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Retinotopic and Spatiotopic Factors in Metacontrast:
The Role of Apparent Spatial Separation

Madeleine Côté

A Thesis

in

The Department

of

Psychology

Presented in Partial Fulfillment of the Requirements
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ABSTRACT

Retinotopic and Spatiotopic Factors in Metacontrast: The Role of Apparent Spatial Separation

Madeleine Côté

The relative roles of spatiotopic and retinotopic factors in metacontrast are confounded in most metacontrast paradigms because the pattern of retinal stimulation corresponds to the spatial layout of the physical stimulus. In the current experiments, the retinal and spatial variables were separated by embedding metacontrast stimuli within a pictorial scene containing the perspective elements of the Ponzo illusion, such that equal separations between mask and target appeared to be magnified in the background compared to the foreground presentation. Two measures were taken: (1) the amount of masking for a range of spatial separations and SOAs, and (2) an estimate of the magnitude of the size illusion produced by the picture for the same range of spatial separations. Experiment 1 was a calibration experiment. Experiment 2, which was the main study, used the most effective SOAs and spatial separations from Experiment 1. Results indicated that less masking was obtained for masks presented in the background than for masks presented in the foreground, possibly due to the magnification of the separation between target and mask at the background location. Therefore, metacontrast may involve levels of processing that take apparent spatial separation into account.

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Much of the information in our visual world has a spatial and temporal distribution, which leads to a variety of interactions among the various bits of information as they are processed by the visual system. One form of interaction, referred to as visual masking, is the reduction in visibility of one piece of visual information by another piece of visual information. Masking can refer to almost any situation in which one stimulus interferes with the perception of another stimulus. Specifically, visual masking is the phenomenon in which the visibility of a target stimulus is reduced by presenting a second stimulus, the mask, in close spatial and temporal contiguity to the target stimulus. For example, if one presents a disk for a brief duration followed by a concentric ring, then the disk may be less visible than if it were presented alone.

For many years, visual masking has played a leading role in the study of spatial and temporal properties of visual perception and in determining the temporal stages and parameters of these perceptual processes. In attempting to explain visual masking, many hypotheses were proposed. Two main theories of masking were the integration hypothesis, which describes masking as the result of an integration of the target and masking stimuli, and the interference hypothesis, which attributes masking to interference between the target and the mask.

Metacontrast refers to the reduction in the visibility of one briefly presented stimulus, the target, by a spatially adjacent and temporally succeeding second stimulus referred to as the mask

(Breitmeyer, 1984). It is a specific type of the more general backward masking paradigm, where the target and the mask stimuli do not have overlapping spatial contours. Metacontrast varies depending on temporal and spatial variations of the stimuli.

Temporal variables of metacontrast

The time difference between the onset of the target stimulus and the onset of the masking stimulus is known as the stimulus onset asynchrony (SOA). Variations of different stimulus parameters will produce two types of SOA metacontrast functions: Type A and Type B. The Type A function, described as a monotonic function, exhibits maximum masking with simultaneous onset of target and mask (SOA = 0) and decreases as the SOA increases. The Type B function, described as a U-shaped or nonmonotonic function, typically increases to maximum masking at an optimal SOA of 50 to 75 ms and drops again as the SOA increases. The temporal interaction between the target and the mask is influenced by factors such as task parameters, criterion content and physical intensity of the stimuli. Generally a monotonic (Type A) function will be obtained under the following conditions:

1. If the mask energy is greater than the target energy (Breitmeyer, 1978; Kolers, 1962; Weisstein, 1968, 1972);
2. If the task is a target detection task (Ericksen, Becker & Hoffman, 1970; Lefton, 1973; Schiller & Smith, 1966).

On the other hand, nonmonotonic (Type B) functions can be obtained if:

1. The energy of the mask and target are almost equal (Alpern, 1953; Breitmeyer, 1978; Kolers & Rosner, 1960; Stewart & Purcell, 1974; Weisstein, 1968);

2. The target energy is adjusted to some standard in order to obtain the response measure (Alpern, 1953; Ericksen et al. 1970; Lefton, 1973; Schiller & Smith, 1966);
3. The mask interferes with the target's contour, or shape (Burchard & Lawson, 1973; Werner, 1935) or its figural identity (Weisstein & Haber, 1965).

Variations of the target and mask properties or the performed task, will thus influence the shape of the SOA function. The occurrence of two different SOA functions suggests the involvement of different levels of processing.

Spatial variables of metacontrast

Metacontrast is also influenced by spatial variables such as mask and target shape similarity, mask and target orientation, distance between mask and target contours, contour sharpness and retinal locus of stimulation. These variables affect the magnitude of masking, by either increasing or decreasing masking, and in some cases influence the shape of the masking function.

The general effect of similarity between mask and target is that masking declines as similarity decreases (Fehrer, 1966; Sekuler, 1965). Uttal (1970) found strong masking for forms with similar shapes and little masking when shapes differed. Sekuler (1965) found similar results for stimulus orientation. He showed that masking was related in a precise way to the relative orientations of the test and masking contours.

The effects of spacing between the mask and target indicate that masking declines as the distance between target and mask contours increases (Cox & Dember, 1971; Growney & Weisstein, 1972; Lefton, 1973; Werner, 1935). Research has shown that the most effective part of the mask is the part immediately adjacent to the target, which explains why masking decreases as the mask moves farther away from the target. Growney (1976) showed that the interaction between the target edge luminance and the mask edge luminance is also important. He found that masking occured only for target stimuli with sharp or exaggerated edges while no masking was obtain for targets with gradual or blurred edges. In the same study, the width of the mask was a critical variable in the target-mask spacing effects.

Experiments that investigated the retinal locus of stimulation generally indicated that masking increases as the eccentricity of the retinal locus of stimulation increases and that masking is a function of the separation between target and mask and dimensions of the stimuli (Alpern, 1953; Bridgeman & Leff, 1979; Kolers & Rosner, 1960; Stewart & Purcell, 1970; 1974; Weisstein & Haber, 1965; Weisstein, 1966). Kolers and Rosner (1960) found foveal metacontrast only for small separations between target and mask. By contrast, masking with large separations, up to 2 deg of visual angle, can occur in the periphery of the retina (Alpern, 1953; Growney & Cox, 1977). Bridgeman and Leff (1979) showed that, in the fovea, large brightness metacontrast effects can be obtained only with small targets and masks. As the widths of these stimuli increased, foveal metacontrast decreased, unlike parafoveal and peripheral metacontrast which did not decrease with increasing target and mask dimensions.

Peripheral and central processing

Whether masking is a peripheral or a central process has been a main focus of investigations in visual masking research. The problem is to understand whether masking occurs at an early stage in visual information processing or at a more central stage. Distinctions between peripheral levels and more central levels should first be made before elaborating on the site of masking. These terms are a convenient way of describing two separate levels which involve different processes. They are, however, loaded terms for they give the impression of a clear boundary when, in fact, they should rather be seen on a continuum, one level gradually merging into another level. The distinction between the two levels is not an anatomical one, but rather a functional difference between the neural processes and the type of information processed by these levels. The definition of the peripheral levels, also referred to as retinotopic levels, involves the level where the visual information is sensory in nature and is processed according to retinal topology. On the other hand, central levels of processing may be spatiotopic; they are levels where the retinotopic information has been transformed into spatial or environmental coordinates. This level thus involves the perception of the stimuli within the observer's visual world. These two broad levels of visual processing can be set in relation to Uttal's (1981) taxonomy of levels of visual processes. His taxonomy combines 5 levels: (1) a level where the activity is attributed to photoreceptors; (2) a level where the activity is related to neural network interactions, isomorphic to the retinal topology; (3) a level based on spatial and figural organization but still based on retinal distribution of the information; (4) a level involving highly complex neural mechanisms where the information is nonisomorphic to the retinal topology, and multidimensionnally organized; (5) a level where the information is subject to active cognitive manipulations. Level 1, 2 and 3 of Uttal's taxonomy would correspond to peripheral levels of processing, while level 4 and 5 would correspond to central levels of processing.

Several investigators have argued that metacontrast effects were not simply due to interactions between target and mask contour-forming processes at a peripheral level, but are due to more central processes which are involved in the identification of the stimulus. Uttal (1971) stated that because form similarity is a necessary criterion to obtain metacontrast, this phenomenon must involve high level recognition functionsand not simply interactions based on proximity of contours. Uttal reported that facts such as interaction among the stimuli only when they were overlapping in the visual field, no masking of the target when a second masking stimulus followed the first, and the presence of dichoptic masking indicate that masking cannot be explained by lateral inhibition alone, but must also involve higher cognitive mechanisms. Kahneman (1967) suggested that masking effects involved higher levels of the visual system because metacontrast was closely linked with apparent motion. According to Turvey (1973) a critical variable in dichoptic masking by pattern is the SOA and not the target/mask energy ratio. Such results point therefore toward central neural processing because the more centrally a cell is located, the more it will respond to identification information such as form and size rather than simple energy characteristics of the stimuli. When the interaction between target and mask is localized in a central processor, Turvey believes that the interaction can be of two sorts: interaction of one stimulus on the other stimulus, or interaction with the operation of a central processing mechanism. These are a few lines of evidence that argue for the involvement of central processes in metacontrast.

However, most neurophysiological models of visual masking are highly sensory-specific and thus retinotopically organized. This belief is based on the fact that metacontrast is highly sensitive to contour separation, which argues for its occurring at an early stage of visual processing in which retinotopic information is still present. In this context, theoretical models based on peripheral levels of visual information processing have emerged, and several neurophysiological models of metacontrast have been proposed. All of these models are based on quantitatively defined interactions between excitatory and inhibitory neural processes. Weisstein (1968; 1972;) and Weisstein, Ozog & Szoc (1975) have proposed a model composed of a network of interacting neurons where both excitatory and inhibitory processes. The model is a Rashevsky-Landahl neural net model. Bridgeman (1971) has developed a second neural model, the Ratliff neural net, which is based upon lateral inhibitory interactions found in the eye of the horseshoe crab. Bridgeman's model is based on a single-channel approach where masking in the lateral inhibitory network does not suppress the target, but links it to the activity of the mask thus altering the persistence of the target. The third model, developed by Breitmeyer and Ganz (1976), is a dual-channel neural model. This approach relies on different spatiotemporal response properties of sustained and transient channels. Similar models, relying on lateral inhibition as the main process underlying metacontrast, have been proposed (Matin, 1975; Navon & Purcell,1981; Reeves,1982).

A spatiotopic form of masking.

Neurophysiological models are based mainly on studies of static vision in which retinal location of stimulation was confounded with the visual-display location. During fixation, there exists a one-to-one relation between the spatial environmental coordinates and the retinal coordinates of the visual patterns thus confounding the retinotopic and spatiotopic levels of the neural representations of the pattern. Therefore, masking cannot be explained by retinotopic contour-forming interactions alone without first studying the two levels of representations separately and their interaction.

The important problem posed by the above considerations is: Which aspect plays a more critical role in masking—whether the target and mask fall on the same place on the retina or whether they appear to fall in the same place in the visual world of an observer? If one finds that metacontrast is stronger when the target and mask stimulate different parts of the retina rather than when their retinal images are either overlapping or proximal, how can it be explained by retinotopic interactions? It is possible that retinotopic masking may not be the only type of masking and that spatiotopic masking, of more central origin, does exist. There would then be at least two forms of visual masking, one of which is less central and retinotopically organized and one that is centrally located and spatiotopically organized. These two different forms of masking may play different roles in visual information processing.

A spatiotopic form of masking has been investigated in several studies (Breitmeyer, Kropfl & Julesz, 1982; Ritter, 1976; White, 1976). Some of these studies, Breitmeyer et al. and Ritter, were designed to determine the role of masking in saccades. White's study was designed to study masking during pursuit motion. All used eye movement techniques to separate retinal and apparent or display location of stimulation. Perhaps a distinction between display location and apparent spatial location should be made here because some of these studies used the same display location of stimulation while others used the same apparent location. Display location refers to the actual environmental coordinates where a stimulus would be presented while apparent spatial location does not necessarily refer to the actual environmental coordinates but to the perceived coordinates which may not correspond to the real spatial coordinates. In the latter case, the two stimuli could appear to be presented at the same spatial location when in fact they are not. For example, in dynamic vision, when one is fixating a moving dot, dots presented in peripheral vision, may be perceived as farther away than they actually are.

White (1976) attempted to determine what would happen to metacontrast if he separated the perceived coordinates from the retinal coordinates. He found more masking when the target and the mask appeared to be in the same spatial location than when they stimulated the same retinal location but different spatial locations. Moreover, metacontrast was stronger for stimuli separated on the retina by almost one deg than stimuli that were separated by only a few minutes of arc. These results suggested that some masking is centrally located and therefore spatiotopically organized.

Ritter (1976) showed that one can obtain temporal integration of brief double light flashes, one presented prior to, and the other just after a saccade, when the flashes have the same environmental display coordinates but different retinal coordinates. Similar results have been reported by Breitmeyer et al. (1982). These authors attempted to determine whether ~~two~~ segregated patterns, flashed in two separate frames, would temporally integrate to become one pattern when flashed on the same environmental location but different retinal locations. The study included four conditions: two with static vision and two with a saccade between the two frames. No significant amount of integration of the two frames was found in the static viewing conditions either when the two flashes occupied the same retinal location and the same display location or when the flashes occupied different retinal locations and different display location. Thus under static viewing, the persistence did not last long enough to combine with the persistence of the next flash even when the flashes were presented on the same retinal area. However, when the flashes where separated by a saccade and presented on different retinal locations but on the same display location, integration of the flashed pattern occured. This integration was not found under the saccade condition where the two frames were flashed on the same retinal location but disparate display locations. According to the authors, these results point toward the existence of a spatiotopic form of masking.

The effect of spatial location has also been studied in situations involving techniques other than eye movement. One technique used was to vary the depth plane in which the mask and target are presented (Lehmkuhle & Fox, 1980; Patterson & Fox, 1985). The rationale in these studies is that if changing the perceived depth of contours changed the metacontrast function, then it would suggest that more central levels are involved in the interaction process. The depth manipulation was accomplished by using stereoscopic contours generated from dynamic random-element stereograms. Results showed that depth separation was a critical factor in metacontrast. When the mask was displaced in depth farther away from the target, masking declined with increasing depth separation. When the depth separation was reversed, and the mask was closer to the observer, masking did not decrease but actually increased at some SOAs. The authors suggested that when stimuli lie in different planes, the one that is positioned in front of the others and thus closest to the observer is processed preferentially by the visual system. The process of stimulus selection thus explains why more masking is obtained when the mask is presented in front of the target. These results suggest that a model of masking explaining the contour effects in terms of lateral inhibition alone is not sufficient.

Apparent spatial separation

In the present study, a different technique was used to separate retinal and apparent location of stimulation in order to further study whether spatiotopic form of maskings do exist. An eye movement technique was not used, because such a technique requires accurate monitoring of eye position and may involve extraretinal factors in saccadic suppression, which are not directly related to metacontrast. To manipulate spatial and retinal variables independently, metacontrast stimuli were embedded in a pictorial scene that contained the perspective elements of the Ponzo illusion. This created a perceptual illusion such that the separation between stimuli in the background of the scene appeared to be magnified in comparison to the separation between stimuli presented in the foreground. The main experimental question was whether less masking would be obtained at the background location if the apparent separation between target and mask was magnified by the pictorial depth cues.

The Ponzo illusion represented in Figure 1 is a size illusion in which the top line may appear longer than the bottom one although the lines are the same length. Many explanations have been proposed for geometric illusions such as the Ponzo illusion. Gregory's (1963) theory assumes that a two-dimensional figure is treated as a three-dimensional form. According to Gregory, some figures are illusory because they contain depth cues capable of automatically triggering the size constancy mechanism independently of the perceived relief. Gregory calls the mechanism that produces geometric illusion, the depth-cue-scaling mechanism. Leibowitz, Brislin, Perlmutter and Hennessy (1969) supported this hypothesis by showing that when more depth cues are added (such as texture or photographic depth cues) the strength of the illusion increased. Other studies by Gogel (1975) and Schiffman and Thompson (1978) have shown that depth cues are a critical

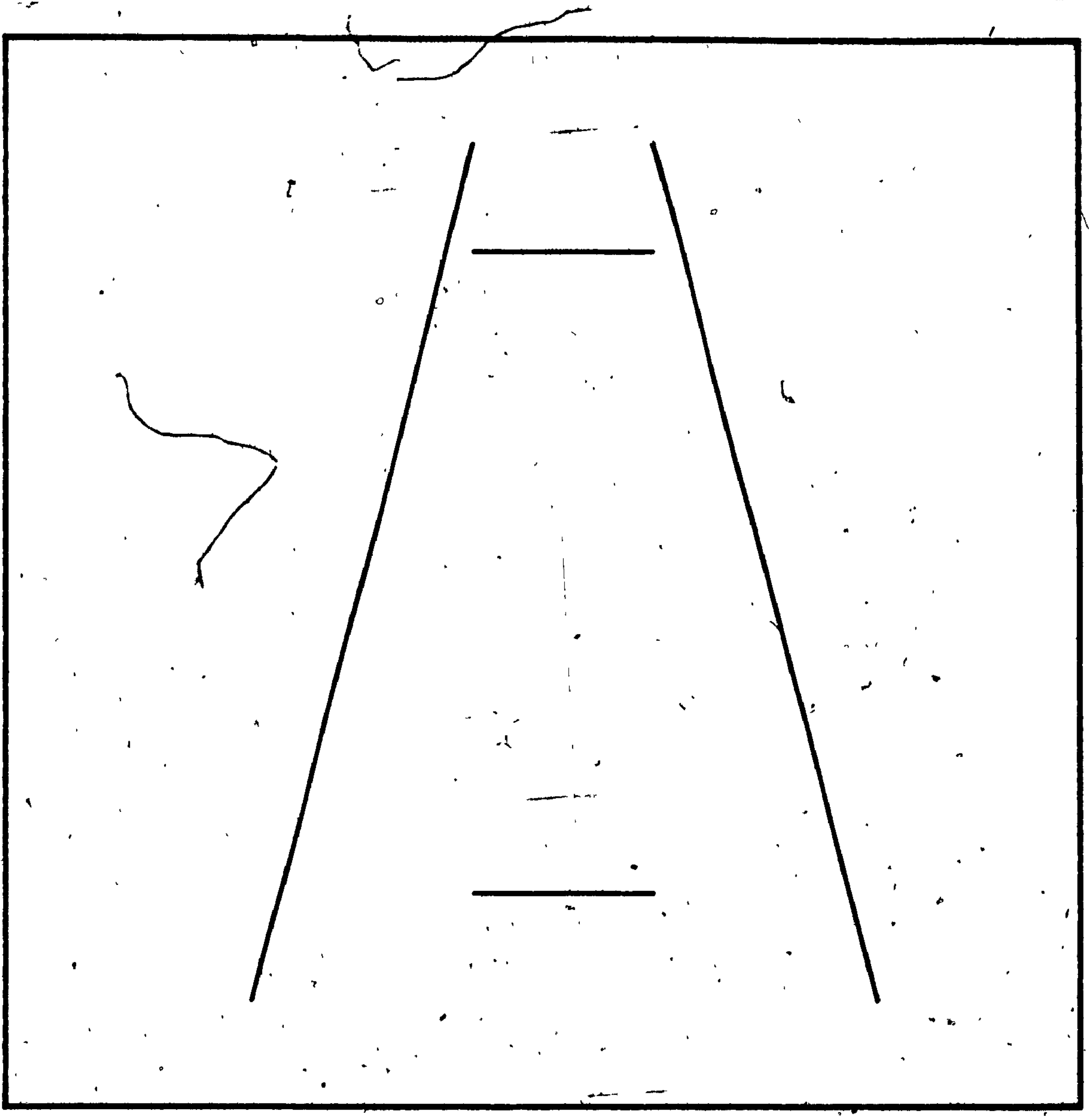

Figure 1. The Ponzo illusion. The top horizontal line appears to be longer than the bottom line even though the lines are of equal length.

variable for eliciting the illusion. Therefore, it appears that the perceived relations between the components of the Ponzo figure play a prevalent role in producing the illusion.

Due to the pictorial depth effect produced by the Ponzo illusion, identical physical and, thus, identical retinotopic separations between targets and masks would be perceived differently depending on whether they were presented in the background or the foreground of the picture. If the occurence of metacontrast masking is dependent upon the apparent separation between the contours of a target and mask configuration, then less masking should occur when the configuration is presented in the background because of the greater apparent separation between the contours of the target and mask.

The design of the experiment was as follows. A photographic transparency of a railroad track scene was projected directly onto a video monitor. Computer-generated stimuli were presented on the monitor either at the foreground location or the background location of the scene. During the experiment, two measures were taken: (1) the amount of masking for a range of spatial separations and a range of SOAs; (2) the magnitude of the illusion produced by the picture for the range of spatial separations used with the masking measure. Experiment 1 was a calibration experiment with a wide range of SOAs and spatial separations to determine which SOAs would produce maximum masking and which separations would produce sufficient illusion at the same time as maximum masking. Experiment 2 used the most effective SOAs and spatial separations from Experiment 1 to test the main hypothesis, that is, that less masking was expected at the background location due to the greater apparent separation between the contours of the target and mask.

Experiment 1

Method

Subjects. Four university students served as paid observers in this experiment. All were naive as to the purpose of the study. The observers were selected according to four criteria: (1) having 20/20 or corrected visual acuity, (2) obtaining an overall magnitude of illusion of at least 10 per cent, (3) scoring at least 70 per cent correct on the baseline trials in which the target alone is presented, and (4) obtaining an overall amount of masking of at least 5 per cent. Ten subjects were tested in order to obtain the four subjects that met the criteria.

Apparatus. The stimuli were generated by an Apple //e microcomputer with a color video monitor (Amdek Colour II Plus). The system controlled the size, location, duration, spatial separation and temporal separation for all stimuli. The railroad track scene (see Figure 2) was projected from a slide projector directly on the color monitor screen, which reflected a sharp and clear picture. Visual acuity was assessed by a standard Bausch and Lomb vision tester (Model 14019).

Stimuli. The masking stimulus consisted of two vertical bars, 60 min high and 2 min wide, presented on either side of the target and at equal distances from the target. The target was a single vertical bar identical to the mask except that it had a gap of approximately 1.2 min positioned either in the middle, near the top or near the bottom of the bar. These stimuli are presented in Figure 2. The monitor screen luminance was adjusted for each subject according to their accuracy in

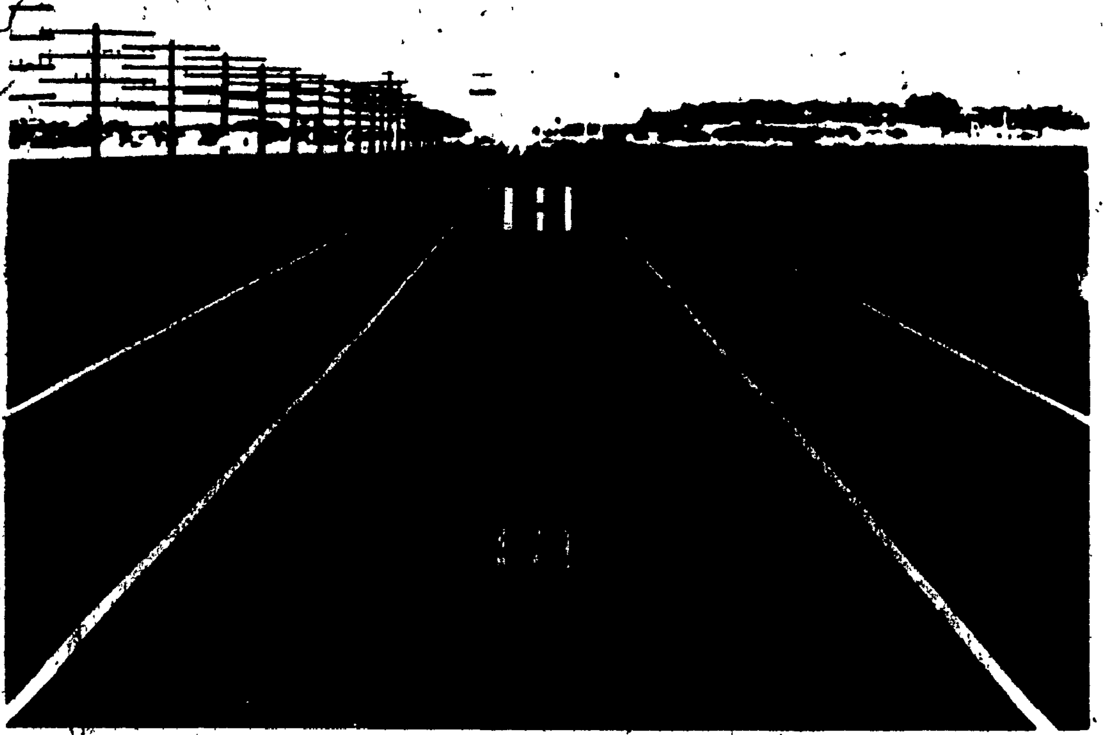

Figure 2. Metacontrast stimuli. These stimuli were embedded in a pictorial scene that magnified the separation presented at the background location as compared to the foreground location as in the Ponzo illusion.

a practice session. To ensure a sufficient amount of masking the luminance was reduced when the task became too easy. Decreasing the screen luminance reduced equally the luminance of the target and the mask. The background luminance (luminance of the railroad track scene projected on the screen) was .28 cd/m^2 and the average luminance of the stimuli was .18 cd/m^2. The luminance contrast ratio between the background luminance and the average luminance of the stimuli was .391 (Michelson contrast ratio). The luminance contrast ratio slightly varied at the near and far locations. Given that the background was darker at the far location, the luminance contrast between stimuli and background would be higher at that location than the near location. The exposure duration was less than 17 ms for the target and approximately 51 ms for the mask; thus the target/mask energy ratio was approximately 1/6 which refers to the energy ratio of one target line for one video frame to the energy of two masking lines for 3 video frames. The exposure duration of the stimuli are estimates based on the video frame rate available from the computer. The exact duration of the target was the time taken by the video monitor to draw the vertical line, composed of nine points, estimated as less than 1 ms, plus the duration of the phosphoresence of the screen. The actual mask duration is estimated as about 34 ms plus the screen persistence. The mask and target display were presented at either one of two locations: the far location was situated in the center of the tracks just below the horizon and the near location was in the center of the tracks near the bottom of the screen, as shown in Figure 2. The viewing distance to the monitor screen was 57 cm. The railroad track scene was projected at all times on the monitor screen.

The separation match measure used a different procedure than the masking measure. However, the setup remained the same: The background luminance, the stimulus luminance, the location of the stimuli, and the viewing distance were the same as in the masking procedure. The stimuli for this task were two vertical bars identical to the mask. The duration of the stimuli was 0.5 s at the near location and a variable amount of time at the far location depending on how much time the subject took to make the match.

Procedure. A three-alternative forced-choiced task was employed in the masking procedure. The observer's instruction was to identify the position of the gap found in the target. The observer indicated the top, middle or bottom position by pushing one of three buttons. For each trial a small fixation cross would appear on the monitor to indicate which location the subject was to fixate. Following the cross, the target was presented. It was followed by the mask except in the no-mask condition. The experiment consisted of 42 sessions of 60 trials each in which the various separations, SOAs, gap positions and locations were randomly varied. Each mask and target combination was presented at 9 spatial separations measured from the center of the target to the inside edge of the mask: 14, 19, 24, 29, 35, 41, 46, 59, and 65 min of arc. Six SOAs: 17, 34, 51, 68, 85, and 102 ms. The total number of stimulus conditions was 360, 6 SOAs x 2 Locations x 10 Separations (including the no-mask baseline) x 3 Target gap positions. Each block of 6 sessions included 3 trials per separation per location and 18 baseline trials per location. Over the whole experiment each location had 21 trials per separation and 126 baseline trials. All observers were tested for no more than 2 hours per day, with at least half an hour break within the 2 hour block. Each hour of testing contained 4 sessions with a few minutes break in between.

The magnitude of illusion was estimated by a separation adjustment task. Observers adjusted the width of the far stimuli to match the width of the near stimuli. A small fixation cross was presented at the near location before the vertical lines, which appeared for 0.5 s at one of the 9 separations used in the masking task. The stimuli were then presented at the far location and the subject's task was to adjust the separation of these stimuli to match the separation of the stimuli previously seen at the near location, using a joystick. For each trial, the separation was randomly varied. This measure was taken four times as the masking sessions progressed: at the beginning of the masking sessions, after session 14, after session 28 and at the end of the masking sessions. Each session consisted of 72 trials, and over the four sessions, each separation was tested for a total of 32 trials.

Results

Illusion results. The separation adjustment results were analysed as differences between the matching width score and the constant width of the comparison stimulus. This difference, represents the actual amount of overestimation of the matched separation, done at the far location, referred to as the magnitude of illusion. A two-way repeated-measure analysis was done of the main variables, session and separation. The ANOVA summary table is shown in Table A-1 in Appendix A. Table B-1 in Appendix B shows the means and standard deviations.

The illusion results, shown in Figure 3, revealed that subjects adjusted the widths of the far stimuli significantly smaller than the comparison width presented at the near location. The separation main effect was significant at ($\underline{F}(8,24) = 2.702$, $\underline{p} < .028$). Paired comparisons, using Tukey's honestly significant difference (HSD) method, indicated only one significant difference among the separations: The illusion for the separation of 14 min of arc was significantly less than the separation of 65 min of arc ($p<.05$). The session main effect was not significant, which implies that the amount of illusion did not change appreciably from one session to the next.

Masking results. The masking analysis was done on differences from baseline scores. The data represented in Figure 4 and 5 are the difference scores expressed as percentage average over 21 trials. The analysis of variance, summarized in Appendix A-2, is a three-way repeated-measures design of the main variables, SOA, location, and separation. Table B-2 of Appendix B shows the means and standard deviations. The overall mean error rate was 11.7 per cent of 21 trials.

The masking results revealed that the magnitude of masking varied between SOAs, and between separations. Figure 4 indicates that relatively more masking occurred at 17 ms SOA and that as the SOA increased, the masking leveled off. The SOA main effect was significant ($\underline{F}(5,15) = 6.88$, $\underline{p} < .0016$). Paired comparisons using Tukey's HSD method indicated that the shortest SOA, 17 ms, produced significantly more masking than the longer SOAs. Figure 5 indicates that most masking is produced at the shortest separations and as the separations increase less masking was found except for the two widest

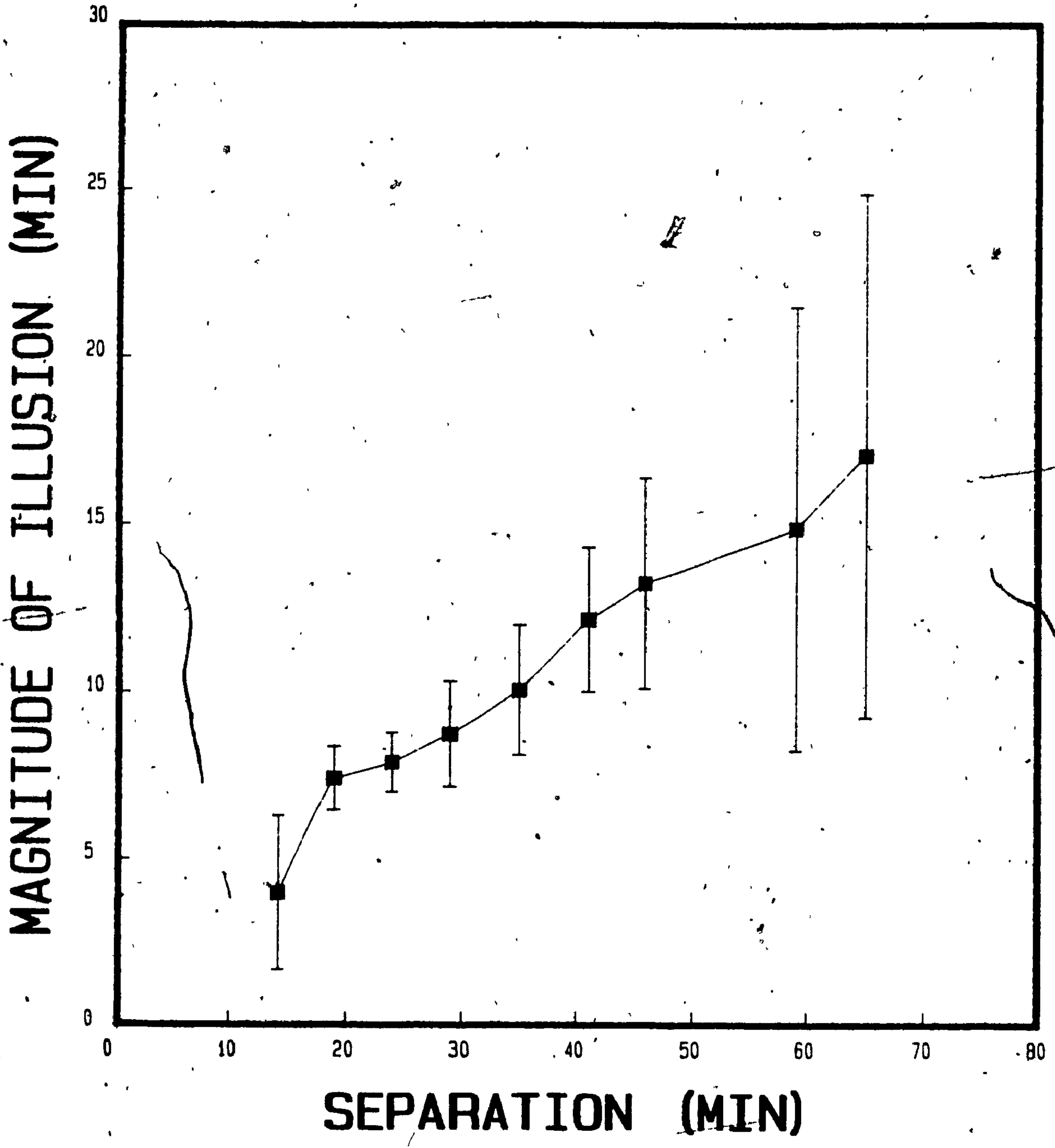

Figure 3. Magnitude of illusion as a function of spatial separation in Experiment 1. Standard error bars are shown.

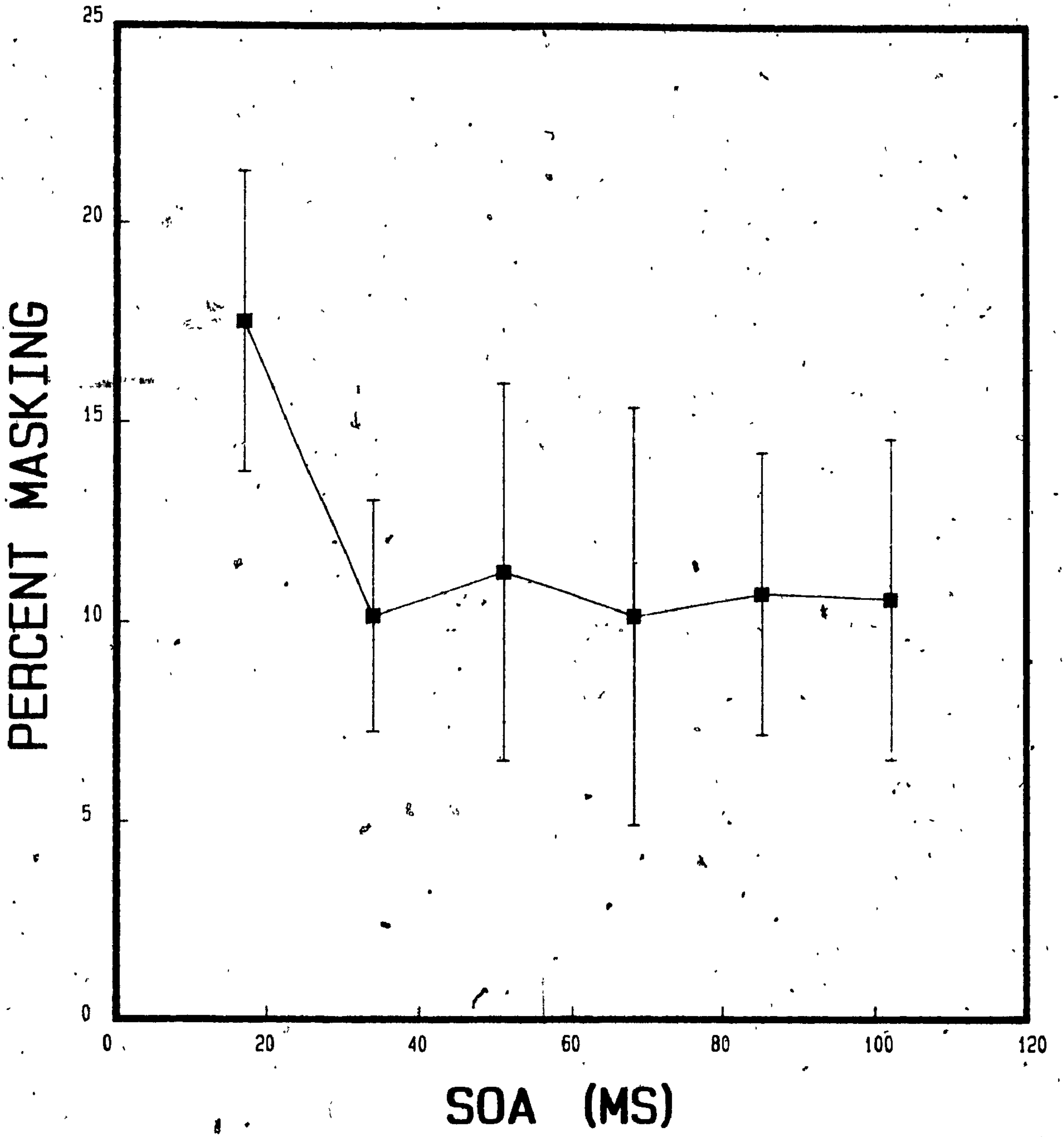

Figure 4. Percent masking as a function of stimulus onset asynchrony (SOA) in Experiment 1. Standard error bars are shown.

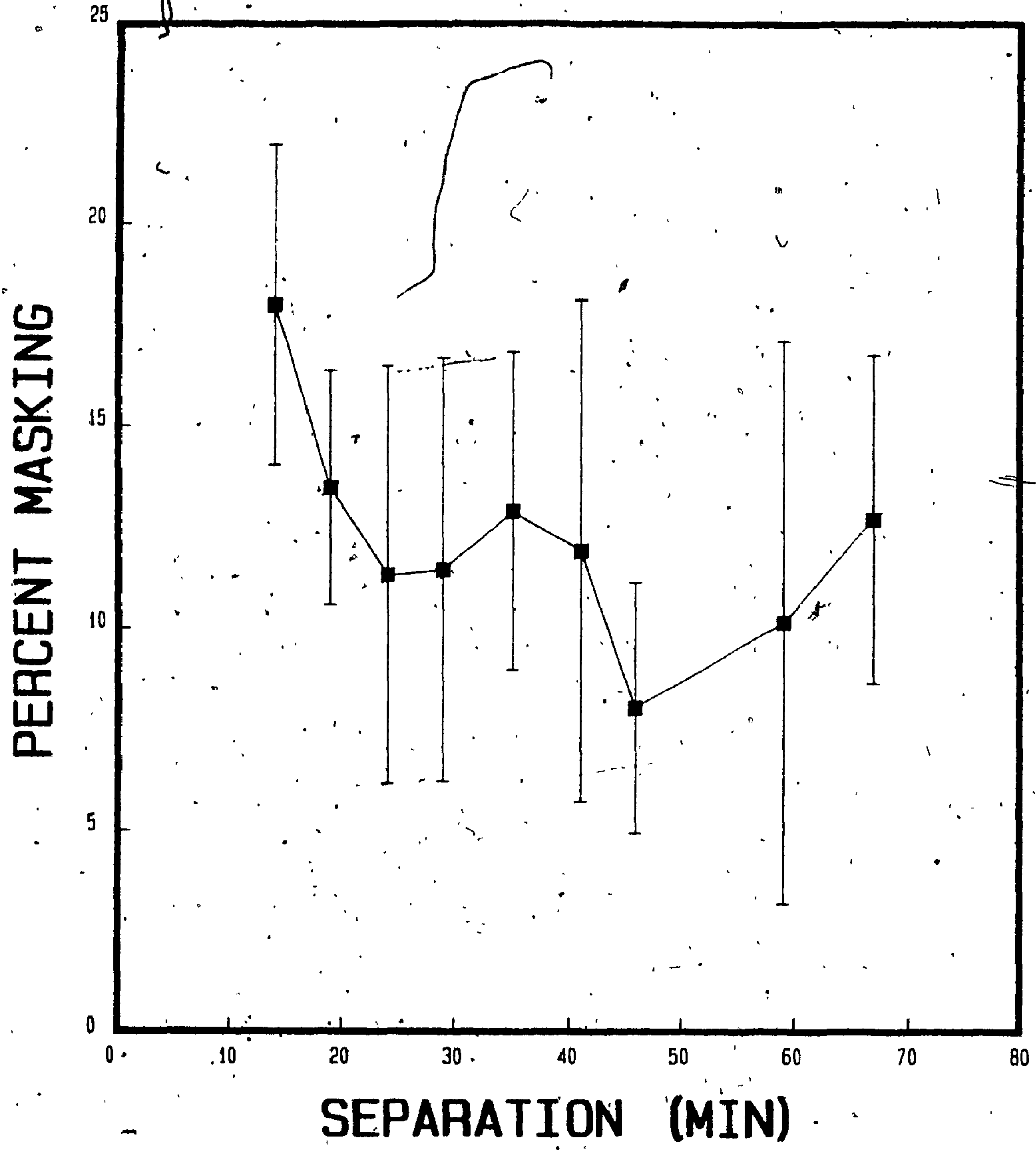

Figure 5. Percent masking as a function of spatial separation in Experiment 1. Standard error bars are shown.

separations where masking increases again. The separation main effect was significant ($F(8,24) = 2.53$, $p < .0372$). Paired comparisons with the HSD test reveal that the separation of 14 min, where the most masking is produced, differs only from the separations 46, 59 and 65 min of arc. Thus what the results showed is that optimal masking occurred when the mask followed the target by 17 ms and when the intercontour distance between the mask and the target was 14 min of arc. The location main effect was not significant, nor were any of the interactions.

Experiment 2

Experiment 1 showed that the most masking was produced at the shortest SOA and the smallest separation. Experiment 2 used only the three shortest SOAs and the five smallest separations in order to maximize the masking effect. Moreover, a between-subjects variable was introduced whereby half the subjects were assigned to a condition in which the railroad track scene was projected on the screen and the other half were assigned to a no-picture condition.

As indicated before, the far location was expected to yield less masking than the near location, due to the apparent separation of the contours. Such results would imply that the difference in the magnitude of masking between the two locations was due to the apparent separation, not the retinal separation. In order to test this assumption, it was necessary to verify whether the masking difference between the two locations would be absent if the apparent separations were the same for the two locations. To reduce the illusion, a condition without the picture was introduced where the expected masking functions of the two locations should be similar. The separation match task was expected to show relatively little illusion without the picture, although some illusion was anticipated due to a relative elevation effect at the far location. Objects higher in the picture plane tend to be seen as bigger, and the separation match measure could show some of this effect.

Method

Subjects. The subjects for this experiment were 20 university students. Each group, picture and no-picture, had 10 subjects. They were selected according to the same criteria used in Experiment 1 except that the masking criterion required an overall amount of masking of at least 10 percent instead of 5 percent. Thirteen subjects were tested in the picture condition to obtain the 10 subjects that met the criteria, while in the no-picture condition, the first 10 subjects tested met the criteria.

Procedure. The apparatus and stimuli were the same as in Experiment 1. The luminance contrast ratio between the background luminance and the average luminance of the stimuli, in the picture condition, was, as in Experiment 1, .391. In the no-picture condition, the background luminance of the screen was .00013 cd/m^2 and the average luminance of the stimuli was .026 cd/m^2. The luminance contrast ratio between the background luminance and the average stimuli luminance was, for this picture condition, 1.00. The masking procedure consisted of 8 sessions of 108 trials each. The first session was a practice session. Each mask and target combination was presented at 5 spatial separations (14, 19, 24, 29, and 34 min of arc) and at 3 SOAs (17, 34, and 51 ms). The total number of stimulus conditions was 108, 3 SOAs x 2 Locations x 6 Separations (including no-mask baseline) x 3 Target gap positions. The 7 data collection sessions included a total of 21 trials per separation per location and 63 baseline trials per location. As in the first experiment, each observer was tested for no more than 2 hours a day with at least half an hour break in between the two hours. Each hour of testing contained 3 sessions.

The magnitude of illusion was measured three times as the masking experiment progressed for both the picture condition and the no-picture condition. The first measure was taken at the beginning of the experiment, the second after the third masking session and the third at the end of the experiment. The comparison widths presented at the near location were the 5 separations used in the masking task. Each session consisted of 80 trials, and over the three sessions, each separation was tested for a total of 48 trials.

Results

The dependent variables were the same as in Experiment 1: illusion magnitude and masking. Both the illusion results and the masking results resembled the results obtained in Experiment 1.

Illusion results. The analysis performed on this measure was identical to the analysis performed in the previous experiment, with the addition of the picture condition. The ANOVA summary table is shown in Table A-3 in the Appendix A. Moreover, a summary of the means and standard error deviations is shown in Table B-3 in Appendix B.

The general results for the magnitude of illusion indicate that matching widths were less than the comparison widths. Figure 6 shows that as separation increases up to 29 min, the illusion increases gradually, then decreases at 34 min. There were main effects of separation ($F(4,72) = 79.14$, $p < .0001$) and picture condition ($F(1,18) = 31.14$, $p < .0001$). Paired comparisons by Tukey's HSD test revealed that the illusion was significantly greater than zero at all separations ($p<.05$). Figure 6 also shows that the picture condition produced more illusion than the no-picture condition. The no-picture condition produced an overall illusion, in min, of 7.58 min while the picture condition had an overall illusion of 12.74 min. Thus the no-

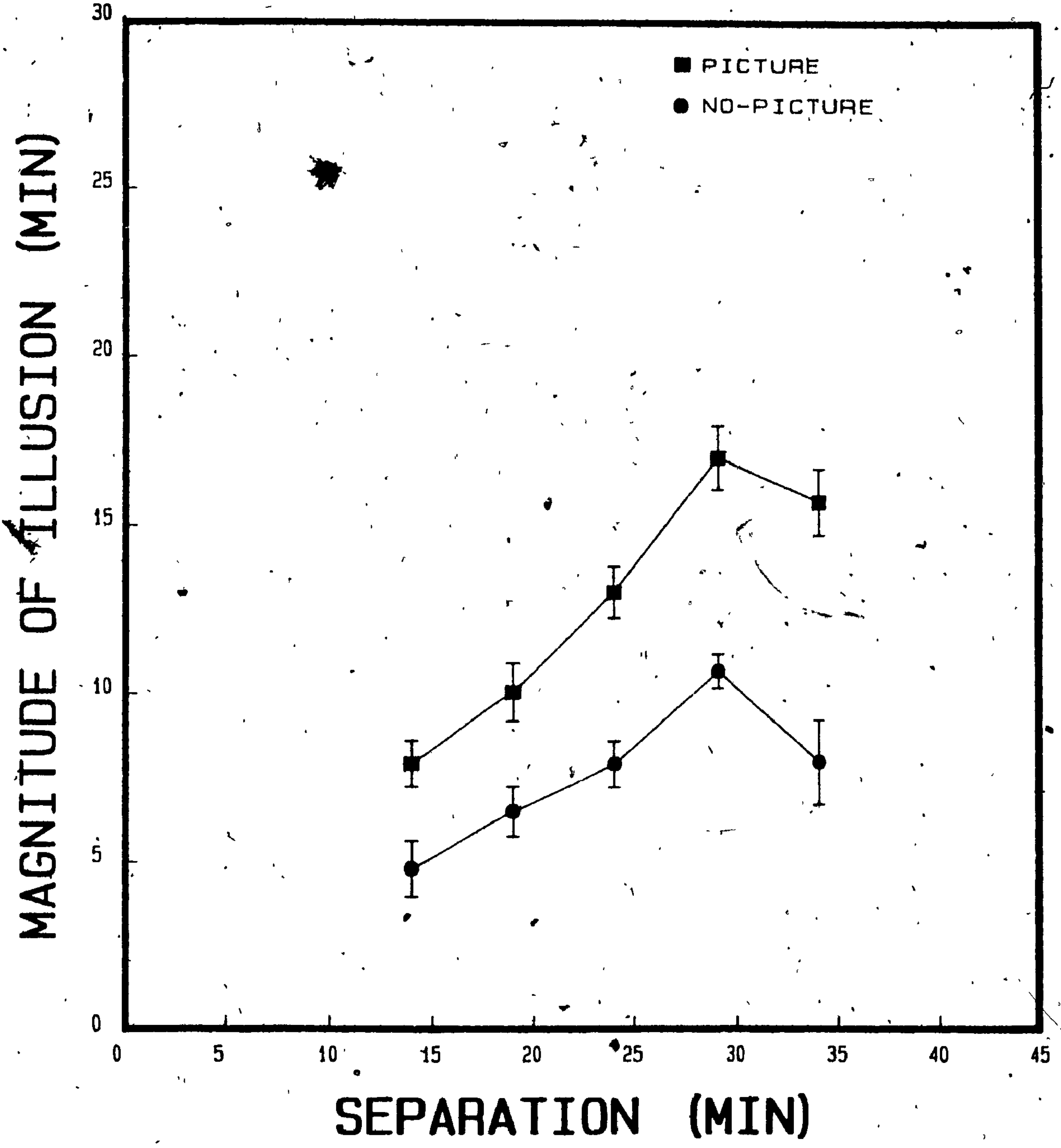

Figure 6. Magnitude of illusion as a function of spatial separation for both picture conditions in Experiment 2. Standard error bars are shown.

picture condition produced a significantly smaller illusion than the picture condition.

The main effect of time of testing was not significant, which implied that the amount of illusion did not change over time. However, depending on the time of testing, variations among the magnitude of illusion occured at some separations. This interaction was significant ($F(8,144) = 4.67$, $p < .0001$), as was the three-way interaction among time of testing, separation, and picture condition ($F(8,144) = 2.35$, $p < .0210$). Paired comparisons (HSD test) indicate that for each session the largest separations generally differed from separation 14 and 19 min of arc. These results, plotted in Figure 7 show an increase in magnitude of illusion as the separation increases for all sessions. For all sessions, the magnitude of illusion decreased at the largest separation.

Masking results. The analysis performed on the masking results was a three-way analysis of variance on three factors (SOA, location and separation), with one between-subjects condition (picture condition). The ANOVA summary table is shown in Table A-4 in Appendix A and the means and standard deviations are shown in Table B-4 in Appendix B. The data represented in the masking Figures are the difference scores expressed as percentage of 21 trials.

The SOA and separation main effects produced monotonic functions similar to Experiment 1. More relevant to the main issue was the difference between the picture and no-picture condition for the location by separation interaction. More masking was obtained at the near location for the picture condition compared to the no-picture

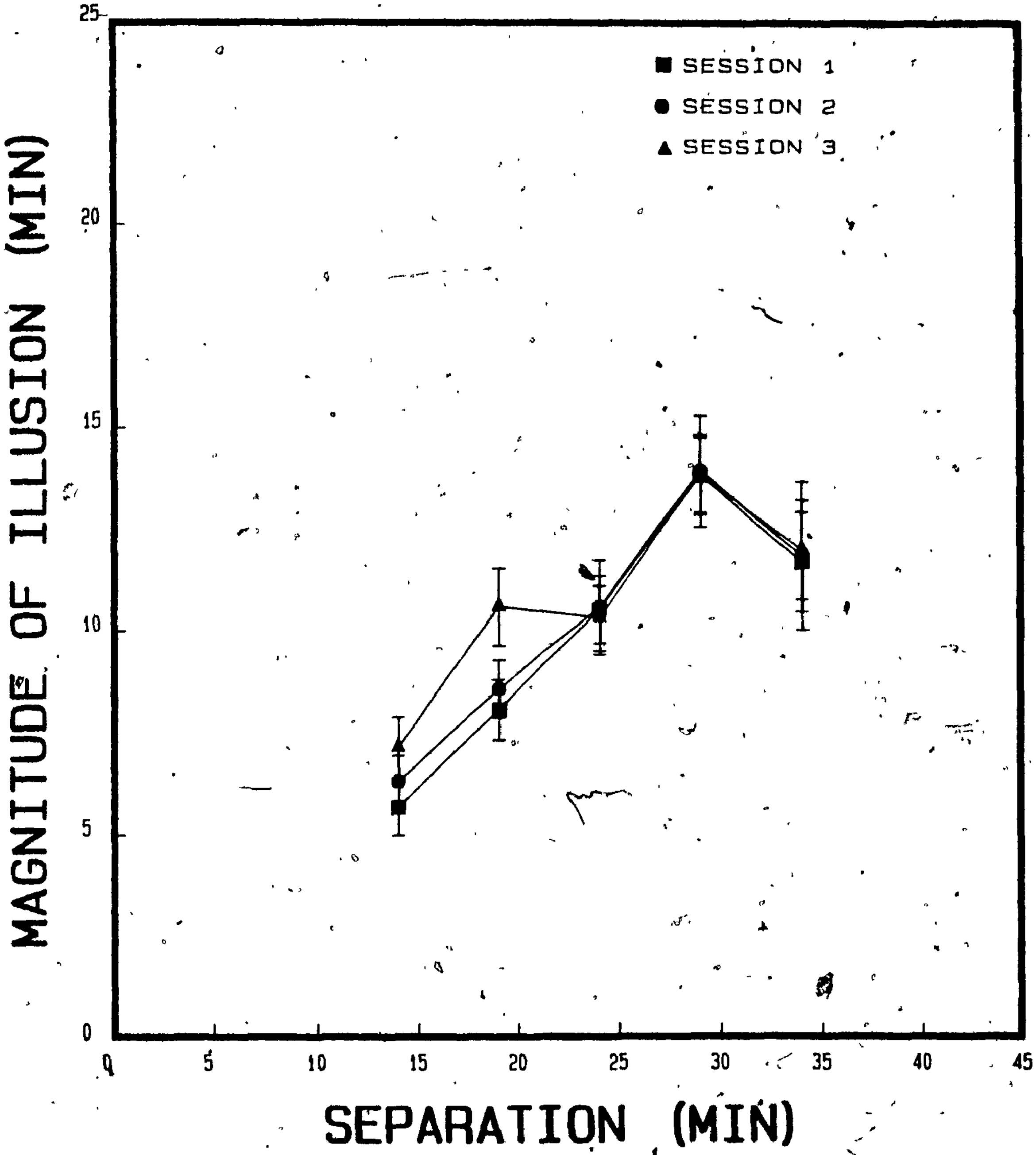

Figure 7. Magnitude of illusion as a function of spatial separation at each time of testing in Experiment 2. Standard error bars are shown.

Table 1

Average baseline scores of the near and far locations for both picture conditions

	Average baseline (%)	
Condition	Near	Far
Picture	86.3	85.6
No-picture	87.6	85.6

condition where more masking is found at the far location. The average baseline scores for the two picture conditions, at the near and far locations, are shown in Table 1. The average baseline was lower at the far location than the near location for both picture conditions. The baselines at the near and far locations do not vary between the two picture conditions. The SOA function is plotted in Figure 8 showing that a 17 ms SOA produced more masking than longer SOAs. The SOA main effect was significant at ($F(2,36) = 7.36$, $p < .0021$). Paired comparisons with HSD tests revealed that 17 ms SOA produced significantly more masking than the longest SOA, 51 ms. The separation results shown in Figure 9 reveal that as the intercontour distance increases, the magnitude of masking decreases. The separation main effect was significant ($F(4,72) = 14.77$, $p < .0001$). HSD comparisons produced significant differences in masking between the two smallest separations, 14 and 19 min, and the three largest separations. Figure 10 indicates that the largest difference between SOAs is found at the smallest separations. This SOA by separation interaction was significant, ($F(8,144) = 4.00$, $p < .0003$). Paired comparisons (HSD test) indicate that at 17 ms SOA, significant masking is found at a separation of 14 min and for 34 ms SOA significant masking occurs at a separation of 19 min. The shortest SOA, which produces significantly more masking than the longest, shows a curve very similar to the main separation function. The picture condition by location by separation effect indicates that maximum masking for the two conditions is obtained at different locations. Figure 11 shows that masking was generally higher at the near location for the picture condition while

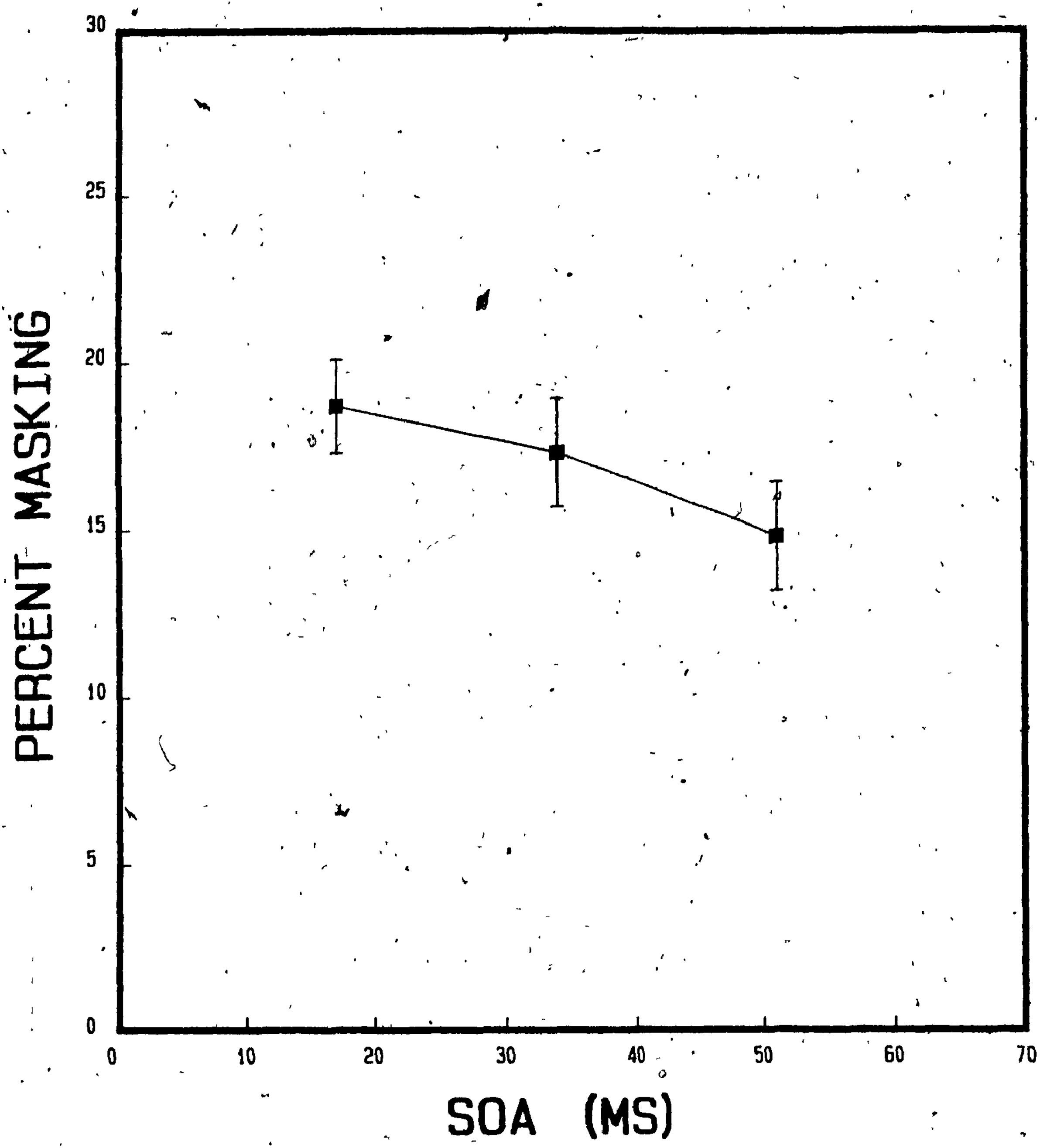

Figure 8. Percent masking as a function of stimulus onset asynchrony (SOA) in Experiment 2. Standard error bars are shown.

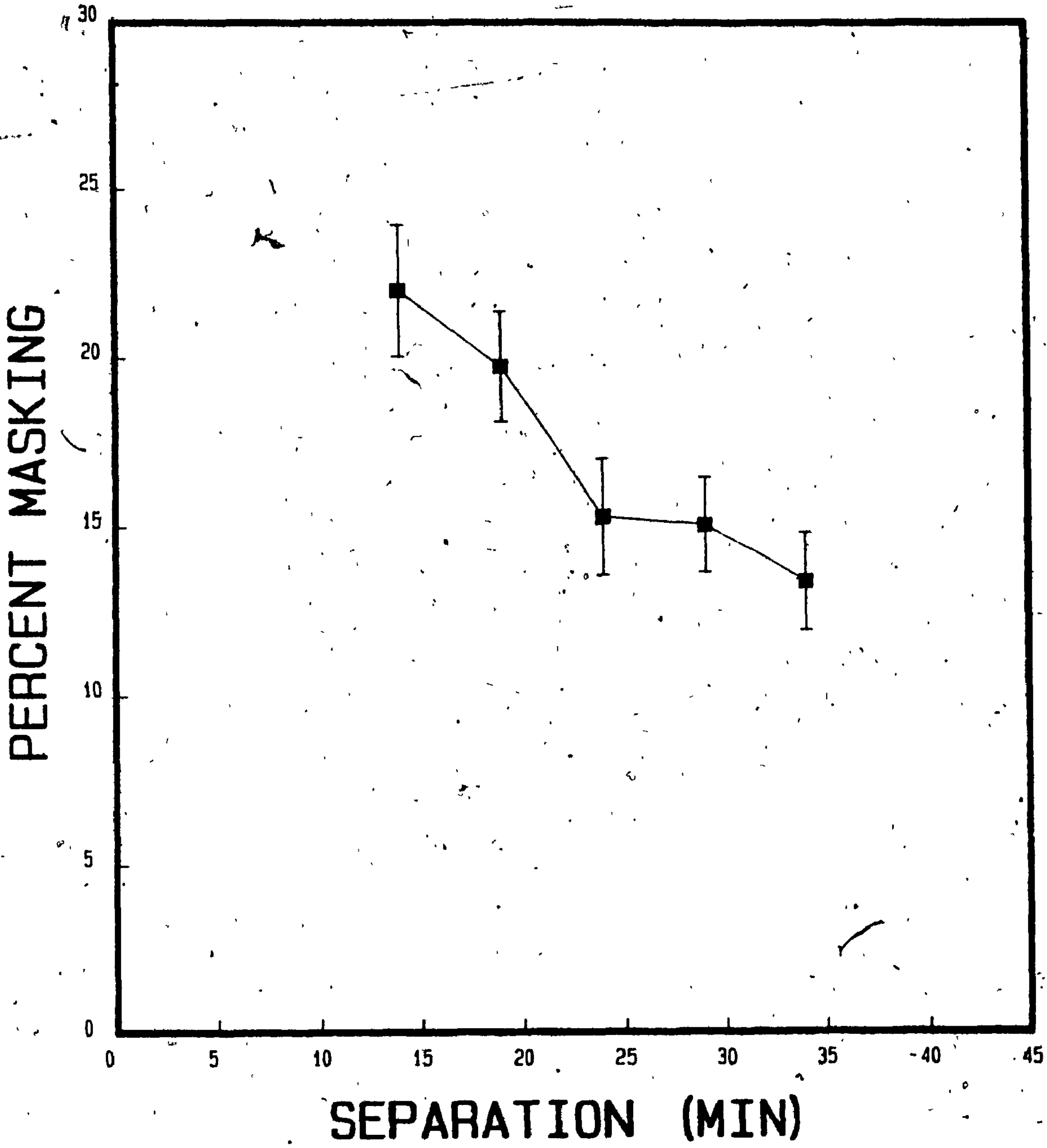

Figure 9. Percent masking as a function of spatial separation in Experiment 2. Standard error bars are shown.

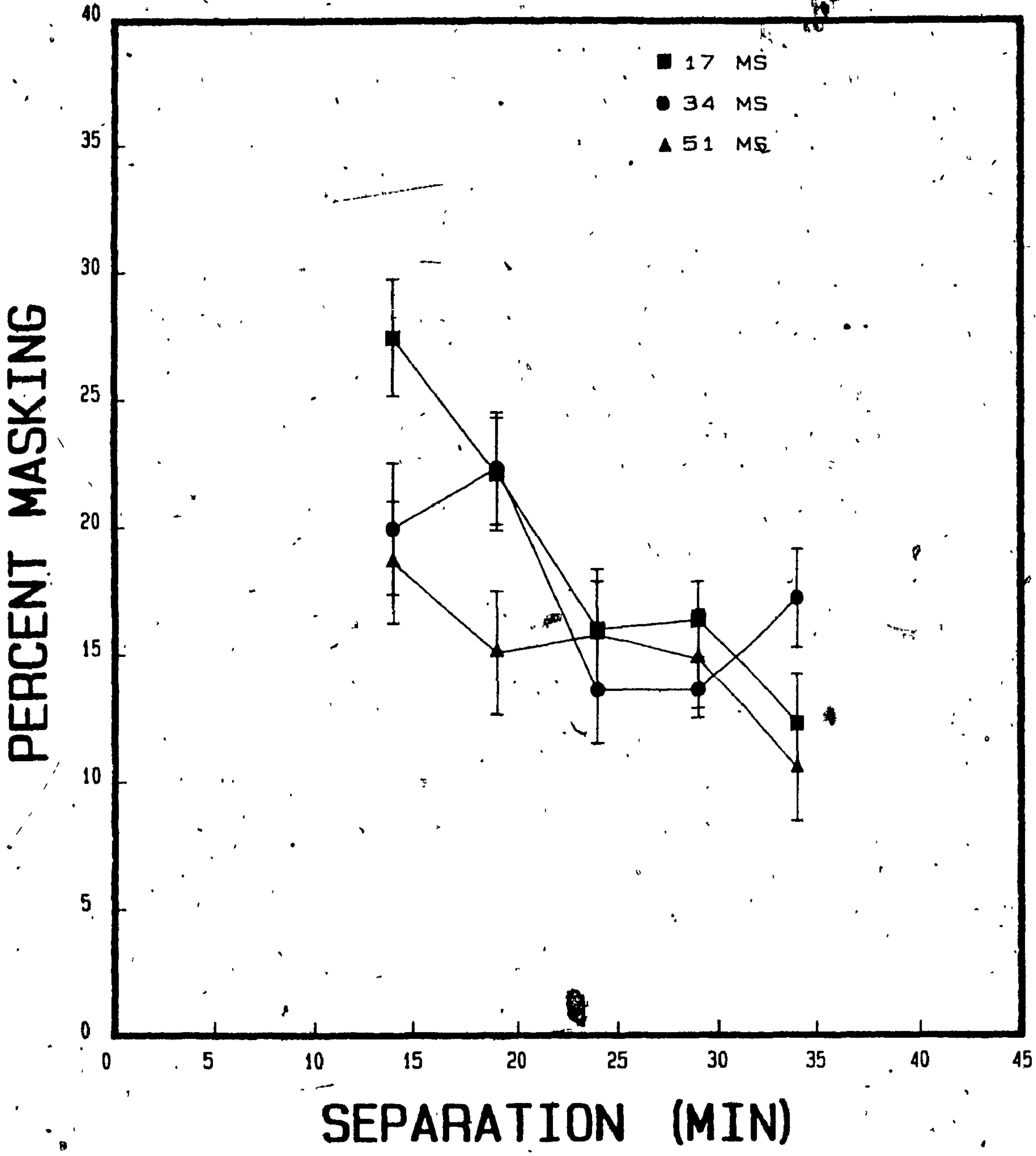

Figure 10. Percent masking as a function of spatial separation produced by each SOA in Experiment 2. Standard error bars are shown.

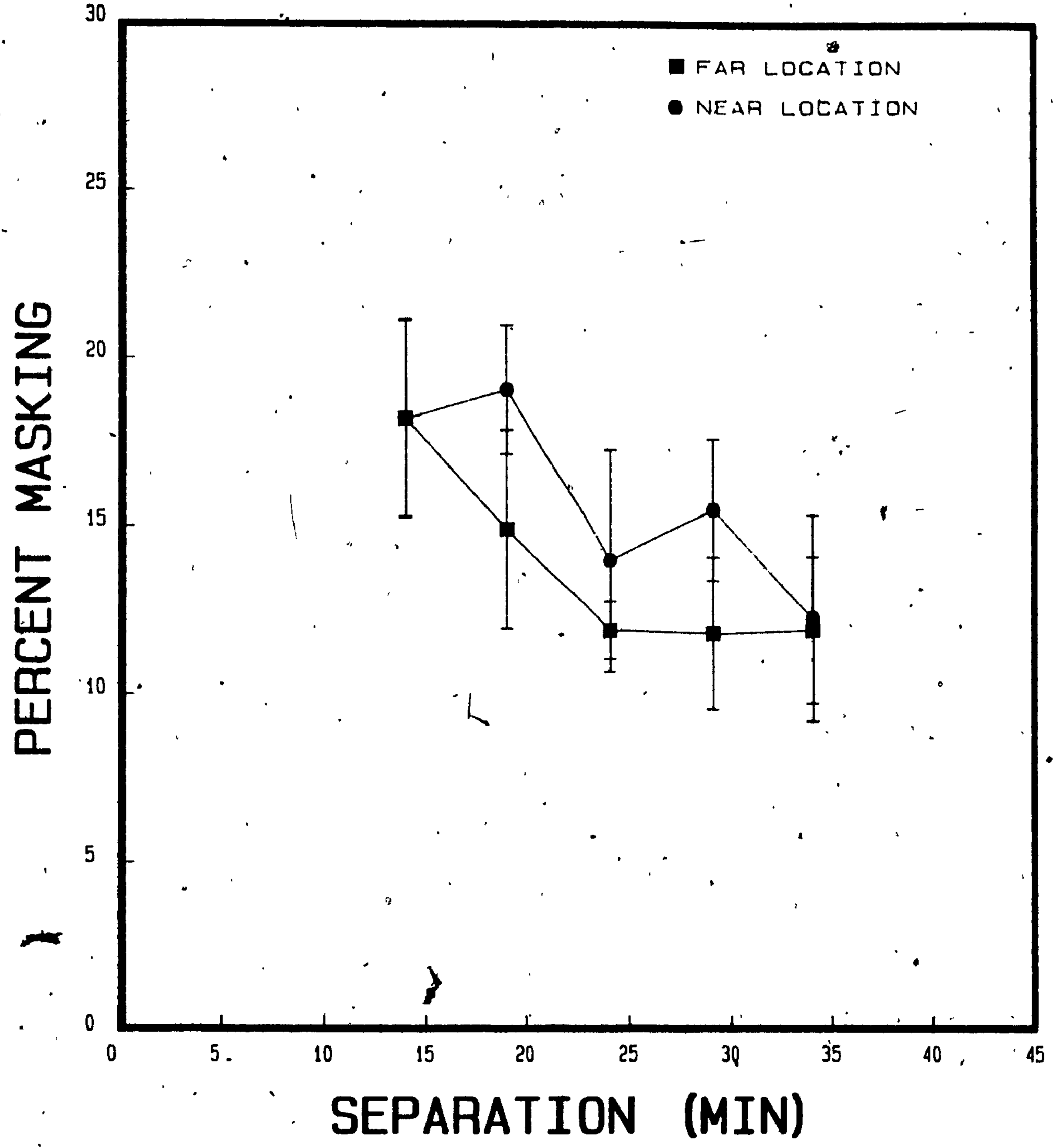

Figure 11. Percent masking as a function of spatial separation and locations, for the picture condition in Experiment 2. Standard error bars are shown.

Figure 12 shows that more masking was obtained at the far location for the no-picture condition. This interaction was significant ($F(4,72) = 2.81$, $p < .0316$). Paired comparisons (HSD) revealed no consistent difference between the locations for each picture condition or between the separations for each location.

Since that the results indicated a difference between near and far locations for each picture condition, Pearson product-moment correlations were calculated between the magnitude of illusion and the masking differences between near and far location. The correlations shown in Table 2, done on the shortest SOA, 17 ms, indicate no significant relationship between masking difference and magnitude of illusion. However, for some correlations, especially in the no-picture condition, there was a tendency for larger masking difference to correlate with stronger magnitude of illusion.

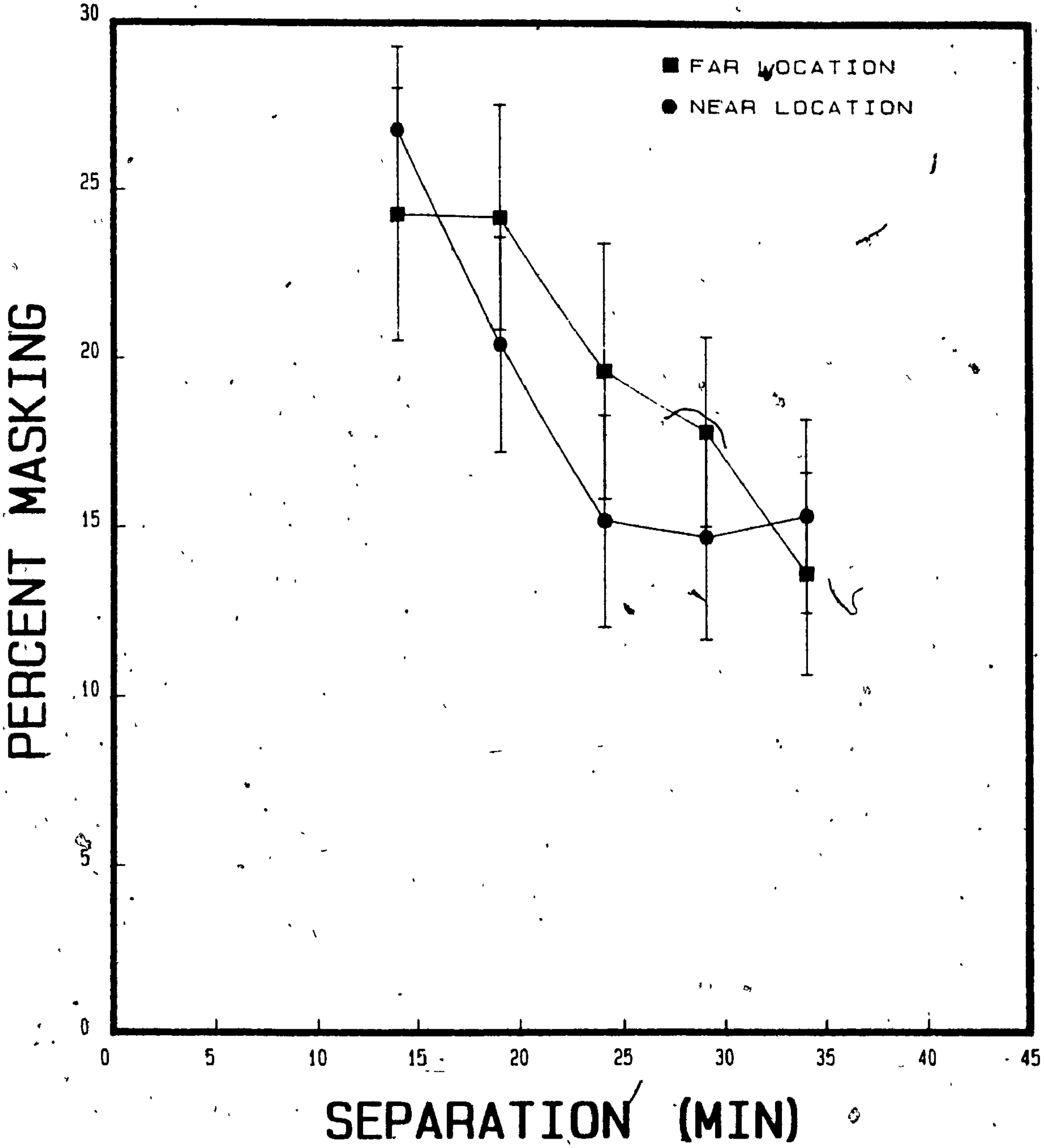

Figure 12. Percent masking as a function of spatial separation and locations, for the no-picture condition in Experiment 2. Standard error bars are shown.

Table 2

Correlation between magnitude of illusion and masking difference for a SOA of 17 ms

	Separation (min)				
Condition	14	19	24	29	34
Picture	−0.09	0.06	−0.10	0.15	0.59
No-picture	0.65	0.31	0.39	−0.28	0.35

Discussion

The primary question of this research concerned the role of apparent spatial separation in masking, and the results suggest that apparent separation exerts an effect on masking. When a picture condition and a no-picture condition were compared, there was a difference in masking between near and far locations. In the picture condition, as expected, more masking was obtained at the near location than the far location. In the no-picture condition, however, the near location produced less masking than the far location. These results, although suggestive of the involvement of apparent separation, are ambiguous, which makes it difficult to make any strong conclusion.

Magnitude of illusion

In both experiments, the pictorial scene produced a significant amount of illusion at all separations. The magnitude of illusion increased from one separation to the other except in Experiment 2 where the illusion dropped for the longest separation. These results are typically found in experiments measuring magnitude of illusion. They follow the first postulate of Pressey's (1972) assimilation theory, which states that whenever judgements are made of a series of magnitudes, the smaller magnitudes will tend to produce less illusion than the larger magnitudes. This effect is often refered to as the anchoring effect. Why the illusion drops at the largest separation is explained by the position of the stimulus which, at this separation, may be in the periphery of the attentive field of an observer. Pressey (1972) postulated that the effectiveness of a contextual stimulus will start decreasing, at one point, as it moves from the center to the periphery of the attentive field because the stimulus is located in an area where the observer is not focusing his attention and thus the influence of the distortion is minimal.

When the pictorial scene was not projected on the monitor screen, as in the no-picture condition, the magnitude of illusion was reduced but not eliminated. The residual illusion may have been due to the influence of three factors: relative elevation in the visual field, recall task, and anchoring effect. Objects higher in the visual field tend to be seen as farther away from the observer and thus appear larger than similar stimuli presented below (Girgus and Coren, 1975). This processing strategy was believed to be a main contributing factor to the illusion in the no-picture condition. Moreover, since the measure was taken using an adjustment task, error could have been introduced due to the fact that standard and comparison stimuli were not presented simultaneously and the observer would rely on memory to adjust the comparison stimuli which could have increased the difference between standard and comparison stimuli. The anchoring effect, mentioned previously, may also add to this difference. These factors that contribute to the illusion in the no-picture condition would be present in the picture condition as well, but they do not account fully for the illusion.

No major change in the magnitude of illusion over time was obtained. The magnitude of illusion was approximately constant from the beginning of the experiment to the end. Thus the effect of apparent separation should have ~~been~~ constant over the whole experiment.

Masking

The SOA function in Experiment 1 (Figure 4) indicated that masking decreased as SOA increased, with maximum masking at 17 ms SOA. Experiment 2 used only the shortest SOAs and the results were similar to Experiment 1. The SOA effects are typical of masking experiments and can be explained by the influence of three factors, two of which have already been pointed out: the target-to-mask energy ratio and the detection task. When the target energy is less than the mask energy, the masking function should be monotonic, and a target detection task also tend to produce a monotonic function. The third influencing factor could have been apparent motion. At some SOAs, apparent motion between target and mask was reported by most subjects, a phenomenon also observed by the experimenter. The phenomenon was such that the target appeared to split in two halves, which moved outward to both sides to become the mask. The gap in the target appeared to go with the motion, and it was sometimes seen in both lines of the mask (an optimal apparent movement referred to as beta movement) or at other times seen in only one line of the mask (a partial movement known as phi movement). Wertheimer (1912) showed that when two objects are flashed in succession, some kind of movement could be seen for ISIs between 30 ms and 200 ms, which is approximately the same range of temporal delays in which apparent movement was seen in this experiment. Observations indicated that long SOAs tend to produce beta movement while shorter SOAs produced phi movement. These considerations suggest that the integration of the gap in the mask made the task easier. One could believe that in carrying over a specific characteristic of the test line, in this case the gap, the percept of the gap would be either prolonged or made stronger.

A similar effect, which has been observed in other masking experiments (Stewart and Purcell, 1970; Wilson and Johnson, 1985), has been termed the "transposition effect". Wilson and Johnson studied the reliability of the transposition effect in a masking experiment. They found that under conditions that enhance the transposition effect, a gap inserted on a horizontal test line appeared to transfer to a solid masking line. This effect increased up to ISIs of 100 ms. For longer ISIs, the transposition effect progressively diminished. Stewart and Purcell found that when the letter C was used as a target, at ISIs of 20 ms and greater, the masking ring appeared as a large "c" with the same orientation as in the target.

For both experiments, the separation function showed that masking declined as separation between target and mask edges increased, a relationship found in other studies of contour masking. In Experiment 2, similar separation functions were obtained for the picture and the no-picture conditions. Embedding the stimuli in ~~the~~ pictorial scene apparently did not affect the typical relationship of separation between target and mask. This indicates that some retinotopic factors were present but hopefully held constant at both locations during the experiments.

The difference in overall magnitude of masking found between the picture condition and the no-picture condition appears to be mainly due to the difference in luminance contrast between stimuli and background. Given that the background in the picture condition was brighter, because the pictorial scene was projected on the screen, the contrast between the stimuli and the background luminance was low and correspondingly the brightness difference between target and mask was low. In the no-picture condition, the background was darker because no picture was projected on the screen, and consequently, the contrast between background and stimuli was higher. Considering that the stimuli in this condition were more clearly seen than in the picture condition, the mask, being exposed longer than the target, might appear brighter and therefore closer than the target. Ittleson (1960) found that when one of two identical objects, viewed in a dark space, is brighter, it is reported as nearer than the dimmer object. In studies varying the depth plane of target and mask (Lehmkuhle & Fox, 1980; Patterson & Fox, 1985), more masking was obtained when the mask appeared in front of the target due to a "front effect" where according to the authors, the foreground information is processed preferentially. In the no-picture condition, at both locations, the front effect may have been effective and consequently more masking was obtained than in the picture condition. The effect of the brightness of the masking stimulus could also have an influence on the apparent separation between target and mask. Since the visual angle was constant for both the target and the mask, the mask, appearing closer, should be perceived as having a smaller separation and thus produce more masking. In the picture condition, the effect of size brightness and preferential processing of stimulus were also present but weaker, because the low contrast between background and stimuli would decrease the brightness difference between mask and target.

The masking difference between the two conditions, could have been avoided if, to create equal contrast between the two conditions, a gray slide, approximating the luminance of the pictorial scene, had been projected on the screen during the no-picture condition. However, it was assumed that the difference between background and stimuli contrast, for the the two picture conditions, would only change the relative amount of masking, holding other variables constant.

Another factor which could have contributed to the difference in masking between the two picture conditions, is related to possible fixation errors. In the no-picture condition, once the observer was given the location to fixate, it may have been difficult for the observer to maintain fixation at that location since there were no background cues on the screen. Thus the subject's fixation could have deviated more easily in the no-picture condition, which may have increased the masking due to the fact that masking increases at retinal eccentricity.

Apparent spatial separation and masking

More pertinent to the main question of this study are the results obtained in Experiment 2 which point to the role of apparent separation in metacontrast. In Experiment 2, the picture condition produced less masking at the far location than at the near location. While the stimuli presented at the two locations had the same retinal separation, the separation presented at the far location was perceived as being wider due to the pictorial depth cues. At the near location, the ~~separation~~ appeared to be less and thus no magnification of the separation between mask and target was seen. Relatively more masking was, therefore, obtained at the near location suggesting a difference due to apparent separation.

In the no-picture condition less masking was obtained at the near location. However, since some illusion was obtained in the no-picture condition, one would expect to get some difference between near and far locations, with slightly more masking at the near location, due to the difference in apparent separation. Instead the results showed more masking at the far location than at the near location. These results, although contradictory to the expected results, do not necessarily refute the role of apparent spatial separation in the picture condition but instead could indicate the involvement of different influencing factors in the no-picture condition. A possible explanation of why more masking was obtained at the far location combines the effect of brightness and distance cues, preferential processing and relative elevation. It was previously mentioned that more masking may have been obtained in the no-picture condition than in the picture condition because the mask in appearing brighter also appears closer to the observer than the target and is therefore processed preferentially. With this effect, the apparent separation between target and mask was reduced which produced more masking in the no-picture condition than the picture condition. This effect, was presumably present at both locations. However, if the size of the mask at the far location is likewise affected by the relative elevation effect, where objects higher in the visual field appear larger than similar objects presented below, then it is possible that the far mask was perceived as being larger than the mask at the near location, resulting in more masking at the far location. The effect is presumed to be on the size of the mask lines and also on the apparent separation between target and mask, given that the magnitude of illusion in the no-picture condition is in the same direction as the picture condition. Less masking should then be expected if the relative elevation increases the size and the separation of the mask but, given that the mask also appears in front of the target because it is brighter, then the increase in separation may be conteracted in the masking task by the size of the mask lines and the frontal effect. Such an explanation for the results found in the no-picture condition suggests the possibility that in both conditions the difference in masking between near and far location was due to processes involving central levels of processing.

The interpretation of these results is complicated by the lack of significant correlations between masking differences and magnitude of illusion. Theoretically, the difference in masking between near and far locations should correlate with the magnitude of the separation illusion. However, the relationship between these two factors may be weak due to the fact that masking is also affected by factors other than apparent separation of the stimuli and these factors make it harder to tease out the effect of apparent separation. Moreover, the sample size was probably too small for correlational statistics. The correlations (Table 2) revealed for the picture condition, only a slight tendency, at some separations, for large masking differences to be associated with large magnitudes of illusion. That this trend is better in the no-picture condition is interesting but not surprising because one might expect less variance in the no-picture condition since fewer contextual variables would interfere with the masking and the illusion effect. Moreover, in the no-picture condition, a correlation of 0.65 was obtained for a separation of 14 min of arc, where the near location produced more masking. These trends suggest that the difference in masking between near and far location may be due to apparent separation and not retinal separation.

Spatiotopic masking: a central form of processing

That masking is not solely a retinotopic phenomenon has been shown previously in several experiments. The present findings add to the evidence and make it difficult for neurophysiological models to explain visual masking by the activity of retinotopic neural interactions alone. The results obtained in this study suggest that perceived separation, not retinal separation, caused the masking difference between near and far location in the picture condition. This effect of perceived separation on the interaction of target and mask suggests the presence of central levels of processing. These results support the idea that different types of masking are due to interactions at different levels of visual information processing because different type of information is coded at different levels. In the course of information processing, the first levels involve the intake of sensory information in a retinotopic manner in which the sensory information of incoming stimuli, arriving in close temporal contiguity, is subject to integration and inhibition effects. Masking at early levels would, therefore, be a retinotopic form of masking. At higher levels in the visual system, this information becomes less dependent on retinal projection and subject to a different order of time and space. A spatiotopic form of masking would be expected at these central levels. The levels involving a retinotopic form of masking corresponds to Uttal's (1981) level 2 and 3 in his taxonomy of levels of visual processing, which involves neural interactions at peripheral levels. Most models of masking depend on these levels of processing, mainly level 2, to explain the masking phenomena. However, spatiotopic masking, involving higer order perceptual and cognitive processes cannot be explained solely by peripheral neural interaction. This form of masking would correspond to levels 4 and 5 of Uttal's taxonomy.

Toward an explanation of a central form of masking

The investigation of a second stage of information processing is not an easy task due to the involvement of highly complex phenomena of which little is known. Currently, only scanty knowledge about the physiology of certain perceptual mechanism exists. Due to the meager information concerning the physiology of complex processes and the interactions among these processes, the interpretation of the perceptual mechanisms, involved in spatiotopic masking, is beyond our current knowledge of the neurophysiological factors involved.

Research on the involvement of central processing in masking has pointed to individual perceptual and cognitive processes but has not attempted to establish a general model of central processing and masking. Some experiments showed that variables such as form similarity are critical in producing visual masking (Uttal, 1970). Experiments with dichoptic masking, in which the target is presented to one eye and the mask is presented to the other eye, showed that both retinal and central interactions are involved in metacontrast (Turvey, 1973; Uttal, 1971). Studies varying the depth plane of spatially adjacent contours demonstrated that stimulus selectivity, where a stimulus is preferentially processed by the visual system, is a critical variable (Lehmkhule & Fox, 1980). Moreover, experiments assesing the role of eye movements in visual masking have shown that metacontrast can be stronger for stimuli that are presented at different retinal locations but identical spatial locations than for stimuli presented at the same retinal location (White, 1976). Secondly, it has been found that that target and mask information may be integrated across a saccade when presented at the same spatial location but different retinal locations (Breitmeyer et al., 1982; Ritter, 1976). Furthermore, it was demonstrated that the context of a three-dimensional pattern facilitates the recognition of an embedded object, which suggests the involvement of a global perceptual construction of the object in visual masking (Williams & Weisstein, 1981).

In the present study, the results suggest the involvement in masking of another high level process, size constancy. As mentioned previously, Gregory (1963) explained some geometric size illusions by cues in the illusion that trigger a mechanism that is normally used by our visual system to make size and distance jugdments. Thus the occurence of misplaced size constancy in an illusion depends on the fact that the illusion contains information that an observer would usually used to make decisions about distance, depth or size of objects. These decisions involve sophisticated operations, such as judgements of magnitude, quality, space and time, all related to our experience, which cannot be explained solely by a retinotopic form of information.

Given all the present evidence supporting a spatiotopic form of masking, a model of masking attempting to explain its function at central levels is needed. It is very unlikely that a simple transformation of existing neural, peripheral interactions models will explain the complexity of central processing. Perhaps a central form of masking would be more readily accomplished by first setting it in the context of its functional role in the visual system. Any attempt to reduce a phenomenon to its simplest form usually leads to a reductionist approach and it is unlikely that a thorough knowledge of complex perceptual processes can be achieved by adding pieces to pieces taken from ideal laboratory settings. Instead, an approach that tries to define a perceptual process according to its function in real life and its interaction with other processes, before attempting to study its particularities, seems to be a more promising alternative.

One spatiotopic model of visual masking offered to date explains the role of visual masking in saccadic eye movements. This model by Breitmeyer, Kropfl and Julesz (1982) proposes three functions for saccades as they relate to masking. The first function is concerned with the activity produced by sudden shifts of the retinal image which activate short-latency transient neurons. These neurons, when activated, inhibit the sustained pattern information from persisting into the next fixation. Thus masking here plays the role of inhibitor to prevent the persistence of the information from the previous fixation, to interfere with the next incoming information. Breitmeyer et al. also presumed that when the persistence of the last incoming information is suppressed, the analysis of our environment should be characterized by temporal gaps between the different spatial patterns that are picked up from each fixation. They therefore added two additional functions to saccades that enable us to perceive the environment as stable and constant accross saccades. The second function is the signal coming from extraretinal processes which presumably provides information on eye position and which permits the retinotopic information to be mapped onto a spatiotopic information based on the angle of the saccadic movement made between each representations. Simultaneously, the third function, enhances the visual persistence of the spatiotopic representations at higher central levels. At this higher cortical level, the successive spatiotopic pattern representations reinforce rather than mask the previous information. According to the Breitmeyer et al. model, this is how we see our environment, from one fixation to the other, as being a complete and stable world.

This model is an excellent attempt to explain the role of a spatiotopic forms of masking in saccadic eye movements. However, spatiotopic forms of masking extend beyond saccadic integration. Spatiotopic integrations of visual patterns involve other perceptual and cognitive processes such as size constancy, object superiority or stimulus selectivity, and perceptual grouping. What is needed is a more general model which combines higher level perceptual and cognitive processes, of form recognition, in spatiotopic masking.

Further studies

The biggest difficulty in studying a central form of processing is to separate effects due to peripheral processes from effects due to more central processes. A central process is difficult to assess because it is not directly testable with the physical characteristics and spatial geometry of the stimulus but instead depends on perceptual variables. Visual masking is affected by many variables some of which are of a retinotopic nature, and others, of a spatiotopic nature. Before a spatiotopic form of masking can be studied in isolation from the effects of earlier stages, the effect of these peripheral processes have to be held constant. Uttal (1981) stated three criteria to meet before studying the effect of central processing, corresponding to levels 4 and 5 of his taxonomy of visual processing. These criteria are: (1) the stimulus must be detectable, on the basis of its energy; (2) the neighboring stimuli must not affect or must affect constantly the stimulus; (3) the stimulus has to be seen as a figure or a ground. Whether these criteria are the only ones to held constant, to tease out retinotopic effects, is unknown. They do appear to be the most obvious variables to control in order to held constant the effects of earlier stages. Such variables, however, are not always easy to control in a masking study.

In the present study, the contrast between target and mask was not held constant for the two picture conditions, which made comparing results for the two conditions difficult. Furthermore, within the picture condition, the contrast between target and mask was different for the two locations due to the difference in the background cues. Hence, in this study, Uttal's criteria 1 and 2 were not met. Further studies should control the above variables to hold constant retinotopic effects in masking, in order to clearly define the role of central levels of processing.

General conclusion

This study has shown that a high-level process, size constancy mechanism, may be involved in a spatiotopic form of metacontrast. The results, although suggestive, need to be strengthened before any adequate conclusion can be developed. More research is therefore needed to provide stronger evidence. Further research should be careful to control the effect of retinotopic levels of processing in order to demonstrate what type of central masking is associated with a central form of processing.

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Appendix A

ANOVA Summary Tables of Analysis Done on the Separation Match Measure and the Masking Measure for Both Experiments

Table A-1

Experiment 1. ANOVA Summary Table of Two-way Repeated Measure Analysis for Separation Match Measure

Source	SS	DF	MS	F	
Session	7.72	3	2.57	1.74	
Error	13.30	9	1.48		
Separation	237.65	8	29.71	2.70	*
Error	263.81	24	10.99		
Session x Separation	4.55	24	.19	.73	
Error	18.76	72	.26		
Total	795.16	143			
(Residual)	295.86	105			

* p < .05

Table A-2

Experiment 1. ANOVA Summary Table for Three-way Repeated Measure Analysis for Masking Measure

Source	SS	DF	MS	F	
SOA	129.46	5	25.89	6.88	**
Error	56.48	15	3.77		
Location	21.07	1	21.07	.43	
Error	146.62	3	48.87		
SOA x Location	32.22	5	6.44	1.34	
Error	72.07	15	4.80		
Separation	146.44	8	18.31	2.53	*
Error	173.31	24	7.22		
SOA x Separation	220.74	40	5.52	1.28	
Error	519.19	120	4.33		
Location x Separation	45.26	8	5.66	2.02	
Error	67.16	24	2.80		
SOA x Loc. X Sep.	176.51	40	4.41	1.04	
Error	511.06	120	4.26		

* $p < .05$
** $p < .01$
*** $p < .001$

Table A-3

Experiment 2. ANOVA Summary Table of Two-way Repeated Measure Analysis for Separation Match Measure

Source	SS	DF	MS	F
Picture condition	248.07	1	248.07	31.14 ***
Error	143.38	18	7.97	
Session	3.84	2	1.92	2.56
Session x Picture	4.78	2	2.39	3.18
Error	27.05	36	.75	
Separation	213.48	4	53.37	79.14 ***
Separation x Picture	19.38	4	4.85	7.19 ***
Error	48.56	72	.67	
Session x Separation	6.70	8	.84	4.67 ***
Ses. x Sep. x Pict.	3.37	8	.42	2.35 *
Error	25.79	144	.18	

* $p < .05$
** $p < .01$
*** $p < .001$

Table A-4

Experiment 2. ANOVA Summary Table of Four-way Analysis with Repeated Measure on Three Factors for Masking Measure

Source	SS	DF	MS	F
Picture condition	137.76	1	137.76	3.04
Error	814.95	18	45.27	
SOA	72.80	2	36.40	7.36 **
SOA x Picture	27.50	2	13.75	2.78
Error	178.16	36	4.95	
Location	1.35	1	1.35	.07
Location x Picture	22.23	1	22.23	1.08
Error	369.80	18	20.54	
SOA x Location	.39	2	.20	.05
SOA x Loc. x Pict.	8.73	2	4.37	1.17
Error	134.81	36	3.74	
Separation	277.91	4	69.48	14.77 ***
Separation x Picture	20.73	4	5.18	1.10
Error	338.63	72	4.70	
SOA x Separation	133.16	8	16.65	4.00 ***
Soa x Sep. x Pict.	25.56	8	3.20	.77
Error	599.81	144	4.17	
Location x Separation	3.79	4	.95	.28
Loc. x Sep. x Pict.	38.09	4	9.52	2.81 *
Error	243.91	72	3.39	
SOA x Loc. x Sep.	56.58	8	7.07	1.70
SOA x Loc. x Sep. x Pict.	29.54	8	3.69	.89
Error	600.29	144	4.17	

* $p < .05$

** $p < .01$

*** $p < .001$

Appendix B

Summary Tables of Means and Standard Deviations of the Separation Match Analysis and the Masking Analysis for both Experiments

Table B-1.

Experiment 1. Summary Table of Means and Standard Deviations (mm) for Separation Match Analysis

	Separation	Mean	Standard deviation
Session 1	1	1.40	.54
	2	2.79	.85
	3	2.99	.66
	4	3.14	.85
	5	3.67	1.17
	6	4.35	1.30
	7	4.65	1.79
	8	5.42	3.73
	9	6.60	3.91
Session 2	1	1.27	.42
	2	2.41	.68
	3	2.67	.63
	4	2.87	1.17
	5	3.31	1.14
	6	4.12	.74
	7	4.29	1.12
	8	5.12	3.36
	9	5.15	5.05
Session 3	1	1.38	.44
	2	2.39	.72
	3	2.40	.83
	4	2.87	.84
	5	3.19	1.29
	6	4.03	1.53
	7	4.61	2.12
	8	4.64	3.81
	9	5.80	3.95
Session 4	1	1.25	.28
	2	2.25	.28
	3	2.42	.18
	4	2.72	1.15
	5	3.18	1.32
	6	3.63	1.65
	7	4.05	2.49
	8	4.58	4.52
	9	5.15	5.27

Table B-2

Experiment 1. Summary Table of Means and Standard Deviations for Masking Analysis

SOA	Location	Separation	Mean	Standard Deviation
17	1	14	3.88	2.82
17	1	19	2.13	1.47
17	1	24	4.63	3.29
17	1	29	4.13	3.55
17	1	35	5.38	2.46
17	1	41	1.88	3.27
17	1	46	4.13	2.74
17	1	59	1.63	2.36
17	1	65	2.38	3.34
17	2	14	6.10	0.84
17	2	19	5.10	3.56
17	2	24	4.10	3.58
17	2	29	3.10	3.33
17	2	35	3.60	2.82
17	2	41	3.35	2.68
17	2	46	4.85	3.79
17	2	59	2.35	3.28
17	2	65	3.60	2.78
34	1	14	4.88	2.04
34	1	19	6.38	3.48
34	1	24	2.38	1.89
34	1	29	3.13	1.44
34	1	35	1.38	2.61
34	1	41	1.88	3.27
34	1	46	0.38	2.71
34	1	59	2.63	2.72
34	1	65	0.63	2.29
34	2	14	3.60	1.62
34	2	19	2.10	1.98
34	2	24	1.35	1.45
34	2	29	1.35	1.66
34	2	35	1.85	3.70
34	2	41	2.85	1.70
34	2	46	1.60	2.30
34	2	59	0.85	2.55
34	2	65	-0.15	2.18
51	1	14	4.88	1.58
51	1	19	2.63	2.36
51	1	24	2.38	3.08

Table B-2, continued

SOA	Location	Separation	Mean	Standard Deviation
51	1	29	3.38	2.51
51	1	35	2.13	2.24
51	1	41	1.63	2.17
51	1	46	0.98	2.61
51	1	59	1.78	3.56
51	1	65	2.88	2.96
51	2	14	3.10	2.99
51	2	19	2.35	1.62
51	2	24	2.35	4.48
51	2	29	1.60	1.45
51	2	35	1.35	3.94
51	2	41	4.85	3.03
51	2	46	0.60	2.73
51	2	59	2.10	3.21
51	2	65	1.60	2.50
68	1	14	5.63	3.14
68	1	19	2.13	2.05
68	1	24	3.37	3.39
68	1	29	2.63	4.00
68	1	35	1.37	2.08
68	1	41	1.13	4.37
68	1	46	1.88	0.79
68	1	59	0.88	2.48
68	1	65	2.88	3.20
68	2	14	1.85	2.27
68	2	19	1.60	2.52
68	2	24	1.35	2.21
68	2	29	2.35	2.75
68	2	35	3.35	3.44
68	2	41	2.35	5.82
68	2	46	1.10	1.60
68	2	59	0.35	3.32
68	2	65	2.10	3.08
85	1	14	3.63	2.71
85	1	19	1.63	2.10
85	1	24	1.38	3.36
85	1	29	2.38	2.93
85	1	35	3.38	2.08
85	1	41	3.38	2.08
85	1	46	1.13	3.40
85	1	59	3.13	1.19
85	1	65	4.63	1.73
85	2	14	3.35	3.30
85	2	19	2.10	1.60

Table B-2, continued

SOA	Location	Separation	Mean	Standard Deviation
85	2	24	0.85	2.39
85	2	29	2.60	2.94
85	2	35	1.85	0.47
85	2	41	1.85	4.38
85	2	46	0.85	1.58
85	2	59	-0.41	1.93
85	2	65	2.85	0.94
102	1	14	2.38	2.46
102	1	19	2.88	3.04
102	1	24	2.63	2.49
102	1	29	2.63	2.26
102	1	35	2.38	1.78
102	1	41	2.13	2.65
102	1	46	2.88	1.60
102	1	59	2.38	1.09
102	1	65	2.13	1.37
102	2	14	1.85	3.36
102	2	19	2.60	1.85
102	2	24	1.60	3.65
102	2	29	-0.40	3.72
102	2	35	4.60	3.42
102	2	41	2.60	2.55
102	2	46	1.60	3.83
102	2	59	1.60	1.08
102	2	65	1.60	2.50

Table B-3

Experiment 2. Summary Table of Means and Standard Deviations (mm) for Separation Match Analysis

Session	Separation	Mean		Standard Deviation	
		Pict.	No-Pict.	Pict.	No-Pict.
1	14	2.62	1.16	0.75	0.62
1	19	3.49	1.89	0.88	0.61
1	24	4.48	2.53	0.78	0.67
1	29	5.74	3.47	0.75	0.57
1	34	5.37	2.43	0.80	1.21
2	14	2.47	1.72	0.86	0.97
2	19	3.41	2.30	0.91	0.86
2	24	4.26	2.80	1.13	0.70
2	29	5.56	3.72	1.32	0.64
2	34	5.03	2.86	1.57	1.46
3	14	2.82	1.94	0.79	1.20
3	19	4.72	2.34	0.65	0.84
3	24	4.28	2.60	0.67	0.93
3	29	5.71	3.51	1.12	0.69
3	34	5.29	2.70	1.26	1.22

Table B-4

Experiment 2. Summary Table of Means and Standard Deviations for Masking Analysis

SOA	Location	Separation	Mean		Standard Deviation	
			Pict.	No-Pict.	Pict.	No-Pict.
17	1	14	5.27	5.98	1.98	2.90
17	1	19	3.37	4.88	2.80	3.10
17	1	24	3.67	4.18	1.76	3.05
17	1	29	3.27	3.68	2.89	2.48
17	1	34	2.97	1.88	2.28	2.45
17	2	14	4.83	6.89	2.38	2.32
17	2	19	5.33	4.89	2.17	2.97
17	2	24	2.13	3.39	1.85	3.15
17	2	29	3.83	2.89	2.64	1.14
17	2	34	2.93	2.49	2.78	2.35
34	1	14	3.17	4.88	2.59	2.89
34	1	19	3.77	5.98	2.46	3.22
34	1	24	1.67	3.78	2.09	2.08
34	1	29	1.67	2.78	2.08	1.65
34	1	34	3.17	4.48	1.45	2.58
34	2	14	3.13	5.49	2.12	2.54
34	2	19	3.83	4.99	2.01	2.36
34	2	24	3.13	2.79	3.42	2.34
34	2	29	3.23	3.69	1.65	3.14
34	2	34	3.33	3.39	2.49	2.64
51	1	14	3.17	4.38	2.36	2.91
51	1	19	1.77	4.38	2.42	1.49
51	1	24	1.87	4.38	1.54	3.01
51	1	29	2.27	4.78	2.21	2.43
51	1	34	1.37	2.18	2.29	2.54
51	2	14	3.53	4.49	2.73	2.70
51	2	19	2.83	2.99	2.05	2.29
51	2	24	3.53	3.39	2.30	2.49
51	2	29	2.63	2.69	2.09	2.70
51	2	34	1.43	3.79	2.78	2.57