and was presented at one retinal eccentricity ( $2^{\circ}41'$ ) in either the LVF or RVF, as measured from fixation.

### Procedure

The procedure was identical to that employed in Experiments I and II. As in Experiment II, four Os were tested and both monocular and binocular observations were made. Only the verbal response was changed; i.e., a correct report of triangle orientation and half-field location was required.

Figure 2. Diagram of stimulus material employed in Experiment III. Dimensions of full visual field indicated in inches and degrees of visual angle; size and retinal eccentricity of stimuli indicated in degrees of visual angle. Two stimuli are shown in proper position; the remaining two are shown below.



## RESULTS

### Experiment I

In this experiment, two Os (FC, HC) were tested and only monocular observations at two retinal eccentricities ( $1^{\circ}11'$  and  $2^{\circ}41'$ ) were required. The psychophysical method employed generated per cent correct recognition vs. exposure duration functions for each combination of observer-eye-retinal eccentricity. Figure 3 presents the functions obtained at a  $1^{\circ}11'$  retinal eccentricity in two Os for monocular viewing of letters with either the left eye (labelled OS on the left side of the graph) or the right eye (labelled OD on the right side of the graph) for left (dashed line) and right (solid line) visual half-field presentation. Figure 4 presents, in the same fashion, the data obtained at a retinal eccentricity of  $2^{\circ}41'$ .

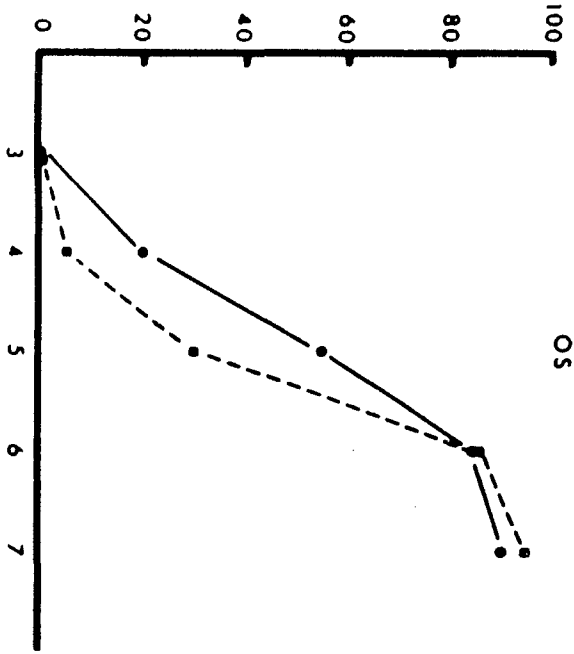
Visual inspection of these functions shows that threshold (50% correct recognition) was reached at shorter exposure durations in the visual half-field contralateral to the viewing eye (i.e., RVF for OS, and LVF for OD). Differences between the two half-fields were minimal at the smaller retinal eccentricity (Figure 3), but became much greater at the larger eccentricity (Figure 4). These differences between half-fields were analyzed across all data points and found to be 8% (mean deviation  $\pm 6.95\%$ ) for an eccentricity of  $1^{\circ}11'$ , and 24.25%

Figure 3. Per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC and HC at a retinal eccentricity of  $1^{\circ}11'$ . Left eye (OS) to the left; right eye (OD) to the right.

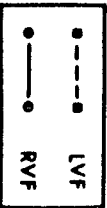
LETTERS

RETINAL ECCENTRICITY (°)

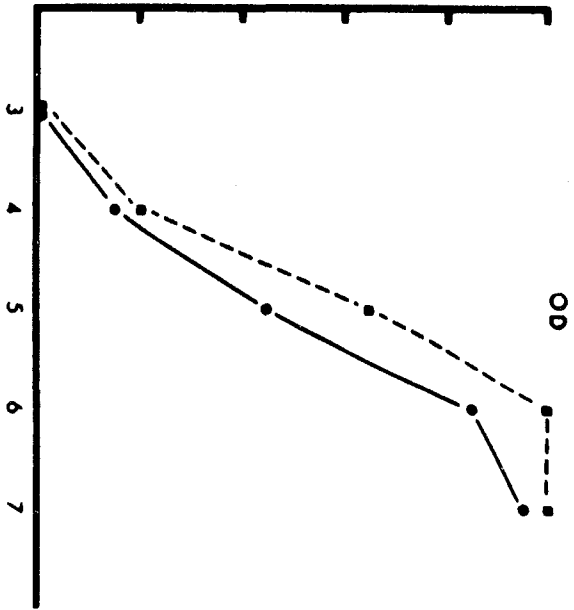
PER CENT CORRECT RECOGNITION



OS

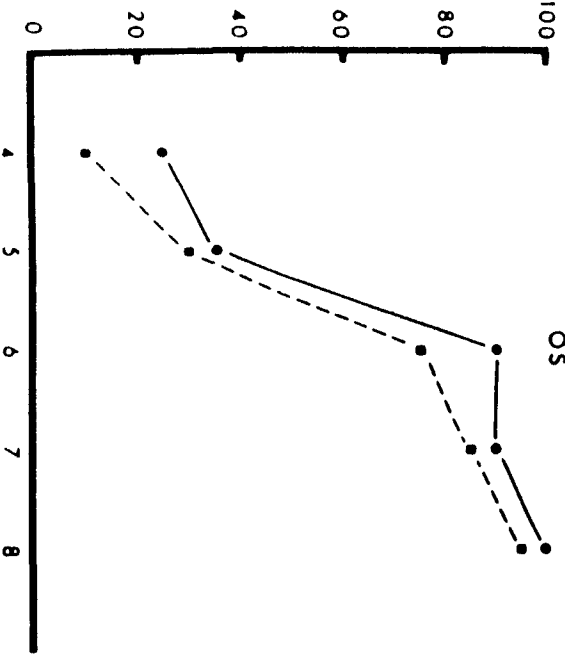


OS

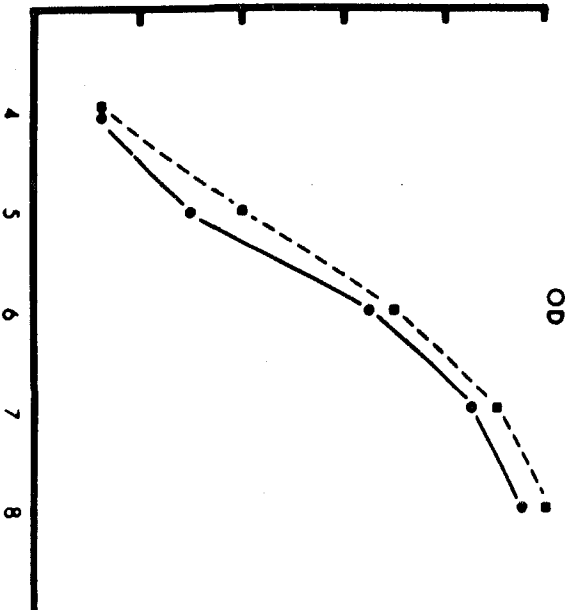


OD

OD



OS

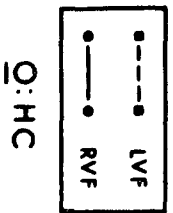
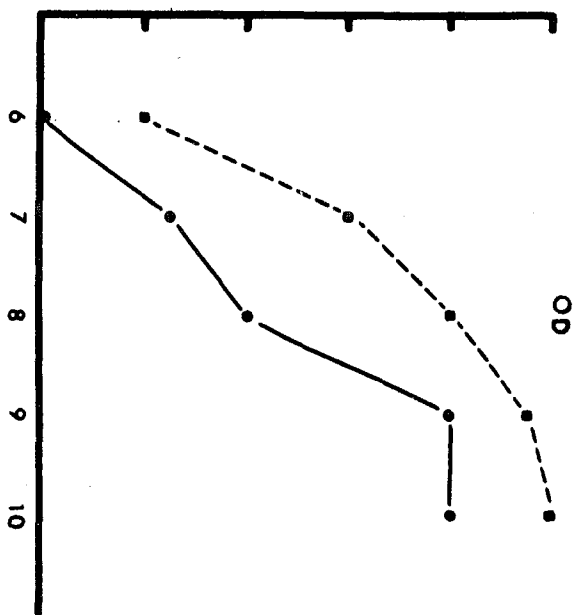
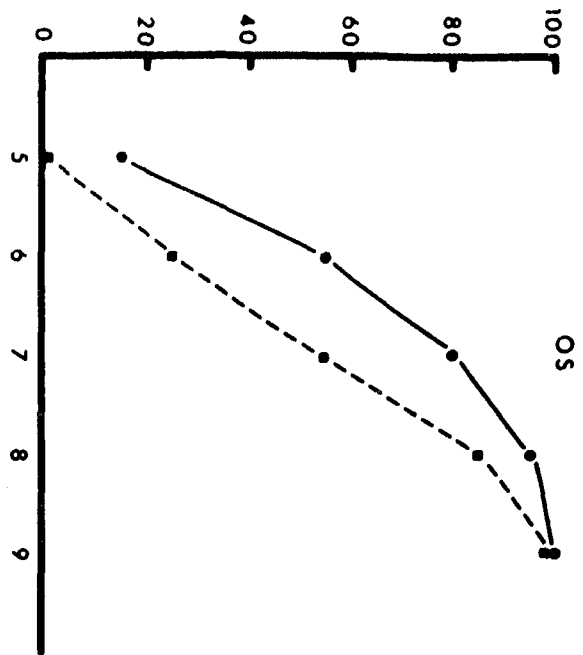


OD

Figure 4. Per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC and HC at a retinal eccentricity of  $2^{\circ}41'$ . Left eye (OS) to the left; right eye (OD) to the right.

LETTERS

RETINAL ECCENTRICITY 2° 41'

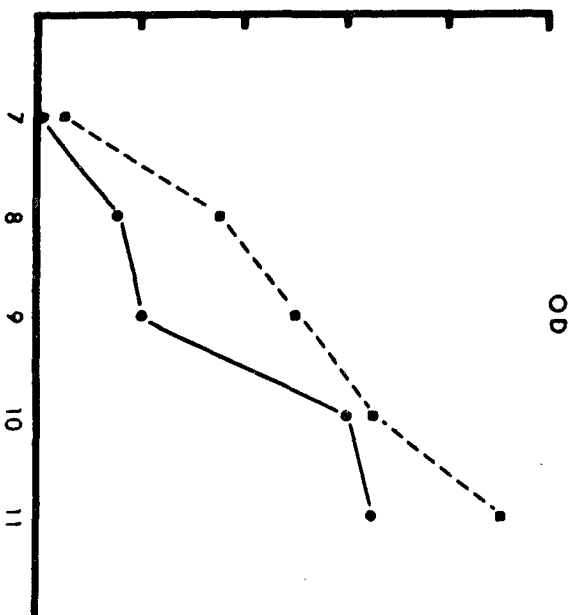
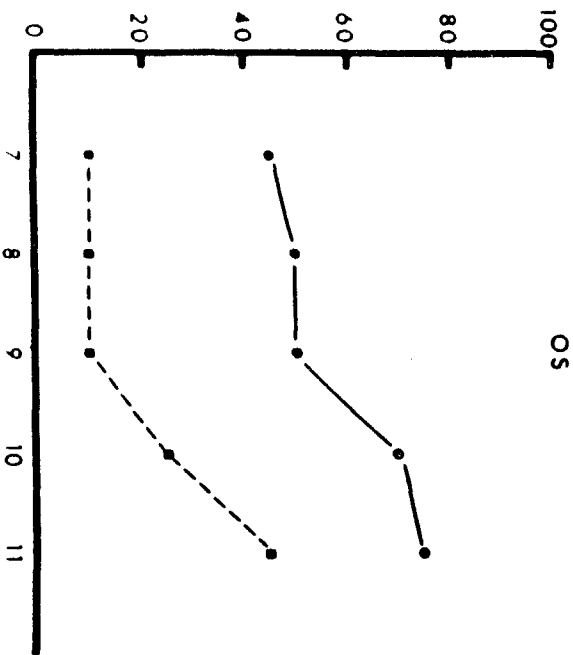


OS

Q:FC

OD

PER CENT CORRECT RECOGNITION



(average deviation  $\pm 12.78\%$ ) for an eccentricity of  $2^{\circ}41'$ . Although individual differences were evident with respect to absolute sensitivity (compare abscissa values) and variability (compare slopes of the functions), the superiority of the nasal half-fields (i.e., the temporal hemiretinae) in letter recognition remained constant for both Os no matter which eye was used.

In order to evaluate the statistical significance of threshold differences (50%) between the visual half-fields,  $\chi^2$  tests were performed on each set of functions (McNemar, 1962). Specifically, the 50% value on each curve was compared to the percentage value on the opposite curve (i.e., the opposite half-field) at the same exposure duration. For each set of curves, therefore, two  $\chi^2$  values were calculated; one going from the LVF to the RVF, the other in the reverse direction. At the smaller retinal eccentricity of  $1^{\circ}11'$ , the  $\chi^2$  values for the difference between half-fields failed to achieve significance for each O. At the greater eccentricity of  $2^{\circ}41'$ , half-field comparisons proved generally significant ( $p < .05$ ) for both Os. For O: FC, both comparisons for right eye viewing proved significant, while for O: HC, the LVF - RVF comparison for the right eye and the RVF - LVF comparison for the left eye proved significant. The majority of the remaining comparisons appeared to be approaching significance. Tables

1 (FC) and 2 (HC) present summaries of these per cent differences and their significance.

When differences between the half-fields were evaluated over the entire dynamic range, the results were clearly significant at the larger eccentricity. Specifically, for each set of functions, additional  $\chi^2$  tests were performed on the differences between half-fields in total per cent correct recognition, summated over all durations (Table 3). This analysis shows, for both Os and for both eyes, that highly significant ( $p < .05$  or better) differences were obtained at the greater retinal eccentricity of  $2^\circ 41'$ . This increase in statistical significance can be attributed to the larger N, and to the fact that there was a consistent half-field difference throughout the entire dynamic range.

With respect to response criterion, both Os adopted a strict criterion as evidenced by the complete absence of false positive responses. Each O, however, did make mistakes in the reporting of stimuli. The most frequent error was to report an H for a T, or an X for a V. The percentage of such inaccurate responses was small (approximately 4% of the total) and was distributed equally in each half-field, regardless of recognition accuracy. More typically, O gave reports of seeing "nothing" or something in the correct half-field at exposure durations that yielded accurate responses in the opposite half-field.

TABLE 1

Monocular Half-Field Differences in Letter Recognition at Threshold and Their Significance for 0: FC Obtained at Two Retinal Eccentricities ( $1^{\circ}11'$  and  $2^{\circ}41'$ ).

		<u>Retinal Eccentricity - <math>1^{\circ}11'</math></u>		
		<u>Half-field Differences at Threshold</u>	<u>Per Cent Differences at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
LEFT EYE		RVF = 50%		
		LVF = 27%	23%	3.60 - n.s.
		LVF = 50%		
		RVF = 66%	16%	1.05 - n.s.
<hr/>				
RIGHT EYE		LVF = 50%		
		RVF = 35%	15%	.92 - n.s.
		RVF = 50%		
		LVF = 68%	18%	1.34 - n.s.
<hr/>				
		<u>Retinal Eccentricity - <math>2^{\circ}41'</math></u>		
LEFT EYE		RVF = 50%		
		LVF = 22.5%	27.5%	3.27 - n.s.
		LVF = 50%		
		RVF = 76%	26%	2.90 - n.s.
<hr/>				
RIGHT EYE		LVF = 50%		
		RVF = 20%	30%	3.96 - p < .05
		RVF = 50%		
		LVF = 83%	33%	4.89 - p < .05

TABLE 2

Monocular Half-Field Differences in Letter Recognition at Threshold and Their Significance for 0: HC Obtained at Two Retinal Eccentricities ( $1^{\circ}11'$  and  $2^{\circ}41'$ ).

		<u>Retinal Eccentricity - <math>1^{\circ}11'</math></u>		
		<u>Half-field Differences at Threshold</u>	<u>Per Cent Differences at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
LEFT EYE		RVF = 50%		
		LVF = 42.5%	7.5%	.226 - n.s.
		LVF = 50%		
		RVF = 58%	8%	.256 - n.s.
RIGHT EYE		LVF = 50%		
		RVF = 42.5%	7.5%	.226 - n.s.
		RVF = 50%		
		LVF = 56%	6%	.144 - n.s.
		<u>Retinal Eccentricity - <math>2^{\circ}41'</math></u>		
LEFT EYE		RVF = 50%		
		LVF = 10%	40%	7.62 - p < .01
		LVF = 45% *		
		RVF = 70%	25%	2.56 - n.s.
RIGHT EYE		LVF = 50%		
		RVF = 20%	30%	3.96 - p < .05
		RVF = 50%		
		LVF = 61%	11%	.490 - n.s.

\* LVF did not reach threshold.

TABLE 3

Monocular Half-Field Differences in Per Cent Total Recognition of Letters and Their Significance for Os: FC and HC Obtained at Two Retinal Eccentricities ( $1^{\circ}11'$  and  $2^{\circ}41'$ ).

		<u>Retinal Eccentricity - <math>1^{\circ}11'</math></u>		<u>Chi<sup>2</sup></u> <u>for</u> <u>Difference</u>
		<u>Half-field Differences</u> <u>in Total Per Cent</u> <u>Correct Recognition</u>		
O: FC	LEFT	RVF = 50%	7%	.984 - n.s.
	EYE	LVF = 43%		
	RIGHT	LVF = 57%	9%	1.62 - n.s.
	EYE	RVF = 48%		
O: HC	LEFT	RVF = 68%	9%	1.74 - n.s.
	EYE	LVF = 59%		
	RIGHT	LVF = 62%	5%	.519 - n.s.
	EYE	RVF = 57%		
		<u>Retinal Eccentricity - <math>2^{\circ}41'</math></u>		
O: FC	LEFT	RVF = 69%	16%	5.38 - $p < .05$
	EYE	LVF = 53%		
	RIGHT	LVF = 71%	26%	13.88 - $p < .001$
	EYE	RVF = 45%		
O: HC	LEFT	RVF = 58%	38%	29.38 - $p < .001$
	EYE	LVF = 20%		
	RIGHT	LVF = 49%	17%	5.99 - $p < .02$
	EYE	RVF = 32%		

When total correct responses for both half-fields were compared for the four different letters, the rank order of ease of recognition was H (60%), T (57%), V (53%) and X (50%).

### Experiments II and III

In both of these Experiments, four Os were tested and both monocular and binocular observation of letters (Experiment II) or triangles (Experiment III) were required. Further, only a retinal eccentricity of  $2^{\circ}41'$  was used. The results are presented below in terms of viewing conditions.

Monocular Viewing of Letters or Triangles. In the same manner as in Experiment I, Figures 5 and 6 present the data obtained at  $2^{\circ}41'$  of eccentricity in the left (dashed line) and right (solid line) visual half-fields for left eye viewing of letters (Figure 5) and triangles (Figure 6) in each of four Os. In analogous fashion, Figures 7 (letters) and 8 (triangles) present the results obtained upon right eye viewing. Regardless of stimulus material, left eye viewing (Figures 5 & 6) clearly produced lower duration thresholds in the RVF for three of the four Os and a small insignificant difference in the remaining O. Right eye viewing of the same stimulus material (Figures 7 & 8) produced clearly lower thresholds in the LVF for all four Os. Thus, monocular viewing produced superior recognition when stimuli of either type were exposed in the nasal

Figure 5. Per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL and MD at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing only.

LETTERS

LEFT EYE - 2.41'

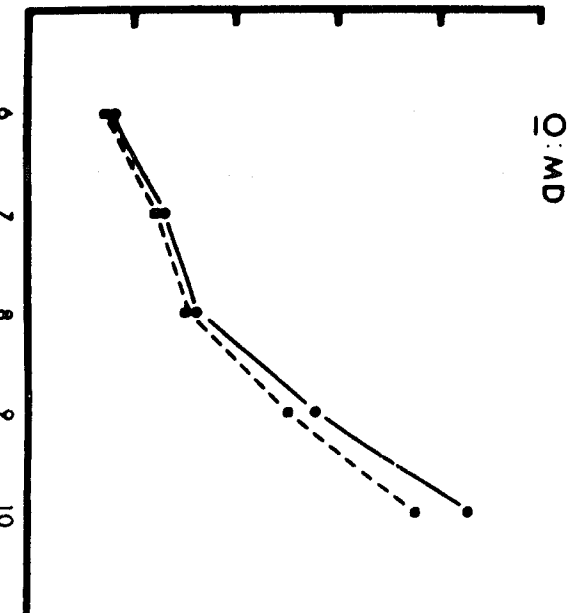
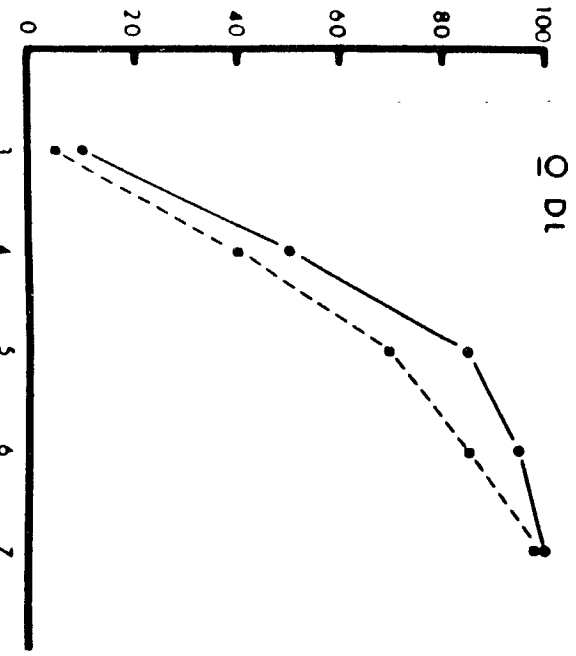
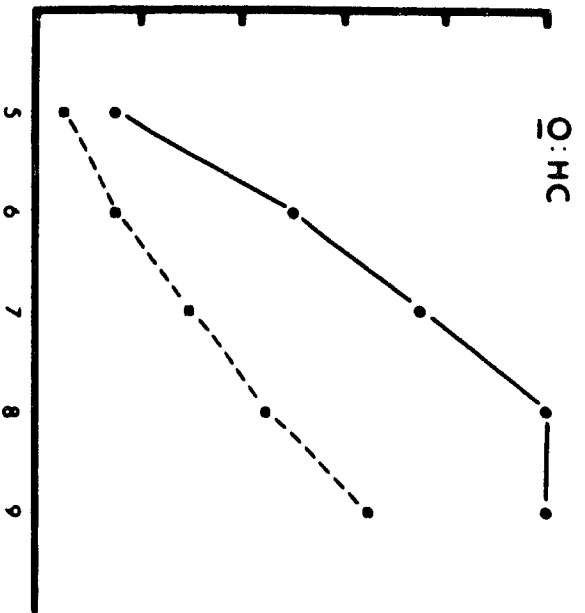
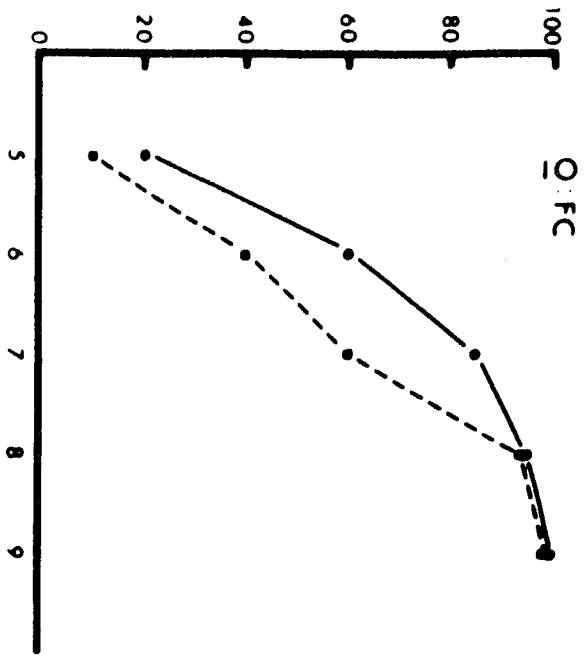


Figure 6. Per cent correct recognition of triangular orientation in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL, and MD at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing only.

TRIANGLES

LEFT EYE - 2 41'

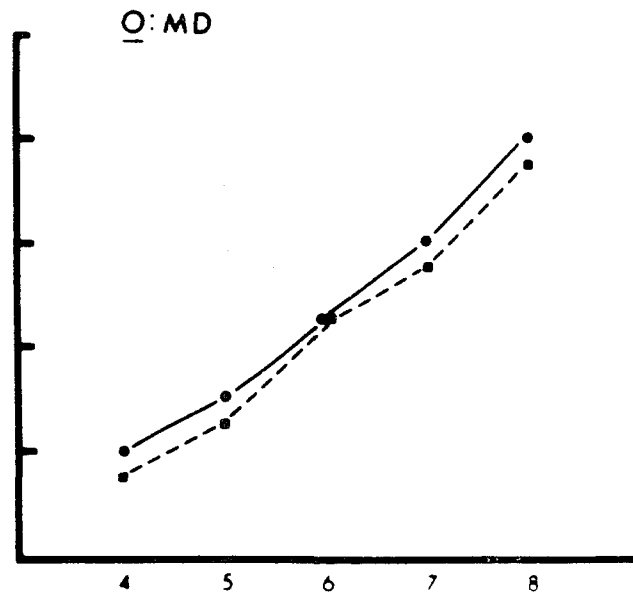
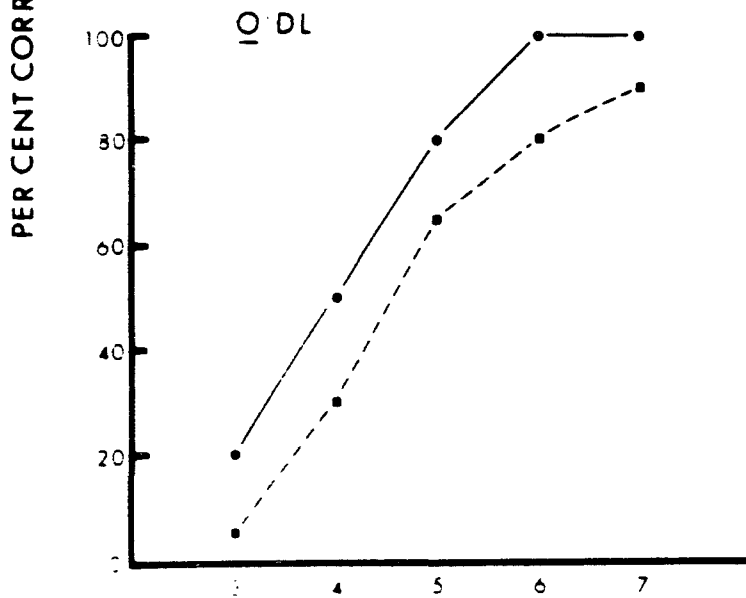
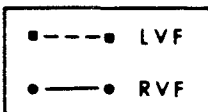
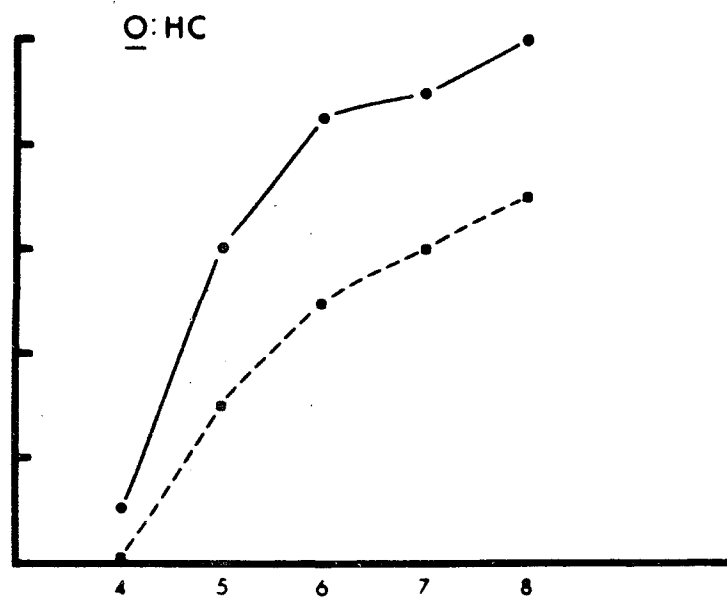
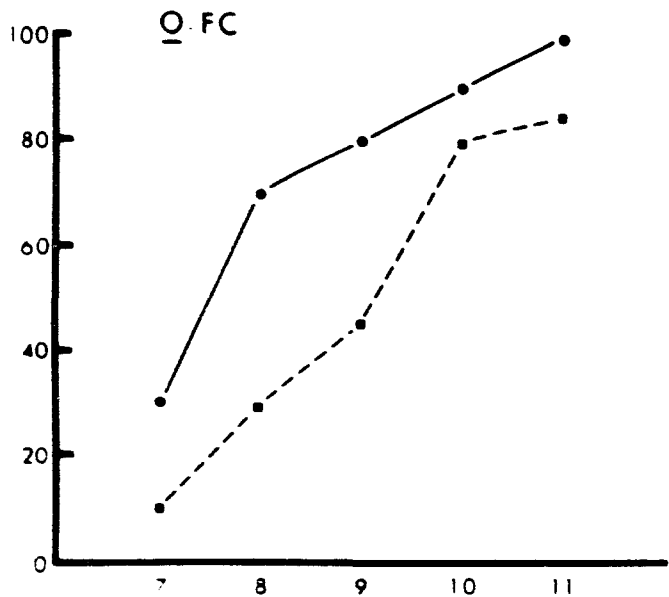


Figure 7. Per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL, and MD at a retinal eccentricity of  $2^{\circ}41'$ . Right eye viewing only.

LETTERS

RIGHT EYE - 2'41'

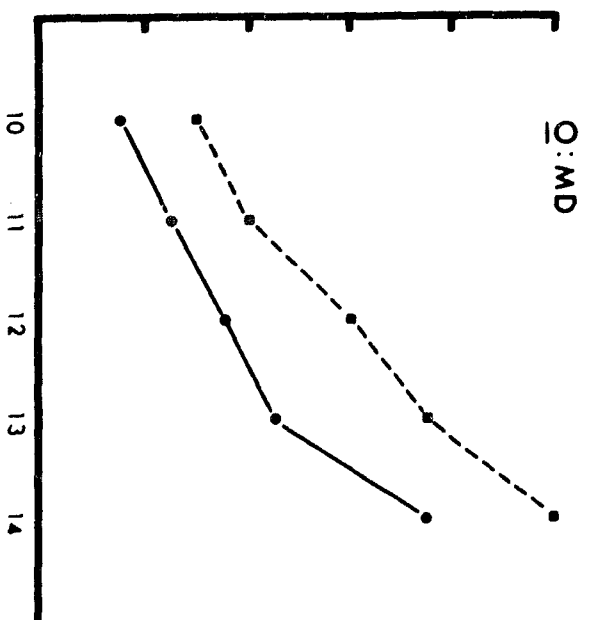
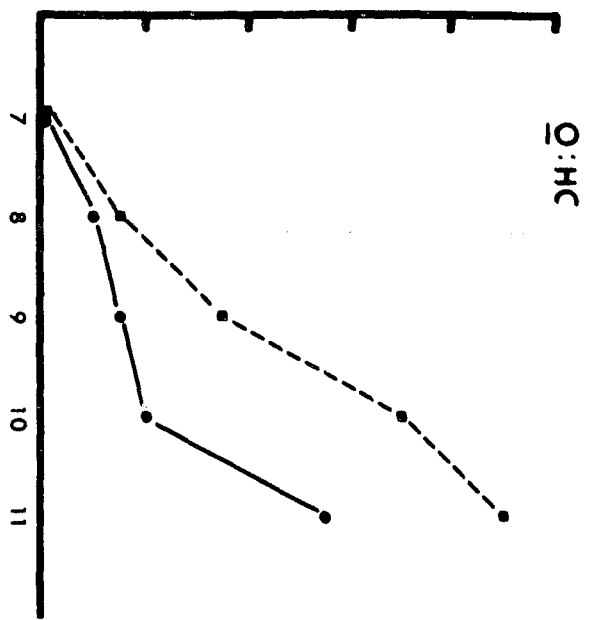
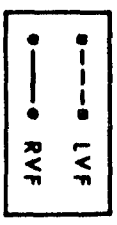
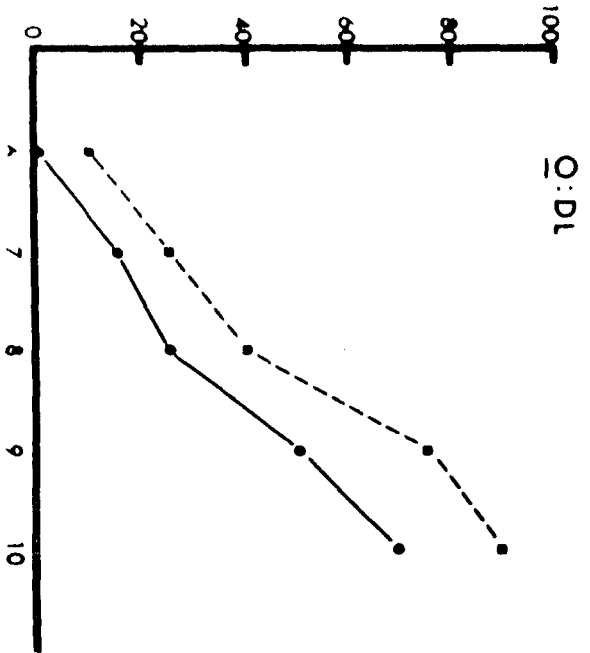
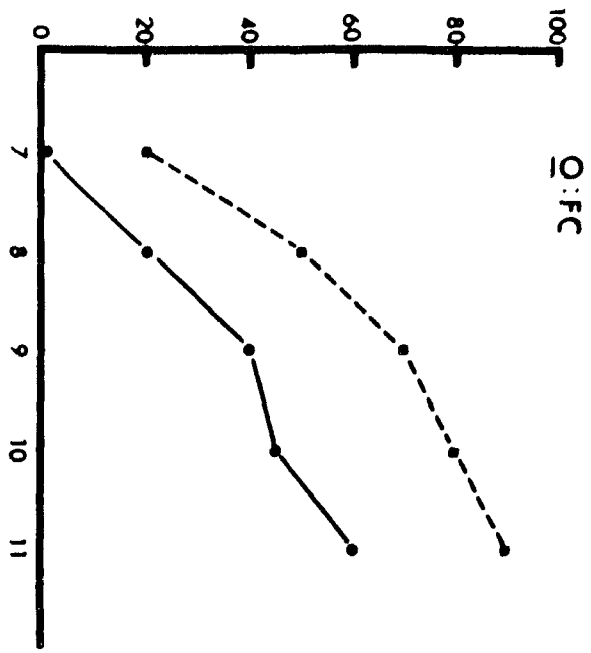
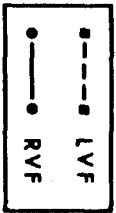
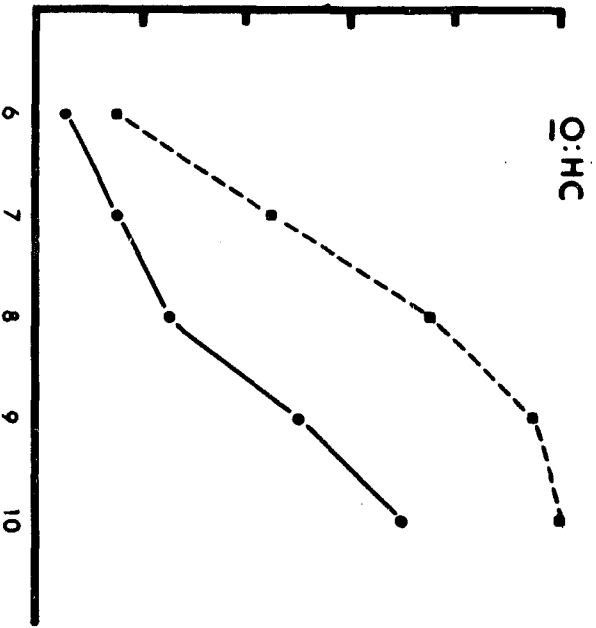
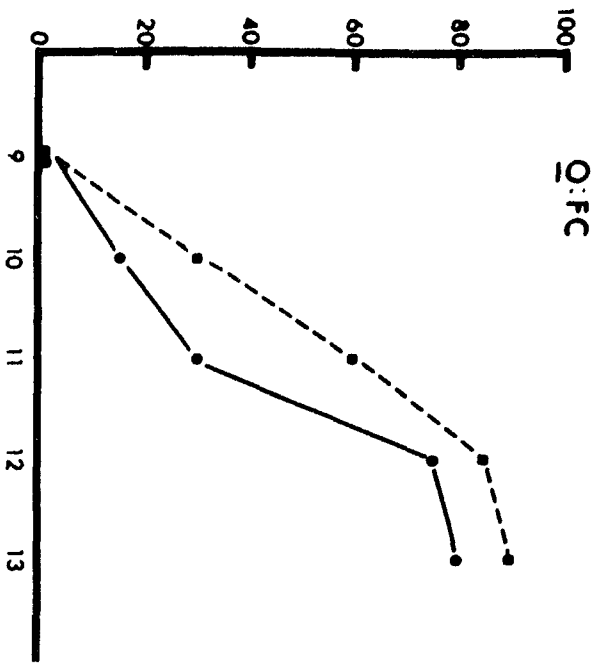


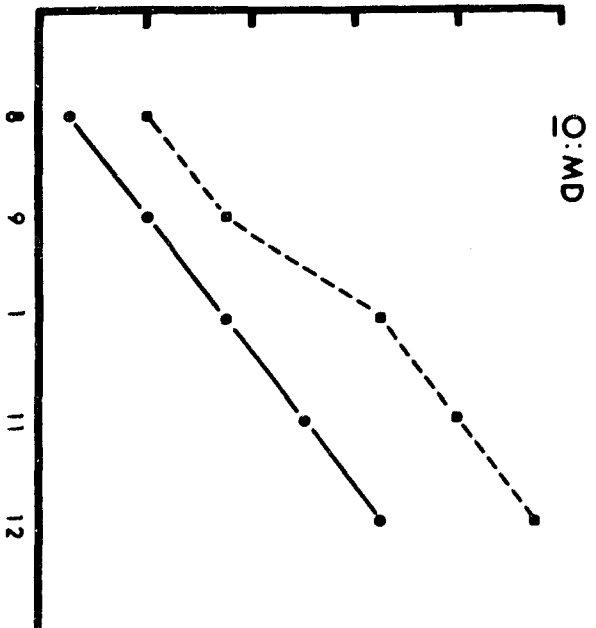
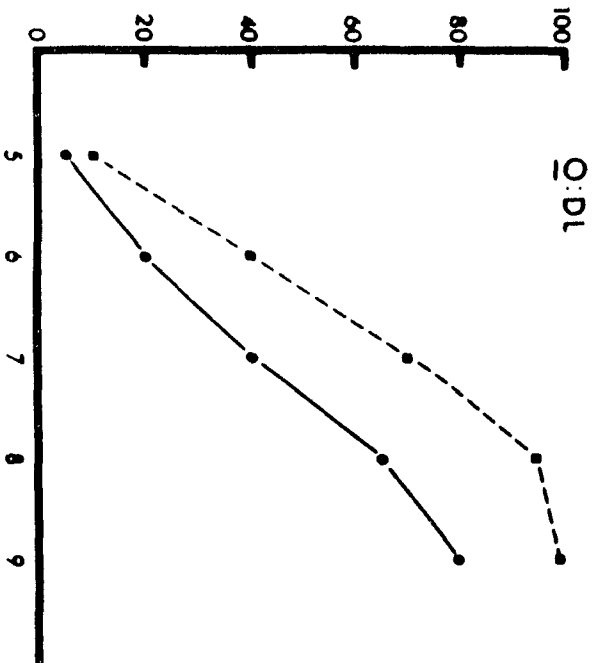
Figure 8. Per cent correct recognition of triangular orientation in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL, and MD at a retinal eccentricity of  $2^{\circ}41'$ . Right eye viewing only.

TRIANGLES

RIGHT EYE - 2'41"



PER CENT CORRECT RECOGNITION



half-fields of either eye (i.e., the temporal hemiretinae). In addition, psychometric functions with steeper slopes were generated when either type of stimulus material was exposed in the nasal half-fields. In brief, to achieve any chosen percentage of correct recognition, smaller energy increments were needed in the nasal half-fields.

In the same fashion as in Experiment I,  $\chi^2$  tests were performed per 0 on each set of functions for both half-field differences in threshold and for the entire dynamic range in terms of the summated total recognition score. For each 0, summaries of the percentage differences at threshold (50%) and their significance are presented in Tables 4 (FC and HC) and 5 (DL and MD) for letters, and in Tables 6 and 7 for triangles. For letters (Tables 4 & 5), these differences proved generally significant only for 0s: FC and HC. For triangles (Tables 6 & 7), again only 0s: FC and HC demonstrated consistently significant differences between visual half-fields. When the entire dynamic range of half-field differences was analyzed, however, (Table 8 for letters, 9 for triangles) the majority of these comparisons proved significant, irrespective of stimulus material.

In order better to compare individual differences in the above presented functions, the data on letter recognition (Figures 5 & 7) and triangle orientation (Figures 6 & 8) for all 0s were replotted on a single extended abscissa, and are presented in Figures 9 (left eye viewing

TABLE 4

Monocular Half-Field Differences in Letter Recognition at Threshold and Their Significance for Os: FC and HC Obtained at a Retinal Eccentricity of 2°41'.

		<u>O</u> : FC		
		Half-field Differences at Threshold	Per Cent Difference at Threshold	Chi <sup>2</sup> for Difference
LEFT EYE		RVF = 50%	17.5%	1.26 - n.s.
		LVF = 32.5%		
		LVF = 50%	23%	2.23 - n.s.
		RVF = 73%		
RIGHT EYE		LVF = 50%	30%	3.96 - p <.05
		RVF = 20%		
		RVF = 50%	33%	4.89 - p <.05
		LVF = 83%		
		<u>O</u> : HC		
LEFT EYE		RVF = 50%	35%	5.58 - p <.02
		LVF = 15%		
		LVF = 50%	50%	13.33 - p <.001
		RVF = 100%		
RIGHT EYE		LVF = 50%	32.5%	4.33 - p <.05
		RVF = 17.5%		
		RVF = 50%	37.5%	6.55 - p <.02
		LVF = 87.5%		

TABLE 5

Monocular Half-Field Differences in Letter Recognition at Threshold and Their Significance for Os: DL and MD Obtained at a Retinal Eccentricity of  $2^{\circ}41'$ .

		<u>O: DL</u>		
		<u>Half-field Differences at Threshold</u>	<u>Per Cent Difference at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
LEFT EYE		RVF = 50%	10%	.404 - n.s.
		LVF = 40%		
		LVF = 50%	12%	.584 - n.s.
		RVF = 62%		
RIGHT EYE		LVF = 50%	17.5%	1.26 - n.s.
		RVF = 32.5%		
		RVF = 50%	25%	2.66 - n.s.
		LVF = 75%		
		<u>O: MD</u>		
LEFT EYE		RVF = 50%	5%	.100 - n.s.
		LVF = 45%		
		LVF = 50%	5%	.100 - n.s.
		RVF = 55%		
RIGHT EYE		LVF = 50%	20%	1.67 - n.s.
		RVF = 30%		
		RVF = 50%	28%	3.40 - n.s.
		LVF = 78%		

TABLE 6

Monocular Half-Field Differences in Orientation Recognition at Threshold and Their Significance for Os: FC and HC Obtained at a Retinal Eccentricity of  $2^{\circ}41'$ .

		<u>O: FC</u>		
		<u>Half-field Difference at Threshold</u>	<u>Per Cent Difference at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
LEFT EYE		RVF = 50%	30%	3.96 - p < .05
		LVF = 20%		
		LVF = 50%	31%	4.25 - p < .05
		RVF = 81%		
RIGHT EYE		LVF = 50%	25%	2.67 - n.s.
		RVF = 25%		
		RVF = 50%	20%	1.67 - n.s.
		LVF = 70%		
		<u>O: HC</u>		
LEFT EYE		RVF = 50%	25%	2.67 - n.s.
		LVF = 25%		
		LVF = 50%	35%	5.58 - p < .02
		RVF = 85%		
RIGHT EYE		LVF = 50%	33%	4.72 - p < .05
		RVF = 17%		
		RVF = 50%	45%	10.16 - p < .01
		LVF = 95%		

TABLE 7

Monocular Half-Field Differences in Orientation Recognition at Threshold and Their Significance for Os: DL and MD Obtained at a Retinal Eccentricity of  $2^{\circ}41'$ .

		<u>O: DL</u>		
		<u>Half-field Differences at Threshold</u>	<u>Per Cent Difference at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
LEFT EYE		RVF = 50%	20%	1.67 - n.s.
		LVF = 30%		
		LVF = 50%	18%	1.34 - n.s.
		RVF = 68%		
RIGHT EYE		LVF = 50%	23%	2.23 - n.s.
		RVF = 27%		
		RVF = 50%	31%	4.25 - p < .05
		LVF = 81%		
		<u>O: MD</u>		
LEFT EYE		RVF = 50%	2.5%	.025 - n.s.
		LVF = 47.5%		
		LVF = 50%	2.5%	.025 - n.s.
		RVF = 52.5%		
RIGHT EYE		LVF = 50%	23%	2.23 - n.s.
		RVF = 27%		
		RVF = 50%	30%	3.96 - p < .05
		LVF = 80%		

TABLE 8

Monocular Half-Field Differences in Per Cent Total Recognition of Letters for Os: FC, HC, DL, and MD Obtained at a Retinal Eccentricity of 2°41'.

		Half-field Differences in Total Per Cent Correct Recognition		Chi <sup>2</sup> for Difference
<u>O</u> : FC	LEFT	RVF - 72%	11%	2.71 - n.s.
	EYE	LVF - 61%		
	RIGHT	LVF - 62%	29%	16.86 - p < .001
	EYE	RVF - 33%		
<u>O</u> : HC	LEFT	RVF - 68%	36%	25.92 - p < .001
	EYE	LVF - 32%		
	RIGHT	LVF - 42%	22%	11.31 - p < .001
	EYE	RVF - 20%		
<u>O</u> : DL	LEFT	RVF - 68%	8%	1.39 - n.s.
	EYE	LVF - 60%		
	RIGHT	LVF - 48%	16%	5.33 - p < .05
	EYE	RVF - 32%		
<u>O</u> : MD	LEFT	RVF - 42%	3%	.187 - n.s.
	EYE	LVF - 39%		
	RIGHT	LVF - 61%	22%	9.68 - p < .01
	EYE	RVF - 39%		

TABLE 9

Monocular Half-Field Differences in Per Cent Total Recognition of Orientation for Os: FC, HC, DL, and MD Obtained at a Retinal Eccentricity of  $2^{\circ}41'$ .

		<u>Half-field Differences in Total Per Cent Correct Recognition</u>		<u>Chi<sup>2</sup> for Difference</u>
<u>Q: FC</u>	LEFT EYE	RVF - 74%	24%	12.22 - p < .001
	RIGHT EYE	LVF - 50%	13%	3.40 - n.s.
<u>Q: HC</u>	LEFT EYE	RVF - 69%	27%	14.76 - p < .001
	RIGHT EYE	LVF - 42%	33%	21.78 - p < .001
<u>Q: DL</u>	LEFT EYE	RVF - 70%	16%	5.43 - p < .02
	RIGHT EYE	LVF - 54%	21%	8.84 - p < .01
<u>Q: MD</u>	LEFT EYE	RVF - 47%	4%	.323 - n.s.
	RIGHT EYE	LVF - 43%	24%	11.56 - p < .001

of letters), 10 (right eye viewing of letters), 11 (left eye viewing of triangles), and 12 (right eye viewing of triangles). On each graph, threshold (50%) is indicated by a dashed line, left half-field is shown at the top, right half-field is shown at the bottom. This comparison shows that there were marked individual differences in absolute sensitivity (extrapolated x-intercept) and variability (slopes of the functions).

Since the primary purpose of the study was to compare differential recognition in the visual half-fields (not to analyze absolute sensitivity), it appeared reasonable to display individual functions in such a way as to normalize the data for differences in sensitivity. Chance alone would indicate that any 0 could be correct an average of 11.11% of the time, since there were four stimuli, one blank and two half-field positions (9 possible combinations or 11.11% of the responses). Fifteen per cent was considered a significant increment above chance level<sup>1</sup>, and individual functions were therefore slid to the left, equalizing all curves at the exposure duration corresponding to 15% correct. Interpolating from the original data points, it was then possible to replot per cent correct recognition as a function of increments in exposure duration above the duration corresponding to 15% correct recognition. This new value was set at 0, and the percentage of correct recognition was plotted against one msec. duration increments above this new value.

Figure 9. Per cent correct recognition of letters in the left (top) and right (bottom) visual half-field as a function of exposure duration in msec. for Qs: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing only. Data replotted from Figure 5.

LETTERS

LEFT EYE - 2'41"

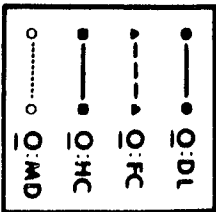
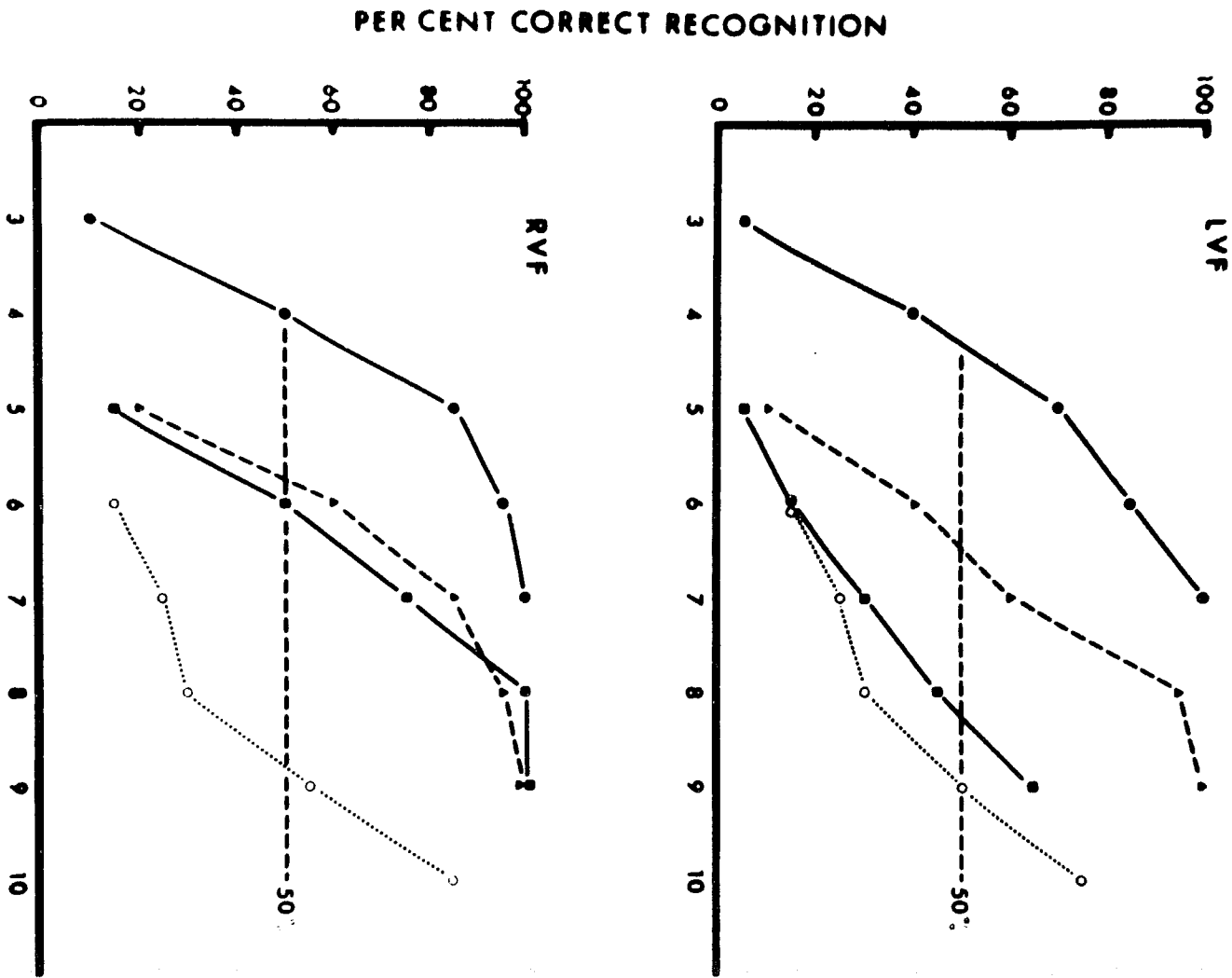
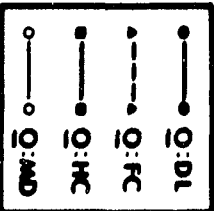
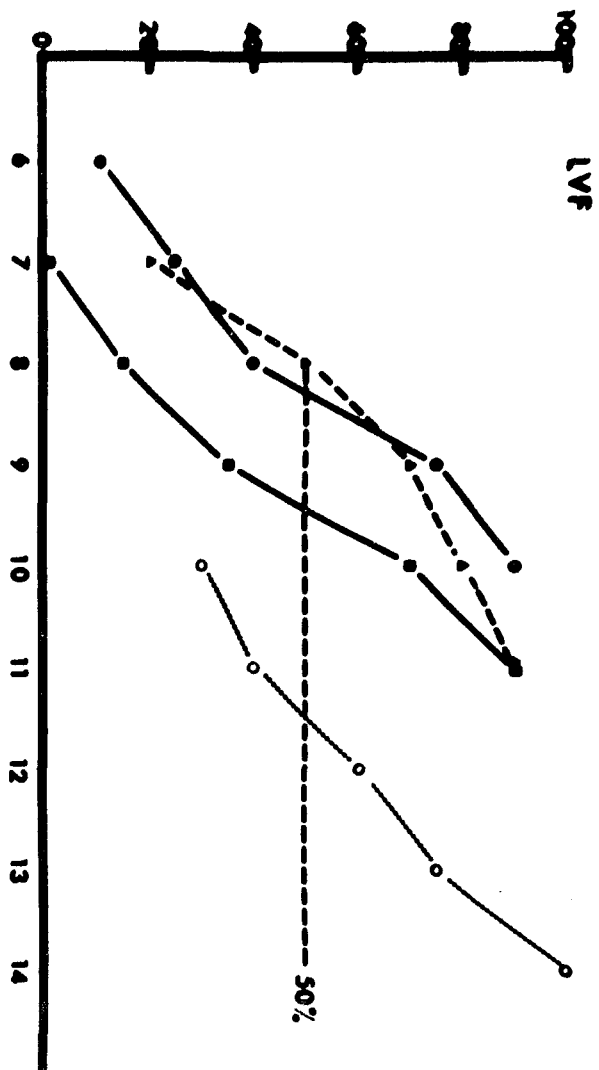


Figure 10. Per cent correct recognition of letters in the left (top) and right (bottom) visual half-field as a function of exposure duration in msec. for Os: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Right eye viewing only. Data replotted from Figure 7.

LETTERS

RIGHT EYE - 2' 41"



PER CENT CORRECT RECOGNITION

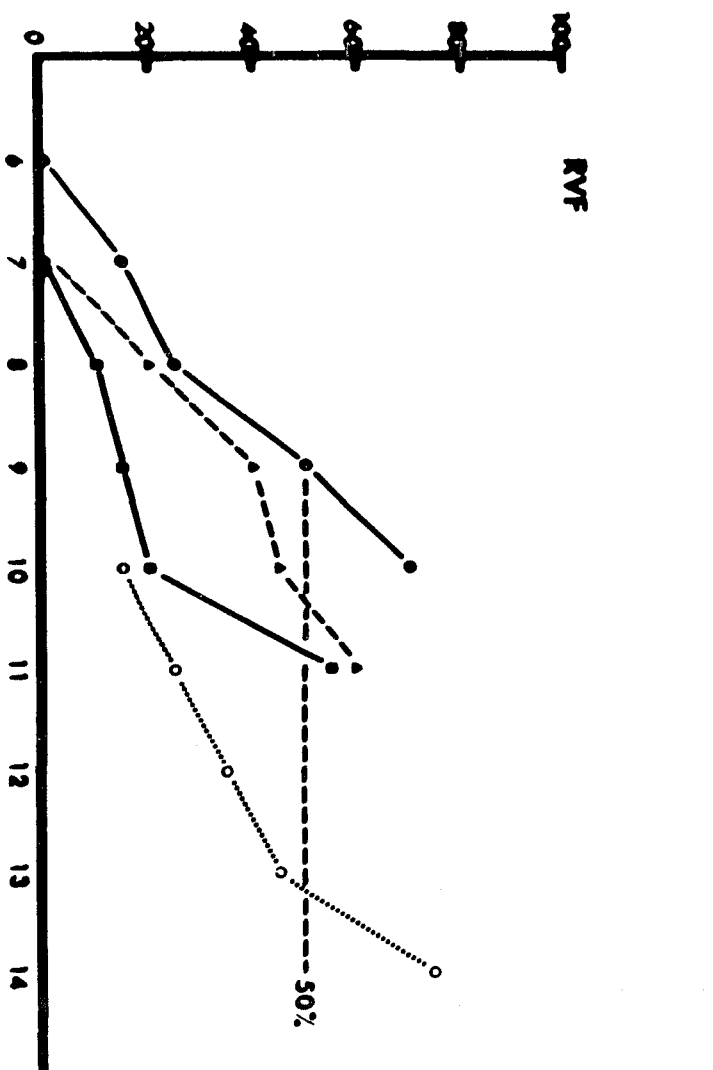
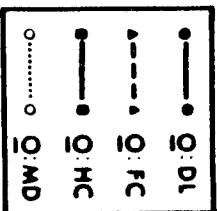
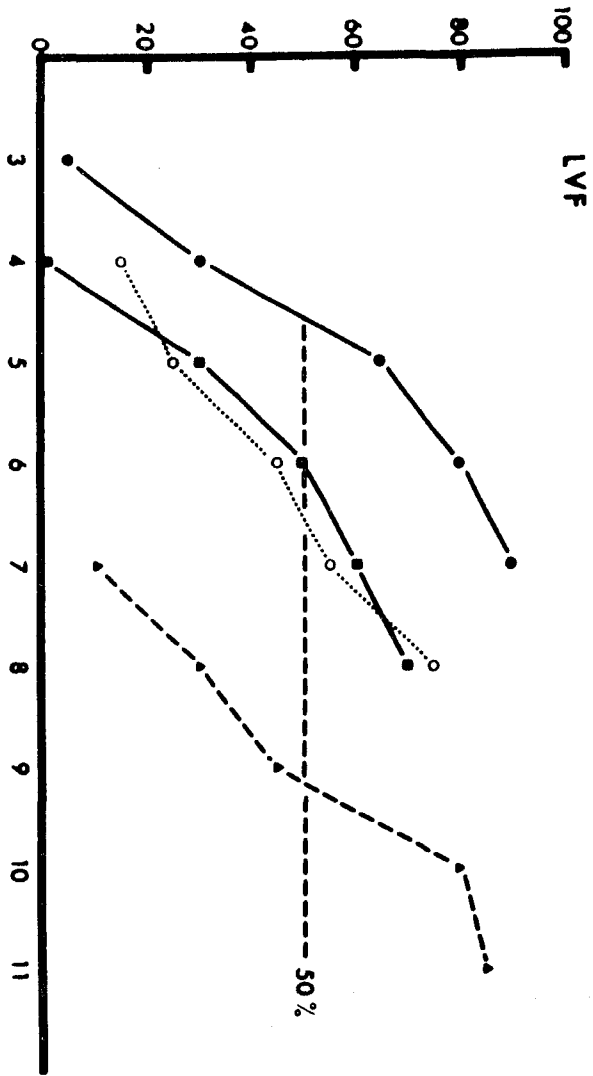


Figure 11. Per cent correct recognition of triangular orientation in the left (top) and right (bottom) visual half-field as a function of exposure duration in msec. for Os: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing only. Data replotted from Figure 6.

TRIANGLES

LEFT EYE - 2° 41'



PER CENT CORRECT RECOGNITION

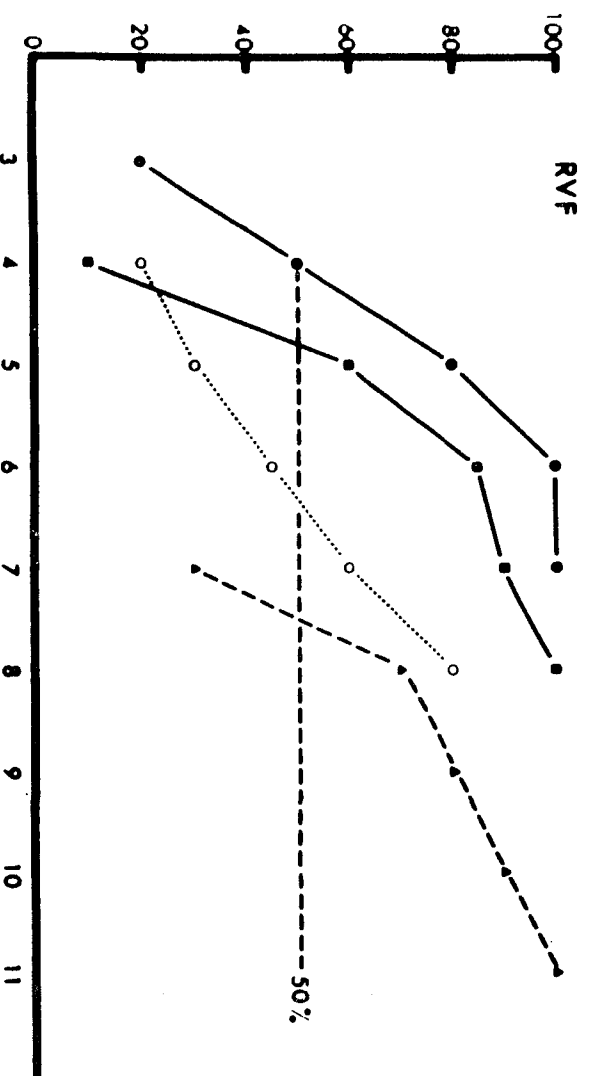
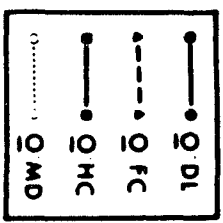
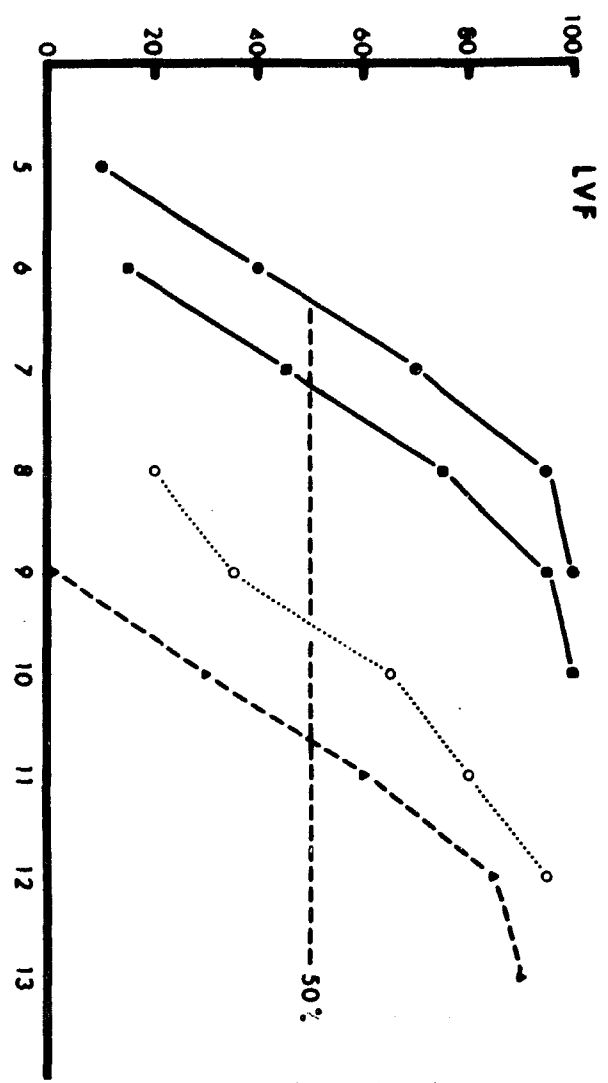


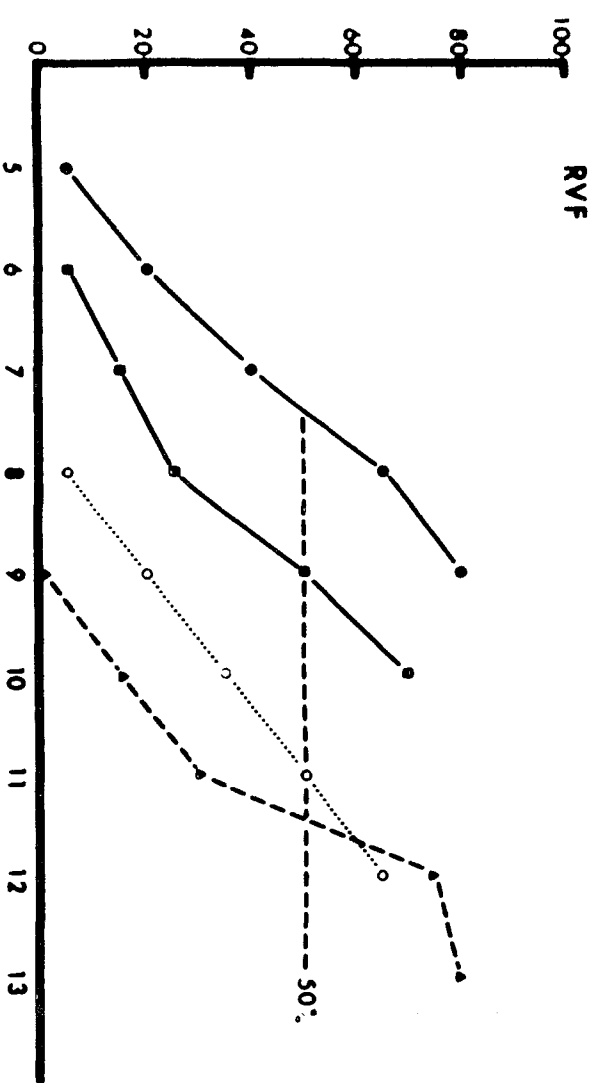
Figure 12. Per cent correct recognition of triangular orientation in the left (top) and right (bottom) visual half-field as a function of exposure duration in msec. for Os: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Right eye viewing only. Data replotted from Figure 8.

TRIANGLES

RIGHT EYE - 2'41"



PER CENT CORRECT RECOGNITION



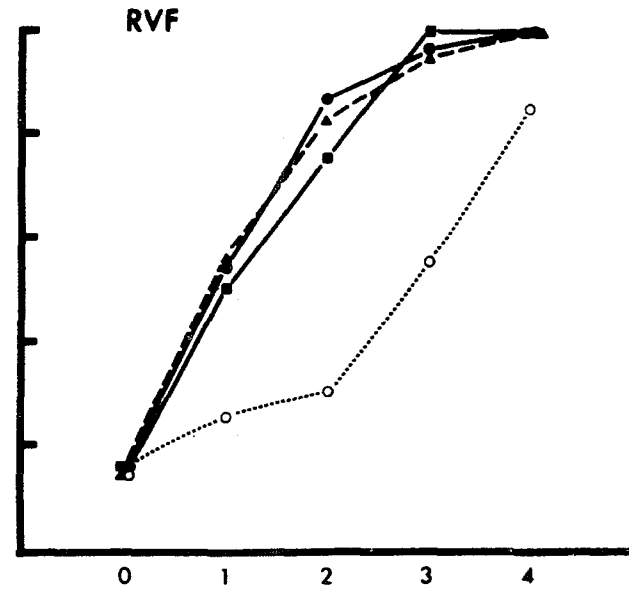
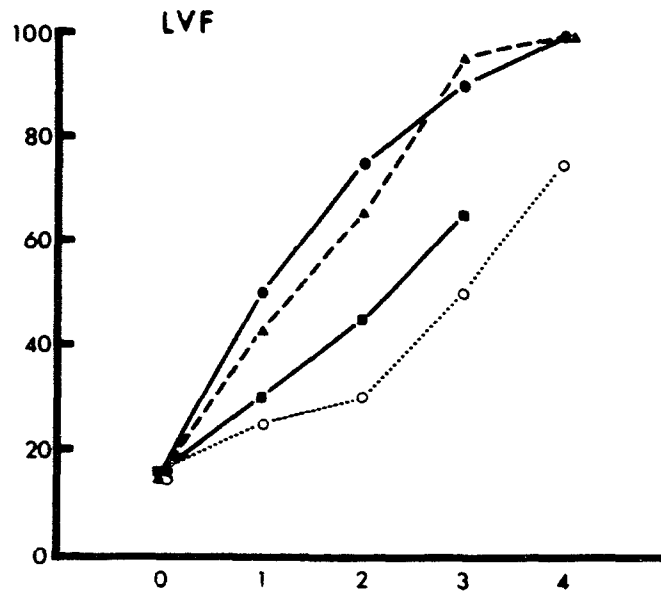
Figures 13 and 14 present the previous data for letters (Figures 5 & 7) and triangles (Figures 6 & 8) re-plotted on these new abscissae transforms, with left eye viewing at the top, right eye viewing at the bottom. For any chosen duration increment above 15% (i.e., 0 on the abscissa), the relative difference among Os in per cent correct recognition can be seen. A comparison of half-field differences across eyes for letters (Figure 13), showed the smallest energy increments at threshold in the nasal half-field of the left eye (i.e., RVF) for three Os. Furthermore, individual functions in this same half-field showed the greatest rate of change, the highest upper asymptote, and the smallest variability among Os. With triangles (Figure 14), both nasal half-fields (i.e., RVF for left eye, and LVF for right eye) showed these same characteristics.

In order to make monocular half-field comparisons for the group, the mean percentage of correct recognition was found at each of the four msec. increment levels shown in Figures 13 and 14. Figure 15 presents the group functions obtained for letters in the left (dashed line) and right (solid line) half-fields under left (labelled OS to the left) and right (labelled OD to the right) eye viewing plotted on normal probability ordinates. Figure 16 shows the same comparison for triangles. The lines of best fit were plotted by visual inspection and indicated that the probability of correct recognition increased linearly as a function of one

Figure 13. Per cent correct recognition of letters in the left (left) and right (right) visual half-field as a function of msec. duration increments above chance level (15%) for Os: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing at top; right eye viewing at bottom. Data replotted from Figures 5 and 7.

LETTERS

LEFT EYE



RIGHT EYE

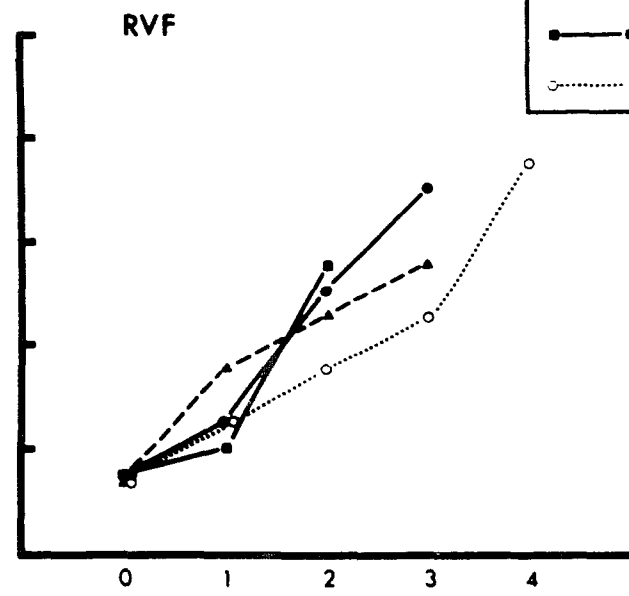
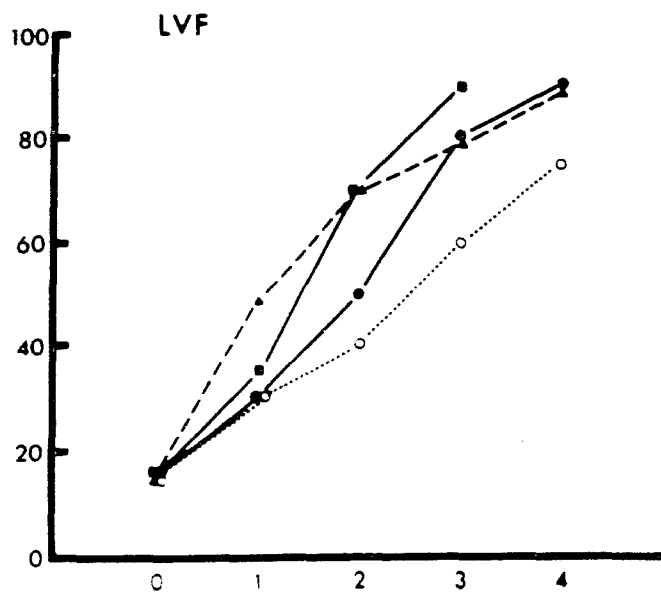
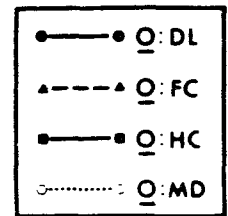
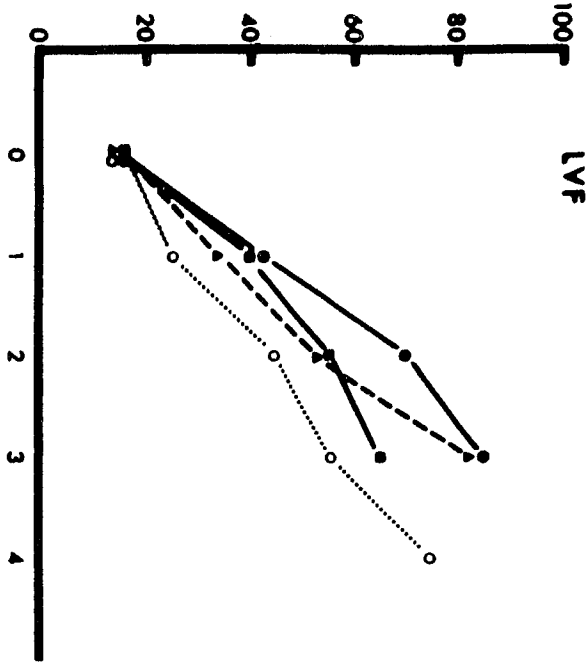


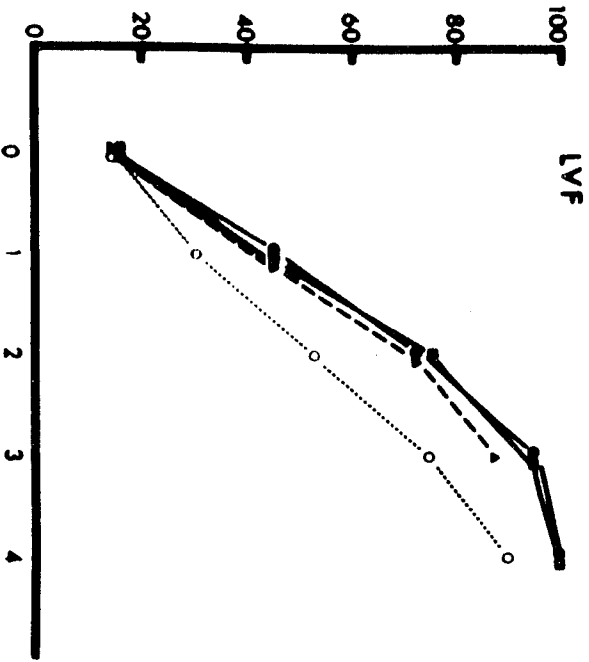
Figure 14. Per cent correct recognition of triangular orientation in the left (left) and right (right) visual half-field as a function of msec. duration increments above chance level (15%) for Os: DL (circle), FC (triangle), HC (square), and MD (unfilled circle) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye viewing at top; right eye viewing at bottom. Data replotted from Figures 6 and 8.

TRIANGLES

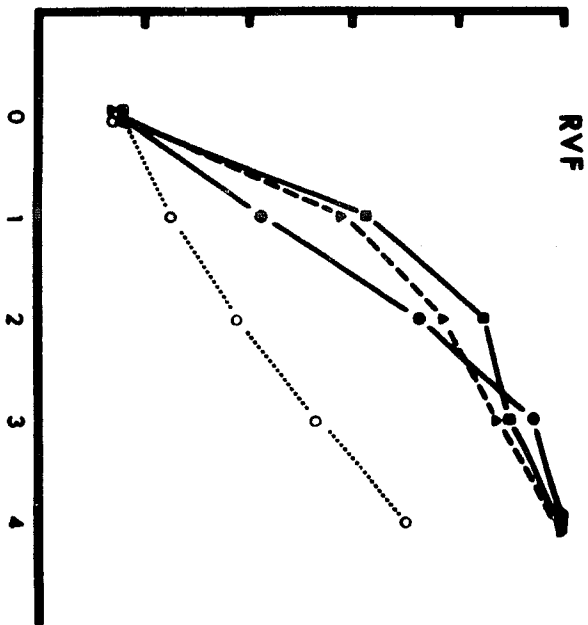
LEFT EYE



RIGHT EYE



LEFT EYE



RIGHT EYE

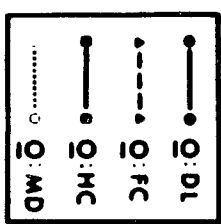
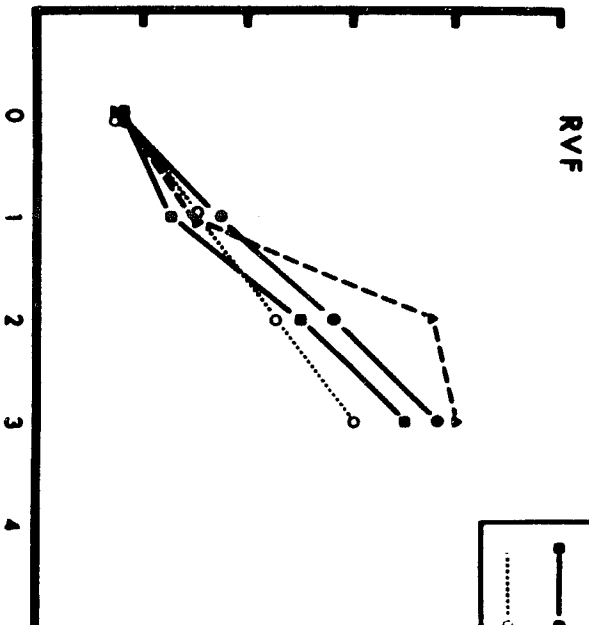
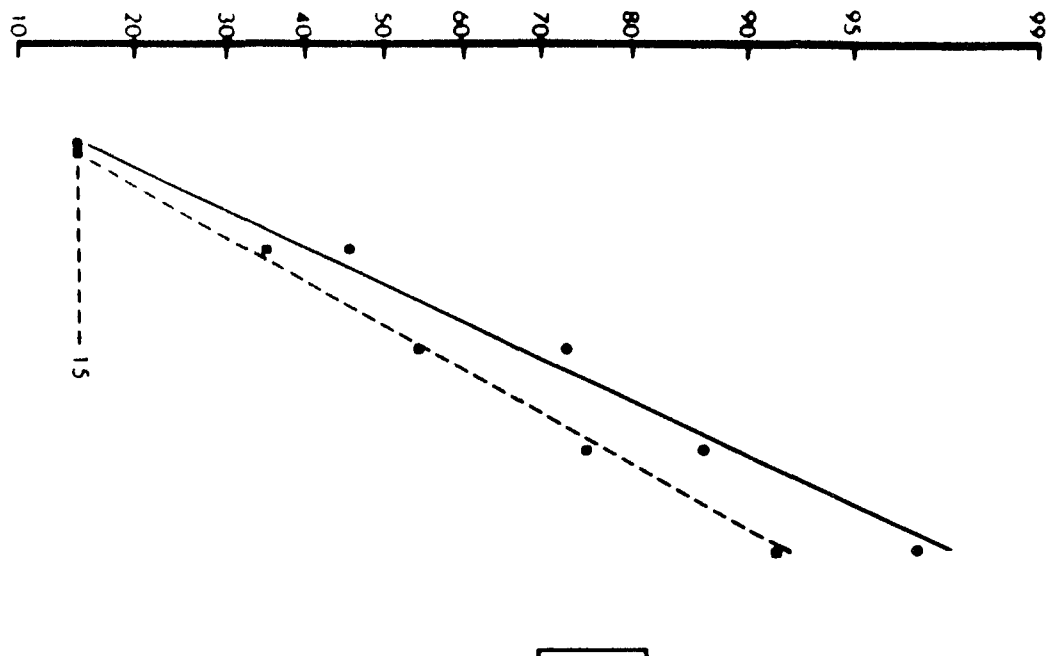


Figure 15. Mean per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of msec. duration increments above chance level (15%) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye (OS) to the left; right eye (OD) to the right. Grouped data obtained from Figure 13.

LETTERS - 2'41'

PER CENT CORRECT RECOGNITION

OS



OD

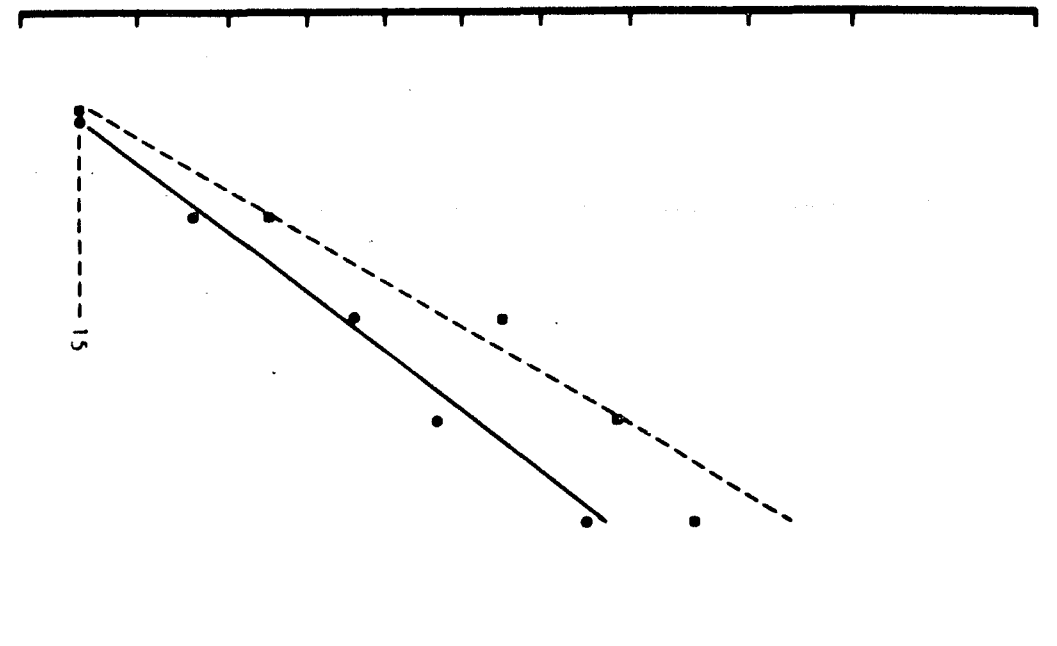
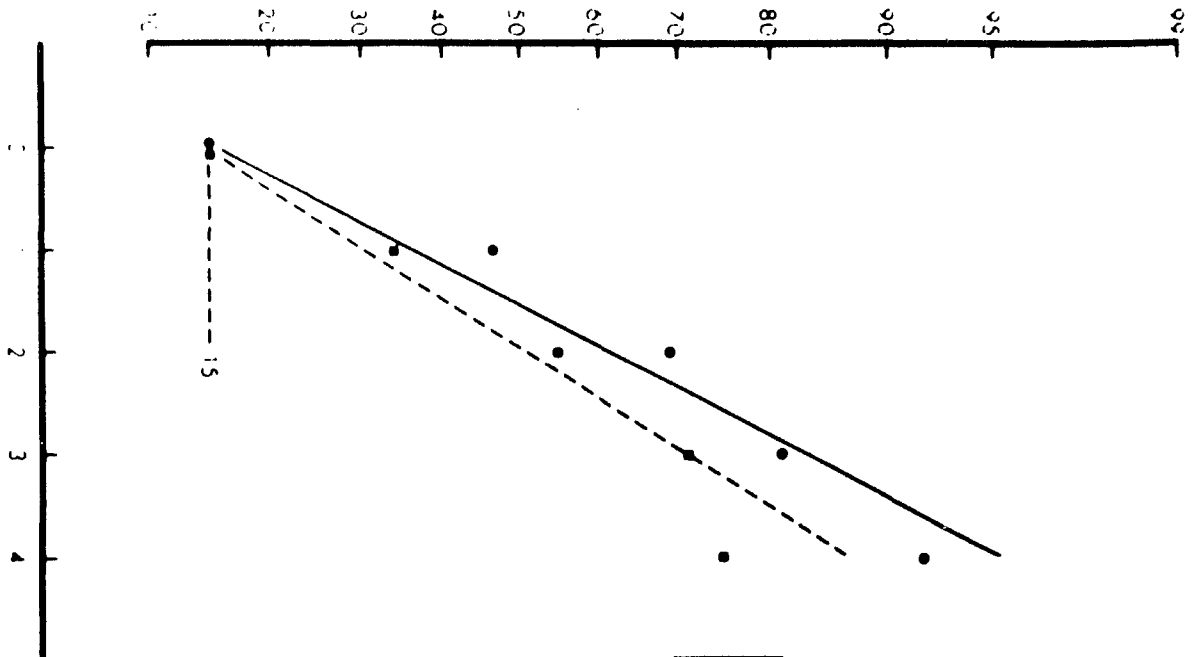


Figure 16. Mean per cent correct recognition of triangular orientation in the left (dashed line) and right (solid line) visual half-field as a function of msec. duration increments above chance level (15%) at a retinal eccentricity of  $2^{\circ}41'$ . Left eye (OS) to the left; right eye (OD) to the right. Grouped data obtained from Figure 14.

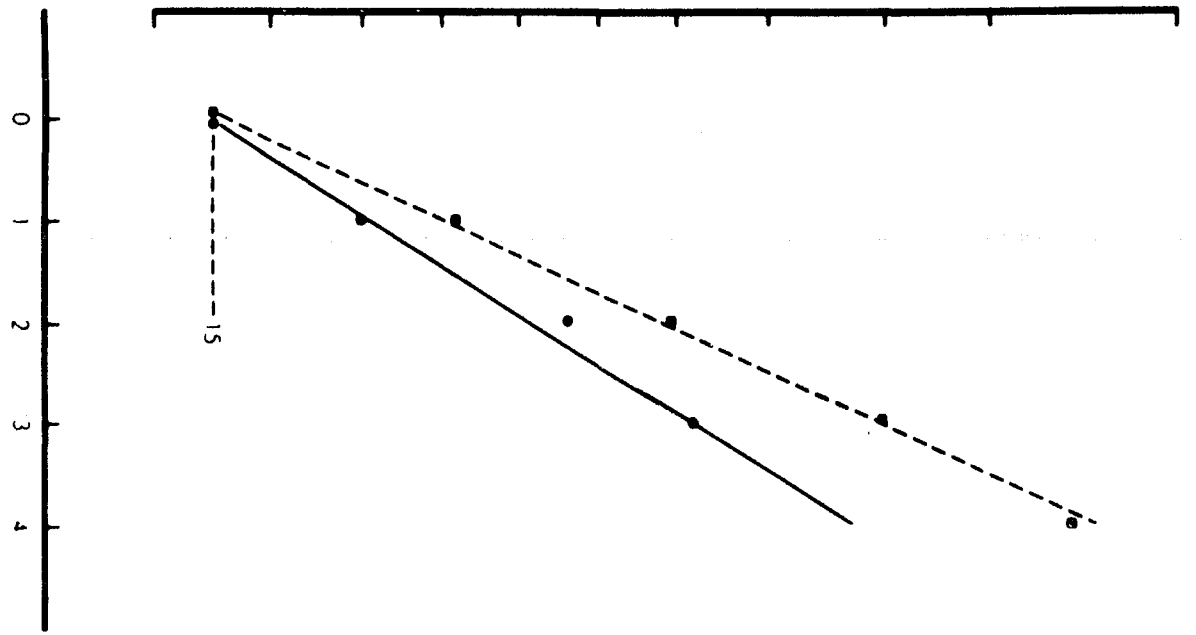
PER CENT CORRECT RECOGNITION

TRIANGLES - 2 4'

OS



OD



INCREMENT ABOVE CHANCE LEVEL (MSEC)

msec. duration increments above 15% in all half-fields, but that the typical Q required less energy to reach threshold when material was exposed in the nasal half-fields of either eye.

Binocular Viewing of Letters or Triangles. In the same manner as described previously, Figures 17 and 18 present the data obtained at 2°41' of retinal eccentricity in the left (dashed line) and right (solid line) half-fields for binocular viewing of letters (Figure 17) and triangles (Figure 18) in each of the four Qs. In comparison to the above monocular data, binocular viewing of the same material produced half-field functions, for all Qs, that either overlapped or were extremely close together. For all Qs, binocular viewing appeared to cancel out the spatially antagonistic half-field differences in recognition obtained monocularly.

In the same fashion as described above,  $\chi^2$  tests were performed on each set of functions for half-field differences in both threshold and summated total recognition. For each Q, summaries of the percentage differences in threshold (top of table) and total recognition (bottom of table), with their significance, are presented in Tables 10 (letters) and 11 (triangles). All of these comparisons, in either threshold or in total recognition, failed to achieve significance.

Overall Half-field Comparisons of Letters and Triangles. Since the results of each experiment indicated that stimuli exposed to the nasal half-field of either eye produced con-

Figure 17. Per cent correct recognition of letters in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL, and MD at a retinal eccentricity of  $2^{\circ}41'$ . Binocular viewing only.

LETTERS

BINOCULAR - 2°41'

PER CENT CORRECT RECOGNITION

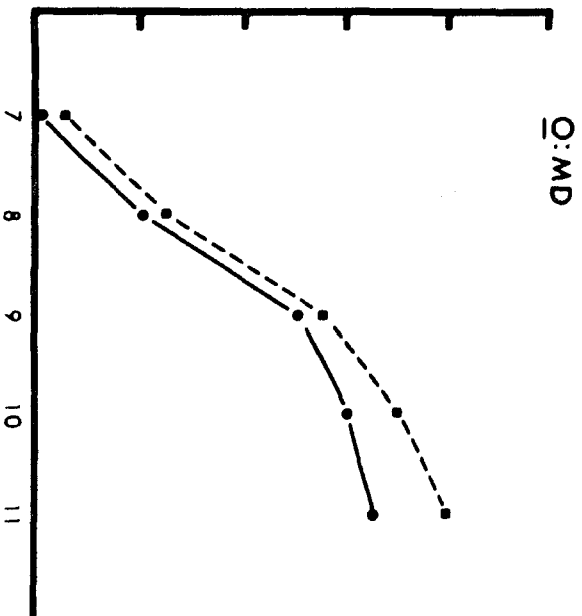
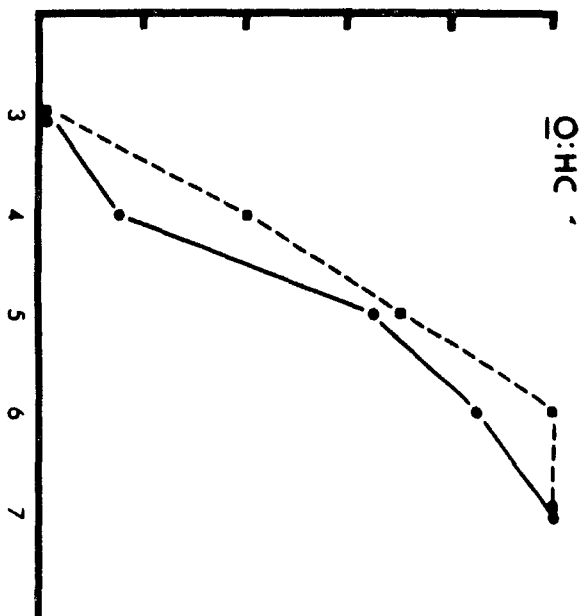
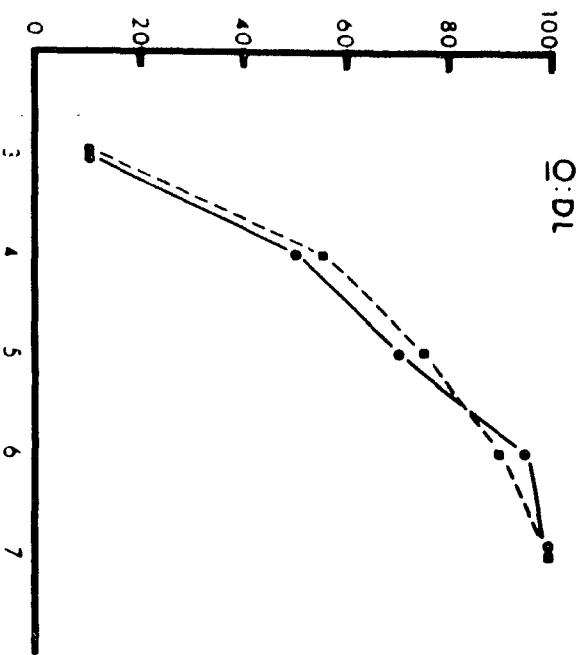
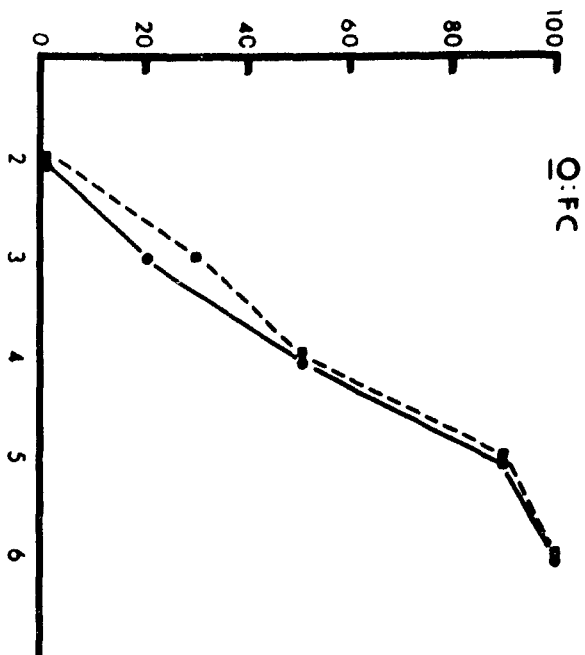
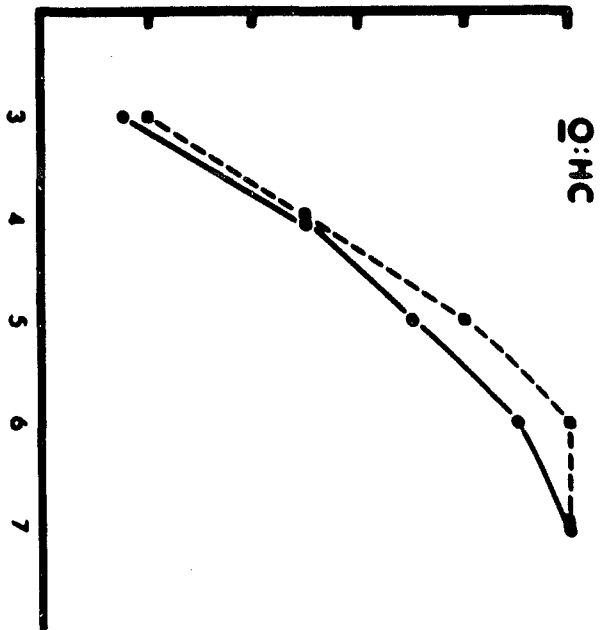
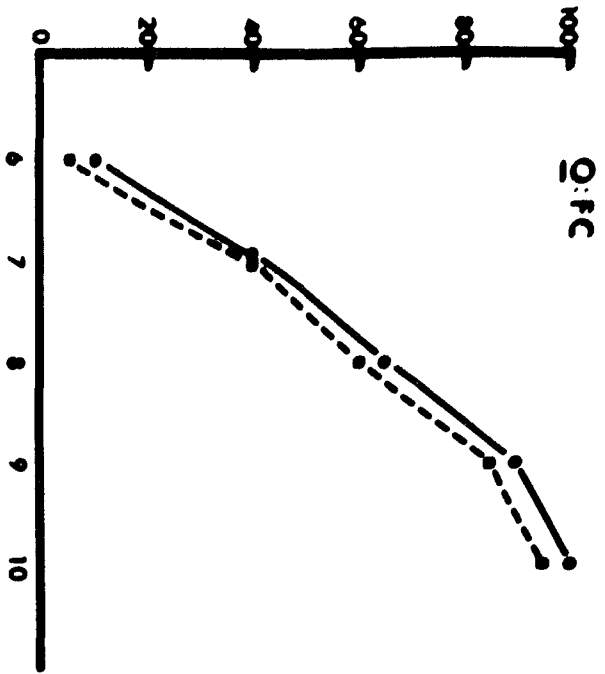


Figure 18. Per cent correct recognition of triangular orientation in the left (dashed line) and right (solid line) visual half-field as a function of exposure duration in msec. for Os: FC, HC, DL, and MD at a retinal eccentricity of  $2^{\circ}41'$ . Binocular viewing only.

## TRIANGLES

BINOCULAR - 2'41'



## PER CENT CORRECT RECOGNITION

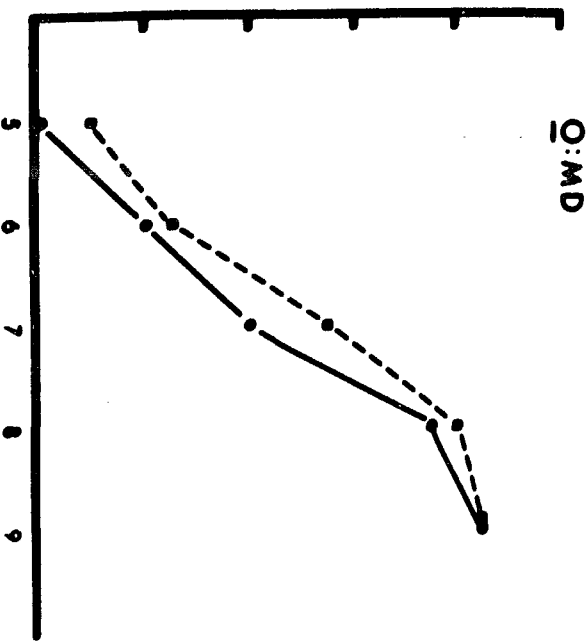
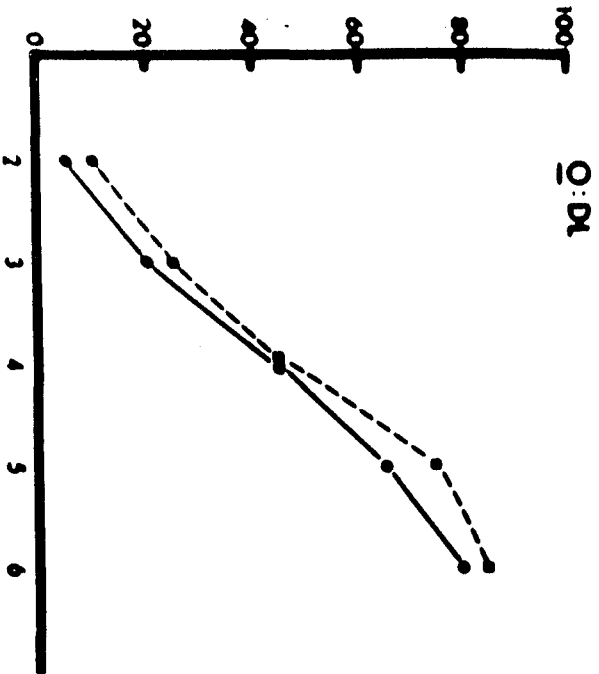


TABLE 10

Binocular Half-Field Differences in Letter Recognition at Threshold and in Total Per Cent Recognition for Os: FC, HC, DL, and MD Obtained at a Retinal Eccentricity of 2°41'.

<u>Half-field Differences at Threshold</u>			
	<u>Half-field Differences at Threshold</u>	<u>Per Cent Difference at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
<u>O</u> : FC	LVF = 50% RVF = 50%	0%	0.0 - n.s.
	RVF = 50% LVF = 50%	0%	0.0 - n.s.
<u>O</u> : HC	LVF = 50% RVF = 32.5%	17.5%	1.26 - n.s.
	RVF = 50% LVF = 61%	11%	.490 - n.s.
<u>O</u> : DL	LVF = 50% RVF = 45%	5%	.100 - n.s.
	RVF = 50% LVF = 55%	5%	.100 - n.s.
<u>O</u> : MD	LVF = 50% RVF = 42.5%	7.5%	.226 - n.s.
	RVF = 50% LVF = 55%	5%	.100 - n.s.
<u>Half-field Differences in Total Recognition</u>			
<u>O</u> : FC	LVF = 54% RVF = 52%	2%	.080 - n.s.
<u>O</u> : HC	LVF = 62% RVF = 53%	9%	1.66 - n.s.
<u>O</u> : DL	LVF = 66% RVF = 65%	1%	.022 - n.s.
<u>O</u> : MD	LVF = 48% RVF = 41%	7%	.992 - n.s.

TABLE 11

Binocular Half-Field Differences in Orientation Recognition at Threshold and in Total Per Cent Recognition for  $\underline{O}$ s: FC, HC, DL, and MD Obtained at a Retinal Eccentricity of  $2^{\circ}41'$ .

<u>Half-field Differences at Threshold</u>			
	<u>Half-field Differences at Threshold</u>	<u>Per Cent Difference at Threshold</u>	<u>Chi<sup>2</sup> for Difference</u>
<u>O</u> : FC	RVF = 50%	2.5%	.025 - n.s.
	LVF = 47.5%		
	LVF = 50%	2.5%	.025 - n.s.
	RVF = 52.5%		
<u>O</u> : HC	LVF = 50%	0%	0.0 - n.s.
	RVF = 50%		
	RVF = 50%	0%	0.0 - n.s.
	LVF = 50%		
<u>O</u> : DL	LVF = 50%	2.5%	.025 - n.s.
	RVF = 47.5%		
	RVF = 50%	2.5%	.025 - n.s.
	LVF = 52.5%		
<u>O</u> : MD	LVF = 50%	12.5%	.635 - n.s.
	RVF = 37.5%		
	RVF = 50%	12.5%	.635 - n.s.
	LVF = 62.5%		
<u>Half-field Differences in Total Recognition</u>			
<u>O</u> : FC	RVF = 61%	4%	.330 - n.s.
	LVF = 57%		
<u>O</u> : HC	LVF = 70%	5%	.569 - n.s.
	RVF = 65%		
<u>O</u> : DL	LVF = 48%	6%	.727 - n.s.
	RVF = 42%		
<u>O</u> : MD	RVF = 51%	7%	.982 - n.s.
	LVF = 44%		

sistently lower duration thresholds, it appeared reasonable to combine the data for both letter and triangle orientation recognition. For each Q, the total number of correct responses at all exposure durations for both types of material was calculated for each eye and half-field. These values were then converted to percentages of the total and ranked in order of overall recognition. In addition, group totals were calculated and ranked according to half-field. Table 12 presents a summary of these monocular data and indicated that the nasal half-fields of the left and right eye ranked one and two in overall recognition for three of the four Qs, while the temporal half-field of the right eye ranked fourth for each Q. Furthermore, the group totals indicated that the nasal half-fields of the left and right eye ranked one and two respectively, while the temporal half-fields of the left and right eye ranked three and four. A comparison of ocular differences between the nasal or temporal half-fields indicated a left eye superiority for both half-fields (bottom of Table 12). The extreme difference in half-field recognition efficiency may be seen in the comparison of the nasal half-field of the left eye (rank order 1 for the group) with the temporal half-field of the right eye (rank order 4 for the group). While 755 out of 1200 stimuli were correctly recognized when exposed in the left nasal half-field, only 456 out of 1200 stimuli were correctly recognized in the right temporal half-field; i.e., a difference of 299 stimuli or 24.92%. This data indicate, most strikingly, the overall superiority in re-

TABLE 12

Half-Field Comparisons of the Total Number of Correct Recognitions of Letters and Orientation Obtained Monocularly for Os: FC, HC, DL, and MD at a Retinal Eccentricity of 2°41'. Group Totals at Bottom.

	<u>Visual Half-Field</u>	<u>Total Number Correct</u>	<u>Per Cent Correct</u>	<u>Rank Order</u>
<u>O</u> : FC	Left Nasal	265/400	66%	1
	Left Temporal	207/400	51.75%	3
	Right Temporal	166/400	41.50%	4
	Right Nasal	243/400	60.75%	2
<u>O</u> : HC	Left Nasal	263/400	65.75%	1
	Left Temporal	153/400	38.25%	3
	Right Temporal	142/400	35.50%	4
	Right Nasal	219/400	54.75%	2
<u>O</u> : DL	Left Nasal	138/200	69%	1
	Left Temporal	114/200	57%	2
	Right Temporal	74/200	37%	4
	Right Nasal	111/200	55.50%	3
<u>O</u> : MD	Left Nasal	89/200	44.50%	2
	Left Temporal	82/200	41%	3
	Right Temporal	74/200	37%	4
	Right Nasal	120/200	60%	1
GROUP	Left Nasal	755/1200	62.92%	1
	Left Temporal	556/1200	46.33%	3
	Right Temporal	456/1200	38%	4
	Right Nasal	693/1200	57.75%	2

cognition obtained in the nasal half-field of either eye (i.e., the temporal hemiretinae).

In the same manner as above, individual and group rank order data were calculated for binocular observations. These values are presented in Table 13 and indicated a slight, but non-significant, overall recognition superiority in the LVF (i.e., the left temporal and right nasal half-fields) for three of the four Os, as well as for the group totals at the bottom. When the monocular group data (bottom of Table 12) were added for left and right homonymous half-fields, the per cent correct scores obtained were essentially the same as those obtained upon binocular viewing (bottom of Table 13).

As in Experiment I, there was a complete absence of false positive responses under either monocular or binocular viewing. However, a small number of inaccurate reports were given (i.e., approximately 2% of the total) and were equally distributed in each half-field, regardless of recognition superiority. The letters H and T ranked first and second in ease of recognition, while triangles in each of the four orientations were equally well recognized.

TABLE 13

Half-Field Comparisons of the Total Number of Correct Recognitions of Letters and Orientation Obtained Binocularly for Os: FC, HC, DL, and MD at a Retinal Eccentricity of  $2^{\circ}41'$ . Group Totals at Bottom

	<u>Visual Half-Field</u>	<u>Total Number Correct</u>	<u>Per Cent Correct</u>	<u>Rank Order</u>
<u>O</u> : FC	LVF	111/200	55.5	2
	RVF	113/200	56.5	1
<u>O</u> : HC	LVF	132/200	66%	1
	RVF	118/200	59%	2
<u>O</u> : DL	LVF	114/200	57%	1
	RVF	107/200	53.5%	2
<u>O</u> : MD	LVF	99/200	49.5%	1
	RVF	85/200	42.5%	2
GROUP	LVF	456/800	57%	1
	RVF	423/800	52.88%	2

## DISCUSSION

The results of the present study indicate that lower duration thresholds (50% correct recognition) were obtained in the nasal, as compared to the temporal, half-fields of either eye for both the monocular recognition of single letters and the spatial orientation of triangles. While such half-field differences were observable at both retinal eccentricities, the magnitude of these differences, between nasal and temporal half-fields, was greater with increased displacement from the fovea. In addition, superior overall recognition (summed over Os and stimulus material) was found in both half-fields of the left eye. In comparison to monocular viewing, binocular viewing of the same material did not produce significant differences in recognition thresholds between left and right homonymous half-fields. As discussed below, these findings are of significance with respect to: (1) previous methodological techniques; (2) to binocular vs. monocular comparisons; and (3) to a number of different theoretical concepts which have been advanced.

Methodological Considerations and Binocular vs. Monocular Comparisons. Most past studies concerned with half-field differences in tachistoscopic recognition have typically relied upon group data; i.e., psychometric functions for individual observers have not been obtained. The present study was the first to attempt such an approach,

with the result that individual comparisons in recognition between the half-fields could be made. Such a comparison revealed differences in both the threshold and precision (slopes of the functions) of recognition between the nasal and temporal half-fields of either viewing eye. In contrast to previous studies, such individual comparisons were based on a much larger number of observations per half-field, and were made for both monocular and binocular viewing.

The lower monocular thresholds obtained upon stimulation of either temporal hemiretinae (i.e., the nasal half-fields) are consistent with previous monocular data involving letter recognition (Neill et al., 1971), visual acuity, as measured with the Landolt C (Markowitz & Weitzman, 1969), resolution of color rivalry (Barrell & Parks, 1969), and the maintenance of perceptual stability (McKinney, 1967). In addition, the increased magnitude in half-field differences found with increased retinal displacement, and the overall superiority of the left temporal hemiretina (i.e., rank order 1 in the group totals) is consistent with previous data concerning monocular word recognition (Overton & Wiener, 1966). The superior overall recognition for both temporal hemiretinae, found in the present study, extends previous findings on the monocular recognition of nonsense syllables (Markowitz & Weitzman, 1969) and English words (McKeever & Huling, 1970; 1971; Overton & Wiener, 1966; Shai et al., 1972), which were

shown to be superior for the temporal hemiretina of only the left eye. However, Overton and Weiner (1966), in general agreement with the present data, showed a slight, but non-significant, superiority for the temporal hemiretina of the right eye as well.

Aside from the few monocular studies mentioned above, most previous studies have employed only binocular viewing. Such binocular studies (which have utilized a successive paradigm), have reported almost all possible half-field superiorities irrespective of the presumed nature of the stimulus material. Thus, a RVF superiority has been reported for certain presumed "verbal" tasks [such as the recognition of letters (Bryden, 1973; Heron, 1957; Neill et al., 1971), nonsense syllables (Fontenot & Benton, 1972), and English words (Mishkin & Forgays, 1952; Orbach, 1952; 1967; Terrace, 1959)], but also for so-called "spatial" tasks as well [such as the recognition of familiar figures (Wyke & Ettliger, 1962) and line orientation (White, 1971)]. Furthermore, a superiority of the LVF has been reported for certain "spatial" tasks [such as the recognition of random shapes (Dee & Fontenot, 1973) and line orientation (Fontenot & Benton, 1972), and the enumeration and localization of dots (Kimura, 1966; 1973; Kimura & Durnford, 1973)], but also for so-called "verbal" tasks [such as the recognition of script letters (Bryden, 1976) and Hebrew words (Orbach, 1952; 1967)]. Finally, there have been a number of binocular studies in

which no significant half-field differences have been obtained for either "verbal" [such as the recognition of script or print-like letters (Bryden, 1976) and CVC nonsense syllables (White & Silver, 1975)], or "spatial" tasks [such as the recognition of stimulus number and direction (Adams, 1971), dot grid patterns (White & Silver, 1975), geometric forms (Bryden, 1973; Bryden & Rainey, 1963; Heron, 1957; Terrace, 1959), and the localization of dots (Bryden, 1973; 1976)]. This is compatible with other studies where no half-field differences have been demonstrated for binocular gap detection (Kinsbourne, 1970) or visual acuity, as measured with line gap detection (Curcio, McKavey, & Rosen, 1974).

Theoretical Critique. As reviewed in the introduction, a number of theoretical concepts have been advanced to account for half-field asymmetries in binocular and monocular tachistoscopic recognition tasks. Differential half-field recognition scores have been attributed to "reading habits" (e.g., Mishkin & Forgays, 1952), to post-exposural scanning processes (e.g., Heron, 1957), to "tendencies to eye movement" (e.g., Crovitz & Daves, 1962), and to attentional biases (e.g., Kinsbourne, 1970), as well as to dominances of hand (Bryden, 1964; 1965), eye (Kershner & Gwan-Rong Jeng, 1972), and cerebral hemisphere (Kimura, 1966; 1973). While each of these concepts was originally conceived to account for specific results obtained under different experimental paradigms and viewing

conditions (typically binocular), they have been generalized as explanatory concepts for many tachistoscopic results. In view of the limitations of previous experimental techniques; i.e., the emphasis upon group data, usually with a small number of observations, and the general failure to employ both binocular and monocular viewing within a single study, conclusions regarding the underlying processes involved in correct recognition must necessarily be guarded. Generalizations based on binocular viewing alone are dangerous, since the absence of monocular observations does not allow for an analysis of possible differences in ocular or hemiretinal sensitivity.

As mentioned above, both "reading habits" and "post-exposural scanning" hypotheses are predicated upon the existence of a binocular RVF superiority for successively presented English words. The former accounts for the effect in terms of presumed preferential left cerebral hemisphere training, while the latter postulates compatible "neural tendencies" which mimic normal reading habits. The clear absence of significant binocular half-field differences, as well as the antagonistic monocular spatial half-field differences (i.e., a RVF superiority with the left eye, and a LVF superiority with the right eye) found in the present study does not support either hypothesis. However, the present study was limited to the recognition of single element stimuli; i.e., words were not used, and this may have eliminated the possible effects of "reading habits" or "post-

exposural scanning" processes. Alternatively, the data upon which the above concepts are based is composed of group differences and relatively few observations, making individual comparisons impossible. Hence, generalizations and extensions from the above mentioned data should be avoided.

In order to account for the RVF superiority obtained in the recognition of successively exposed single numbers, Crovitz and Daves (1962) advanced a "tendencies to eye movement" hypothesis, which related half-field recognition accuracy to the direction of initial postexposural eye movements. Under conditions of binocular testing, a strong correlation was found between superior recognition and initial eye movements in the RVF, while monocular viewing produced a similar recognition-eye movement correlation in the temporal half-fields of either viewing eye (Crovitz & Lipscomb, 1963). In the present study, exactly the opposite monocular half-field superiorities were obtained (i.e., the nasal half-fields of either eye), and no binocular half-field asymmetries were demonstrated. Since eye movements were not monitored in the present study, it is not possible to make any statement about their implication for the present data.

As indicated above, a number of researchers have stressed the role of hemispheric dominance, either singly or in combination with dominances of hand and eye, as a critical factor responsible for half-field recognition asymmetries (Bryden, 1964; 1965; Kershner & Gwan-Rong

Jeng, 1972; Kimura, 1966; 1969; 1973; Kimura & Durnford, 1973). In brief, a conceptual dichotomy is made between "verbal" and "spatial" material, with the left hemisphere processing "verbal" material better than "spatial", and conversely with the right hemisphere. This concept presupposes that stimulus material can, in fact, be categorized as being predominantly "verbal" or "spatial" in nature. The data on which these concepts are founded were obtained almost entirely from binocular studies which emphasized group differences only. Generalizations from such data are dangerous for at least four reasons. Firstly, as indicated above, there is no unanimity of binocular results showing a selective RVF superiority for "verbal" material, or a LVF superiority for "spatial" material. Secondly, the strict reliance upon group data has eliminated the possibility of exploring individual variations in presumed differential hemispheric processing. Thirdly, a number of monocular studies have consistently shown differential ocular and hemiretinal effects (e.g., Markowitz & Weitzman, 1969; McKeever & Huling, 1970; 1971; Neill et al., 1971; Overton & Wiener, 1966), which are not compatible with the notion of hemispheric specialization. This is especially obvious from the data of Markowitz and Weitzman (1969) on monocular visual acuity and Neill et al. (1971) on monocular letter recognition, as well as the present data on monocular letter and orientation recognition. All of these studies have demonstrated

recognition superiorities for the nasal half-fields (i.e., the temporal hemiretinae) of either eye, which in turn project to opposite hemispheres. Finally, as a more basic objection, it should be obvious that the sufficient stimulus conditions which distinguish a "verbal" from a "spatial" task are not presently known. This is not surprising, since any presumed "verbal" stimulus must initially be spatially resolved, while any presumed "spatial" stimulus may be verbally encoded.

The addition of other structural factors, such as handedness or eyedness (i.e., sighting preference), does not appear to strengthen the application of a hemispheric specialization concept to the present data. Since each of our observers was right handed (presumably indicative of left hemisphere dominance), a RVF superiority, with at least "verbal" material (letters), would be expected for both binocular and monocular recognition. In addition, the added factor of right eye sighting dominance in three of our four observers should have increased the probability of a RVF superiority for both binocular and right eye monocular viewing of letters. This follows from the claims of Kershner and Gwan-Rong Jeng (1972), who posulate that the dominant sighting eye provides the stronger hemispheric input. Once again, however, the absence of significant binocular half-field differences and the monocular half-field asymmetries obtained in the present study are incompatible with either of these concepts.

A particular variant of hemispheric specialization emphasizes "attentional" biases (Kinsbourne, 1970), mediated by unilateral hemispheric activation, as determinants of half-field asymmetries in recognition. In order to account for the present monocular data, this hypothesis would have to postulate that "attention" shifts from one side of space to the other when one changes the viewing eye. It is not at all clear why this should be the case.

The Role of Visual Acuity. The results of the present study can perhaps be most parsimoniously explained in terms of differential visual acuity, which manifests itself monocularly, but which balances out upon binocular testing. As replotted in Woodworth and Schlosberg (1954), Wertheim in 1894 (not viewed) provided monocular visual acuity data which demonstrated superior relative sensitivity for the temporal hemiretinae at retinal eccentricities between  $1^{\circ}$  and  $5^{\circ}$ . More recently, Markowitz and Weitzman (1969) have shown that monocular visual acuity, as measured with the Landolt C, is superior in the temporal hemiretinae of either eye. Furthermore, Curcio et al. (1974) have shown that binocular visual acuity (not monocular), as measured with a line gap detection task, is equal in both half-fields, out to retinal eccentricities of  $3^{\circ}$ . Riggs (1965; 1972) has discussed four types of acuity tasks (i.e., detection, localization, resolution, and recognition), and has indicated that visual acuity is a far more complex capacity than the frequently mentioned type of acuity measured using a gap detection task.

In view of Rigg's considerations, one would be hard pressed to discover a visuo-spatial task that did not involve some degree or type of visual acuity.

In the present study, a small number of single element stimuli were used repetitively, increasing the probability that specific details of the stimuli could be used for initial discrimination and eventual recognition. In fact, subjective reports from each of the observers indicated that correct responses were felt to be mediated by the detection of some critical element in each stimulus. Thus, a T was distinguished from an H because it contained only a single vertical line, while an X differed from a V because the location of line intersection was higher in visual space. Similarly, the correct recognition of triangle orientation was felt by the observers to depend upon detection of the differential location (i.e., up, down, left or right) of the critical apex. On this basis, one could argue that single letters need not necessarily be "verbal" stimuli. On the other hand, it would be most difficult to eliminate the obvious spatial character of both letters and triangles. In light of these considerations, it would appear desirable to reassess both the conceptual framework and the empirical evidence, which has been cited to support the notion of right hemispheric "spatial" specialization.

Such a reassessment could best be implemented with studies employing dichoptic, as well as binocular and monocular, stimulation, in an attempt to analyze the retro-chiasmal influences on tachistoscopic recognition. In

addition, a greater diversity of stimulus material should be employed and individual comparisons should be emphasized. Further, an attempt should be made to operationally clarify and define the nature of "spatial" and "verbal" material. In brief, future experimental studies should attempt to determine whether a measurable boundary exists between "verbal" and "spatial" material, or whether visual functioning should best be considered as a continuous, hierarchical process.

## APPENDIX

1. To determine whether 15% was a significant increment above chance level (11.11%) the following formula was used to find Z, the standard normal deviate (Edwards, 1974):

$$\frac{P - P}{\sqrt{NPQ}}$$

Substituting the necessary numerical values, yields a Z of 1.78.

$$\frac{15 - 11.11}{\sqrt{48 (.111)(.888)}} = 1.78$$

From the table of the standard normal curve, we found that the probability of Z equal to or greater than 1.78 is .0369 (one tailed). Therefore, values of p equal to or greater than 15% would be expected to occur approximately 3% of the time.

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