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SPATIAL AND TEMPORAL DETERMINANTS OF VISUAL BACKWARD MASKING[1]

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Duration thresholds were obtained for a single test stripe succeeded by a masking pattern of alternating dark and bright bars delivered to the same retinal region. The effect of the angle (alpha) between test stripe and masking contours was studied in conjunction with both vertical and horizontal test stripes. With either of the test-stripe orientations duration threshold decreased as alpha increased from 0° to 90°. In another experiment both alpha and the interstimulus interval (ISI) were varied. The effectiveness of alpha as a determinant of masking seemed to be restricted to ISI below 60 msec.

When two brief flashes are presented in rapid succession to the same retinal area the detectability of the first is reduced. This phenomenon has been termed visual backward masking. The effect of the spatial relationship between the first (or "test") stimulus and the second (or "masking") stimulus has yet to receive adequate systematic analysis though several lines of evidence testify to its importance.

Battersby and Wagman (1962, 1964) have shown the important role played by the spatial relationship between the perimeters of otherwise contourless test and masking flashes. Kolers (1962; Kolers & Rosner, 1960) has extended the analysis using a concentric disk and ring as test and masking stimuli.

In order to understand the contribution of contours *within* the masking field one must turn to studies using spatially overlapping, patterned test and masking stimuli. In many of these studies, however, the amount of overlap between the successively presented contours cannot be precisely stated because of the stimulus configurations employed (Kinsbourne & Warrington, 1962a, 1962b; Schiller, 1965; Schiller & Wiener, 1963). All of them used letters of the English alphabet as test stimuli and the diversity of their form caused the test figures to be overlapped in a different fashion by the microstructure of the masking field. In addition, the masking patterns used do not facilitate the analysis of the specific contour relationships between stimuli.

A more precise statement of the role played by contour relationships in backward masking might be derived from experiments using geometrically simple test and masking contours. In the three experiments to be reported backward masking is measured by the duration threshold for a small dark stripe masked by a pattern of alternating dark and bright stripes. The particular spatial relationship selected for study is the angle (alpha) between the test stripe and the orientation of the masking

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contours. In Exp. I and II backward masking is measured for different values of alpha for both vertical and horizontal test stripes. In Exp. III both alpha and ISI are varied in an effort to study the interaction between these spatial and temporal determinants of backward masking.

METHOD

Subjects.—The *O*s in Exp. I and II were five undergraduates. Following three practice sessions, they were paid at an hourly rate of $1.25. The four *O*s in Exp. III, none of whom had served in the two preceding experiments, were also undergraduates. These *O*s were paid the hourly rate plus a bonus of 1/10 cent for each correct response. All *O*s had corrected acuity of 20/20 or better.

Apparatus.—All observations were made in a darkened, sound-resistant chamber. The *O* viewed the targets from a distance of 200 cm., his head steadied by a fixed chin and headrest. Binocular viewing with natural pupils was used throughout. Centered about the middle of the target area was a white adapting screen subtending 16° of arc on the horizontal by 19° of arc on the vertical. In the center of the adapting background was a circular aperture with diameter subtense of 2°44′ of arc. Directly behind this aperture was a rear projection screen. Stimuli for the experiments were projected onto the back of this screen by an electronic projection tachistoscope.

The three-channel tachistoscope was located behind the rear projection screen with each channel consisting of a glow modulator tube (Sylvania, R1166) and optics suitable for focusing the interposed stimulus transparency upon the rear projection screen. Measurements with a calibrated photomultiplier tube indicated that the maximum difference between channels constituted 1.5–2.0% of total light output. Over the course of repeated observations flashes generated by the glow modulator tubes rose to 90% of maximum within 1 msec. Decay times were somewhat less.

The stimulus patterns to be presented were photographically reduced and imaged on glass photographic plates. Carefully machined channels in front of the glow modulators permitted a slide to be inserted, withdrawn, and reinserted with a negligible change in position.

The adapting field and circular target area were illuminated by a 300-w. projector located behind and above *O*. The luminances of the adapting screen and target area, measured with a Salford Electrical Instruments, Ltd. (SEI) photometer, were 10.12 mL. and 2.35 mL.

On each trial the initial flash contained either a small dark test stripe or a homogeneous flash of equivalent luminance. The test stripe subtended 57′ × 6′ of arc and its longer axis was vertical. The masking pattern, photographically reduced from a Ronchi ruling (Edmund Scientific Company, Barrington,N. J.) had bright and dark stripes of equal width, 6′ of arc. The contrast of the test stripe and that of the masking stripes was measured under full experimental conditions. These values were .14 and .28. The luminance of the circular area surrounding the test stripe was .65 mL. while the luminance of the center of each bright stripe in the masking pattern was 1.67 mL. A dot of 1.5′ of arc subtense was located in the center of the target area, providing a fixation point. The test stripe was centered about this point.

EXPERIMENT I

Procedure

Each session began with a minimum of 6-min. adaptation to the background screen at the luminance used in the experiment. Each trial consisted of a first (test) flash of variable duration, an interstimulus interval (ISI) of 40 msec., and a masking flash of 100-msec. duration. During ISI the photometric condition of the target area was the same as between trials.

Alpha, the angle between test stripe and masking contour orientation, was the independent variable. The following alphas were used: 0, 7.5, 15, 22.5, 30, 45, 60, 67.5, 75, 82.5, and 90°. Two different conditions prevailed with alpha = 0°. In one condition the region of the target area upon which the dark test stripe appeared was subsequently occupied by a section of dark stripe in the masking pattern; in the other this same position was occupied by a bright portion of the masking pattern.

Stimulus presentations were initiated by *O* at the termination of a .5-sec. auditory signal. The *O* then used a switch to indicate whether he had seen the test stripe on that trial. The interval between trials was approximately 15 sec., during which time *O* confined his gaze to the target area.

Each alpha to be studied was presented in a block of 25 trials. The test stripe was omitted on a preselected 7 of the 25; on these "catch" trials a homogeneous field of equivalent luminance was presented in place of the test-stripe field. Within the 25-trial block an "up-down" or tracking procedure was used to measure the duration threshold. On the first trial of any block the test stripe was presented at a duration of 7 msec. If *O* responded "No" (that he had not seen the stripe), the stripe was presented with increased duration on the next trial; if *O* responded "Yes" (that he had seen the stripe), the next presentation would be shorter. The *O*'s responses themselves controlled the signal duration, keeping it in oscillation about some central or threshold value.

Six different alphas were used in any session and over the course of the experiment an *O* was run in four sessions with each condition. The order of testing with the different alphas was individually randomized for each *O* under the restriction that no condition could be run $n + 1$ times until all other alphas had been used n times. Knowledge of results was not provided. The *O* had been informed that the test stripe would be omitted on some trials but was not told the frequency of its omission.

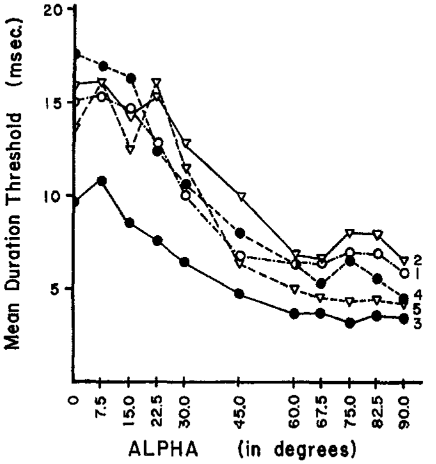

FIG. 1. Mean duration threshold as a function of alpha, the angle between test stripe, and masking contour orientation. (Test stripe oriented vertically; ISI = 40 msec. Each curve is for a single *O*, identified at right.)

Results

The duration threshold was defined as the mean of the test-stripe durations associated with transition responses, shifts from Yes to No or vice versa. The results of Exp. I are summarized in Fig. 1. Each point plotted is the mean of the four threshold determinations for a single *O* and alpha value. The threshold for the detection of the black vertical test stripe decreases with increasing alpha. It will be recalled that two different conditions were studied at alpha 0° (see above). Since analysis showed the difference between thresholds for the two 0° alphas to be statistically nonsignificant—t (44) = 0.097— for simplicity of representation, the points plotted against alpha = 0° are mean values taken across both conditions. An analysis of variance indicated that both the alpha and Alpha × *O* effects were significant beyond the .01 level, F (11, 180) = 46.30; F (44, 180) = 1.77. In every case the normal or unmasked threshold was found to lie between 2.5 and 3.0 msec. below the threshold for the largest alpha values studied. This suggests that some small amount of backward masking is occurring even with the large alpha conditions. Tests of the significance of the difference between means of successive alphas indicated that beyond 45° the effects of increasing alpha were not statistically significant ($p > .05$; t test based on the alpha term with $df = 11$). This confirms the impression given by Fig. 1, that the function relating backward masking to alpha is composed of two main portions. In the first part of this function, from 0° to 45°, alpha influences the amount of backward masking while beyond 45° masking may be described as independent of orientation.

The mean false-alarm rate, the probability of *O*'s responding "Yes" on catch trials, was 2% and was not related in any systematic fashion to alpha.

EXPERIMENT II

This was an attempt to extend the findings of the first experiment to the case in which the test stripe was oriented horizontally rather than vertically. Photometric and psychophysical conditions were as in Exp. I and the same *O*s served, the only difference being that a horizontal test stripe was used.

Results

The results of Exp. II are summarized in Fig. 2. For each of the five *O*s masking decreases with increasing alpha. This observation is confirmed by an analysis of variance. The effect of alpha was highly significant, F (11, 180) = 167.26, $p < .01$, while the $O \times$ Alpha interaction was nonsignificant ($F = 0.40$). In Exp. II, as in the first experiment, the two 0° alpha conditions did not differ significantly, t (44) = 0.66, and the point plotted against alpha = 0° is the mean for both conditions.

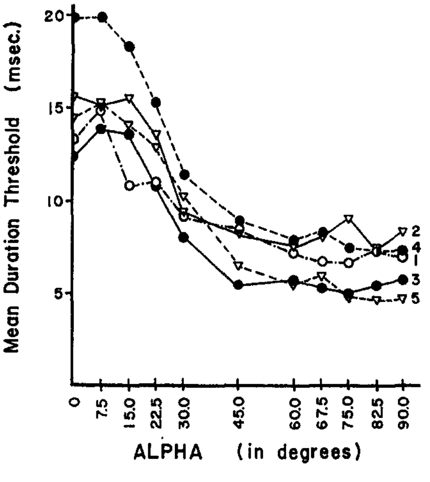

FIG. 2. Mean duration threshold as a function of alpha. (Test stripe oriented horizontally; ISI = 40 msec. Each curve is for a single *O* identified at right with same numbers as in Fig. 1.)

Tests of the significance of the difference between means of successive alphas indicated that beyond 60° the effect of increasing alpha was diminished below the point of statistical significance ($p > .05$). As in Exp. I the function relating backward masking to alpha seems to be composed of two parts, including both orientation-dependent and orientation-independent ranges. The mean rate of false-alarm responses was 1.6%.

The results of Exp. I and II indicate that for an ISI value of 40 msec. backward masking with both horizontal and vertical test stripes is a decreasing function of alpha. Experiment III was designed to measure the effect of alpha at several different ISIs, in order to assess the relationship between spatial and temporal determinants of backward masking.

EXPERIMENT III

Procedure

Three alphas (7.5, 22.5, and 60°) were studied in conjunction with ISIs of 5, 15, 30, 60, and 100 msec. Test-stripe orientation was horizontal. In any session *O* was tested at a single ISI with each of the three alphas presented in separate blocks of 120 trials. The *O* had been informed that the test stripe would be omitted on a randomly chosen .50 of all trials (actual rate of omission was .45–.55).

The tracking procedure, adapted from Campbell (1963), was run in blocks of eight trials with an intertrial interval of 5 sec. In the first block of eight trials the test stripe, when presented, was at 20 msec. If more than six responses to the eight trials had been correct the test stripe was presented at a reduced duration during the succeeding block. If fewer than six had been correct, duration was increased for the next block. If exactly six of the eight were correct, duration was unchanged. In this way *O*'s responses controlled the duration of the test-stripe presentations.

The *O* was given knowledge of results; a buzzer sounded coincidentally with each correct response. This feedback was provided in the belief that it might serve as additional incentive for *O*s operating under the increased strain of the reduced interval between trials. The order of presentation of ISI and alpha was randomized for each *O*. Three of the *O*s served in four sessions with each alpha and ISI combination while the remaining *O* served in only three sessions with each combination.

During the six practice sessions preceding the experiment measures of *O*'s normal, unmasked duration threshold were made. In addition, two series of 120 tracking trials each were run with neutral density filters substituted for the usual masking pattern. The luminance of this blank field was equivalent to the mean luminance of the usual masking pattern of alternating dark and bright stripes. One series was run with the homogeneous masking field at ISI = 5 msec., another at ISI = 100 msec.

Results

The results of Exp. III are summarized in Fig. 3. Each point is the mean taken over all *O*s and sessions with a particular combination of ISI and alpha. As might be expected from the results of earlier experiments (Kolers, 1962; Schiller, 1965; Schiller & Wiener, 1963), backward masking is a decreasing function of ISI. Both main effects, ISI and alpha, are very highly significant, F (4, 12) = 108.71; F (2, 6) = 113.89; $p < .001$, as is the interaction between them, F (8, 24) = 9.02. The difference between alpha = 7.5° and 60° is highly significant ($p < .01$) for ISI = 5, 15, and 30 msec. ($t > 3.71$) while that between alpha = 7.5 and 22.5 is significant only at ISI = 15 msec. The pattern of differences among means for alpha-ISI combinations indicates that the effect of alpha upon backward masking may be greatest at the shorter ISI values.

The unmasked threshold of 3.77 msec. is indicated in Fig. 3 by the dashed line and lies below the duration threshold for any alpha-ISI combination. The location of the normal threshold suggests that some small amount of backward masking occurs even with ISI as great as 100 msec. The filled circles at ISI 5 and 100 msec. represent the mean duration thresholds obtained at those ISIs when a homogeneous masking field was used.

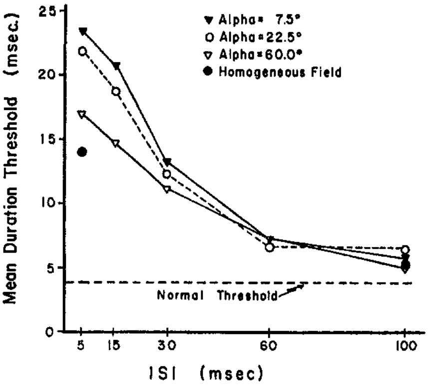

FIG. 3. Mean duration threshold as a function of alpha and ISI. (Test stripe oriented horizontally; four *O*s.)

Taking into account only the last six blocks of eight trials each, the mean false-alarm rate for each *O* was .22, .27, .27, and .18. There was no systematic relationship between false-alarm rate and either alpha or ISI.

DISCUSSION

Experiments I and II showed that backward masking can be related in a precise way to the relative orientations of test and masking contours. Masking decreased with increasing alpha. Experiment III analyzed the interaction between spatial and temporal determinants of backward masking. While the findings of the first two experiments were confirmed at the shorter ISI, at 60 and 100 msec. the effect of alpha had been substantially reduced. At these longer ISIs masking was not appreciably influenced by alpha.

The two 0° alpha conditions in each of the first two experiments differed in successive contrast between test stripe and the superimposed masking stripe. In one case, a bright masking stripe was superimposed upon the dark test stripe while in the other a dark masking stripe appeared in that position. Because of this successive contrast difference it was expected that the two conditions would yield dissimilar threshold values, though it is possible that the relatively low contrast of the stimuli used militated against such a finding.

It may be noted that none of the *O*s, when questioned, reported having seen any beta movement of test and masking stimuli, although such apparent movement has been observed in other masking studies (Fehrer & Smith, 1962).

The tracking procedures adapted for use in these experiments have proven to be useful and efficient. Cornsweet (1962) expressed concern that *O*s in studies employing a tracking technique would quickly become aware of the rules governing the stimulus and that this awareness would limit the value of tracking as a psychophysical method. Logan (1963) avoided this limitation, disrupting the tracking series by occasionally repeating the stimulus value from the immediately preceding trial without regard to *O*'s response. The present experiments used another procedure for disrupting the response-stimulus contingencies inherent in tracking. On some proportion of the trials the test stripe was omitted, this proportion varying from .28 in Exp. I and II to .50 in the last experiment. When questioned following their service, none of the *O*s reported that he had become aware of any relationship between his response and the stimulus duration on succeeding trials. In addition, as Swets (1961) has pointed out, the inclusion of many catch trials permits one to estimate the location of *O*'s response criterion, though this was incidental to the concerns of the present experiments.

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