VISUAL MASKING OF MULTI-CONTOURED STIMULI: AN ASSESSMENT OF SPATIAL AND TEMPORAL PARAMETERS IN RETINAL CONTOUR FORMATION

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Abstract

Spatial and temporal parameters involved in retinal contour formation are investigated in a visual masking paradigm employing concentric stimuli with multiple contours. Previous research on visual masking using a disk followed by a concentric ring presented tachistoscopically is consistent in indicating that, within certain temporal limits of stimulus exposure and interstimulus interval, the disk is not reported. However, when the sequence is reversed both stimuli usually are perceived. This has been interpreted in terms of a developmental advantage of the ring over the disk, whereby the two-contoured ring inhibits the perception of the one-contoured disk more than the latter does the former. The generality of the developmental advantage with the 2:1 mask:target contour ratio is assessed in the present study through the use of mask-target stimulus pairs with N+1:N contour ratios, N ranging from 1 to 3. This is achieved by the addition of appropriate concentric rings to the original disk and ring stimuli. The results show that as the number of contours in the stimulus configuration is increased there is a progressive diminution of the masking advantage, a stimulus with three contours masking a stimulus with four contours as effectively as a four-contoured form masks a three-contoured form, both retroactively and proactively. Masking is found to vary as a function of target and mask duration, inter-stimulus interval, and inter-cycle interval in a similar manner for all contour configurations. Implications of these results for current theoretical explanations of visual masking are discussed.

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Introduction

The temporal developmental processes involved in the formation of the percept of a stimulus have been the subject of much contemporary research. Methodologically, the visual masking paradigm has proven a productive converging operation in determining the nature of the changes that occur in the sensory-perceptual system between the physical stimulation and the perceptual response. Masking is used in the present study to investigate the formation of contours and to assess their retinal developmental microtimes.

Visual Masking - Methodological and Theoretical Background

Briefly, visual masking refers to the phenomenon wherein the threshold for detection of one stimulus (the target stimulus, TS) is raised by the presence of a second stimulus (the masking stimulus, MS) in close temporal and spatial contiguity. Masking paradigms have employed both light flashes and patterned or contoured stimuli for the TS and MS, and these different conditions have given rise to a number of theoretical explanations of the data (see Kahneman, 1968; Raab, 1963, for recent reviews). Basically four distinct paradigms have been employed: (1) detection of a target flash under masking by another flash; (2) masking of a target form by a light flash; (3) masking of a target form by a patterned stimulus; and (4) masking of a target form by spatially adjacent forms. The empirical and theoretical contributions of studies using these different paradigms will be presented, with particular attention being paid to the influence of the relation between target and mask stimulus contours.

<u>(1) Masking of a target flash by a light flash</u>. In this paradigm, the TS is usually a small, brief flash of light, and the MS is a larger, more intense light flash presented at the same locus as the target flash. Characteristically, when the TS precedes the MS by approximately 50-100 milliseconds, the threshold for its detection rises steeply, increasing monotonically as the interval between the onset of each stimulus (stimulus onset asynchrony, SOA) approaches zero, and reaches a maximum when the TS and MS are presented simultaneously. The threshold decreases gradually as SOA increases further, the MS now preceding TS. This finding is sometimes referred to as the Crawford effect.

Boynton (1961) views this masking effect as a measure of on-response, the larger and brighter MS triggering a massive neural discharge which "overloads" the visual system, resulting in its failure to respond to the smaller and weaker TS. Sperling (1965) proposes another theory according to which the increased threshold as SOA=0 is due to poorer contrast discrimination as predicted by Weber's law.

<u>(2) Masking of a target form by a light flash</u>. This paradigm is similar to (1) above, with the exception of the nature of the target stimuli, which are generally

letters of the alphabet (Schiller, 1965; Schiller & Wiener, 1963) or Landolt Cs positioned in several different orientations (Kahneman, 1966). Again, the masking flash impairs the identification of the TS, the greatest masking effect occurring when the TS and MS follow one another immediately, and decreasing monotonically as the inter-stimulus interval (ISI) increases, both when the TS precedes MS and when the TS follows MS (Eriksen & Lappin, 1964; Schiller, 1965b).

The masking of a form by a light flash is a monoptic effect (Schiller, 1965b; Schiller & Wiener, 1963). When the target form is presented to one eye and the flash of light is presented to the other (dichoptic condition), little or no masking occurs. This is also the case when the TS is a flash.

These results have been interpreted in part as being due to temporal summation and reduced figure-ground contrast (Eriksen & Hoffman, 1963; Kahneman, 1965). The TS and MS follow each other closely in time and the gap between them is "bridged" by temporal integration of luminance. This being the case, the luminances of both the target figure and the background field are increased by a constant amount by the masking flash, and the ratio of these luminances decreases. Thus, there will be a reduced level of contrast between the TS and the ground, making identification of the stimulus more difficult.

<u>(3) Masking of a target form by a patterned stimulus</u>. When a target form is presented in conjunction with a

patterned MS (generally various degrees of cross-hatching), the masking effect is quite pronounced, being most severe at ISI=0. Similar functions are found when the MS either follows, or precedes, the TS (Schiller, 1965; Schiller & Smith, 1965; Schiller & Wiener, 1963). Unlike the two previously described paradigms involving masking by light, masking by pattern occurs dichoptically, the TS and MS being presented to opposite eyes. This suggests that the processes of masking involved in this case occur at more central levels where the two monocular fields interact, whereas masking by light seems to be a more peripheral event, occurring prior to the mixing of the two monocular fields (Schiller, 1965).

Sperling (1963) has proposed that the MS interrupts the transfer of the TS from short-term visual storage to a more permanent storage. Another hypothesis is offered by Kinsbourne and Warrington (1962), who conclude that temporal summation renders the MS and TS effectively simultaneous and thus produces a degradation of the TS. Kahneman (1968) notes that this argument is directly analogous to the temporal luminance summation and reduced figure-ground contrast explanations used in interpreting masking by light.

(4) Masking of a form by spatially adjacent forms (often referred to as metacontrast). Three basic displays have been studied which can be categorized under the above heading: (a) The three-object display, where a target form,

either light or dark, is followed by two similar forms which flank it on either side (Alpern, 1953; Fehrer & Raab, 1962; Fehrer & Smith, 1962; Kahneman, 1967); (b) The disk-ring display, where the TS is a disk and the MS is a ring whose inner contour is coincident with the contour of the disk (Heckenmueller & Dember, 1965; Kolers, 1962; Kolers & Rosner, 1960; Schiller & Chorover, 1966; Schiller & Smith, 1966; Werner, 1935, 1940); and (c) An identification paradigm, where the TS is generally a letter and the MS is a surrounding ring (Eriksen & Collins, 1964; Mayzner, Tresselt, Adrignolo & Cohen, 1967; Mayzner, Tresselt & Cohen, 1966; Schiller & Smith, 1965; Weisstein & Haber, 1965).

For all three of these displays two types of masking functions have been found. In one, Type A functions, masking is maximal when the TS and MS are presented simultaneously (SOA=0) and occurs both when the MS follows the TS and when the MS precedes the TS. Type A functions are obtained when the MS is of a much greater intensity or duration than the TS (Fehrer & Smith, 1962; Kolers, 1962).

In Type B masking, on the other hand, the most severe masking occurs when the MS follows the TS by an ISI of 20-80 milliseconds, depending on stimulus durations, luminance, and configuration. There is little masking at SOA=0 or when the MS precedes the TS. This U-shaped function relating probability of detection of the TS to ISI is obtained when contrast, size, and luminance of the TS and MS are similar and of moderate value (Alpern, 1953; Kahneman, 1967; Kolers, 1962; Kolers & Rosner, 1960; Schiller & Smith, 1966; Weisstein & Haber, 1965). Both Type A and Type B functions have been obtained dichoptically (Battersby, Oesterreich & Sturr, 1964; Kolers & Rosner, 1960; Schiller, 1965b; Schiller & Wiener, 1963; Werner, 1940).

The theoretical explanations offered for the other types of masking do not seem wholly adequate to account for Type B masking effects. Boynton's (1961) hypothesis that masking is due to massive bursts of neural activity accompanying onset and offset of the MS, causing an "overload" which interferes with perception of the weaker TS, would not yield the U-shaped functions obtained with equal-energy contoured stimuli. This masking by "noise" would predict either monotonically decreasing functions or functions of zero slope as the ISI increases (Weisstein, 1968). Likewise, luminance summation and contrast discrimination theories (Eriksen & Hoffman, 1963; Kahneman, 1965) cannot account for the U-shaped function, predicting monotonically decreasing curves as the ISI increases.

Sperling's (1963) hypothesis that the TS is held in some temporary visual storage and can be "interrupted" there by a subsequent masking stimulus which prevents it from being transferred to a more permanent storage also fails to explain much of the data. In the case of masking by a pattern, masking can occur when the MS precedes the TS. Here, the TS does not interfere with an item (MS) already in short-term visual storage. This theory can be formulated to predict the U-shaped masking function, but still cannot account for the changes in the minimum of the U which varies with certain changes in stimulus characteristics (Weisstein, 1968).

Another analysis is proposed by Fehrer & Smith (1962), Kahneman (1967), and Schiller & Smith (1966) who note that the Type B masking conditions and functions are very similar to conditions and resulting functions for apparent motion of two forms, which is also a U-shaped function of temporal separation. In Kahneman's view, masking results from a failure of the perceptual system to resolve or synthesize the simultaneous movement of a single object in two directions. Because the motion is "impossible," suppression results. In the case of a light flanked by two others, the center form is set into apparent motion in two directions at once; in the disk-ring sequence the second stimulus would cause the disk to grow in size even as it disappears.

Although a relation between Type B masking and apparent movement seems to exist and has been mentioned by several investigators, Weisstein (1968) notes that there are certain differences between the two phenomena which cannot be ignored; specifically, the amount of spatial separation of the two stimuli affects masking differently than it affects apparent movement. Greater separation can be tolerated in apparent movement, masking requiring nearly coincident contours (Kolers & Rosner, 1960). The relationship between spatial and temporal separation is also a point of divergence between the two.

A lateral inhibitory process has been suggested by Weisstein (1968) which predicts both Type A and Type B functions under appropriate conditions. "A lateral inhibition explanation for meta-contrast would assume that the neurons responding to a surrounding mask inhibit the neurons responding to the target, and thus the target is perceived as dimmer, and in certain cases, is not perceived at all (Weisstein, 1968)."

She assumes that inhibitory processes develop at a faster rate than excitatory processes, given stimuli of equal luminance and duration, which would account for the U-shaped Type B masking function. If the TS and MS are presented simultaneously or if the MS precedes the TS, inhibition will have already reached its maximum before excitatory activity achieves its peak and no masking will occur. If, however, the MS is delayed, its strongest inhibitory activity will correspond to the maximum excitatory response of the TS, which will thus be suppressed, and masking will result.

Type A masking functions, which occur when the MS is a stronger stimulus than the TS, either in luminance or duration, can be explained in the same manner. In this case, if the TS and MS are presented simultaneously, the inhibitory processes due to the MS are sustained throughout the excitatory response to the TS, and masking occurs. Only if the MS is delayed for sufficient time to allow excitation to build up will the TS be reported. Conversely, if the MS is presented sufficiently long before the TS, the inhibitory activity will have declined by the time the TS is presented, and consequently little masking will occur.

Bridgeman (1971) proposes another model for metacontrast based on a lateral inhibitory network in which activity both during and after stimulation is examined. The form of the interaction of the excitatory and inhibitory processes for both the target and mask is "compared" to the response for each stimulus alone. If the interaction resembles one of the individual responses, the model predicts that only that stimulus will be reported (i.e., masking will occur); if components of both stimuli are prominent, no masking results.

Other models of visual masking based on the concept of lateral inhibition have been presented by Purcell, Stewart, & Dember (1968, 1969), Purcell & Dember (1968), and Purcell & Stewart (1969).

The Werner and Kolers & Rosner studies

The present study on contour formation will utilize this last paradigm of masking of a form by adjacent contoured stimuli. Werner (1935) investigated contour formation in masking experiments and introduced the disk and ring stimuli, which have been employed extensively since that time. To review his results, tachistoscopically presenting a small disk followed after a brief pause by a concentric ring whose inner contour was coincident with the contour of the disk, he found that under certain conditions the disk was not seen. The temporal sequence which maximized the masking effect was a repeated cycle of the following form: (1) Disk, 12-25 mseconds; (2) pause (ISI), 120-240 mseconds; (3) ring, 12-25 mseconds; (4) pause (inter-cycle interval, ICI), 280-560 mseconds.

Werner interpreted his results as indicating that the formation of the percept of a figure requires a certain minimum amount of time, and that if the development of the percept is interfered with before this critical "formation time" the figure will not be perceived. He argued that the disk would have just begun forming at its contour when the ring is presented and "appropriates" the contour of the disk to form its (the ring's) inner contour. He posited a "spatial formation gradient" which was highest at the contours of figures. When tne ring is presented before the disk (a reversal of the usual masking paradigm), both figures are seen because "the ring, in this case, is already in the first stage of development which permits the contour of the disk to be built up as a separate configuration. Therefore the whole disk can be seen (Werner, 1935, p. 34)." According to Kolers & Rosner (1960), this "implies that the ring has a developmental advantage over the disk because the former has two borders, and therefore two gradients of formation which summate, while the disk has only one border and therefore only one gradient of formation (p. 3)."

Using thses stimuli, Kolers & Rosner (1960) established that dichoptic masking does occur and examined quantitatively some of the temporal conditions for its occurrence, including the durations of the stimuli, ISI, ICI, and the order of presentation of the stimuli. Holding duration of the target disk and masking ring constant at 35 mseconds each, it was found that the probability of detecting the disk decreased as the ISI decreased from 180 to 80 mseconds, remaining effectively zero as the ISI was further reduced to 40 mseconds. The disk again became visible occasionally at ISIs of less than 40 mseconds (with other stimulus durations, masking remained maximal until ISIs were reduced below 20 mseconds). This is the Type B, U-shaped masking function discussed earlier.

The amount of masking was also increased as the duration of the disk became shorter. Although the effect of varying the ring (second stimulus) duration was not examined systematically by Kolers & Rosner, Alpern (1953), using a rectangular target flash flanked by two adjacent flashes, found that as the duration of the two "inducing" flashes (masking stimulus) increased, the magnitude of the masking effect increased.

Masking was also found to be a function of ICI. Kolers & Rosner found that shortening the ICI to less than 1500 mseconds resulted in additional inhibition of the disk. That is, "There is an inhibitory action of a ring upon the next presentation of the disk when the temporal separation between cycles is short enough (p. 11)."

When the stimulus sequence was reversed, i.e., ring followed by disk, there was, in general, little masking of the ring by the disk, occurring only at very brief durations of the ring. Thus, "a two-bordered form inhibits the appearance of an enclosed one-bordered form more than the latter does the former (Kolers & Rosner, 1960, p.13)."

Finally, masking of the second stimulus by the first was examined. Although this type of masking occurs to a much lesser extent than masking of one stimulus by a subsequent form, it can be found under certain stimulus conditions. As the duration of the first stimulus is increased, the probability of seeing the second decreases. In the ring-disk sequence, again the two-contoured ring masks the one-contoured disk to a greater extent than the disk masks the ring in the reverse order.

The experimental problem

Werner's (1935) basic hypothesis of a developmental contour advantage of a ring over a disk, and its general case, are assessed in the present investigation. The question posed is whether the developmental advantage with the 2:1 mask:target contour ratio is a special case of a general N+1:N mask:target contour ratio developmental advantage. This will be determined by the addition of appropriate concentric rings to the original disk and ring stimuli, with masking effects being evaluated as a function of stimulus configuration (number of contours), order of presentation, TS and MS durations, ISI, and ICI.

Method

Subjects

Three paid observers (Os) with normal vision were used. Due to the somewhat complex nature of the response system employed, as well as the nature of the viewing task itself, the Os were well trained. It has been previously shown (Kolers & Rosner, 1960) that the range of variation of individual data is greatly reduced by protracted training.

Apparatus

The apparatus employed was a three-channel tachistoscope (Scientific Prototype Manufacturing Company, Model GB-see Figure 1) driven externally by a Hewlett-Packard Model 2116B computer.

The stimulus fields were illuminated by mercury vapor argon lamps (General Electric F8T5-D-HH) coated with magnesium tungstate phosphor, having a color temperature of 7200° K. The luminance of each stimulus field was set at 26 foot lamberts, calibrated with a Pritchard Spectra photometer placed at the viewing hood.

The utilization of the computer time-base generator in conjunction with its relay system allowed complete automation of the stimulus presentation schedule. Each channel of the tachistoscope was triggered by a relay which was activated for a specified duration by the time-base generator. Periods of no stimulation were achieved by having no relays activated for any desired duration. Each entire experimental session was programmed for a predetermined

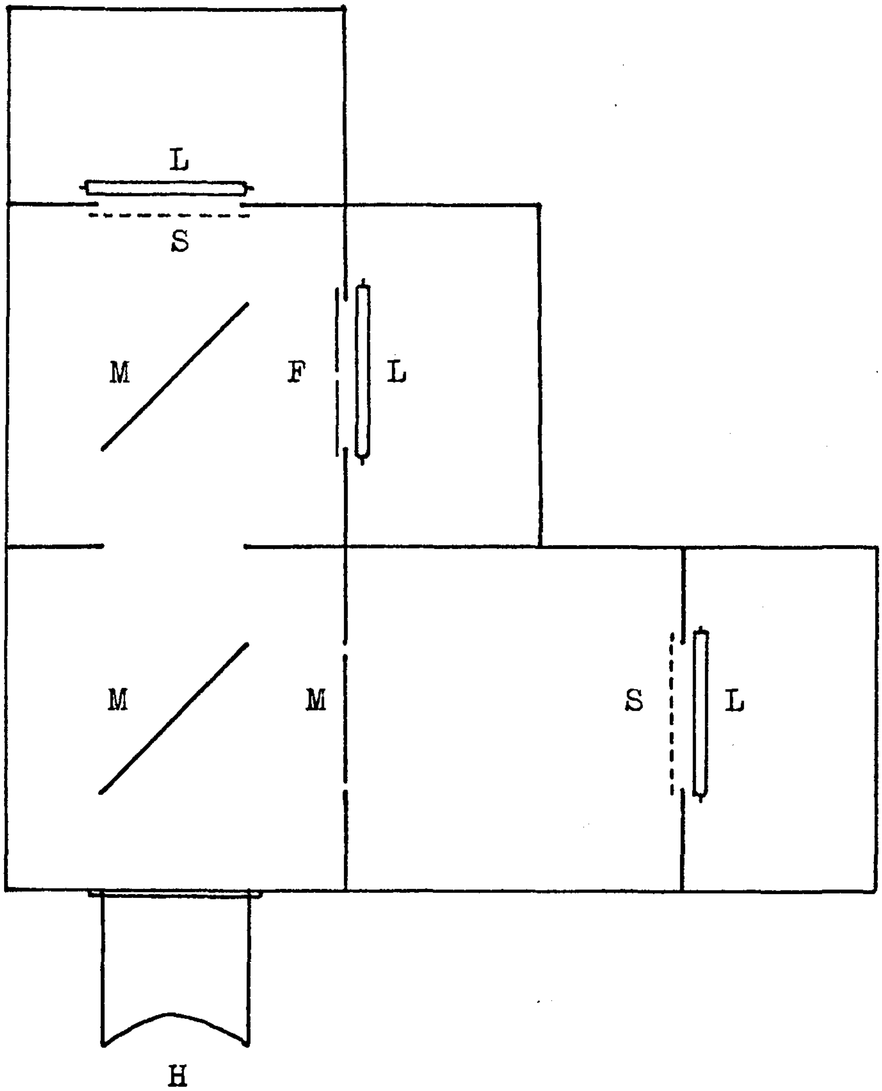


Fig. 1. Top view of Scientific Prototype Model GB three-channel tachistoscope - S - stimulus forms; L - field lamps; M - half-silvered mirrors; F - fixation point; H - viewing hood

number of presentation cycles. Any cycle could be followed immediately by a new cycle with different exposure durations specified for each stimulus, as well as the duration between any two stimulus presentations. Stimulus fields could be presented in any order.

The O's head was held immobile by a head rest and bite-board with a dental impression positioned directly before the viewing hood of the tachistoscope. The hood was padded with foam rubber contoured to fit snugly against O's face, thus preventing any ambient light from reaching his eyes. Viewing was monocular (left eye).

Responses were recorded on videotape, the camera positioned to provide a clear view of O's hands on the table before him. The only illumination in the testing room was a spotlight directed at O's hands. A microphone was situated nearby to record any comments by either O or E during a testing session.

Stimuli

The four stimulus forms were black (opaque), each centered on a 5" x 7" transparent film base (Kodalith Ortho), produced from photographs of precision-made forms. The film was held rigid in the stimulus holders by a sheet of clear plexiglass used for backing, allowing transillumination during presentation times.

The stimuli (shown in Figure 2) were as follows: (1) a disk (D), with diameter subtending a visual angle of $1^{\circ}2'$; (2) a ring (R), with inner diameter of $1^{\circ}2'$ and outer diameter $1^{\circ}27'$; (3) a disk within a concentric ring (D+R'),

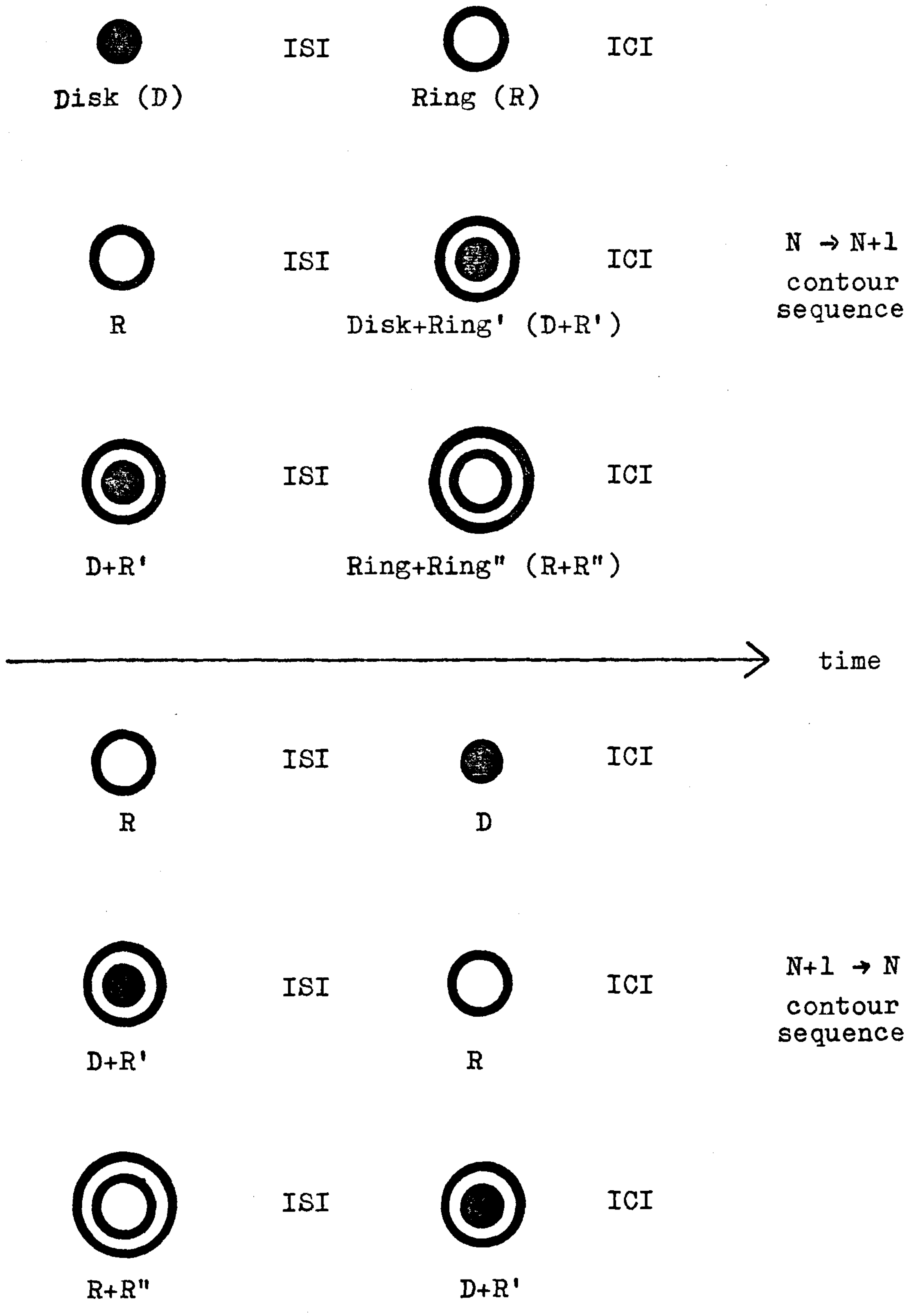


Fig. 2. Stimulus configurations - Stimulus 1 followed after inter-stimulus interval (ISI) by Stimulus 2. Inter-cycle interval (ICI) separates repititions of a given sequence. All stimuli were presented centrally.

the disk as in (1), the inner diameter of the ring subtending 1°27' of visual angle, the outer diameter 1°52' of arc; (4) a ring within a larger concentric ring (R+R"), the smaller ring as in (2), the larger ring with inner diameter of 1°52' and outer diameter subtending 2°17' of arc. The wall thickness of each ring was 12.5' of visual angle.

When any two succeeding stimuli, i.e., D → R, R → D+R', and D+R' → R+R", were presented simultaneously for purposes of alignment, the contours of one stimulus form were set so as to be exactly coincident with the contours of the other. That is, when the disk (D) and the ring (R) were superimposed, the circumference of D coincided with the inner contour of R. When R and D+R' were superimposed, the inner contour of R matched the circumference of D, while the outer contour of R matched the inner contour of R'. Likewise, superimposition of the D+R' and R+R" was such that the appropriate contours coincided.

The fixation field consisted of a small, dim, red point of light, approximately 1mm in diameter, produced by placing an opaque sheet with a pinhole in the center into one of the fields of the tachistoscope. The pinhole was covered with a red color filter and was transilluminated by the field lamps.

Design

Each stimulus cycle consisted of the following sequence: Stimulus 1 presentation, inter-stimulus interval (ISI), stimulus 2 presentation, and inter-cycle interval (ICI). During the ISI there was no illumination, whereas during the ICI, the fixation field was on, producing a central red point of light in an otherwise dark field.

Four predetermined levels each of stimulus 1 and stimulus 2 durations (10, 20, 40, 80 mseconds) were completely crossed, yielding a factorial total of 16 combinations. Two predetermined levels of ISI (20, 60 mseconds) were completely crossed with two predetermined levels of ICI (1750, 3500 mseconds), giving a total of four ISI-ICI combinations. The 16 stimulus 1 - stimulus 2 durations were crossed with one each of the ISI and ICI durations per run. Thus, each entire experimental run was comprised of 64 different stimulus cycles. Since stimulus 1 - stimulus 2 combinations and ISI-ICI combinations were not themselves completely crossed, the design was a partially crossed factorial.

The two levels of ISI were chosen to be within the optimal range for masking, as determined by Kolers & Rosner (1960). Similarly, an ICI of 3500 mseconds was selected on the basis of Kolers & Rosner's finding that at this duration effects of the second stimulus of a given cycle on the first stimulus of the subsequent cycle were minimized. This was an attempt to ensure the independence of adjacent cycles. The ICI of 1750 mseconds was employed to assess the extent of the above-mentioned effects of a stimulus on the subsequent cycle.

Each experimental session utilized one of six stimulus configurations. Stimuli were paired such that if one stimulus had N contours (N = 1,2,3), the other stimulus had

N+1 contours. The disk (D), having one contour, was paired with the ring (R), having two contours. R, in turn, was also paired with D+R', the latter having three contours. D+R' was also presented in conjunction with the four-contoured R+R". Each of these three pairings was presented in two orders, the N - contoured stimulus followed by the N+1 - contoured stimulus, and the reverse order, giving a total of six stimulus configurations.

Response measure. Employing a repeated measures design, the masking effect was measured in terms of the percentage of times the target stimulus was seen in a particular configuration. The lower this percentage, the greater the degree of masking. The stimulus designations "target" and "mask" were not applied to the stimuli either by O or E during testing, but were used only in the later analysis of the data. When the first stimulus was designated the target (TS) and the second the mask (MS), a measure of "retroactive" masking resulted. When the second stimulus was designated the TS and the first the MS, a measure of "proactive" masking resulted.

Summary of variables

A. Stimulus variables
  1. Number of contours in stimulus pairs -3 levels
    a. one contour (D) - two contours (R)
    b. two contours (R) - three contours (D+R')
    c. three contours (D+R') - four contours (R+R")
  2. Order of presentation -2 levels
    a. N - contoured stimulus followed by N+1 - contoured stimulus
    b. N+1 - contoured stimulus followed by N - contoured stimulus

3. Durations of stimulus 1 and stimulus 2 - 4 levels each
    a. 10 milliseconds
    b. 20 milliseconds
    c. 40 milliseconds
    d. 80 milliseconds

B. Additional variables
  1. Inter-stimulus interval (ISI) - 2 levels
    a. 20 milliseconds
    b. 60 milliseconds
  2. Inter-cycle interval (ICI) - 2 levels
    a. 1750 milliseconds
    b. 3500 milliseconds

Procedure

At the beginning of each experimental session O was positioned before the tachistoscope with both hands on the table directly in front of him, and was shown the two stimuli that would be employed during that session. He was instructed to tap the table with his left hand if he saw only the figure having fewer contours, to tap with his right hand if he saw only the other stimulus, and to tap with both hands if both stimuli were detected. Thus, for example, if O detected the R in the D → R sequence, he would tap with his right hand. If he detected only the R in the D+R' → R sequence (in a separate experimental session) he would tap with his left hand. It was explained that the discrimination was between certainty and uncertainty. That is, if O was unsure if he had seen one of the figures, or if he had seen "something" but could not identify the form, he was to respond as if he had not seen it. Os found no difficulty in responding in the above manner after practice.

Each experimental session had the following form: (1) familiarization with the two stimuli and the appropriate responses; (2) approximately 2 minutes of dark adaptation, after which the fixation point came on for a period of 5 seconds; (3) 16 practice trials; (4) 30 seconds of rest in darkness followed by 5 seconds with the fixation point on; (5) 16 experimental presentations, with the stimulus 1 - stimulus 2 durations randomly ordered, ISI and ICI values held constant; (6) steps (4) and (5) were repeated three more times, each time with a different combination of ISI-ICI durations, randomly selected; (7) 30 seconds of rest in darkness followed by 5 seconds with the fixation point on; (8) repetition of steps (5), (6), and (7) for a total of five complete runs of 64 experimental trials each. After a 5.5 minute rest, another five runs were performed.

Each O performed two experimental sessions per day for a total of twelve sessions, each lasting approximately 65 minutes. The daily sessions were separated by four hours to avoid possible fatigue effects. A different stimulus configuration was used for each of the first six sessions, the same set of configurations being repeated in the second six sessions in the opposite order of presentation.

Thus, a total of 20 trials for each condition were performed by each O, 10 trials in each of the two corresponding sessions.

Results

Analyses of variance were applied separately to the data for the two stimulus sequences, (1) an N - contoured stimulus followed by an N+1 - contoured stimulus, and (2) an N+1 - contoured stimulus followed by an N - contoured stimulus. The five variables in each analysis were stimulus 1 duration, stimulus 2 duration, number of contours in the stimulus configuration, ISI, and ICI. A separate analysis was performed for each of the two dependent variables, (1) the percentage of trials in which stimulus 1 was reported as having been perceived, and (2) the percentage of trials in which stimulus 2 was reported. These represent, respectively, measures of the amount of masking of the first stimulus by the second, or retroactive (backward) masking, and the amount of masking of the second stimulus by the first, or proactive (forward) masking.

Masking of Stimulus 1 by Stimulus 2 (Retroactive)

A. N - contoured stimulus followed by N+1 - contoured stimulus

Results for each stimulus configuration averaged over stimulus 2 (mask) durations are shown in Figure 3 a,b,c. The number of contours in the configurations did not significantly affect the amount of masking, over all other factors. That is, in each case the N+1 - contoured stimulus masked the N - contoured stimulus to approximately the same extent. As was evident in each of

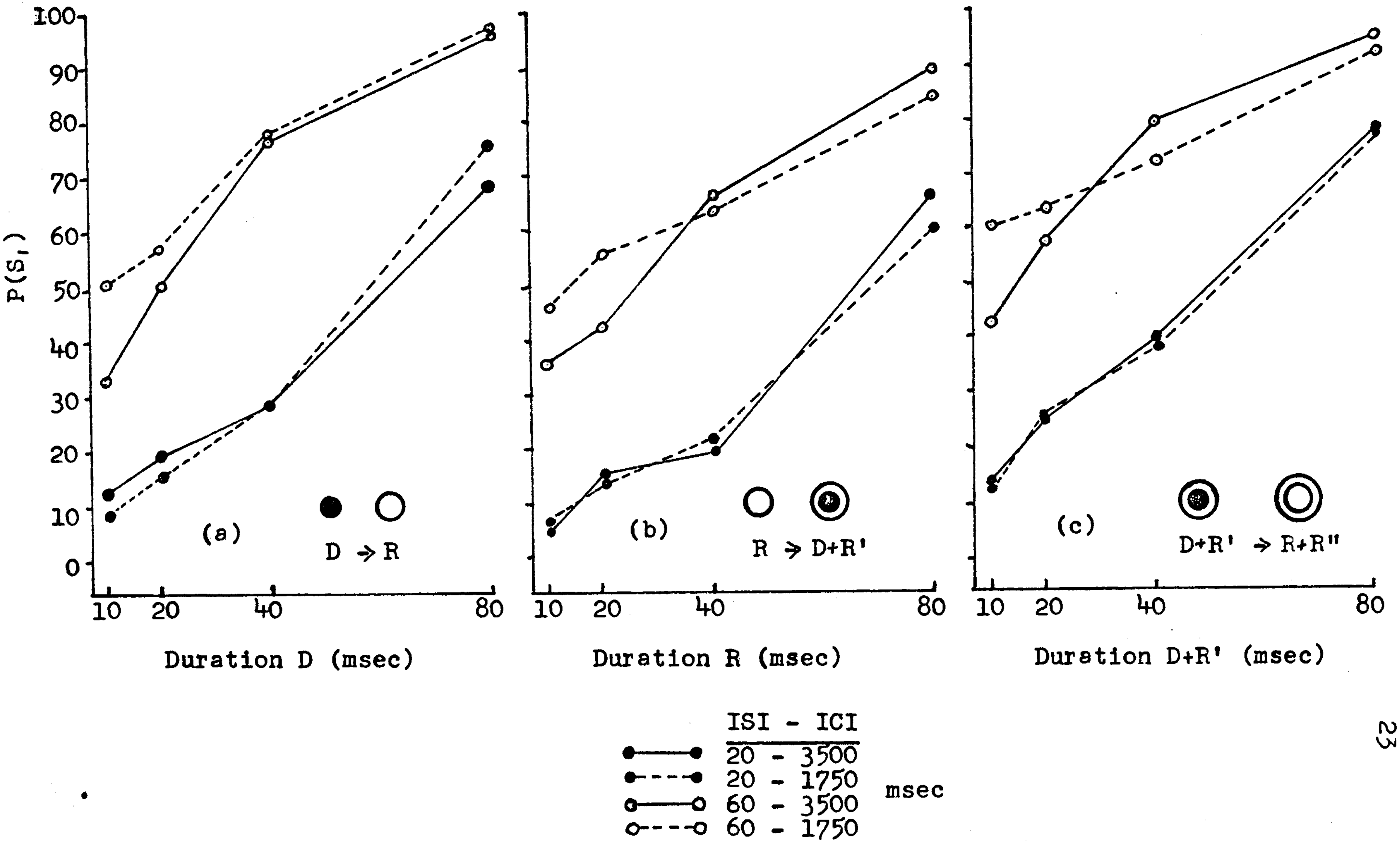


Fig. 3. Percentage of trials Stimulus 1 reported, $P(S_1)$, in N → N+1 target-mask contour sequence configurations as a function of target duration, ISI, and ICI. Averaged over mask durations.

the three cases, there was a significant main effect due to stimulus 1 (target) duration, $F(3,6)=184.3$, $p<.001$. As the target increased in duration, masking decreased markedly. Although the mask duration main effect approached significance, $F(3,6)=3.86$, $p<.1$, the range of differences between the maximum and minimum average masking levels was relatively restricted. As the mask duration increased, masking increased, except in the case of the longest mask duration, 80 mseconds, where the trend reversed and the amount of masking decreased. This result will be presented in greater detail when the relationship of target and mask durations is examined in particular cases (see Figure 4 a,b,c).

The effect of ISI on masking is also shown in Figure 3, where ISI=20 mseconds consistently produced a greater level of masking than did ISI=60 mseconds, $F(1,2)=11.15$, $p<.1$. Over-all, the effect of ICI was not significant, there being very little difference in degree of masking between ICI= 3500 and ICI=1750 mseconds for any of the stimulus pairs.

Levels of target duration, mask duration, ISI, and ICI did not affect masking differentially for the three sets of stimuli (D → R, R → D+R', D+R' → R+R"), the two-way interactions between the number of contours and each of these factors being insignificant.

Differences in amount of masking under the two values of ISI did not vary significantly as a function of target duration. However, for ISI=60 mseconds, at the shortest target durations, ICI=3500 mseconds produced slightly more masking than did ICI=1750 mseconds. For ISI=20 mseconds, the two values of ICI yielded similar masking levels (see Figure 3, ICI x target duration interaction, F(3,6)=21.9, p<.005, ISI x ICI x target duration interaction, F(3,6)= 6.4, p<.05). This pattern was found for each of the stimulus configurations.

There was a significant mask duration x ISI interaction, F(3,6)=7.5, p<.025, which also took the same form for each contour configuration. For ISI=20 mseconds, masking increased as mask duration increased, except for the longest duration, in which the trend was reversed, as in the mask main effect; for ISI=60 mseconds, masking decreased monotonically as mask duration increased, although the range of differences was relatively small.

The mask duration x ICI interaction was significant, F(3,6)=9.5, p<.025, but the range of differences was extremely limited, and again the interaction was of the same form for each configuration of contours.

Since masking was maximal for ISI=20 mseconds, and differences in masking between levels of ICI were very small, only the data for ISI=20 mseconds and ICI=3500 mseconds are presented in Figure 4 a,b,c for purposes of examining the relationship of target and mask durations to amount of masking obtained for each stimulus set of N followed by N+1 contours. While consistent with the general effects of target and mask durations described previously, several characteristics of these masking functions might be noted: (a) For each configuration, while the

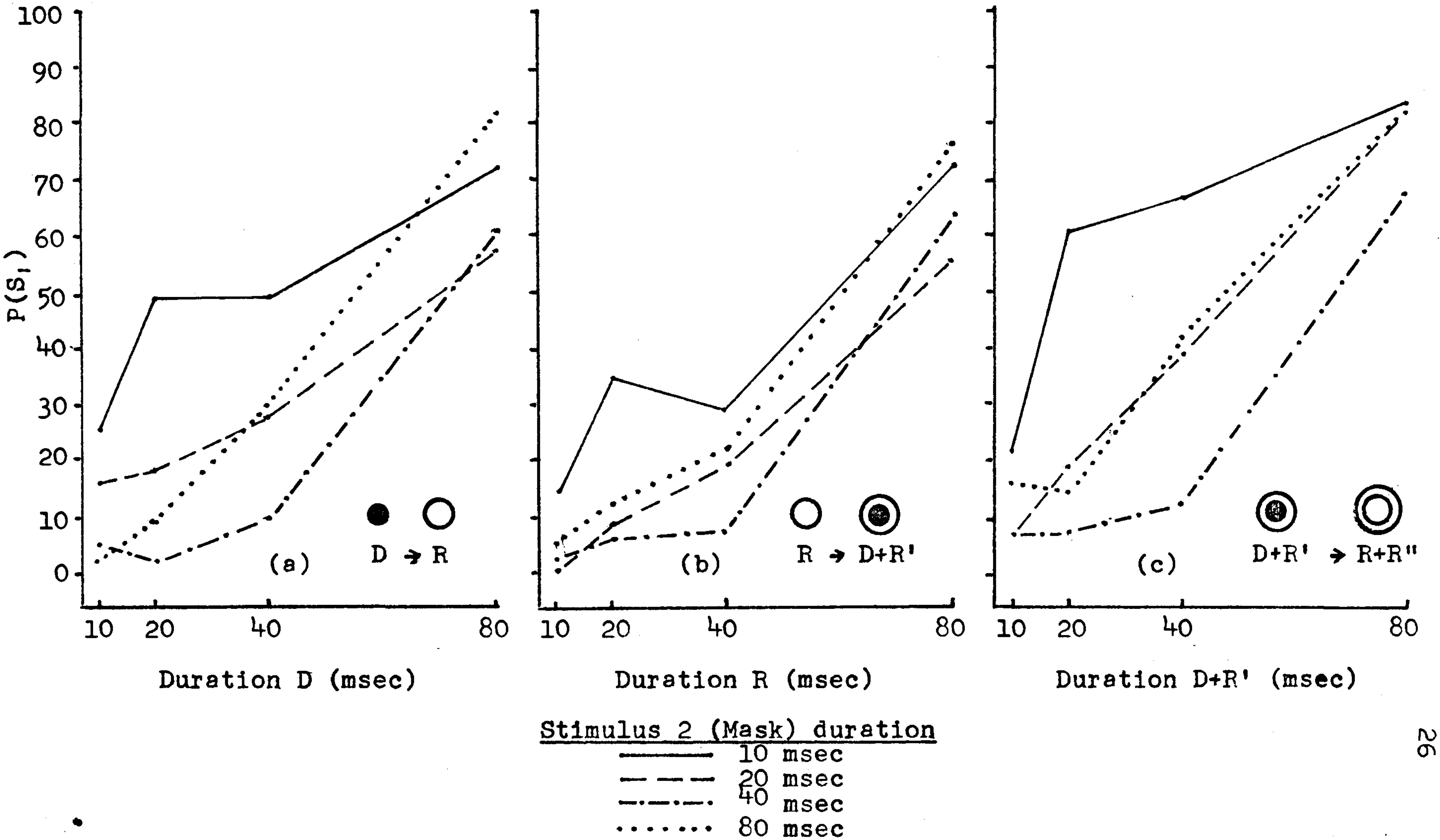


Fig. 4. Percentage of trials Stimulus 1 reported, P(S$_1$), in N → N+1 target-mask contour sequence configurations as a function of target, mask duration. ISI=20 msec., ICI=3500 msec.

curves for the 20, 40, and 80 msecond masks rose (decreased in masking) gradually for increasing target durations (with the exception of the longest target) the curve for the 10 msecond mask rose sharply as the target duration was increased from 10 mseconds to 20 mseconds, thereafter rising at approximately the same rate as the others. That is, the 10 msecond mask was maximally effective only when it followed the most brief target, whereas longer mask durations yielded high masking levels over a wider range of target durations. (b) Again, in each of the three cases, the 80 msecond mask was not the most effective mask duration, as might be expected from the general pattern established at the shorter durations. Although in most cases producing masking levels greater than the shortest mask duration, it masked less effectively than the shorter 40 msecond stimulus and often the 20 msecond mask.

B. N+1 - contoured stimulus followed by N - contoured stimulus

As in the previous N → N+1 contour conditions, Figure 5 a,b,c shows that for each configuration masking decreased as target (stimulus 1) duration increased, $F(3,6)=16.27$, $p<.005$. However, here there were significant differences in masking between the three contour configurations, $F(2,4)=19.77$, $p<.01$, as well as a significant contour x target duration interaction, $F(6,12)=7.38$, $p<.005$. In the R → D sequence there was very little masking, except at the shortest target durations. The D+R' → R sequence yielded much greater masking, especially at the shorter

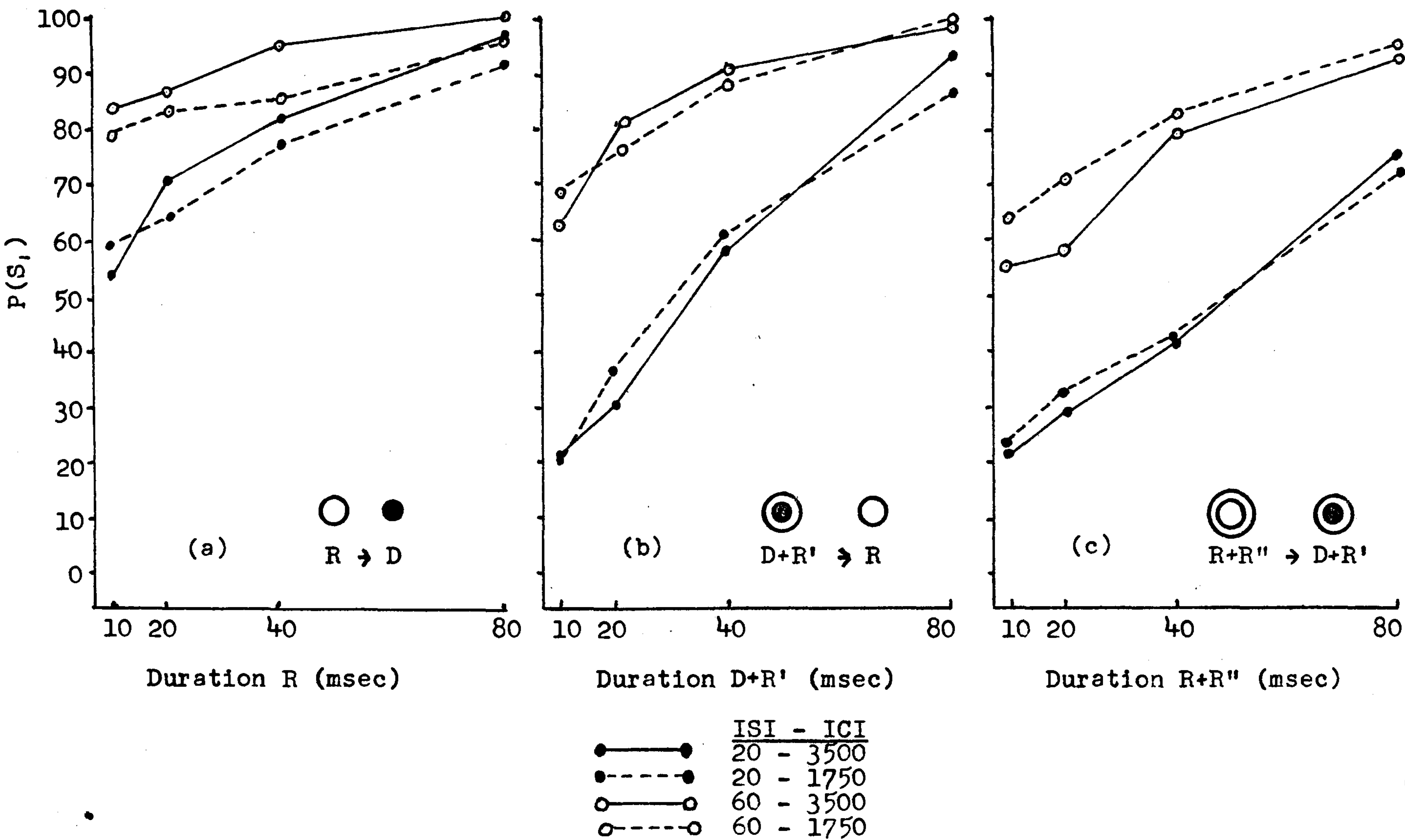


Fig. 5. Percentage of trials Stimulus 1 reported, $P(S_1)$, in N+1 → N target-mask contour sequence configurations as a function of target duration, ISI, and ICI. Averaged over mask durations.

target durations, and the D+R' masked the R+R" to a still greater extent.

Figure 6 a,b,c provides a comparison of the degree to which the second stimulus masked the first for both orders of presentation in each contour configuration. In the case of the D and R (1 and 2 contours, respectively), the order of the stimuli determined whether there was substantial masking (D → R) or only a weak effect (R → D). This stronger retroactive masking effect found in the N → N+1 contour sequence as compared to the N+1 → N sequence was maintained for the three-contour D+R' and the two-contour R, but to a much lesser degree. When the number of contours involved was increased by one again, neither the N → N+1 nor the N+1 → N contour sequence showed any marked masking advantage over the other. That is, the three-contour D+R' masked the four-contour R+R" to the same extent the R+R" masked the D+R'.

For the N+1 → N contour configurations, mask (stimulus 2) duration did not significantly influence masking overall, and the contour x mask duration interaction was also insignificant. It might be noted, however, that again the 80 msecond mask was not the most effective duration, as shown in Figure 7 a,b,c, producing intermediate degrees of masking over most target durations. There was a significant target duration x mask duration interaction, $F(9,18)=4.0$, $p<.01$, reflecting a consistent pattern for each stimulus condition, wherein, for an ISI of 20 mseconds the 10 msecond mask yielded less masking at the shorter target durations

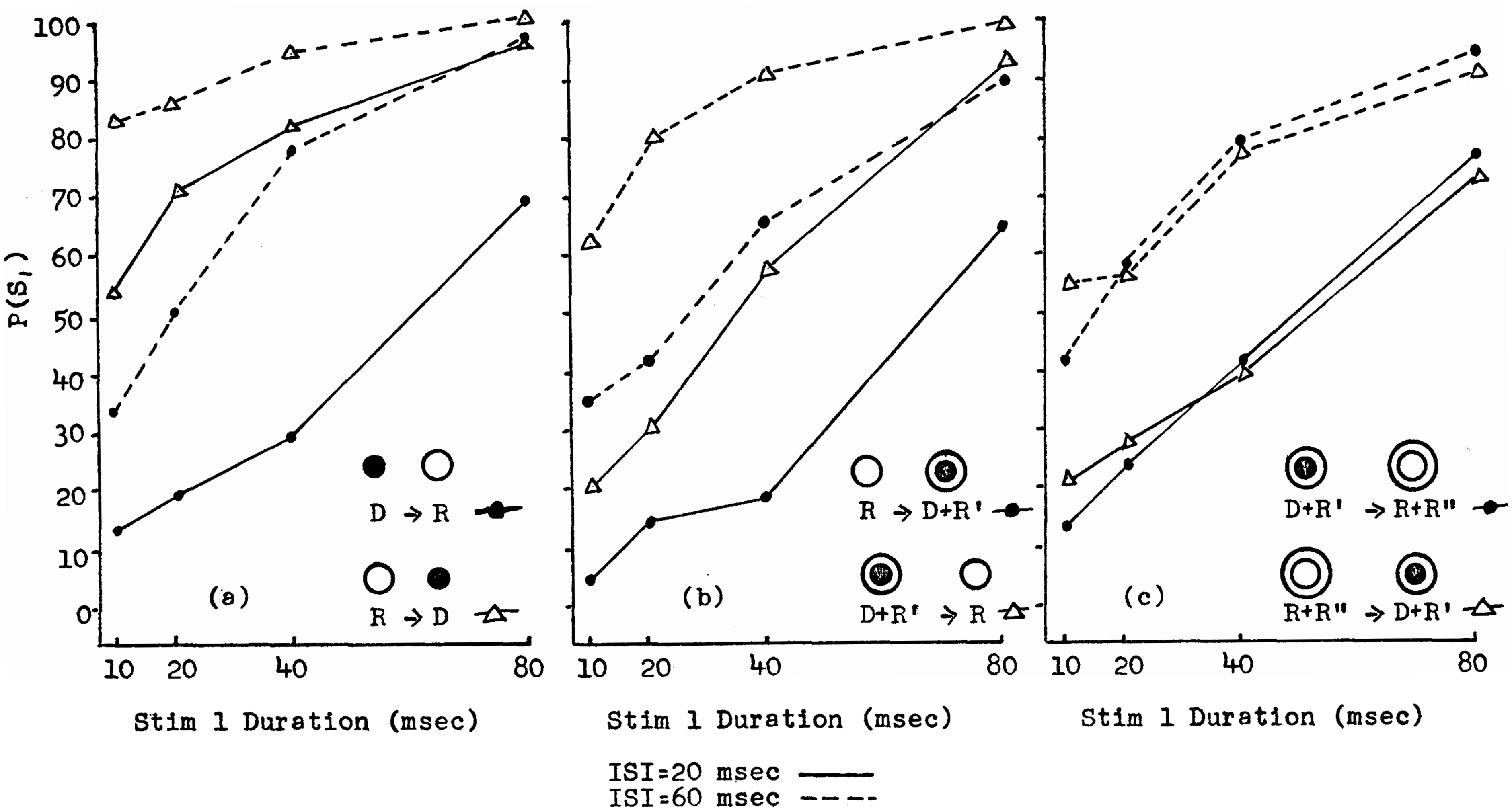


Fig. 6 Comparison of retroactive masking, $P(S_1)$, in N → N+1 and N+1 → N target-mask contour sequences as a function of target duration and ISI. ICI = 3500 msec. Averaged over mask durations.

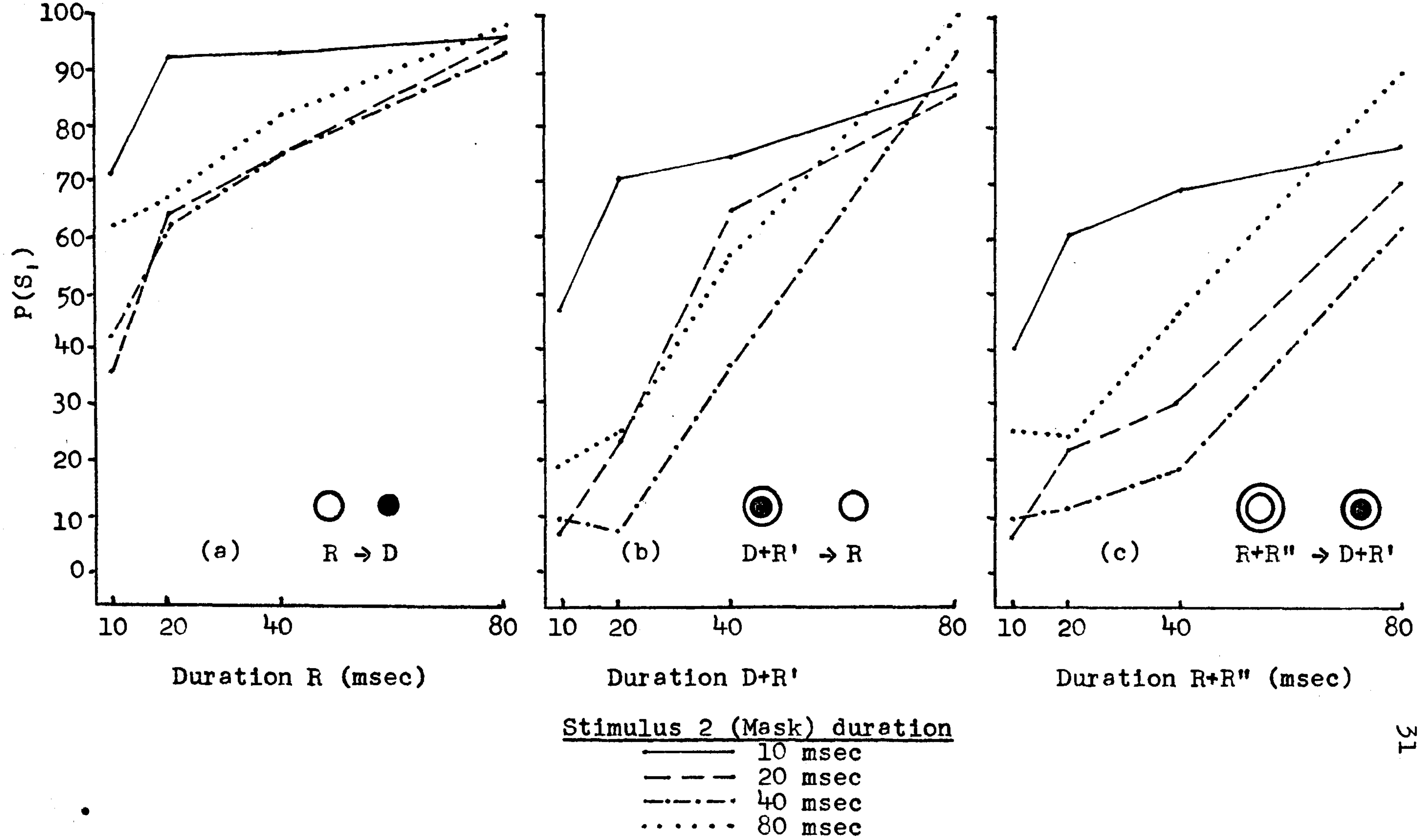


Fig. 7. Percentage of trials Stimulus 1 reported, P(S$_1$), in N+1 → N target-mask contour sequence configurations as a function of target, mask duration. ISI=20 msec., ICI=3500 msec.

than did the other masks, while at an ISI of 60 mseconds there was very little effect of varying mask duration.

Masking with an ISI of 20 mseconds was again consistently greater than that at 60 mseconds. While this ISI main effect failed to reach significance, F(1,2)=7.3, p<.1, the contour x ISI interaction was significant, F(2,4)=9.19, p<.05, the increase in masking as the number of contours increased being greater for the shorter ISI.

The differences between the two levels of ICI were not significant over-all, and the range of differences found in interactions involving ICI was relatively small.

Masking of Stimulus 2 by Stimulus 1 (Proactive)

A. N - contoured stimulus followed by N+1 - contoured stimulus

In this and the following section, stimulus 2, whose detectability is being examined, will be designated as the target, while stimulus 1 now becomes the mask. In Figure 8 a,b,c the percentage of trials in which the target (stimulus 2) was detected is plotted as a function of target duration, ISI, and ICI for each contour configuration. Again target duration was a factor in determining the extent of the masking effect, F(3,6)=4.64, p<.1. Over all other factors, as stimulus 2 duration increased, the amount of masking decreased. However, as evident in each of the contour conditions in Figure 8 a,b,c, this was the case only when ISI=20 mseconds, there being virtually no masking for ISI=60 mseconds [target duration x ISI interaction,

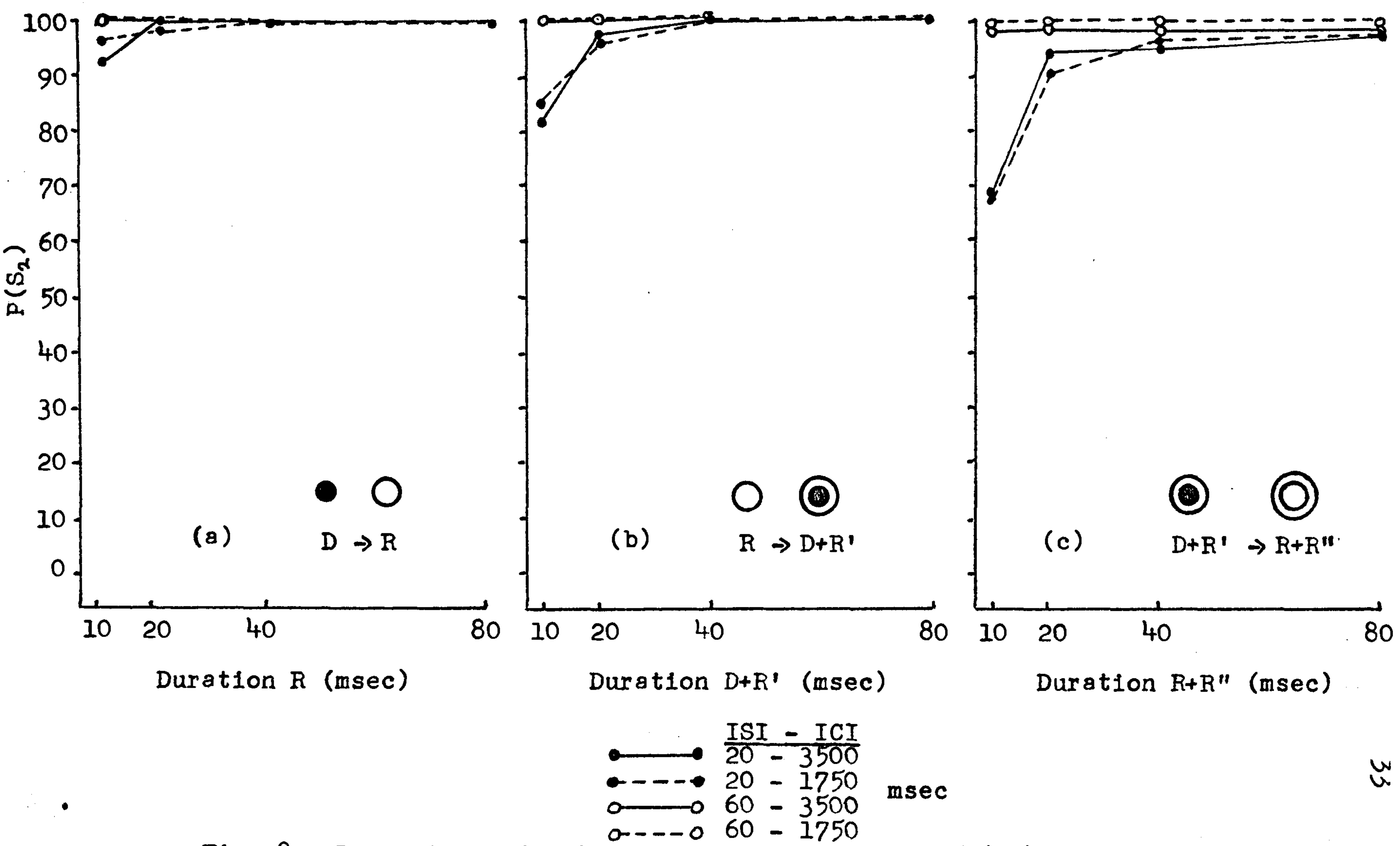


Fig. 8. Percentage of trials Stimulus 2 reported, $P(S_2)$, in N → N+1 mask-target contour sequence configurations as a function of target duration, ISI, and ICI. Averaged over mask durations.

F(3,6)=4.62, p<.1].

When ISI=20 mseconds, in the D → R sequence, the R was masked to a very small extent only at its shortest duration, 10 mseconds. When the number of contours was increased, R → D+R', the R masked the D+R' to a greater extent than in the previous case when the D+R' was presented for 10 seconds, as well as producing a slight masking effect for D+R' duration of 20 mseconds. For the D+R' → R+R" configuration, masking at target (R+R") durations of 10 and 20 mseconds was again increased and extended, occurring also at 40 mseconds. The extent and level of the above proactive masking effects were markedly less than those obtained in the corresponding retroactive cases (see Figure 3 a,b,c). In addition, the differences in masking between the contour configurations described above failed to achieve significance level, either for the contour main effect or for higher order interactions involving contour configuration.

Differences due to mask (stimulus 1) duration were significant, F(3,6)=5.11, p<.05, but were limited to the ISI=20 mseconds condition, ISI=60 mseconds failing to produce masking at any mask duration [mask duration x ISI interaction, F(3,6)=5.73, p<.05]. As shown in Figure 9 a,b,c the range of masking levels over mask durations was relatively restricted, the longer mask durations yielding greater masking, although the longest mask presentation (80 mseconds) was not the most effective in any of the contour conditions. Even under the strongest mask,

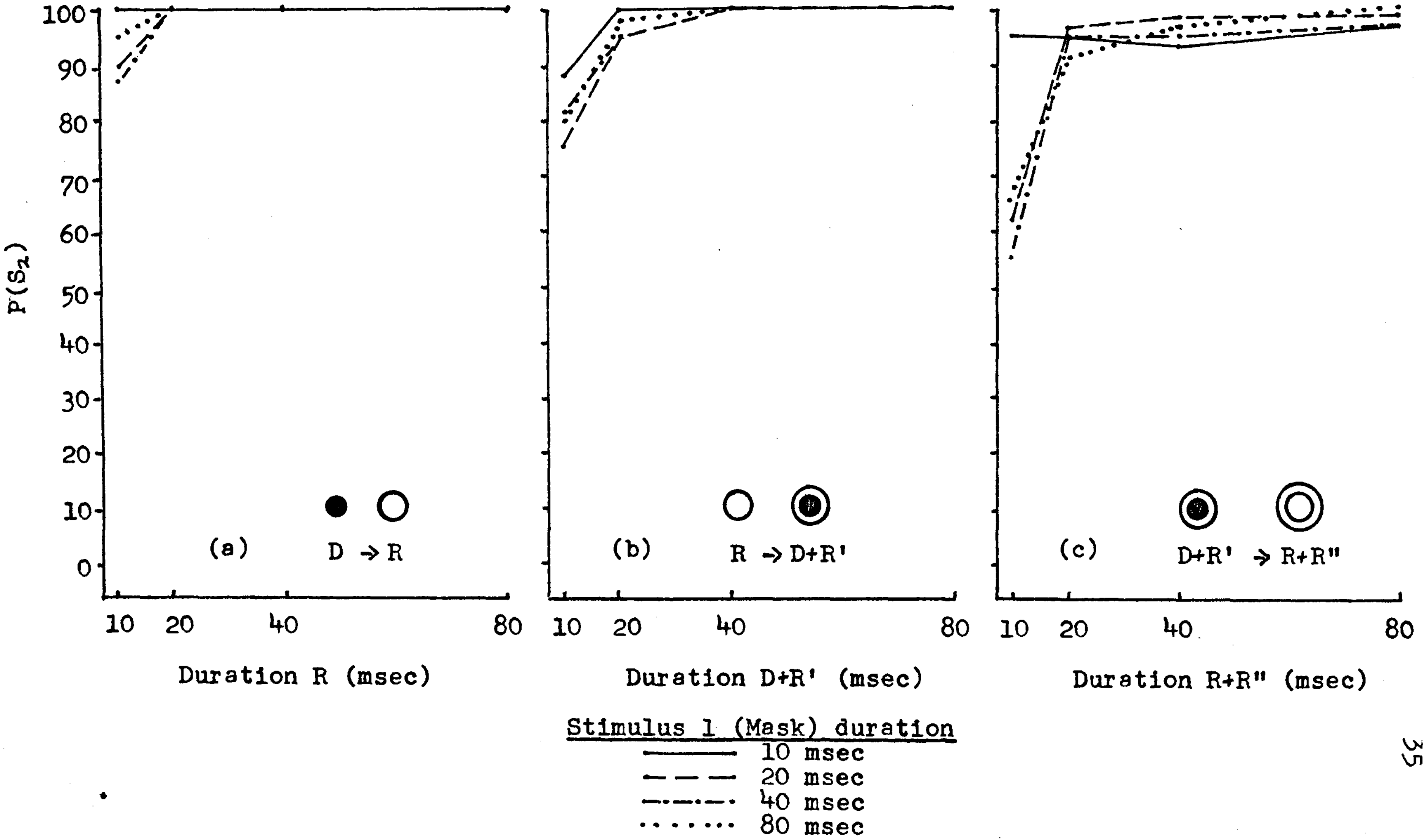


Fig. 9. Percentage of trials Stimulus 2 reported, $P(S_2)$, in N → N+1 mask-target contour sequence configurations as a function of target, mask duration. ISI=20 msec., ICI=3500 msec.

stimulus 2 (target) was masked only at its shortest durations [target duration x mask duration interaction, F(9,18)=4.9, p<.005].

The differences in masking between the two levels of ICI were negligible for all conditions.

B. N+1 - contoured stimulus followed by N - contoured stimulus

Target (stimulus 2) duration was a significant factor in determining the amount of masking obtained, F(3,6)=9.27, p<.025, masking decreasing as target duration increased (see Figure 10 a,b,c). This was the case for each contour configuration, the contour configuration main effect as well as the contour x target duration interaction being insignificant. As for the previous order of stimuli, the masking levels achieved here were less than those for the corresponding retroactive cases (see Figure 5 a,b,c).

For all stimulus contour configurations, ISI=20 mseconds produced somewhat more masking than did ISI=60 mseconds, F(1,2)=11.89, p<.1, the longer interval yielding almost no masking, while for the shorter, considerable masking occurred at brief target durations, decreasing rapidly as target duration increased [ISI x target duration, F(3,6)=12.58, p<.01]. ICI=3500 mseconds yielded more masking at shorter target duration than did ICI=1750 mseconds [ICI x target duration, F(3,6)=29.05, p<.001]. This was especially evident for the longer ISI, and again this applied to each configuration.

Figure 11 a,b,c shows the amount of proactive masking

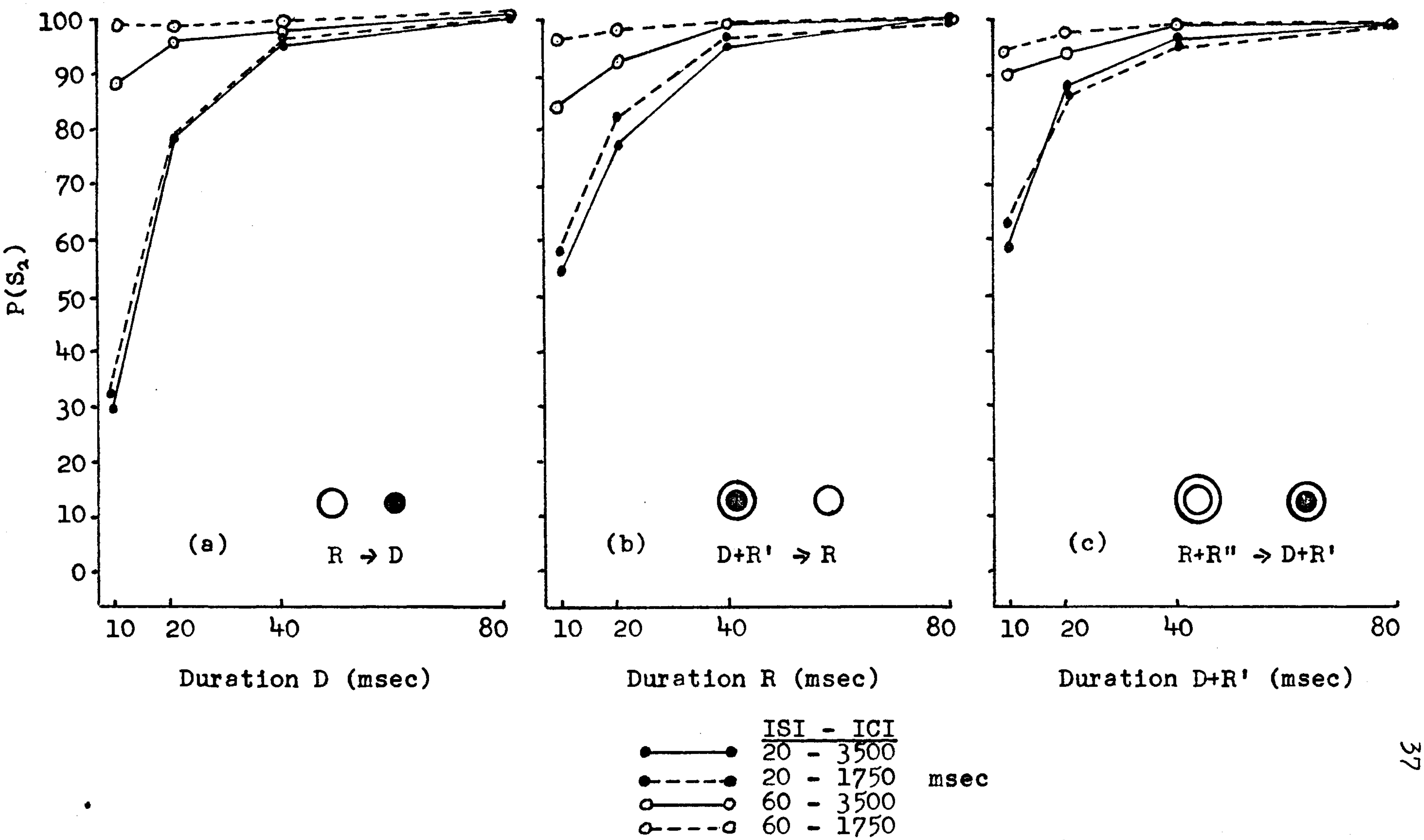
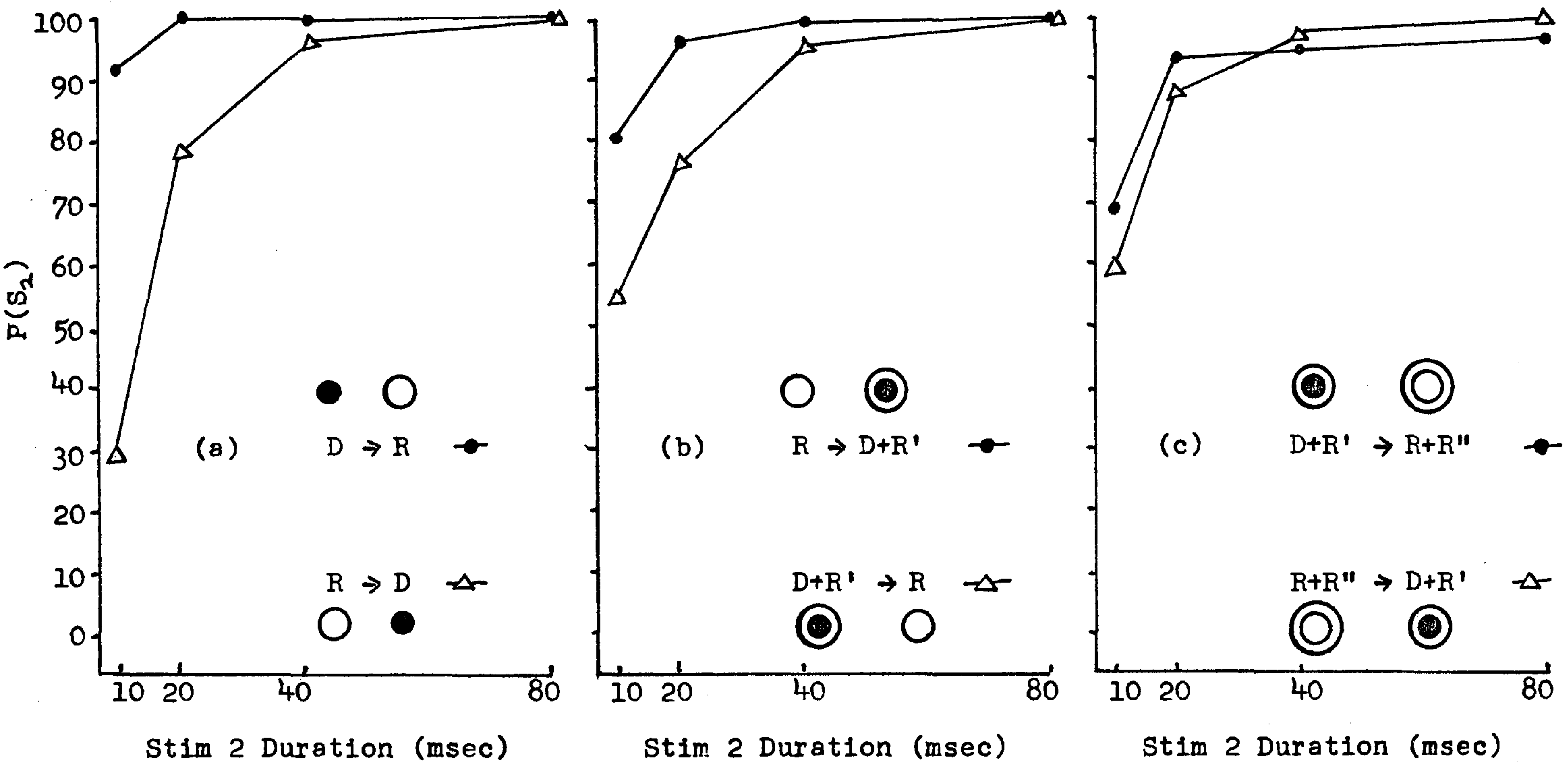


Fig. 10. Percentage of trials Stimulus 2 reported, $P(S_2)$, in N+1 → N mask-target contour sequence configurations as a function of target duration, ISI, and ICI. Averaged over mask durations.

obtained for both orders of stimulus sequence in each contour configuration. Only the results for ISI=20 mseconds are given, since, for both orders, ISI=60 mseconds produced negligible masking effects. In the first contour condition the two-contoured R masked the one-contoured D to a much greater extent than the latter masked the former in the reverse order. This difference was less for the two- and three-contoured R and D+R', respectively, and in the case of the highest order contour configuration, the three-contoured D+R' masked the four-contoured R+R" to approximately the same extent as the R+R" masked the D+R'.

For the N+1 → N contour configuration, there was a significant effect due to mask (stimulus 1) duration, $F(3,6)=5.66$, $p<.05$, but as was the case for the target effect, it was due to the masking effect only at ISI=20 mseconds, where, as mask duration increased, masking increased monotonically [mask duration x ISI, $F(3,6)=14.08$, $p<.005$]. The relationship between target and mask durations is shown in Figure 12 a,b,c. There was almost no masking at the longest target duration, briefly presented targets being masked most effectively at longer mask durations [target duration x mask duration, $F(9,18)=7.11$, $p<.001$].



ISI=20 msec
ICI=3500 msec

Fig. 11. Comparison of proactive masking, $P(S_2)$, in N → N+1 and N+1 → N mask-target contour sequences as a function of target duration. ISI=60 msec yielded negligible masking (not shown). Averaged over mask durations.

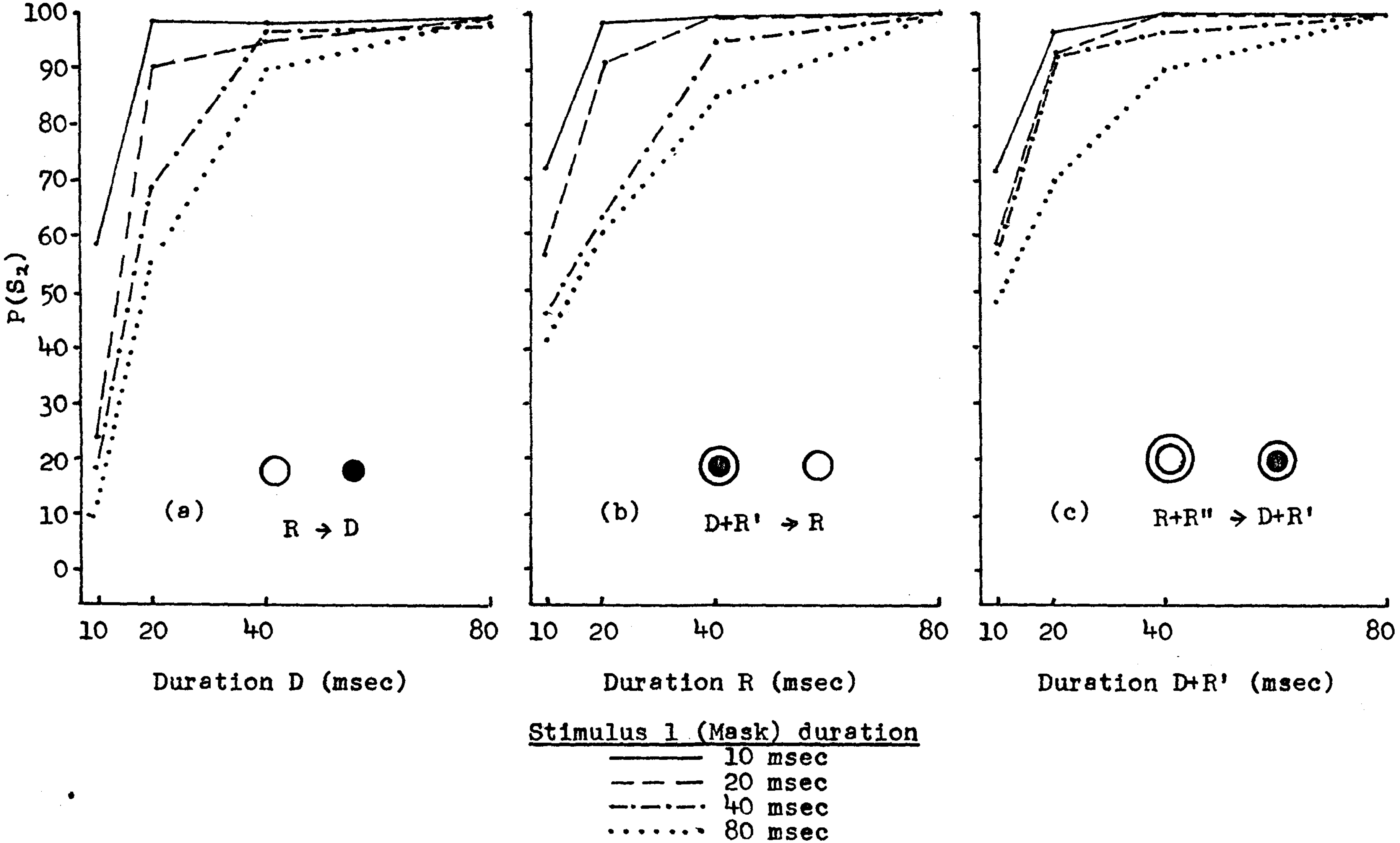


Fig. 12. Percentage of trials Stimulus 2 reported, P(S_2), in N+1 → N mask-target contour sequence configurations as a function of target, mask duration. ISI=20 msec., ICI=3500 msec.

General Summary of Results

Retroactive Masking

1. For all stimulus configurations, and for both sequences, as target (stimulus 1) duration increased, masking decreased.

2. In general, as mask (stimulus 2) duration increased, masking increased, although the longest duration was not always the most effective. The range of effects over mask durations was relatively small compared to that over target durations.

3. For all conditions, an ISI of 20 mseconds yielded higher masking levels than did an ISI of 60 mseconds.

4. ICIs of 1750 and 3500 mseconds produced approximately the same degree of masking.

5. An N+1 - contoured stimulus 2 consistently masked an N - contoured stimulus 1, within certain temporal limits. When the order of the stimuli was reversed (i.e., N+1 - contoured stimulus followed by N - contoured stimulus), the following occurred: (a) In the R → D sequence, the one - contoured D did not effectively mask the two - contoured R; (b) the D+R' → R configuration yielded greater retroactive masking than in (a); and (c) the R+R" → D+R' sequence produced still greater masking levels, approximately comparable to those in the D+R' → R+R" sequence. That is, for stimulus configurations of three and four concentric, adjacent contours, an N - contoured stimulus masked an N+1 - contoured stimulus as effectively

as an N+1 - contoured figure masked one of N contours.

Proactive Masking

1. In general, proactive masking effects were not as strong as retroactive effects.

2. Effects of ISI, ICI, target (stimulus 2) duration, and mask (stimulus 1) duration were similar to those observed with the retroactive paradigm.

3. An N+1 - contoured stimulus 1 proactively masked an N - contoured stimulus 2, again within certain temporal limits, although as noted, these proactive effects were of a lesser magnitude than the corresponding retroactive effects. When the stimulus sequence was reversed (i.e., N - contoured stimulus followed by N+1 - contoured stimulus), the following occurred: (a) In the D → R sequence, the one - contoured D did not mask the two - contoured R; (b) the R → D+R' sequence yielded an intermediate degree of proactive masking; and (c) the D+R' → R+R" configuration produced yet greater masking, comparable to that in the R+R" → D+R' sequence. That is, as the number of contours involved increased to three and four, an N - contoured stimulus proactively masked an N+1 - contoured stimulus as effectively as an N+1 - contoured figure masked one of N contours.

Discussion

The results obtained for the one-contoured disk and the two-contoured ring stimuli were in general agreement with earlier studies employing similar stimuli. Specifically, this study found that within certain temporal limitations the presentation of the disk → ring sequence resulted in masking of the disk, _O_ reporting only the presence of the ring, an outcome well-substantiated by an extensive literature. Consistent with Kolers & Rosner's (1960) and Alpern's (1953) results, the probability of seeing the disk (target stimulus) was greater when it was exposed for a longer duration.

The pattern followed by the data as a result of prolongation of the ring (masking stimulus) was also similar to that found by Alpern (1953), who employed rectangular flashes of light. That is, the effectiveness of the masking stimulus increased rapidly at the shorter durations, longer exposures producing less change. However, whereas Alpern's results maintained asymptotic masking levels for the longer mask durations, the present findings indicated a slight decrease in masking effectiveness for the longest duration (80 mseconds) as compared to the 40 msecond mask.

Reversing the stimulus sequence, i.e., ring → disk, yielded results again in agreement with those of Werner (1935) and Kolers & Rosner (1960), the magnitude of retroactive masking being greatly reduced as compared to the disk → ring sequence. Further supporting Kolers & Rosner's data, a proactive masking effect was found to operate concurrently with the retroactive effect, although to a much lesser extent, a form's masking potency being greater when it was presented second in the sequence than when it was first. As in the retroactive cases, the two-contoured ring proactively masked the one-contoured disk to a greater extent than the latter masked the former.

Although the inter-stimulus values of 20 and 60 mseconds were chosen to lie within a temporal region yielding maximal masking effects (Kolers & Rosner, 1960), the 20 msecond ISI resulted in consistently greater masking levels than that of 60 mseconds. This could have been partially due to what Kolers and Rosner called "anchoring effects," whereby "The amount of masking obtained...(was) found to vary with the range of conditions explored (p.8)." If ISI values of 60 and 80 mseconds had been assessed instead, the ISI of 60 mseconds might have produced more masking than did, in fact, occur.

The possibility of eye movements occurring during the ISIs must also be considered, since the longer interval would allow greater opportunity for such movement and hence might lead to lower masking levels. This is unlikely, however, since in both cases the stimulus field flashes appeared to be (phenomenally) almost contiguous. In addition, in pilot sessions it was noted that if the stimuli were flashed as an O̲ was initiating a voluntary eye movement, he would report seeing both stimulus forms, but they would obviously not be aligned properly, the images appearing to overlap one another. This effect was not reported in regular experimental sessions, where O was instructed to fixate his gaze. As will be discussed, factors such as retinal position of the stimulation and nature (light vs. dark) of the inter-stimulus interval could have affected the range of ISI over which masking occurs.

The inter-cycle intervals examined, 3500 and 1750 mseconds, produced similar masking levels, which can reasonably be accepted, on the basis of Kolers and Rosner's findings, as providing independent masking trials. It was thought that the shorter ICI might have resulted in reduced masking levels due to an additional effect from "neighboring" cycles, e.g., a given target form could have been affected retroactively by its normal masking stimulus as well as proactively by the second stimulus in the preceding presentation cycle. However, the data indicated that 1750 mseconds was probably a sufficient time interval to ensure independence between trials, given the values selected on the other parameters in the present study.

As evidenced above, the data for stimulus forms of one and two contours, the disk and ring, replicate the major findings of Kolers and Rosner (1960) as well as those of Werner (1935) and Alpern (1953). Thus, the present methodology would seem to provide a reasonable basis for examining the generality of the developmental advantage theory by extending the paradigm to stimuli of multiple concentric adjacent contours.

The 2:1 mask:target contour ratio configuration (ring:disk) resulted in a sizable advantage in masking ability of the two-contoured figure over the one-contoured figure. The addition of a concentric ring (R') to the original disk yielded a three-contoured form which, when paired with the original ring (R → D+R' ; D+R' → R) maintained the masking advantage of the N+1 - contoured stimulus over the N - contoured form, both in retroactive and proactive aspects. The magnitude of this advantage, however, was substantially decreased from that occurring in the 2:1 contour ratio case. This decrease is attributable to an increase in the effectiveness with which the two-contoured stimulus (R) masked the three-contoured stimulus (D+R'), the masking levels for the reverse condition (masking of the R by the D+R') remaining effectively unchanged.

This trend established by increasing the number of concentric adjacent contours of the paired stimuli to two and three continued with the addition of a larger outer ring (R") to the original ring, R" having its inner contour coincident with the outer contour of D+R'. When the three-contoured D+R' was paired with the four-contoured R+R" neither stimulus exhibited any appreciable masking advantage over the other in either retroactive or proactive measures.

Hence, Werner's (1935) and Kolers & Rosner's (1960) postulated developmental contour advantage in masking paradigms did not generalize to more complex stimuli containing multiple adjacent contours. That is, the 2:1 mask:target contour ratio, which resulted in considerable masking of the one-contoured disk by the two-contoured ring (producing very little masking when the roles were reversed), was not simply a specific case of a more general N+1:N mask:target contour ratio advantage situation. Above a certain number of concentric contours, the stimulus having the greater number of contours no longer retained a "developmental advantage" over the other, the N - contoured figure masking the N+1 - contoured figure to the same extent the N+1 - contoured figure masked one of N contours.

Certain factors determining the magnitude of masking with the disk and ring stimuli continued to operate in similar fashion with the more complex stimuli. The effects of target and mask duration, ISI, and ICI remained relatively unchanged, and retroactive masking continued to be more powerful than proactive masking.

The present results were obtained using monocular presentation. However, sufficient evidence exists establishing that masking by pattern or adjacent forms (e.g., disk, ring) also occurs under dichoptic conditions (Kolers & Rosner, 1960; Mayzner, Tresselt, Adrignolo, & Cohen, 1967; Schiller & Wiener, 1963; Werner, 1940) to support the conjecture that similar data would have resulted had dichoptic presentation been utilized in the current study. This would preclude the hypothesis that this form of visual masking can be explicated solely in terms of retinal interaction, interaction between the target and masking stimuli occurring at a central locus.

The retinal location which is stimulated has been shown to be an important determinant of the magnitude of the masking effect. Alpern (1953), using adjacent rectangular flashes of light in a metacontrast situation, found that when the center of the test (target) object was fixated virtually no masking could be demonstrated, but as the fixation was shifted so that the stimuli fell on the peripheral region of the retina, masking increased as the distance from the fovea increased. Similar results were found in later studies by Eriksen, Becker, & Hoffman (1970) and Stewart & Purcell (1970) employing letter stimuli masked by a ring. However, other investigators (Heckenmueller & Dember, 1965; Kolers, 1962; Schiller, 1965; Werner, 1940) have obtained masking with central fixation. Kolers and Rosner (1960) reported data primarily using peripheral presentation of stimuli, but also noted that foveal masking did occur, although it was much less extensive than masking in the periphery. This might account for the generally lower masking levels and the somewhat more restricted range of inter-stimulus interval over which maximal masking occurred in the current study, in which central fixation was employed, as compared to Kolers and Rosner's data.

Another factor contributing to this discrepancy may be the nature of the inter-stimulus interval itself. Kolers and Rosner used an illuminated blank field during the ISI and ICI, while here both intervals were dark. Although this variable has for the most part been ignored by previous investigators, Stewart and Purcell (1970) demonstrated that a lighted ISI significantly enhances the masking effect.

The effects of the adaptation level of the O have not been systematically examined in earlier studies of visual masking by adjacent forms, nor does the present methodology afford an analysis of such effects. The frequent stimulation by repeated presentations of the target and mask fields would affect O's adaptation level in a complex fashion, depending upon the intervals between flashes, field luminance, and duration of exposures. However , the procedure followed provided reasonable control in that each block of sixteen trials occurred under similar conditions of adaptation, being preceded by a 30 second dark interval and a 5 second dim, red, fixation point, and since the blocks, as well as the trials within each block, were presented in random order, systematic biasing of the results is unlikely. The initial state of adaptation for the experimental trials was the result of pre-adaptation to normal room illumination followed by approximately two minutes of dark adaptation, sixteen practice trials, and 35 seconds of darkness (the fixation point being on for the last 5 seconds). It was hoped that the practice trials and subsequent dark interval would establish a somewhat uniform pattern of adaptation for the experimental trials, which followed the same sequence of stimulation and darkness. The five minute rest period occurring in the middle of each session was spent under very dimly lighted room conditions.

Attempts to explain the processes involved in visual masking of the kind exhibited in this study and the effects of various contour relationships have generally centered around temporal summation of luminance and contrast discrimination, failure of the perceptual system to resolve "impossible" motion, and various models encompassing lateral inhibitory processes, as reviewed in the Introduction section of this report. At present, none of these theories seems wholly adequate to account for the data. While an explanation in terms of a reduction in the effective contrast of a figure might apply in the case of masking by a light flash, or when target and mask luminances are unequal, when the stimuli are of equal intensity it cannot account for U-shaped masking functions as ISI increases (not examined in detail here), nor does it distinguish between the disk → ring sequence and the ring → disk sequence, which do not yield similar masking levels.

The present findings concerning stimuli of multiple adjacent contours perhaps bear more directly on the hypothesis relating masking to apparent movement (Kahneman, 1967; Schiller & Smith, 1966). The disk → ring sequence is analyzed in terms of the disk "moving" outward in all directions simultaneously, an "impossible" movement which cannot be resolved by the perceptual system. The reverse sequence, ring → disk, is not discussed. However, since little masking occurs in this order, it might be assumed that the conditions for apparent motion do not apply in identical fashion, i.e., the ring is not perceived as "shrinking" to form the disk. If this distinction is accepted, the retroactive masking results for the more complex stimuli seem to form a contradiction. While the greater-contoured (and larger) R+R" successfully masked the D+R' in the D+R' → R+R" sequence (analogous to the D → R sequence), the reverse case, R+R" → D+R', now yielded equally low masking levels. To be theoretically consistent this would be analyzed as the larger figure's components "shrinking impossibly" into the smaller form, which was not the case for the ring → disk sequence. This discrepancy would seem to form an obstacle for the "impossible" movement hypothesis. Apparent movement might account for some of the visual masking data, but the parameters governing its applicability remain to be specified.

A similar problem is encountered when attempting to reconcile the present data with the lateral inhibition theories for masking. The spatial relationships determining the amount of inhibition are not strictly defined, and how the models would resolve the following results is not clear: In the D → R sequence the surrounding ring (R) inhibited the neurons responding to the target disk (according to the lateral inhibition model proposed by Weisstein, 1968) and thus the disk was not perceived. In the R → D sequence the smaller stimulus, D, did not greatly inhibit the larger ring. If it is the case that a larger, surrounding stimulus is a more powerful inhibitor of a smaller, enclosed stimulus, then contradictory results are provided by the R+R" → D+R' sequence in which the smaller stimulus inhibited the larger stimulus to the same extent the latter did the former in the reverse order. That is, if the inhibitory processes at the contours of a figure act to interfere with the formation of adjacent contours, the models would predict that the smaller, enclosed figure, all of whose contours were coincident with those of the greater-contoured form, would be rendered "contourless" and hence not be perceived. However, the finding that a surrounding figure was "inhibited" by a smaller figure (e.g., in the R+R" → D+R' configuration) seems inconsistent in that there was no adjacent contour to interfere with the formation of the outer contour of the larger form. Further difficulties arise when results for both retroactive and proactive masking are considered. Certain temporal relationships involved in lateral inhibition are not clear, and the conditions under which the second stimulus will inhibit the first or under which the first form will inhibit the second are not specified.

Despite certain weaknesses, the models incorporating lateral inhibitory processes in accounting for visual masking offer a promising approach in that they can be formulated so that they present a unified explanation for both Type A and Type B masking functions (monotonic and U-shaped, respectively), as well as relying only on "classical" neuronal inhibitory mechanisms which appear to play an important role in the closely related visual phenomenon of contour enhancement (border contrast) or Mach bands (Ratliff, 1972; Ratliff, Hartline, and Miller, 1963). It should be noted that these theories are usually built upon certain crucial assumptions drawn from simpler neuronal structures than the human cortex, and as such they often lack direct empirical support.

In reviewing the vast and diverse body of literature on visual masking and related topics, it might be argued that this diversity has lead to a certain amount of confusion. Differing methodologies have made the task of comparing and integrating results extremely difficult. It now seems likely that there are several contributing factors involved, and the task presented is one of determining the nature of these processes, the conditions under which they operate, and the extent of their effects.

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Appendix A: Analysis of Variance Table - Retroactive masking (frequency of reporting Stimulus 1) as a function of Configuration (number of contours), Target duration, Mask duration, ISI, and ICI.

N → N+1 contour sequence

Source	df=	MSS=	F=	p<
Configuration -borders- (B)	2	246.6	1.71	ns
Target duration (T)	3	3248.7	184.3	.001
Mask duration (M)	3	138.9	3.86	.1
ISI (I)	1	6621.8	11.15	.1
ICI (C)	1	32.58	1.06	ns
Subjects (S)	2	1777.5	--	--
SxB	4	143.8	--	--
SxI	2	593.6	--	--
BxI	2	6.31	.093	ns
SxC	2	30.6	--	--
BxC	2	2.51	1.53	ns
IxC	1	40.6	6.18	ns
SxT	6	17.6	--	--
BxT	6	8.05	.341	ns
IxT	3	126.3	1.15	ns
CxT	3	25.05	21.9	.005
SxM	6	35.9	--	--
BxM	6	13.77	.373	ns
IxM	3	309.5	7.52	.025
CxM	3	5.5	9.56	.025
TxM	9	10.42	1.43	ns
SxBxI	4	68.26	--	--
SxBxC	4	1.63	--	--
SxIxC	2	6.56	--	--
BxIxC	2	.296	.063	ns
SxBxT	12	23.6	--	--
SxIxT	6	109.5	--	--
BxIxT	6	11.12	1.19	ns
SxCxT	6	1.14	--	--
BxCxT	6	5.37	1.71	ns
IxCxT	3	32.8	6.45	.05
SxBxM	12	36.9	--	--
SxIxM	6	41.1	--	--
BxIxM	6	10.77	.383	ns
SxCxM	6	.575	--	--
BxCxM	6	1.83	1.68	ns
IxCxM	3	.653	.219	ns
SxTxM	18	7.28	--	--
BxTxM	18	2.32	.786	ns
IxTxM	9	41.3	5.91	.001

Appendix A - continued

Source	df=	MSS=	F=	p<
CxTxM	9	.852	.459	ns
SxBxIxC	4	4.68	--	--
SxBxIxT	12	9.35	--	--
SxBxCxT	12	3.14	--	--
SxIxCxT	6	5.08	--	--
BxIxCxT	6	3.25	3.40	.05
SxBxIxM	12	28.17	--	--
SxBxCxM	12	1.09	--	--
SxIxCxM	6	2.98	--	--
BxIxCxM	6	2.45	2.28	ns
SxBxTxM	36	2.95	--	--
SxIxTxM	18	6.98	--	--
BxIxTxM	18	4.13	1.19	ns
SxCxTxM	18	1.85	--	--
BxCxTxM	18	1.59	1.00	ns
IxCxTxM	9	2.57	1.24	ns
SxBxIxCxT	12	.957	--	--
SxBxIxCxM	12	1.07	--	--
SxBxIxTxM	36	3.45	--	--
SxBxCxTxM	36	1.58	--	--
SxIxCxTxM	18	2.08	--	--
BxIxCxTxM	18	1.41	.76	ns
SxBxIxCxTxM	36	1.85	--	--

Appendix B: Analysis of Variance Table - Retroactive masking (frequency of reporting Stimulus 1) as a function of Configuration (number of contours), Target duration, Mask duration, ISI, and ICI.

N+1 → N contour sequence

Source	df=	MSS=	F=	p<
Configuration -borders- (B)	2	999.4	19.77	.01
Target duration (T)	3	1773.3	16.27	.005
Mask duration (M)	3	220.3	1.80	ns
ISI (I)	1	3969.	7.30	ns
ICI (C)	1	.111	.002	ns
Subjects (S)	2	767.9	--	--
SxB	4	50.5	--	--
SxI	2	543.0	--	--
BxI	2	214.4	9.19	.05
SxC	2	73.4	--	--
BxC	2	30.55	7.13	.05
IxC	1	1.36	.195	ns
SxT	6	108.9	--	--
BxT	6	64.7	7.38	.005
IxT	3	174.4	4.61	.1
CxT	3	8.64	2.24	ns
SxM	6	122.2	--	--
BxM	6	7.79	.382	ns
IxM	3	252.4	4.85	.05
CxM	3	10.93	4.58	.1
TxM	9	28.12	4.00	.01
SxBxI	4	23.32	--	--
SxBxC	4	4.28	--	--
SxIxC	2	6.98	--	--
BxIxC	2	8.36	1.67	ns
SxBxT	12	8.76	--	--
SxIxT	6	37.7	--	--
BxIxT	6	21.28	9.17	.001
SxCxT	6	3.85	--	--
BxCxT	6	2.75	.82	ns
IxCxT	3	2.70	1.54	ns
SxBxM	12	20.4	--	--
SxIxM	6	51.98	--	--
BxIxM	6	3.93	.71	ns
SxCxM	6	2.38	--	--
BxCxM	6	2.33	.903	ns
IxCxM	3	3.69	1.03	ns

Appendix B - continued

Source	df=	MSS=	F=	p<
SxTxM	18	7.03	--	--
BxTxM	18	1.51	.316	--
IxTxM	9	25.22	6.57	.001
CxTxM	9	1.90	.726	ns
SxBxIxC	4	4.99	--	--
SxBxIxT	12	2.319	--	--
SxBxCxT	12	3.355	--	--
SxIxCxT	6	1.75	--	--
BxIxCxT	6	5.45	3.01	.05
SxBxIxM	12	5.54	--	--
SxBxCxM	12	2.58	--	--
SxIxCxM	6	3.58	--	--
BxIxCxM	6	3,78	3.01	.05
SxBxTxM	36	4.77	--	--
SxIxTxM	18	3.837	--	--
BxIxTxM	18	5.298	1.38	ns
SxCxTxM	18	2.622	--	--
BxCxTxM	18	1.77	.852	ns
IxCxTxM	9	3.123	1.29	ns
SxBxIxCxT	12	1.809	--	--
SxBxIxCxM	12	1.254	--	--
SxBxIxTxM	36	3.828	--	--
SxBxCxTxM	36	2.079	--	--
SxIxCxTxM	18	2.416	--	--
BxIxCxTxM	18	1.704	1.19	ns
SxBxIxCxTxM	36	1.424	--	--

Appendix C: Analysis of Variance Table - Proactive masking (frequency of reporting Stimulus 2) as a function of Configuration (number of contours), Target duration, Mask duration, ISI, and ICI.

N → N+1 contour sequence

Source	df=	MSS=	F=	p<
Configuration -borders- (B)	2	53.75	1.719	ns
Target (stim 2) duration (T)	3	97.15	4.647	.1
Mask (stim 1) duration (M)	3	8.144	5.112	.05
ISI (I)	1	177.7	5.608	ns
ICI (C)	1	.562	4.32	ns
Subjects (S)	2	36.17	--	--
SxB	4	31.27	--	--
SxI	2	31.69	--	--
BxI	2	35.31	1.65	ns
SxC	2	.130	--	--
BxC	2	.519	.005	ns
IxC	1	.173	.179	ns
SxM	6	1.59	--	--
BxM	6	2.52	1.703	ns
IxM	3	8.819	5.728	.05
CxM	3	.224	.750	ns
SxT	6	20.9	--	--
BxT	6	15.96	1.48	ns
IxT	3	93.94	4.62	.1
CxT	3	.831	3.28	ns
TxM	9	5.39	4.90	.005
SxBxI	4	21.29	--	--
SxBxC	4	1.104	--	--
SxIxC	2	.970	--	--
BxIxC	2	1.22	4.09	ns
SxBxM	12	1.48	--	--
SxIxM	6	1.539	--	--
BxIxM	6	2.88	2.25	ns
SxCxM	6	.299	--	--
BxCxM	6	.514	2.984	.1
IxCxM	3	.150	.477	ns
SxBxT	12	10.76	--	--
SxIxT	6	20.32	--	--
BxIxT	6	14.84	1.42	ns
SxCxT	6	.250	--	--
BxCxT	6	.403	2.448	.1

Appendix C - continued

Source	df=	MSS=	F=	p<
IxCxT	3	1.06	4.842	.05
SxTxM	18	1.10	--	--
BxTxM	18	1.55	1.896	.1
IxTxM	9	6.06	5.250	.005
CxTxM	9	.310	2.141	.1
SxBxIxC	4	.298	--	--
SxBxIxM	12	1.28	--	--
SxBxCxM	12	.172	--	--
SxIxCxM	6	.315	--	--
BxIxCxM	6	.475	2.949	.1
SxBxIxT	12	10.39	--	--
SxBxCxT	12	.164	--	--
SxIxCxT	6	.219	--	--
BxIxCxT	6	.248	1.864	ns
SxBxTxM	36	.817	--	--
SxIxTxM	18	1.15	--	--
BxIxTxM	18	1.88	1.978	.05
SxCxTxM	18	.145	--	--
BxCxTxM	18	.323	1.932	.05
IxCxTxM	9	.335	1.63	ns
SxBxIxCxM	12	.161	--	--
SxBxIxCxT	12	.133	--	--
SxBxIxTxM	36	.951	--	--
SxBxCxTxM	36	.167	--	--
SxIxCxTxM	18	.205	--	--
BxIxCxTxM	18	.308	2.343	.05
SxBxIxCxTxM	36	.131	--	--

Appendix D: Analysis of Variance Table - Proactive masking (frequency of reporting Stimulus 2) as a function of Configuration (number of contours), Target duration, Mask duration, ISI, and ICI.

<u>N+1 → N contour sequence</u>

Source	df=	MSS=	F=	p<
Configuration -borders- (B)	2	52.04	.769	ns
Target (stim 2) duration (T)	3	1030	9.269	.025
Mask (stim 1) duration (M)	3	197.3	5.665	.05
ISI (I)	1	1299.	11.89	.1
ICI (C)	1	28.00	29.80	.05
Subjects (S)	2	305.6	--	--
SxB	4	67.65	--	--
SxI	2	109.1	--	--
BxI	2	53.34	1.95	ns
SxC	2	.939	--	--
BxC	2	1.78	.387	ns
IxC	1	6.04	2.232	ns
SxM	6	34.84	--	--
BxM	6	5.387	.478	ns
IxM	3	51.93	14.08	.005
CxM	3	2.69	1.032	ns
SxT	6	111.1	--	--
BxT	6	25.58	1.09	ns
IxT	3	551.6	12.58	.01
CxT	3	10.74	29.05	.001
TxM	9	46.63	7.114	.001
SxBxI	4	27.33	--	--
SxBxC	4	4.610	--	--
SxIxC	2	2.707	--	--
BxIxC	2	.1185	.005	ns
SxBxM	12	11.27	--	--
SxIxM	6	3.688	--	--
BxIxM	6	6.185	1.663	ns
SxCxM	6	2.608	--	--
BxCxM	6	.7017	1.69	ns
IxCxM	3	4.945	2.876	ns
SxBxT	12	23.45	--	--
SxIxT	6	43.82	--	--
BxIxT	6	31.24	2.754	.1
SxCxT	6	.369	--	--

Appendix D - continued

Source	df=	MSS=	F=	p<
BxCxT	6	1.139	.719	ns
IxCxT	3	2.469	.906	ns
SxTxM	18	6.554	--	--
BxTxM	18	2.259	.581	ns
IxTxM	9	17.59	2.02	ns
CxTxM	9	1.807	1.126	ns
SxBxIxC	4	2.383	--	--
SxBxIxM	12	3.719	--	--
SxBxCxM	12	4.979	--	--
SxIxCxM	6	1.719	--	--
BxIxCxM	6	.6441	.858	ns
SxBxIxT	12	11.34	--	--
SxBxCxT	12	1.584	--	--
SxIxCxT	6	2.725	--	--
BxIxCxT	6	1.225	.931	ns
SxBxTxM	36	3.886	--	--
SxIxTxM	18	8.704	--	--
BxIxTxM	18	2.387	.800	ns
SxCxTxM	18	1.605	--	--
BxCxTxM	18	.529	.589	ns
IxCxTxM	9	2.830	4.228	.01
SxBxIxCxM	12	.751	--	--
SxBxIxCxT	12	1.316	--	--
SxBxIxTxM	36	2.986	--	--
SxBxCxTxM	36	.898	--	--
SxIxCxTxM	18	.669	--	--
BxIxCxTxM	18	.874	.783	ns
SxBxIxCxTxM	36	1.115	--	--