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SPATIAL FACTORS IN BACKWARD VISUAL MASKING

by

James K. Habinek

A Thesis Submitted to the Faculty of the Graduate School  
of Loyola University of Chicago in Partial Fulfillment  
of the Requirements for the Degree of  
Master of Arts

May

1977

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## VITA

The author, James Keith Habinek, is the son of George Anthony Habinek and the late Margaret Rita (Brincka) Habinek. He was born March 14, 1951, in Cleveland, Ohio.

His elementary education was obtained at St. Mel Grade School in Cleveland, Ohio, and his secondary education at St. Edward High School in Lakewood, Ohio, from which he was graduated in 1968.

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The author served in the United States Army from July, 1972, through June, 1974. In September, 1974, he was awarded an assistantship in experimental psychology at Loyola University of Chicago.



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## INTRODUCTION

The term visual masking has been used as a general label for a class of phenomena that occur when two visual stimuli are presented to an observer in close spatial and temporal contiguity. Some aspects of one stimulus (the target stimulus or TS) such as detectability or apparent size, clarity, or brightness are degraded by the prior or subsequent presentation of the other stimulus (the masking stimulus or MS). A few basic categories of visual masking have been delineated on the basis of the temporal order and spatial arrangement of the two stimuli. In general, the term masking has been reserved for those cases in which the TS and MS are spatially overlapping (Kahneman, 1968). When the MS precedes the TS the paradigm and subsequent effects are referred to as forward masking. Backward masking, on the other hand, is the term used to describe the retroactive effects upon a target of a mask that follows the TS in time. The terms paracontrast and metacontrast refer to the analogous procedures and effects for spatially non-overlapping stimuli (Stigler, 1910). Paracontrast refers to those instances in which a MS precedes a non-overlapping TS, while metacontrast refers to those instances in which a non-overlapping MS follows a TS.

A wide variety of stimuli, ranging from homogeneous fields of luminance to alphanumeric characters to complex pictures, have been used as stimuli in visual masking studies. Some researchers have delineated further classifications of masking procedures on the basis

of the composition of the TS and MS. Schiller (1969), for example, differentiates between masking that involves contour interaction between TS and MS and masking that does not involve such interaction. Others (Breitmeyer & Ganz, 1976; Turvey, 1973) draw a distinction between masking by patterned or structured masks and masking by random "visual noise."

In addition to the parameters of the spatial and temporal arrangement of stimuli and of stimulus type, investigators have studied the effects upon masking of varying such parameters as the contrast, luminance and retinal position of the stimuli, the method of presentation (monoptic or dichoptic), and the task required of the observer. The appropriate changes in the contrast or luminance of the TS and MS, for example, can produce masking effects that are either monotonic or non-monotonic functions of the time interval separating the stimuli (Kolers, 1962; Scharf & Lefton, 1970; Turvey, 1973; Weisstein, 1971). Similarly, changes in retinal position can reduce masking effects--presentation of stimuli closer to the fovea--or enhance them--presentation of stimuli further into the periphery (Kolers & Rosner, 1960; Stewart & Purcell, 1970; Sturr & Frumkes, 1968).

The degree of masking also seems to be dependent upon the nature of the observers' task. Masking studies have utilized reaction time measures (Fehrer & Raab, 1962), magnitude estimation (Donchin & Lindsley, 1965; Weisstein, Jurkens & Onderisin, 1970), forced-choice identification and detection tasks (Heckenmueller & Dember, 1965; Schiller & Smith, 1966), and phenomenal reports (Mayzner, 1975; Mayzner, Tresselt & Helfner, 1967; Schoenberg, Katz & Mayzner, 1970; Werner, 1935). The results of such studies indicate that some aspects of a TS, its figural

properties, for instance, may be eliminated by the appropriate presentation of a MS, while other aspects, its detectability, for instance, are at the same time unaffected.

Comparisons of the effect upon masking resulting from monoptic versus dichoptic presentation of stimuli have been made in attempts to determine whether masking occurs peripherally or centrally (Battersby & Wagman, 1962; Schiller & Smith, 1968; Turvey, 1973; Weisstein, 1971). Masking stimuli which overlap the TS and are composed of homogeneous fields of luminance or random visual noise will only be effective under conditions of monoptic presentation, suggesting a peripheral locus for some masking effects (Schiller, 1969). Patterned stimuli containing some internal contours, on the other hand, can quite effectively mask target stimuli when the two are presented dichoptically, suggesting that in some instances masking is central in origin (Turvey, 1973). For a comprehensive treatment of relevant visual masking parameters the reader is referred to several excellent reviews (Breitmeyer & Ganz, 1976; Kahneman, 1968; Raab, 1963; Turvey, 1973).

Although the present study employs a backward masking paradigm, reference will be made to studies employing other experimental procedures. The assumption will be made that despite differences in spatial and temporal arrangement of stimuli, the basic physiological processes underlying the masking phenomena produced by the various procedures are closely related, and therefore comparisons among studies are possible.

## REVIEW OF THE RELEVANT LITERATURE

The present study is concerned with a parameter that has received considerable attention in studies using a metacontrast paradigm, limited attention in studies using a forward masking paradigm, and little attention in studies using a backward masking paradigm, namely, the spatial relationship between the TS and MS. Regardless of the paradigm, one result has been consistently found: as the spatial separation between the borders or contours of the two stimuli is increased the extent of masking, measured in terms of a decrement in the detectability of the target stimulus, decreases. This general rule seems to hold true whether the two stimuli are overlapping (as in masking studies) or merely adjacent (as in metacontrast studies). The following studies are exemplary of the techniques employed in the investigation of the spatial separation parameter and of the results obtained in the various paradigms.

Werner (1935) was perhaps the first to note that in a metacontrast procedure increasing the intercontour distance between a disk (TS) and an annulus (MS) leads to a decrease in the effectiveness of the mask. In fact, Werner reported the complete absence of masking when any intercontour distance was introduced between the TS and MS. He interpreted his results in terms of the interference of the ring's inner contour upon the formation of the contour of the disk--an essential process for the perception of the disk. More recent investigators, however, have reported masking effects at nonzero contour separations, but

always as an inverse function of the intercontour distance (Cox & Dember, 1971; Cox, Dember & Sherrick, 1969; Kolers & Rosner, 1960; Streicher & Pollack, 1967).

Kolers & Rosner (1960), for example, using black disks and rings, found that the amount of masking of the target disk was inversely related to the separation in visual angle between the disk and the inner diameter of the masking ring, but only for peripheral presentation of stimuli. When stimuli were presented foveally masking effects disappeared at the slightest nonzero intercontour distance. Cox et al. (1969), again employing a disk-ring sequence, used a forced-choice procedure to investigate the degree of masking as a function of both intercontour distance and target size. They found that the magnitude of the effect shrank as the intercontour separation grew.

Cox & Dember (1971) investigated metacontrast effects while varying target field luminance, interstimulus interval, and the spatial separation of the TS and MS. While their stimuli differed appreciably from the disk-ring sequences used in the previously mentioned studies--their target was a thin black strip 2' of arc wide and 36' high, and their mask was a wide black field flanking the target on the left side of the visual field--their results were quite similar. Subjects' ability to detect the presence of the TS improved as the distance between the TS and MS increased. In addition, increases in the target field luminance led to a decrement in detection performance across all conditions.

In a study concerned with the effects of mask size and target contour-mask contour separation in a masking paradigm (i.e., spatially overlapping stimuli), luminance thresholds were determined for a brief flash of light (TS) as a function of conditioning flash (MS) size and



the conditioning-flash-onset to target-flash-onset interval (Battersby & Wagman, 1962). The TS consisted of a homogeneous patch of light  $40'$  of angular subtense, and the MS consisted of a concentric patch of light either  $40'$ ,  $1^{\circ}20'$ ,  $2^{\circ}$ , or  $4^{\circ}40'$  of angular subtense. TS duration was 5 msec while MS duration was either 500 or 1500 msec in duration. The MS was maintained at a luminance of 2.0 mL throughout all conditions of the experiment. The conditioning-flash-onset to target-flash-onset intervals studied by the experimenters ranged from -200 to 1500 msec, where negative values refer to instances in which the target flash onset preceded the conditioning flash onset, and positive values refer to instances in which the opposite was true.

In separate conditions of the experiment stimuli were presented either monoptically or dichoptically. The results for monoptic presentation revealed that for all mask sizes threshold rose sharply at negative intervals, reaching a maximum at a 0 msec ISI. At positive intervals--when the MS preceded TS onset--thresholds slowly declined until MS offset (either 500 or 1500 msec), at which point TS threshold rapidly returned to its resting level. The amount of threshold rise varied inversely with the size of the MS: the smaller the MS, the higher the threshold. A special effect was obtained when both the TS and MS were of equal diameter ( $40'$ ). At negative intervals threshold rose to a maximum at an interval of -25 msec. At positive intervals thresholds declined to a minimum at a point midway through the duration of the MS, and then rose to a second maximum at the offset of the MS.

The results for dichoptic presentation of stimuli revealed that again thresholds at negative intervals (backward masking) rose sharply to a maximum at a 0 msec interval. Thresholds then declined slowly at

positive intervals, decreasing sharply only at MS offset. Again, amount of threshold elevation varied inversely with the size of the MS. With dichoptic presentation there was no secondary threshold maximum at MS offset for the 40' MS. Overall a proportionately greater change in threshold as a function of MS size was found in the dichoptic viewing condition than in the monoptic condition.

In a later study Battersby and Wagman (1964) employed a variable duration method to study the effects of the spatial relationship between TS and MS upon luminance thresholds. Instead of varying the onset-onset interval of the target and masking flashes, in this experiment Battersby and Wagman chose to fix the onset of the target flash at the offset of the concentric, variable duration masking flash. The TS was always 5 msec in duration and subtended 40' of visual angle. The MS was fixed in luminance at 3.0 mL, but varied in duration from 5 to 1500 msec and in angular subtense from 40' to 4°40' in four steps. Target stimuli were presented on an adapting background of 1.0 mL and centered at 7° parafoveal displacement in the right eye. Monocular thresholds were obtained for two trained observers by varying the luminance of the TS. In addition to the finding that all thresholds rose as the duration to prior light exposure increased, the experiment also revealed that the rate of threshold change, as well as the asymptotic level finally achieved, became greater as the diameter of the conditioning flashes grew smaller.

Sturr, Frumkes and Veneruso (1965) extended the generalizability of the findings of Battersby and Wagman by employing a different threshold measure and different stimuli, and by investigating the effects at different retinal positions. Duration thresholds for small (10' of arc) black disk targets were determined at various retinal positions

(foveally, and  $2^{\circ}$ ,  $5^{\circ}$  and  $7^{\circ}$  in the horizontal meridian of the left visual field) after previous exposure to a concentric black disk mask (either 15', 22.5', or 30' of arc). The experimenters found decreasing masking effects at all four retinal positions as mask size was increased. The effectiveness of each mask size was also lessened the more central the site of stimulation. In fact foveal presentation of the largest mask actually facilitated detection of the target--the duration threshold was lower than the threshold obtained in the absence of any mask.

Streicher and Pollack (1967) criticized the study of Sturr et al. for its use of forward masking procedures. They argued that the results, including the facilitation effects noted at foveal presentation, could have been due to the interaction of an afterimage of the masking disk with the target disk. To avoid the complication of a MS afterimage, Streicher and Pollack used a backward masking paradigm, but one in which non-overlapping stimuli were employed (i.e., metacontrast). They varied the size of their grey target disk (10', 15', 20', or 25' of arc in diameter) while maintaining the inner diameter of the white masking annulus at a constant 30' of arc. TS and MS were presented for 15 msec. The interstimulus interval separating the two was varied to determine the minimum ISI at which the target was detectable. Their findings resemble those of other metacontrast studies in which interest was focused on intercontour distance: duration of the masking interval was inversely related to mask size.

Matthews (1971) conducted a series of adaptation or forward masking studies in which he varied the spatial relationship of the TS and MS. In Experiments 1-3, a target probe and a MS of homogeneous luminance were presented simultaneously for a duration of 1 sec. The

2.5' target probe was located either in the center of a disk of variable width (Experiment 1), in the center of a bar of variable width (Experiment 2), or 2' from one edge of a bar of variable width (Experiment 3). In Experiments 1 and 2 luminance thresholds for the target probe were inversely related to the diameter or width of the MS. In Experiment 3 the threshold remained constant over a wide range of bar widths. In Experiments 4 and 5 the same spatial configurations of Experiments 1 and 2 were used, but various intervals between the onsets of a 10 msec TS and a 1000 msec MS were introduced. Results from these experiments indicated that, again, degree of threshold elevation (masking) depended upon the width or diameter of the MS, and that masking effects such as these take time to develop.

Sturr and Frumkes (1968) conducted a pair of experiments to further investigate the facilitation effect evidenced in their earlier study (Sturr et al., 1965), and to make some comparisons between the effects produced by light and dark stimuli in a paradigm in which MS size is varied. In Experiment 1, a replication of the earlier study over a broader range of MS sizes, the TS employed was a black disk 10' of visual angle, while the MS was one of nine overlapping black disks ranging in size from 15' to 20'. Thresholds were obtained by adjusting the duration of the TS. The experimenters state that the temporal interval between TS and MS was fixed, but they do not make it clear whether this was with respect to onset or offset of the stimuli, or whether the TS preceded or followed the MS. By determining the target threshold in the absence of a mask (resting threshold) and comparing this control condition to the thresholds obtained in the presence of a mask, they determined that as mask size increased, target threshold

decreased according to a negatively accelerating function and approached asymptote below the resting threshold. Thus, at the larger mask sizes, facilitation was in evidence.

In the second experiment a Maxwellian viewing system was used to present white light stimuli monoptically to the observer. The 5 msec circular TS had a constant diameter of  $1^\circ$ , while the 250 msec,  $34$  mL concentric masking flash varied in diameter from  $1^\circ$  to  $6.2^\circ$ . The TS and MS were pulsed synchronously at either their onsets or offsets. Thresholds were determined by adjusting the luminance of the TS. The results indicated once again that the threshold was a negatively accelerating function of mask size. In the light stimuli condition, however, asymptote was reached above the resting threshold. There was no evidence of facilitation even at the largest mask size. The finding that thresholds were higher for target flashes presented at mask onset than for flashes presented at mask offset corroborated the findings of Battersby and Wagman (1962).

Frumkes and Sturr (1968) simultaneously varied luminance, retinal position, and size of conditioning flash (MS) in order to study the effects of these variables on the excitability of a target flash. Luminance levels of the 25 msec MS used in the experiment included a bright photopic (15.9 mL), a dim photopic (0.50 mL), and a scotopic level (0.016 mL). MS diameter took on four different values:  $57'$ ,  $1^\circ 50'$ ,  $2^\circ 43'$ , and  $3^\circ 30'$ . The MS and TS were projected either centrally or  $7^\circ$  or  $15^\circ$  in the horizontal meridian of the nasal field. The TS was 5 msec in duration and appeared at various intervals before, after, or coincident with the MS onset. Thresholds were determined by varying the luminance of the TS. All stimuli were presented monocularly to the right eye.

Results indicated that with photopic luminances and central and  $7^{\circ}$  stimulation, increment thresholds decreased as the diameter of the MS increased. With peripheral, scotopic stimuli the test threshold first increased then decreased as MS diameter increased. On the other hand, with photopic stimuli at  $15^{\circ}$  the threshold tended to increase as the conditioning flash (MS) diameter increased.

## RATIONALE FOR THE CURRENT STUDY

The current study has been designed to expand the investigation of the effects of varying the spatial relationship of the TS and MS in several ways. For example, a backward masking paradigm is employed since this particular procedure has been largely neglected in past studies of the spatial separation variable. Furthermore, a different type of MS (that is, a pattern or punctate masking field) is used rather than the type employed in previous studies (homogeneous fields of luminance). Also, a new method for varying the spatial separation of the two stimuli has been introduced--changing the position of the TS relative to the position of the MS.

Perhaps the most critical difference between previous studies and the current one involves the nature of the stimuli employed. All the existing data have been obtained in experiments in which homogeneous masking fields have been used. In the present study pattern or punctate masks consisting of regular arrangements of discrete points of light are used as the MS. Evidence suggests that differences in masking may be produced by homogeneous and non-homogeneous (pattern) masking stimuli (Kolers, 1962; Scharf & Lefton, 1970; Turvey, 1973; Weisstein, 1971). For example, under most conditions masking with a MS of homogeneous luminance produces a monotonic masking function, whereas masking with a non-homogeneous MS may produce either monotonic or non-monotonic functions. Furthermore, it has been suggested that the origin of the masking

effects produced (whether central or peripheral) differs for the two types of masking stimuli (Turvey, 1973). Thus it will be of interest to learn whether or not the same types of effects due to the manipulation of the spatial relationship between the MS and the TS result when pattern masks are employed as have resulted when masks of homogeneous luminance were employed.

Some recent evidence (Mayzner & Habinek, Note 1) indicates that in a backward masking paradigm involving patterned target stimuli and punctate masking stimuli, recognition or identification of at least some types of target stimuli is an increasing monotonic function of mask size. These findings suggest strongly that systematic differences in masking as a function of the spatial separation of the TS and MS may be expected in the current study.

The technique that is used for varying the spatial separation between TS and MS has been chosen for the following reasons. Almost exclusively, previous investigations have relied upon the technique of varying MS size or TS size to manipulate the spatial relationship between the two stimuli. While the methods of holding target size constant and varying mask size, or conversely of varying target size and holding mask size constant do produce variations in the spatial separation between the two, they yield results which may be subject to difficulties of interpretation. Since in the first case smaller masking stimuli produce greater masking effects, and in the second case smaller target stimuli produce lessened masking effects (i.e., targets are more easily detected), one might argue that size-tuned mechanisms in the visual system are producing these effects: smaller stimuli, because of the efficiency of some hypothetical "small stimulus detecting mechanism", produce a more



indelible or effective trace than do large stimuli. Thus, concepts such as contour interaction or maximal inhibition at borders (the usual explanations offered) need not be invoked to explain many of the results previously discussed. The current study, while it uses the traditional technique of varying mask size, also introduces the technique of changing the position of an otherwise non-varying TS relative to the position of each MS to produce changes in the spatial separation of the two.

This method, since it permits us to probe or map the effectiveness of the MS at various points (see Schoenberg, Katz, & Mayzner, 1970, for a related mapping paradigm), allows an assessment to be made of both the effects of stimulus size and the effects of spatial separation between TS and MS upon degree of masking. For example, the effects produced by varying MS size and leaving TS location constant may be compared with the effects produced by varying MS size and adjusting the location of the target so that a constant spatial separation between TS and MS is maintained at each MS size in order to answer the objection raised above. If, as previous investigators have claimed, the spatial separation between TS and MS is the relevant variable, then equal effects at equal separations, regardless of mask size, should be produced in this study.

An additional benefit that will be realized from this method is the fact that the condition of TS and MS border coincidence may be studied without introducing a problem that arises when same-size stimuli are used, that is, a change in the nature of the information available to the observer. When two identical stimuli are presented successively to an observer who must judge whether or not he detects the presence of a TS, he may (or must) base his judgment on the presence of a gap,

interval, or flicker between the two successive stimuli. This is a different criterion than the one that may be employed when different-size stimuli are involved in the task. Indeed, this particular arrangement of stimuli has traditionally been studied as a two-flash paradigm rather than as a masking paradigm. To put it another way, when two same-size stimuli are presented asynchronously the observer may only base his judgment on the presence of temporal transients. When two different-size stimuli are presented asynchronously, the observer may base his judgment on the detection of either spatial or temporal transients (Sperling, 1965). By always employing different-size stimuli but varying the location of the TS relative to the MS, the present study allows for the condition of coincident contours to be studied without reducing the type of information available to the observer.

To summarize, in the present experiment a backward masking paradigm with non-homogeneous masking stimuli is utilized. The spatial separation between TS and MS is varied both by varying MS size and by varying the relative location of the TS. Detection performance will be characterized by a family of psychometric functions relating proportion of TS detected to duration of TS for each combination of MS size and TS-MS spatial separation. It is predicted that detection performance will be systematically related to the spatial separation as previous investigators have suggested but failed to demonstrate conclusively because of problems in design.

## METHOD

### Subjects

Six graduate student volunteers at Loyola University (including the author) served as observers. All subjects had normal or corrected-to-normal vision.

### Apparatus

Stimuli were presented via a computer-based cathode ray tube (CRT) display system. Elements of this system, located in two adjacent rooms, consist of a high-speed DEC PDP 8/E digital computer interfaced to a VR-14 CRT. The CRT display surface is coated with an ultra-short persistence phosphor (P24) with a decay time of a few microseconds. This feature of the CRT allowed very precise control of stimulus durations and temporal relationships between stimuli.

The CRT rested on a table in a lightproof room. The observers sat at the same table with their heads in a chinrest to minimize movement and to insure that a constant 60 cm distance between display screen and observer was maintained at all times. The experimenter remained in the next room with the computer to record responses and to oversee presentation of stimuli. Observer and experimenter communicated by

way of a small intercom system between the two rooms.

The system utilized a program that allows stimuli to be composed of discrete points of light or various arrangements of discrete points of light whose location and spatial arrangements on the CRT display surface could be precisely controlled. Stimulus durations, which could be varied in 1 msec steps, could be as short as 1 msec or as long as desired. In addition, because of the rapid decay phosphor and the nature of the computer, the offset of one stimulus and the onset of the next could be instantaneous if so desired. The combined hardware and software employed therefore provided the spatial and temporal flexibility required for presentation of the stimuli used in the experiment.

### Stimuli

All stimuli were composed of arrangements of discrete point of light. A fixation cross presented on the center of the display screen preceded each trial by 750 msec and remained on for the duration of the trial (Figure 1a). Three masking stimuli were employed, each in the shape of a square matrix of points. The smallest mask (Mask I) was a 6x6 dot matrix subtending  $.60^\circ$  visual angle on a side (Figure 1b). The next mask (Mask II) was an 8x8 matrix subtending  $.84^\circ$  on a side (Figure 1c). The largest mask (Mask III) was a 10x10 matrix subtending  $1.08^\circ$  on a side (Figure 1d). Interpoint distance for all masks was identical and was approximately  $.12^\circ$  visual angle. The distance between segments of the fixation cross was  $2.10^\circ$  visual angle.

Target stimuli were single points of light. Twenty targets were

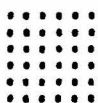
:

.....-2.10°-.....

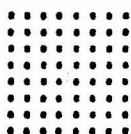
.

:

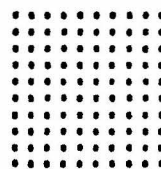
(a) Fixation Cross



.60°

(b) Mask I  
6 X 6

.84°

(c) Mask II  
8 X 8

1.08°

(d) Mask III  
10 X 10a b  
c da b  
c da b  
c da b  
c da b  
c d

i

ii

iii

iv

v

(e) Five Groups of Target Stimuli  
(Each group consists of four target stimuli)

Figure 1. Stimuli employed in the experiment.

employed, each of which was a point coincident with one of the points of the masks. These targets were chosen so that each fell on one of the two imaginary diagonal lines that may be drawn connecting opposite corners of the MS. The twenty targets can be divided into five groups with membership in a group determined on the basis of the minimal distance between the target point and the nearest border of the MS (Figure 1e). Table I provides the precise distances in visual angle between stimuli of each group and the nearest border of each MS. As may be observed, Mask I was used in conjunction with three groups of targets, Mask II with four, and Mask III with all five target groups.

Target and masking stimuli were all presented foveally at a luminance level of 0.8 mL. A Gamma Scientific photometric system (Model 2020 EA) was used to insure that stimulus luminance was maintained at the desired level. The duration of the MS was always 500 msec. Target stimuli varied in duration but always assumed one of the following five values: 12, 24, 36, 48, or 60 msec. The offset of the TS always coincided with the onset of the MS. TS onset always followed a 750 msec presentation of the fixation cross. Figure 2 relates schematically the temporal ordering of the fixation markers, target, and mask.

### Procedure

Presentation of stimuli was divided into three blocks of trials or sessions for each observer. Only one MS size was used per session, but all values of TS duration and location were included in each session. A unique random order for presentation of stimuli was used for each

TABLE 1 .

DISTANCES BETWEEN TARGET STIMULI AND NEAREST BORDER OF MASKING STIMULI  
(DEGREES VISUAL ANGLE)

Target Stimuli	Masking Stimuli		
	Mask I	Mask II	Mask III
Group i	.24°	.36°	.48°
Group ii	.12°	.24°	.36°
Group iii	.00°	.12°	.24°
Group iv	*	.00°	.12°
Group v	*	*	.00°

\*These conditions were not investigated.

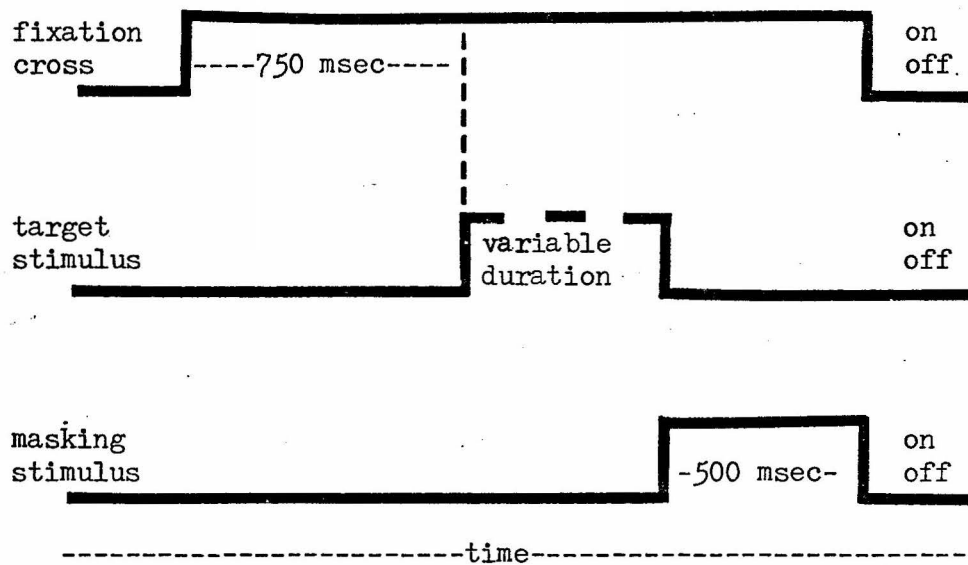


Figure 2. Temporal relationships of stimuli in the experiment.



observer, and the ordering of the three sessions was counterbalanced across the six observers. A total of 1440 experimental trials were presented to each observer, a number representing six repetitions of the 240 target location x target duration x mask size combinations studied. In the session with the smallest masking stimulus (Mask I), five target durations and twelve target locations were repeated six times, yielding a total of 360 experimental trials. In the session using Mask II, five target durations and sixteen target locations were combined and repeated six times for a total of 480 experimental trials. In the session employing the largest MS (Mask III), five target durations and twenty target locations were combined and repeated six times to yield a total of 600 trials. In addition to the experimental trials in each session, a number of catch trials (equal to 10% of the total of experimental trials for that session: 36, 48, and 60), in which no TS was presented, were randomly introduced among the experimental trials. Responses recorded for the catch trials were used to correct for the response biases of the individual observers according to the formula (Kling & Riggs, 1971, p. 34):

$$P_c = \frac{P_h - P_{fa}}{1 - P_{fa}}$$

where  $P_c$  = proportion corrected for guessing;  $P_h$  = proportion of hits; and  $P_{fa}$  = proportion of false alarms.

Prior to the first session the observers were given instructions regarding the task required of them. They were told that on each trial

a briefly presented single-point target would precede a longer masking stimulus. Their task was simply to report whether or not they had detected the presence of the target stimulus on each trial. Before each session observers received 30 practice trials similar to the experimental trials that were to follow.

Subjects were dark-adapted for five minutes before the practice trials and remained in a lightproof room throughout the experimental sessions. This length of dark-adaptation time was chosen since foveal presentation of stimuli primarily elicits the activity of the photopic system which can be completely dark-adapted in approximately five minutes (Cornsweet, 1974).

## RESULTS

In the present study, target groups (i.e., i - v in Figure 1e) consisted of four different target stimuli (i.e., a - d in Figure 1e), each of which was an equivalent distance from the border of a given MS. For each observer chi square tests ( $df = 3$ ) were carried out to determine whether performance on the targets within each group differed significantly from target to target (i.e., from a to b to c to d). Since all tests failed to show significant differences among the individual targets in each group, responses were combined within each group in subsequent analyses.

Table 2 (analogous to Table 1 on p.20) shows the mean per cent "Yes" responses corrected for guessing (according to the formula on p. 19) for each of the twelve target group x masking stimulus combinations employed in the experiment. The empty cells in the table reflect the fact that not all target group x masking stimulus combinations were used. Two three-way analyses of variance with repeated measures on all factors were conducted to examine the data.

In the first ANOVA, which treated the data represented in the top three rows of Table 2, factor A (mask size) consisted of three levels:  $.60^\circ$  width,  $.84^\circ$  width, and  $1.08^\circ$  width. Factor B (target group) also consisted of three levels: group 1, furthest from the MS border; group 2, nearer to the MS border; and group 3, nearest to the MS border. Factor C, (TS duration) consisted of five levels: 12, 24,

TABLE 2

MEAN % "YES" RESPONSES (TARGET DETECTED)  
FOR EACH TARGET AND MASKING STIMULUS COMBINATION

(N = 6)

Target Stimuli	Masking Stimuli		
	Mask I	Mask II	Mask III
Group i	<u>64.5</u>	71.8	74.7
Group ii	<u>53.0</u>	<u>64.6</u>	72.8
Group iii	<u>52.1</u>	<u>55.2</u>	<u>65.5</u>
Group iv	*	<u>52.1</u>	<u>53.6</u>
Group v	*	*	<u>51.1</u>

\*These conditions were not investigated.

36, 48, and 60 msec. The main effects of size ( $F = 19.305$ ,  $df = 2/10$ ,  $p < .001$ ), target group ( $F = 10.659$ ,  $df = 2/10$ ,  $p < .005$ ), and TS duration ( $F = 145.097$ ,  $df = 4/20$ ,  $p < .001$ ) were all significant. In addition, the interactions of mask size and target group ( $F = 4.986$ ,  $df = 4/20$ ,  $p < .025$ ), mask size and target duration ( $F = 5.748$ ,  $df = 8/40$ ,  $p < .001$ ), target group and duration ( $F = 5.212$ ,  $df = 8/40$ ,  $p < .001$ ), and mask size, target group, and duration ( $F = 2.984$ ,  $df = 16/80$ ,  $p < .025$ ) were significant. These latter three interactions can probably be attributed to a "basement" effect: at the shortest duration performance cannot extend below 0% "Yes" responses, the value approached by all the functions at that point. Figure 3 portrays the relationship between mask size and target group, while Figures 4 and 5 show the relationship between mask size and TS duration, and target group and TS duration, respectively. As can be seen, detection performance improves as the distance or spatial separation between the TS and the border of the MS is increased, whether this increase is brought about by shifting the position of the target group or increasing the size of the MS. Also, Figures 4 and 5 show that performance on the three masking stimuli and the three target groups changes from approximately 0% to approximately 100% in an ogival fashion over the range of duration values tested. A complete summary of the ANOVA is given in Table 3.

The second ANOVA treated the data represented by the underlined means in Table 2. Factors A and C were again MS size and TS duration, respectively, but factor B consisted of three values of spatial separation between TS and the MS border:  $.00^\circ$ ,  $.12^\circ$ , and  $.24^\circ$  visual angle (refer to Table 1, p. 20). For each MS size, those target groups were chosen that yielded these three values of target-mask separation, in

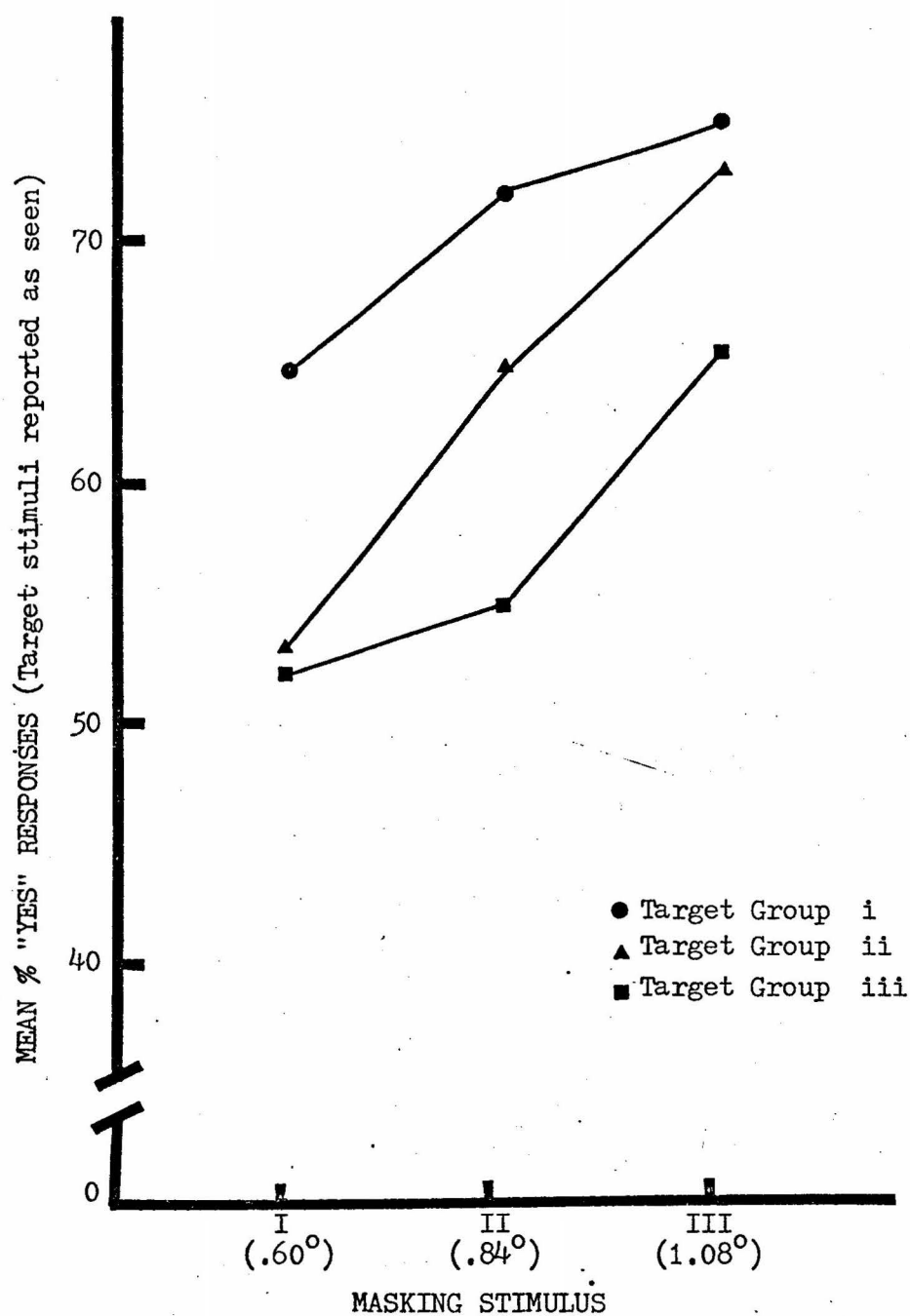


Figure 3. Frequency of seeing targets as a function of masking stimulus.  
(Parameter is Target Group).

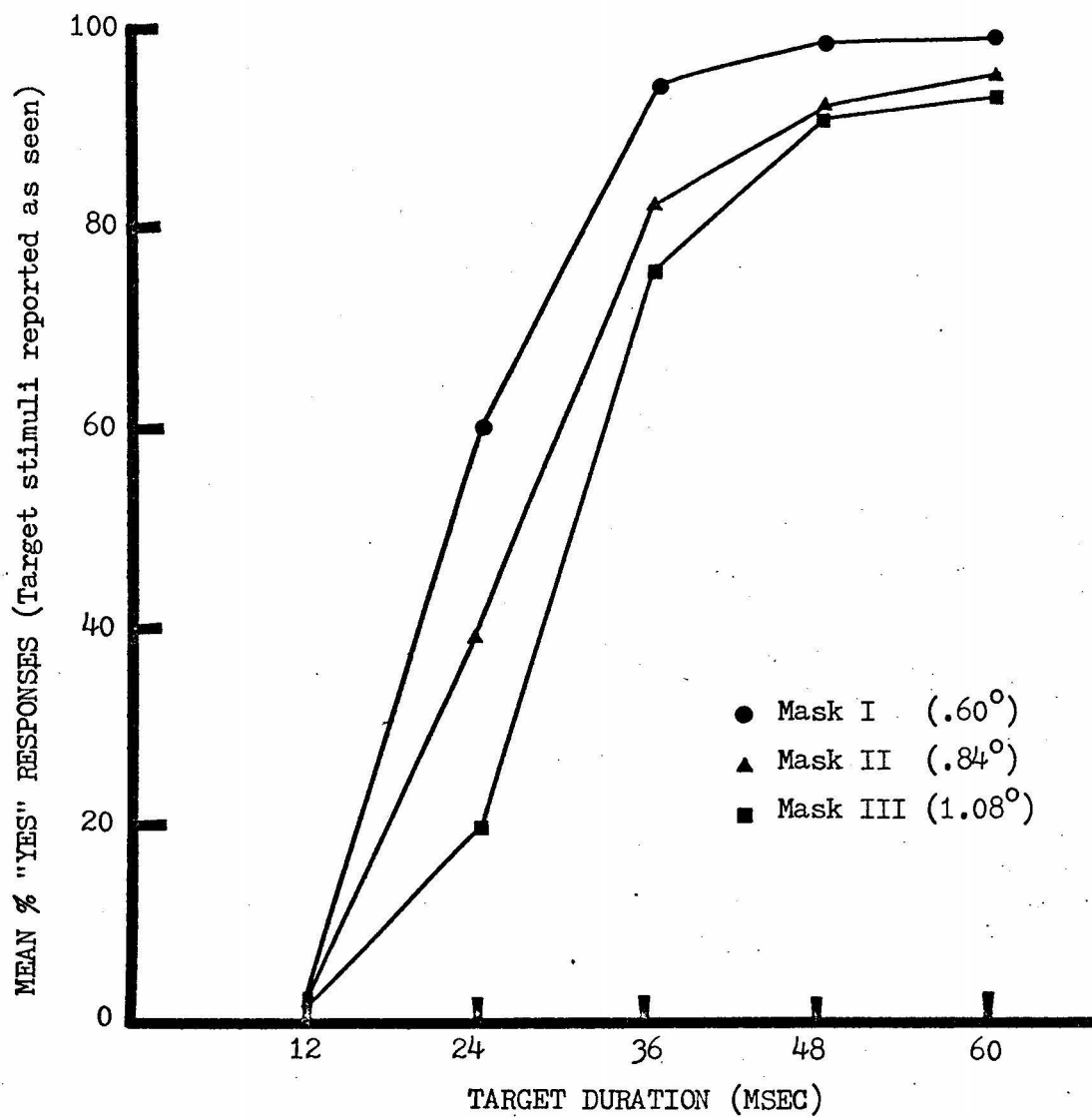


Figure 4. Frequency of seeing targets as a function of target duration. (Parameter is Masking Stimulus).

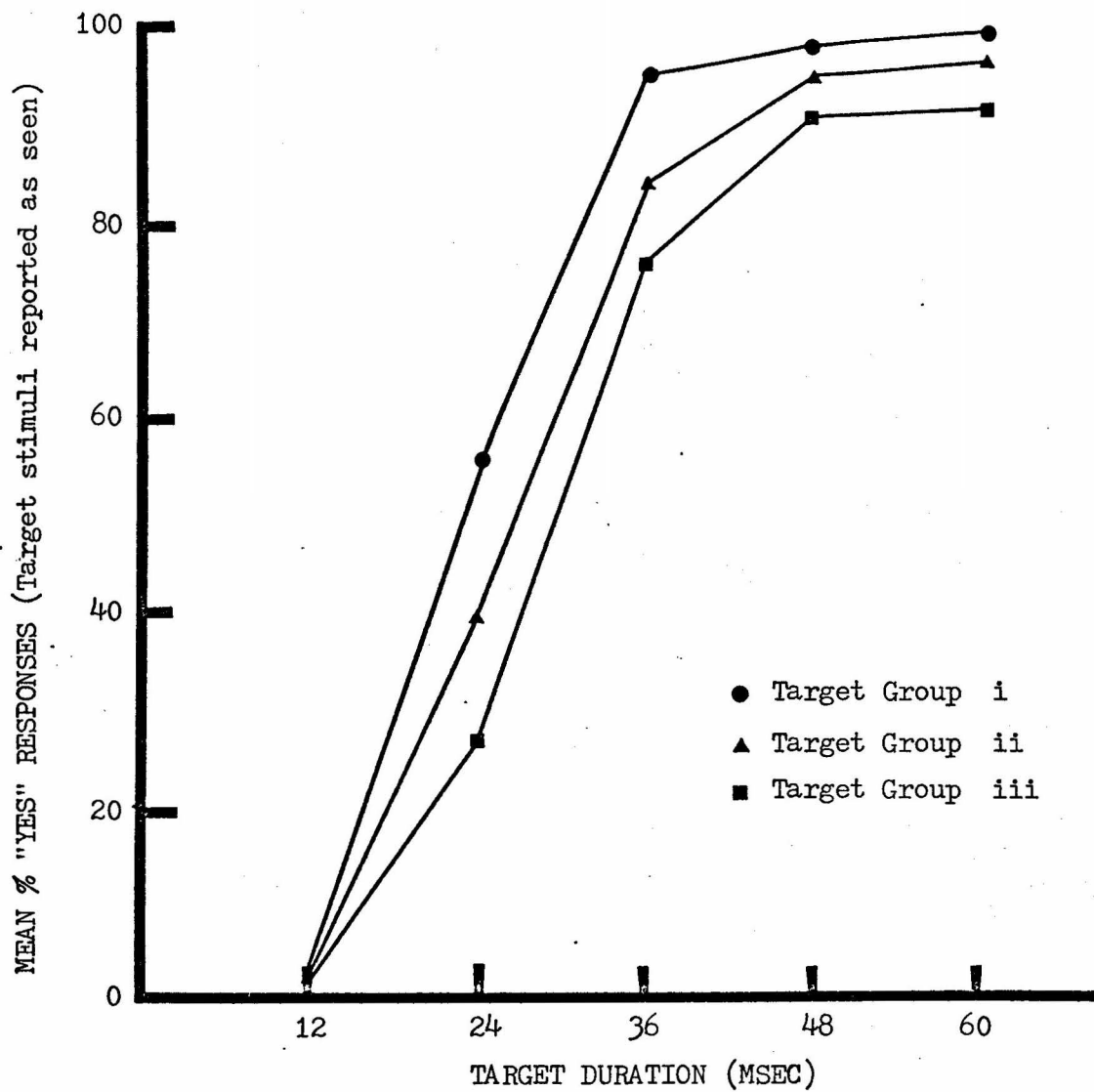


Figure 5. Frequency of seeing targets as a function of target duration.  
(Parameter is Target Group).



TABLE 3

## SUMMARY TABLE FOR THE FIRST ANALYSIS OF VARIANCE

Source	Error Term	df	Mean Square	F
Mean	S	1	109.9916	225.3712
Subject (S)		5	.4880462	
Masking Stimulus (M)	SM	2	.4753510	19.3052***
Target Stimulus (T)	ST	2	.3617452	10.6590**
Target Duration (D)	SD	4	9.244362	145.0971***
SM		10	.0246288	
ST		10	.0339380	
MT	SMT	4	.0276804	4.0868*
SD		20	.0637115	
MD	SMD	8	.1102886	5.7483***
TD	STD	8	.0618763	5.2129***
SMT		20	.0067731	
SMD		40	.0191864	
STD		40	.0118699	
MTD	SMTD	16	.0164821	2.9846*
SMTD		80	.0055223	

\* $p < .025$   
 \*\* $p < .005$   
 \*\*\* $p < .001$

order that the effects of mask size might be investigated independently of concomittant changes in spatial separation. The main effects of spatial separation ( $F = 9.761$ ,  $df = 2/10$ ,  $p < .001$ ) and duration ( $F = 80.593$ ,  $df = 4/20$ ,  $p < .001$ ) were significant, while the main effect of mask size failed to achieve significance ( $F = 0.914$ ,  $df = 2/10$ ). The only significant interaction was that between factor B, spatial separation, and factor C, TS duration ( $F = 3.588$ ,  $df = 8/40$ ,  $p < .005$ ). Again, it would seem that the interaction might be explained in terms of a base-ment effect. The significant main effect of spatial separation demonstrated that the probability of detection increased as the fixed distance between the TS and the MS border increased, whereas the failure of the mask size factor to achieve significance suggests that performance for a fixed distance remains the same regardless of the mask size involved. Figure 6 portrays this relationship. For each separation performance changes very little across the three mask sizes. The relationship between spatial separation and duration is shown in Figure 7. Performance on each of the three separations changes from approximately 0% "Yes" responses to 100% "Yes" responses over the range of TS durations tested. A complete summary of the ANOVA is given in Table 4.

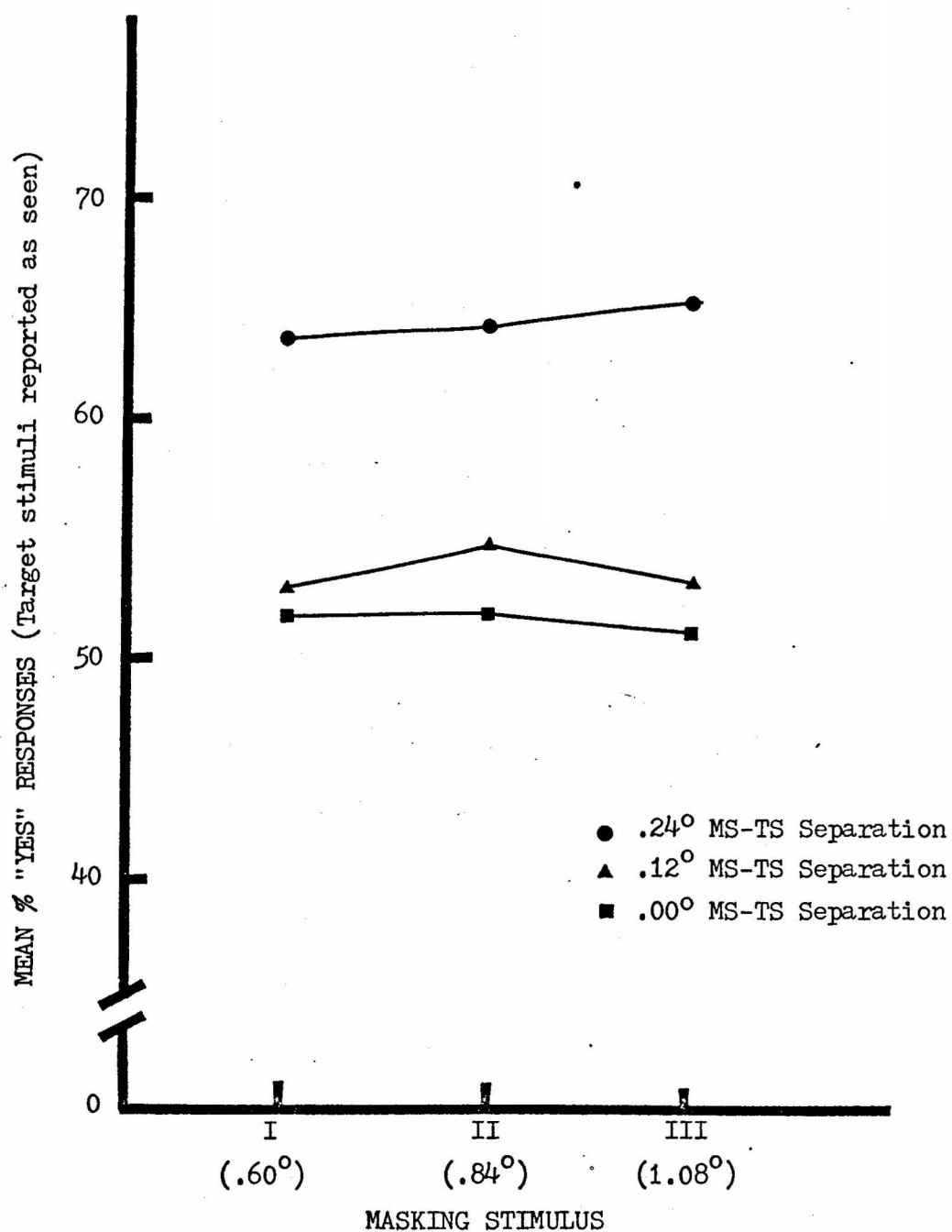


Figure 6. Frequency of seeing targets as a function of masking stimulus. (Parameter is MS-TS Separation).

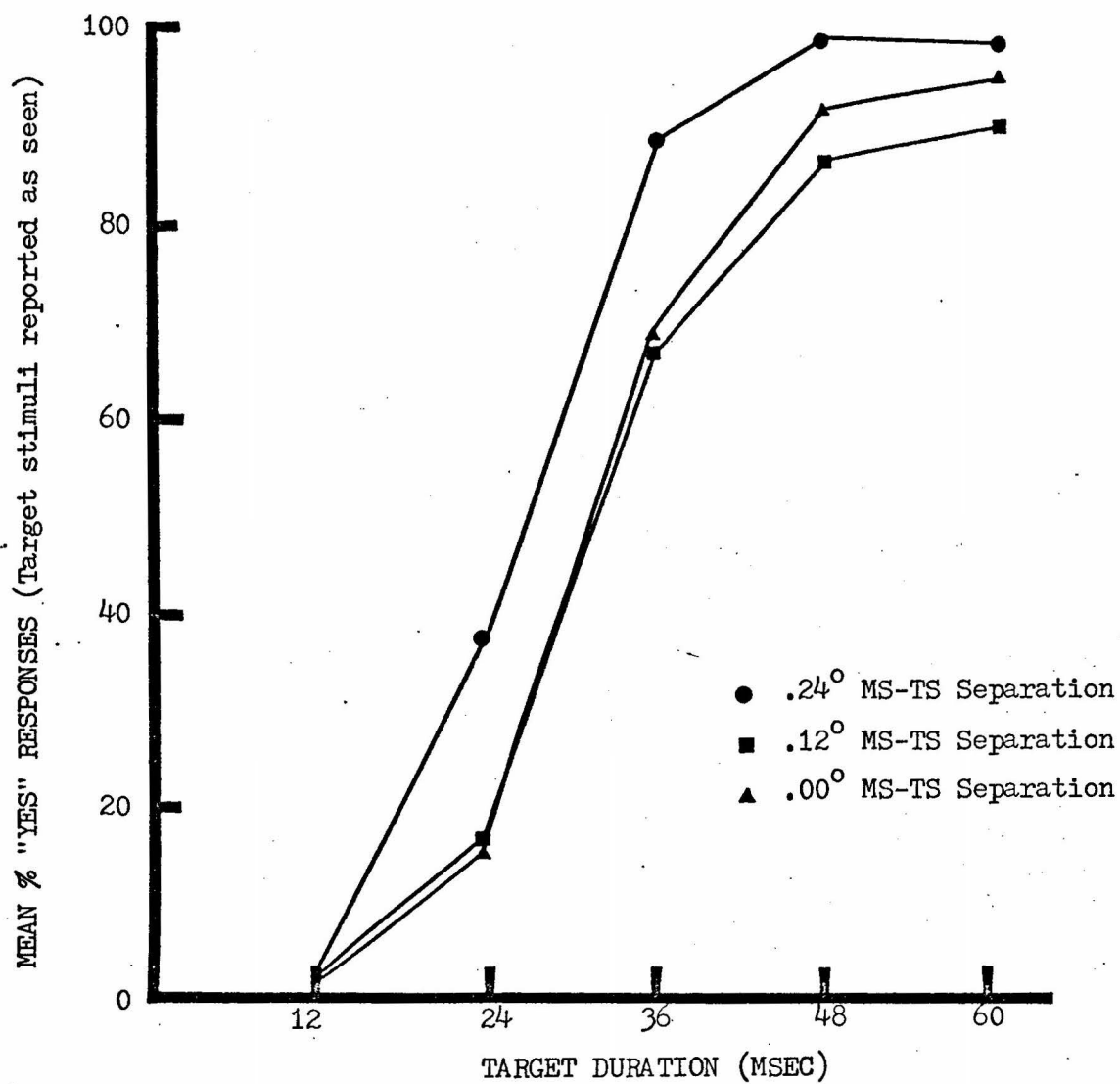


Figure 7. Frequency of seeing targets as a function of target duration. (Parameter is MS-TS Separation).

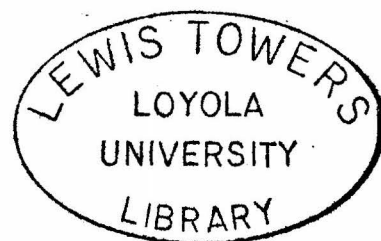


TABLE 4

## SUMMARY TABLE FOR THE SECOND ANALYSIS OF VARIANCE

Source	Error Term	df	Mean Square	F
Mean	S	1	87.34866	102.6545
Subject (S)		5	.8508995	
Masking Stimulus (M)	SM	2	.0015022	0.1941
Target-Mask Separation (X)	SX	2	.4389978	9.7616*
Target Duration (D)	SD	4	9.655682	80.5933**
SM		10	.0077378	
SX		10	.0449717	
MX	SMX	4	.0022383	0.4042
SD		20	.1198074	
MD	SMD	8	.0086021	1.4092
XD	SXD	8	.0644493	3.5889*
SMX		20	.0055380	
SMD		40	.0061042	
SXD		40	.0179578	
MXD	SMXD	16	.0033790	1.0220
SMXD		80	.0033062	

\*p &lt; .005

\*\*p &lt; .001

## DISCUSSION

In the present experiment, detection performance improved steadily (that is, masking effects declined) as the separation between the TS and the border or contour of the MS was increased, regardless of the size of the MS used, for masking stimuli of  $.60^\circ$ ,  $.84^\circ$ , and  $1.08^\circ$  in width. In addition, equal separations produced equal effects for all three mask sizes, as Table 2 clearly shows. These findings demonstrate that the variable responsible for the effects reported is indeed separation between the TS and the MS border, as other researchers have contended, and that any argument for an explanation in terms of stimulus size per se can be rejected.

The results of the current experiment are consistent with results obtained in masking studies employing stimuli of homogeneous luminance, whether black on luminous backgrounds or luminous on black backgrounds (e.g., Battersby & Wagman, 1962 and 1964; Frumkes & Sturr, 1968; Matthews, 1971), and in metacontrast studies (e.g., Cox et al., 1969; Kolers & Rosner, 1960), showing that a patterned mask can behave as a homogeneous mask for at least one parameter (spatial separation of TS and MS). The similarity of results across the various paradigms suggests that perhaps a common underlying process operates to produce the effects in all cases.

Theories to account for these spatial separation effects have varied. All the previous investigations have rejected, either implicitly

or explicitly, a signal detection theory of masking for foveally presented stimuli. This theory supposes that the masking stimulus works by producing background noise in the visual system against which the signal of the target stimulus is more difficult to detect (Sturr et al., 1965). A logical deduction of such a theory, assuming that the system integrates over area, is that a larger masking stimulus will produce greater total noise, thereby increasing the difficulty of detection of the target stimulus. For all instances of foveally presented stimuli including the present experiment, the results obtained have been exactly the opposite of the prediction of the signal detection model. Hence, the theory has been rejected in most cases.

Purcell et al. (1968) have offered a model, based on the concept of lateral inhibition, to account for the data produced by the various metacontrast experiments reviewed above. Basically, the model assumes (for the case of dark stimuli on a light background) that the masking stimulus protects the target stimulus from any inhibitory effects caused by the bright area in the visual field surrounding the target. The target can therefore undergo "brightness reversal" and be maximally sensitive to masking effects. Masking declines as the borders of the target and mask are increasingly separated because this increase reduces the possible extent of brightness reversal upon which the masking effects depend. The model does not consider the effects of contour enhancement produced by lateral inhibition.

While this model seems capable of accounting for some of the results reported above in a general way, it is ultimately unsatisfactory, in part because of its lack of generalizability to certain masking paradigms and in part because of recent developments in our understanding

of metacontrast phenomena (Bowen, Pokorny, & Cacciato, in press; Breitmeyer & Ganz, 1976). For example, the model requires an inter-stimulus interval between the target and mask for masking to occur, while the current study and others demonstrate that masking can occur when TS offset and MS onset are simultaneous. Battersby and Wagman (1962), for instance, found strong masking effects contingent upon spatial separation for a TS presented at various intervals before, after and during a concentric MS. Furthermore, it is not clear that the model can account for the masking effects produced by spatially overlapping stimuli. In the current study, since luminous stimuli are used, the Purcell et al. model would suggest that the area excited by the TS should initially undergo more inhibition than the surrounding areas, with the result that when the MS is subsequently presented the area where the TS appeared should be less capable of excitation than the surrounding areas. According to the model, this would lead to the portion of the MS that overlaps the TS appearing less bright than the remainder of the MS. This is clearly not the case: subjective reports of the observers indicate that no such perceptual experience occurs in the present study.

A more attractive theory to accommodate the masking data involves the concept of interaction between contours of stimuli. Werner (1935) was perhaps the first to suggest such an explanation for the results he obtained in a metacontrast study. He suggested that the inner contour of the masking annulus in some manner interfered with the perceptual formation of the contour of the target disk. Without a clearly perceived contour, the target could not be detected. Lack of physiological data and theory prevented Werner from going beyond this fairly simple



phenomenological explanation.

Because of recent advances in our understanding of retinal physiology, current investigators have been able to add more detail and a firmer physiological underpinning to this basic explanation of the spatial separation phenomenon. A theory based on the unique behavior of the visual system in response to a luminance step (contour) resulting from lateral inhibition among cells at the retinal level, seems to be best able to account for the data obtained in the masking experiments treated here.

It has long been known that the apparent brightness of a stimulus is not a simple function of intensity, but rather depends in part upon the distribution of luminance within the stimulus. Many human psychophysical data related to this fact have been interpreted in light of findings from studies of the Limulus eye (Cornsweet, 1970; Ratliff, 1965). These studies have demonstrated that individual receptors interact with one another in a manner that can be characterized as lateral, recurrent, reciprocal inhibition. Since the inhibitory effect of one receptor upon another diminishes with increasing distance on the retina, when a luminance step of some sort is presented as a stimulus the net effect will be an enhancement of the borders or contours between regions of different luminance values. That is, receptors stimulated by more luminous portions of the stimulus will be less inhibited the nearer they happen to be to receptors stimulated by less luminous portions of the stimulus, since these latter receptors--being less excited--are less capable of producing inhibitory effects in their neighbors.

The simple assumption that areas of the retina subject to greater amounts of lateral inhibition will have lower thresholds for the

detection of subsequent stimuli (i.e., will be less capable of masking subsequent stimuli) permits the most parsimonious explanation of the foveal forward masking data. This is precisely the type of explanation offered by Sturr and Frumkes (1968) and Matthews (1971) to account for their data.

In the present experiment, one additional assumption is necessary for a lateral inhibitory model. It must be assumed that the neural response to the second, larger stimulus--the mask--overtakes the neural representation of the smaller target stimulus in some manner and causes the system to either fail to respond to the target stimulus or to respond to the TS and MS together in a fashion that is not discernibly different from the response to the MS alone. Schiller (1969), recording from single units in the cat lateral geniculate nucleus, has determined that as the borders of a TS and MS presented in close succession are brought closer together, the response of the unit within whose receptive field the stimuli fall becomes more and more like the response to a single stimulus. This failure of the system to generate distinct signals for each of the two stimuli when their borders or contours are close together indicates that the presence of the target is effectively masked. In the context of the present experiment it is irrelevant whether this masking is interpreted as an integration of the target and mask information or an interruption of the processing of the target by the mask. The point to be made is that the degree of masking is dependent upon the spatial relationship between the TS and MS.

The metacontrast data reviewed earlier are not incompatible with a model that takes into account the special contour enhancement effects produced by lateral inhibition. Two recent papers have proposed that

metacontrast masking involves inhibition between two populations of neurons with different functional properties (Bowen et al., in press; Breitmeyer & Ganz, 1976). Specifically, it is suggested that activity of "phasic" (transient) units inhibits that of "tonic" (sustained) units in the visual system to produce metacontrast effects. While the underlying mechanism accounting for backward masking is presumed to be different according to this approach--that is, inhibition of tonic cell activity by other tonic cells--it is probably accurate to say that the role of lateral inhibition in creating an enhanced response at a contour is of critical importance in both cases in yielding the type of separation effects noted here. Available evidence suggests that both types of units can produce such a response when stimulated by a luminance step (Ingling & Drum, 1973).

In the current experiment it can be seen (Table 2) that detection performance improves with increasing separation of the stimulus borders; hence, different regions of the MS are more effective than others at masking the TS. The effectiveness of the mask does not appear to be a smooth gradient from border to center, however, although there is no reason to suspect that it would be. Considering the data for the largest mask as presented in Table 2, for example, it can be seen that the change in the detectability of a TS coincident with the MS border (group v) from the detectability of a TS  $.12^\circ$  from the border (group iv) --i.e.,  $53.6 - 51.1 = 2.5$ --is almost an order of magnitude smaller than the change in detectability of a TS  $.12^\circ$  from the border and a TS  $.24^\circ$  from the border (group iii)--i.e.,  $65.5 - 53.6 = 11.9$ . The next step away from the border, from a separation of  $.24^\circ$  to one of  $.36^\circ$  (group ii), produces about the same change in detectability--i.e.,  $72.8 - 65.5 = 7.3$ .

For the final step, to a separation of  $.48^\circ$  (group i), the change in detectability has begun to taper off--i.e.,  $74.7 - 72.8 - 1.9$ . Presumably, greater separations than this would add little improvement in detectability. Matthews (1971) argues that a similar result in his Experiments 1 and 2 might be explained in terms of the concept of disinhibition: increasing the MS beyond a certain critical area produces inhibition of inhibition.

Several objections might be raised to a lateral inhibition model for the results of studies such as the present one, but none of them seems insurmountable. Matthews (1971) cites the failure of researchers to find a dip in threshold on the dark side of the contour corresponding to the rise in threshold found on the bright side of the border, but argues that the dark side threshold is elevated by scattered light from the bright side. Frumkes and Sturr (1968) argue that their apparently discrepant finding, that in the periphery ( $15^\circ$  in the horizontal meridian of the right nasal field) and at scotopic luminance levels the increment threshold for a TS tends to increase as MS size increases, can be explained by the great amounts of neural convergence--and therefore spatial summation or energy integration--that occur peripherally under scotopic conditions. The mechanisms responsible for masking in the periphery of the retina are different from those in the fovea.

Perhaps the most serious threat to an interpretation based on retinal interactions is the fact that Battersby and Wagman (1962) were able to produce the spatial separation effects using dichoptic stimulation. They argue that the effects are therefore probably mediated by some central (retrochiasmal) mechanism and cannot be strictly retinal in origin. This objection does not preclude the possibility that lateral

inhibitory effects can occur at higher levels of processing as well as at the retina. It has been argued (Matthews, 1971) that it is likely that either particular patterns of information processing occur at several levels in the visual system or that a processing pattern at an early level is held in a certain form so that it can be operated upon at higher levels. Schiller's (1969) findings that masking can occur in a binocularly sensitive unit of the cortex (area 17) of the cat when stimuli are presented dichoptically in close spatial contiguity lends some support for this notion.

Another possible objection relevant to the present experiment might be that in moving the TS closer to the MS border one is also moving it away from the fovea, and that the increased masking effects produced in this fashion are somehow related to a change in the sensitivity of the retina. Two things argue against this objection. First, the presentation of the target stimuli occurs within an area with a diameter of about one degree of visual angle. Foveal sensitivity changes little if at all within such a small area at the center of fixation (Cornsweet, 1970). Second, the virtual equality of effects for targets of equal separations from the MS border, regardless of their location relative to the center of fixation, suggests that the objection is untenable.

It would appear, then, that the results of the present experiment can most simply be explained by appealing to the concept of lateral inhibitory processes in the visual system that result in an enhancement of borders or contours. Further research into the locus of the effect (whether central or peripheral) for patterned stimuli in a masking paradigm, perhaps by means of a comparison between monoptic and dichoptic

modes of presentation, would appear to be needed.

#### REFERENCE NOTE

1. Mayzner, M. S., & Habinek, J. K. Visual recognition processing of simple intersecting and parallel line patterns. Paper presented at the annual meeting of the Psychonomic Society, St. Louis, Missouri, 1976.

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APPROVAL SHEET

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Arts.

May 2, 1977  
Date

Mark S. Mayzner  
Director's Signature