Journal of Experimental Psychology:
Human Perception and Performance
1976, Vol. 2, No. 2, 167–173

U-Shaped Backward Contour Masking During Stroboscopic Motion

Bruno Breitmeyer, Frank Battaglia, and Catherine Weber
University of Houston

Two stationary and spatially separated visual stimuli, presented briefly and successively in time, are known to produce stroboscopic motion whose vividness is a U-shaped function of the stimulus onset asynchrony. Contour masking is also known to occur under such stimulus conditions. The findings show that the contour masking is confined to only the first stimulus and that it, like metacontrast, is a backward U-shaped function of the stimulus onset asynchrony. A simple model, based on known psychophysical and neurophysiological properties, is proposed to explain these results.

It is known that metacontrast, besides producing U-shaped backward brightness suppression (Alpern, 1953; Weisstein, 1972), can also produce U-shaped backward contour suppression (Breitmeyer, Love, & Wepman, 1974; Burchard & Lawson, 1973; Sukale-Wolf, 1971). In a metacontrast situation a briefly presented target pattern is followed at variable stimulus onset asynchronies (SOAs) by a briefly presented, spatially adjacent (i.e., nonoverlapping) mask pattern. Optimal contour masking occurs at an intermediate SOA of roughly 100 msec and decreases at progressively lower or higher SOAs, thus yielding the characteristic, inverted U-shaped, metacontrast masking function.

However, contour adjacency of two sequentially and briefly presented patterns is not required to produce U-shaped contour masking. For instance, Breitmeyer et al. (1974) demonstrated that such contour masking occurs during stroboscopic motion when two stimuli with nonadjacent contours, which are separated by more than 1° visual angle, are used. In particular, they showed that errors in reporting the contour similarity of, or differences between, two sequentially presented stimuli, similar to those shown in Figure 1, were directly related to the degree of observed stroboscopic motion, which under optimal conditions appears as smooth motion in the direction from the first to the second stimulus. Since for briefly presented stimuli the degree of stroboscopic motion was a U-shaped function of SOA (see also Kahneman, 1967; Wertheimer, 1912), contour masking, reflected in the errors of reporting the contour similarity or difference of the two stimuli, also was a U-shaped function.

In the Breitmeyer et al. (1974) study, a subject's forced-choice response (which was *same*, if the subject perceived or guessed the contours of the two stimuli to be the same, and *different* otherwise) was made on the basis of comparing the contour detail in *both* stimuli rather than verbally identifying the contour detail of *each* stimulus individually. Consequently the source of error could have been due to the masking of the contour of the first stimulus by the second and thus would reflect a backward U-shaped contour masking as in metacontrast. Alternatively, however, the error source could have been due to the suppression of the contour of the second stimulus by the first and thus would reflect a forward U-shaped or paracontrast effect (Kolers & Rosner, 1960; Weisstein, 1972), or possibly both.

However, it seems unlikely that a paracontrast effect could have been responsible for the results obtained by Breitmeyer et al. (1974), since substantial paracontrast usually is obtained only when the luminous energy or spatial contrast of the mask is substantially higher than that of the target

---

Requests for reprints should be sent to Bruno Breitmeyer, Department of Psychology, University of Houston, Houston, Texas 77004.

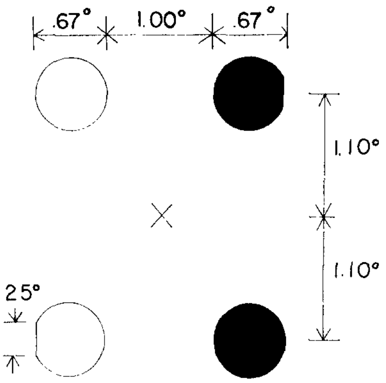

FIGURE 1. Spatial dimensions and locations of the visual stimulus displays. (The X designates the fixation cross. Outline shapes designate stimuli presented first in a stimulus sequence; in actuality all stimuli were filled shapes like those appearing to the right. On any trial only the stimuli above or only the stimuli below fixation were presented.)

(Kolers & Rosner, 1960; Weisstein, 1972). In their study, Breitmeyer et al. (1974) used stimuli whose space-time integrated energies were equal. Thus, it seems more likely that the U-shaped contour masking attending stroboscopic motion is a backward masking effect like metacontrast. This implies that U-shaped contour masking should be confined to the first of the two stimuli producing stroboscopic motion. A corollary implication is that for the second stimulus the masking function should essentially be flat or uniform with respect to SOA.

METHOD

Subjects

Two female undergraduates at the University of Houston, both 21 years old, volunteered as subjects. Both subjects had normal vision and were inexperienced and naive psychophysical observers.

Apparatus and Stimuli

To display stimuli a three-field, Scientific Prototype tachistoscope was used. Stimuli were drawn with black india ink on 5 × 7 in. (12.7 × 17.8 cm) white index cards and were front illuminated, yielding a reflected luminance of 15 millilamberts (47.74 cd/m^2). The contrast of the black stimuli against the white surround was .9. Representative samples of stimuli used in this study and their visual field locations relative to the center of vision are shown in Figure 1. As noted, all stimuli were at a contrast of .9; the outline drawing of a stimulus in Figure 1 simply designates that it was presented first in the total stimulus sequence. Moreover, all stimuli had sharp edges or contours. On any trial only the upper two or only the lower two stimuli were sequentially presented. This procedure (see below) was used to minimize attentional bias effects.

The left or first stimulus was located in Field 1 of the tachistoscope; Field 2 was blank except for the fixation cross as shown in Figure 1; and Field 3 contained the right or second stimulus. Moreover, again as shown in Figure 1, the left stimulus could be either a complete disk or a disk with a .25° contour deletion on its left side and, likewise, the right stimulus could either be a complete disk or a disk with a .25° contour deletion on its right side. Thus, for presentations above or below fixation, four combinations of stimulus contours could be used: left complete – right complete; left complete – right deleted; left deleted – right complete; left deleted – right deleted. A viewing distance of 125 cm was used and at this distance each display field was 8.00° wide and 5.75° high.

Procedure

By depressing a button on a given trial, the subject initiated the stimulus sequence, which consisted of a 10-msec presentation of Field 1 containing the first (left) stimulus, followed by the blank Field 2 of variable duration, in turn followed by a 10-msec presentation of Field 3 containing the second (right) stimulus, and finally followed by Field 2, which remained on until the initiation of the next trial. The variable durations of Field 2 were chosen to produce on any given trial one of the following seven SOAs: 10, 50, 90, 130, 170, 210, and 250 msec. After a given stimulus sequence, the subject identified each of the two stimuli with respect to its contour detail. A forced-choice technique was used in which the response to the first stimulus could be either "complete" or else "deleted," and similarly for the second stimulus. For example, correct forced-choice responses to a display sequence above fixation as shown in Figure 1 would be "left complete, right deleted." All viewing was binocular.

In the experiment proper each subject was run in one daily session of 56 trials for 6 consecutive days. In a session, one half or 28 of the trials were used for presentations above fixation and one half for presentations below fixation. Of the 28 trials in each of the two subsets four were devoted to each of the seven SOAs such that at a given SOA each of the four possible left–right stimulus sequences listed above was used once. The location of the stimulus sequence presentation (above or below fixation), the type of left–right stimulus sequence, and the SOA were, subject to the above restrictions, randomized within a given 56-trial session. For a given subject, treatment of data involved collapsing results across the stimulus-sequence-location dimension and the stimulus-sequence-type dimension. Thus over 6 days, 48 observations (correct or incorrect responses) were recorded for the left or first stimulus at each SOA and

48 observations were recorded for the right or second stimulus. From these observations, error proportions were calculated at each SOA.

Prior to each experimental session, each subject was given a 5-min practice session consisting of several trials (not included in the 56 trials of the experimental session) to refamiliarize herself with the procedure and to allow her visual system to adapt to the prevailing luminance level. In all, each daily session lasted about 40–50 min. Initially, three to four such daily sessions were run with each subject, to train her in the procedure and to establish stable response criteria. Results from these preexperimental sessions were not included in the data analysis.

RESULTS

The results are shown separately for each subject in Figure 2. At each SOA the proportion of errors in identifying a stimulus contour is plotted for the left and right stimuli. A greater proportion of errors reflects a greater degree of contour suppression. Several aspects of the data are obvious from inspection of Figure 2. First, the overall contour masking effects are greater for the first than for the second stimulus. Collapsed over SOAs, the error proportions for the first versus the second stimulus and for Subjects MW and EE, respectively, are .46 vs. .33 and .28 vs. .15. The standard error of these proportions never exceeded .027.

Second, the shapes of the masking functions obtained for first and second stimuli differ from each other. For both subjects, the first stimulus yields pronounced U-shaped masking functions whereas the second stimulus yields a flat, although somewhat noisy, function. In regard, to the first stimulus, Subject MW obtained a peak masking effect at an SOA of 90 msec; Subject EE obtained a peak at an SOA of 130 msec. For both subjects, a within-subjects trend analysis of variance as a function of SOA showed that the quadratic trend was significant at the .05 probability level, $F(1, 329) > 4.0$. However, for the second stimulus, no trends proved to be significant at the .10 probability level, $F(1, 329) < 2.5$. All this confirms the expectation that the contour masking functions for the first stimulus are essentially U-shaped with respect to SOA, whereas the functions for the second stimulus are basically flat or uniform with respect to SOA.

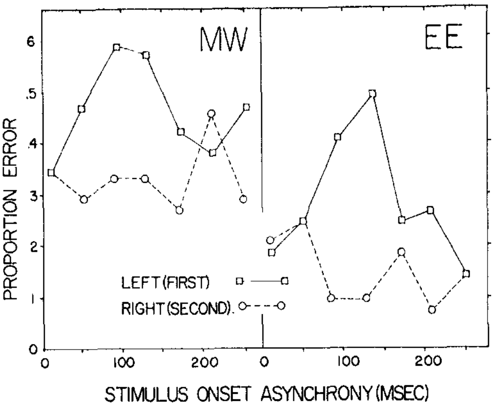

FIGURE 2. The proportion of errors in identifying the contours of the left or first stimulus and the right or second stimulus as a function of their stimulus onset asynchrony.

It should also be noted that although the subjects were not required to report any perceptions of stroboscopic motion, they did voluntarily report such perceptions, which were particularly strong at intermediate SOA values.

DISCUSSION

The results confirm the expectations that in stroboscopic motion the second stimulus has a backward contour masking effect on the first stimulus and that the strength of this effect is a U-shaped function of SOA. Also as expected, the first stimulus has no forward U-shaped or paracontrast contour masking effect on the second. In fact, the analyses of the data failed to show any consistent variation in the identifiability of the contour of the second stimulus as a function of SOA. This suggests that contour suppression mechanisms activated in a stroboscopic motion situation are basically the same as the contour suppression mechanisms activated in metacontrast situations. The relationship between stroboscopic motion and metacontrast has been noted and studied previously (Breitmeyer et al., 1974; Kahneman, 1967; Weisstein & Growney, 1969). Kahneman (1967) has made the strongest claim concerning the relation between stroboscopic motion and metacontrast. According to his formulation, metacontrast *is* stroboscopic motion, albeit it is an anomalous stroboscopic motion which is partially suppressed by the perceptual system.[1] This suppression, according to Kahneman, is responsible for also suppressing the visibility of the first of the two stimuli in a metacontrast situation. This formulation has been criticized by Weisstein and Growney (1969) on the grounds that the empirical spatio-temporal relationships which govern stroboscopic motion effects deviate substantially from the spatio-temporal relationships governing metacontrast masking effects.

The present study and that of Breitmeyer et al. (1974) also bear on Kahneman's (1967) formulation, but in a somewhat different way. In those studies, the stroboscopic motion was not an anomalous or impossible type; it was perceptually highly possible and vividly apparent. Consequently, one need not invoke impossible or suppressed stroboscopic motion as a mechanism for U-shaped backward contour suppression. Contour suppression therefore is a phenomenon attending perceptually possible and vivid stroboscopic motion.

This raises the issue as to whether or not the perception of stroboscopic motion is causally involved in U-shaped backward contour masking. For instance, it is feasible that the perception of stroboscopic motion interferes with the perception of the contour detail of a stimulus. However, this raises the secondary issue as to why this interference occurs only with the first of the two sequentially presented stimuli in the stroboscopic motion situation.

Nonetheless, perception of stroboscopic motion may be a sufficient condition for producing contour masking, even if only in the first stimulus. However, it is unlikely that it is a necessary condition. For instance, Stoper (Note 2) reports the existence of metacontrast masking when no stroboscopic motion is observed. Moreover, as observed by Weisstein and Growney (1969), the temporal sequence required for optimal metacontrast may be quite different and dissociated from that required for optimal stroboscopic motion. Thus, the temporal stimulus sequence giving rise to stroboscopic motion perception cannot always be identical to the sequence giving rise to metacontrast. This suggests that it is a specific temporal sequence of stimuli per se which is a necessary condition for metacontrast or U-shaped backward masking effects, irrespective of whether or not stroboscopic motion is perceived.

Although we do not exclude models of visual pattern masking based on cognitive or higher decision processes (Turvey, 1973; Uttal, 1970, 1971) for an explanation of the current results, we choose to restrict ourselves to recent models (Breitmeyer & Ganz, 1976; Matin, 1975; Weisstein, Ozog, & Szoc, 1975) which in one way or another and with varying degrees of emphasis incorporate the notion of two types of neurophysiologically identified visual cells, or channels distinguishable on the basis of their spatio-temporal response characteristics. One type of cells or channels, commonly called sustained response cells or channels, is concerned with the processing of figural and spatial detail, whereas another type, commonly called transient response cells or channels, detects temporal changes of stimulation such as those produced by rapid motion, flicker, and abrupt stimulus onsets and offsets.

A review of the details of activity within and interactions between sustained and transient channels and how they relate to visual masking are given elsewhere (Breitmeyer & Ganz, 1976). However, the essential aspects for an explanation of a wide variety of masking phenomena, including the one reported in the present paper, relate to two known properties of sustained and transient channels. From psychophysical (Breitmeyer, 1975a, 1975b), as well as neurophysiological studies (Dow, 1974;

---

[1] Stroboscopic motion can be observed in metacontrast situations (Biederman, Note 1) and therefore cannot be totally suppressed. Stoper (Note 2) also reported this observation of "split" stroboscopic motion in some metacontrast situations where presentation of a target rectangle is followed by the simultaneous presentation of two flanking masking rectangles. Moreover, this split stroboscopic motion was found to be strongest when the target-mask display was centered in the visual field and was not found when the display was presented eccentrically.

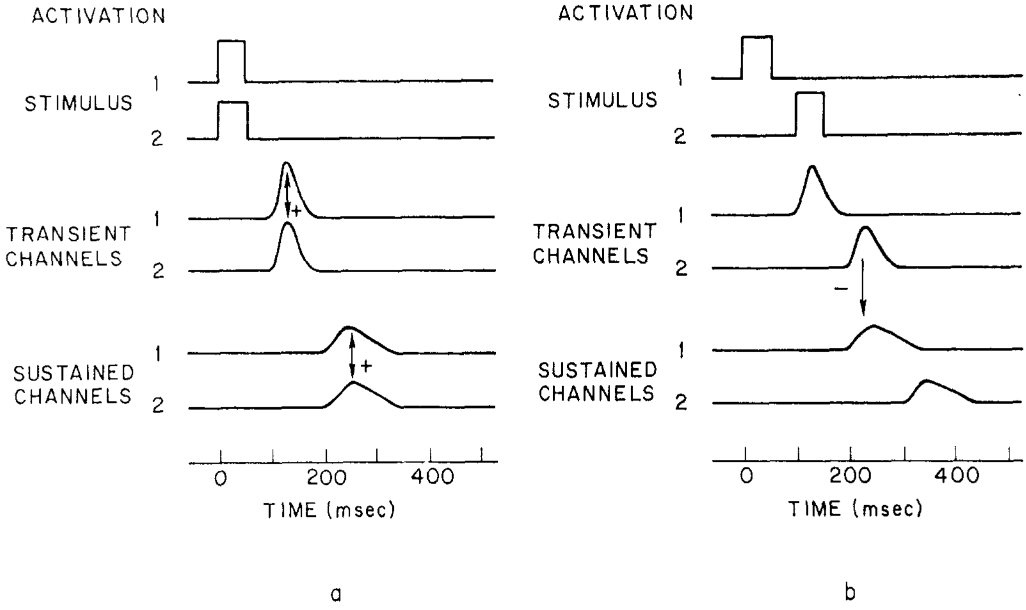

FIGURE 3. Hypothesized interactions within and between sustained and transient channels (a) when the onsets of two stimuli are concurrent and (b) when the onsets are separated. (Arrows indicate direction of interaction. The positively signed arrows [a] designate integration within channels; the negatively signed arrow [b] designates inhibition of sustained channels by transient ones.)

Singer & Bedworth, 1973), it is known that (a) transient channels have a response latency shorter by several tens of milliseconds (sometimes in excess of 100 msec) than that of sustained channels and (b) the activity of transient channels inhibits that of sustained channels.

Using these two properties, the essential aspects of a model for explaining U-shaped backward masking effect obtained in a variety of situations such as stroboscopic motion and metacontrast are illustrated in Figure 3. Both parts of the figure indicate that a briefly presented stimulus activates transient channels at a latency which is 50–100 msec faster than the latency required to activate sustained channels. Consider the stimulus activation shown in Figure 3a where the first and second stimuli are presented concurrently. The neural responses which they generate respectively in transient and sustained channels also occur concurrently; however the transient channel activity generated by the second stimulus precedes and therefore cannot inhibit the sustained channel activity generated by the first stimulus. This state of transient-sustained channel activity corresponds to the observed absence of contour suppression in the first of the two sequential stimuli that are used, say, in a stroboscopic motion or metacontrast situation. Contour masking could occur only if the two stimuli, unlike in stroboscopic motion or metacontrast, were to have spatially overlapping contours, in which case masking by temporal integration (positively signed arrows in Figure 3), similar to Eriksen's (1966) proposed mechanism of contrast reduction by luminance summation, could prevail. As the SOA temporally separating the second from the first stimulus increases from 0 msec, one eventually approaches the situation depicted in Figure 3b. Here the transient channel activity generated by the second stimulus is sufficiently delayed to have a maximal inhibitory effect (negatively signed downward arrow) on the sustained channel activity generated by the first stimulus. Hence, initial increases in SOA, up to the optimal value depicted in Figure 3b, should produce a steady increase in the contour masking effect observed in the first stimulus. As one increases the SOA beyond this optimal value, it is easy to see that the asynchrony between the transient channel activity generated by the second stimulus and the sustained channel activity generated by the first increases. Hence the contour masking effect observed in the first stimulus should decrease. In this way a U-shaped backward masking function can be generated.

At first glance, one may object to the above analysis on the ground that the strong contour suppressing effects reported in the present study and the study of Breitmeyer et al. (1974) are highly unlikely if lateral inhibition is to act over as large a spatial separation as was used in these studies. However, it is known that transient cells have substantially larger receptive fields than do sustained cells, and this may provide for rather large spatial interactions (see Matin, 1974, for a similar view). Moreover, electrophysiological studies by Hess, Negishi, and Creutzfeldt (1975) of cat visual cells comprising cortical neural columns (Hubel & Wiesel, 1962, 1968) reveal that in cortical space the activity between cells of neighboring columns is almost exclusively inhibitory and extends radially for about 400 μm. Translated to retinal space at or near the fovea (of cats), this corresponds to about 4° visual angle. The center-to-center interstimulus distance in the present study was only 1.67° visual angle. Inhibitory interactions over this spatial separation therefore cannot be ruled out.

Another objection to the present analysis could be the fact that Eriksen and Colgate (1970) found no evidence for U-shaped backward masking when subjects were asked to identify the first of two letters presented in a stroboscopic motion situation. Firstly, Eriksen and Colgate used highly discriminable letters such as A, T, and U which may not be as easily masked as the contour detail used in the present study. This is consistent with Harmon and Julesz's (1973) finding that the blurring or elimination of contour detail does not necessarily decrease the ability to recognize patterns; in fact, they report the reverse effect when certain types of facelike portrayals are employed. An obvious illustration may be instructive. The blurring of sharp contours produced by slightly squinting or defocusing one's eyes should not appreciably reduce the identifiability of the following sequence of letters: U A T.

Finally, it is noteworthy that all of the presently reported stimulus interactions were obtained across the vertical meridian. In metacontrast such interactions between target and mask have also been reported by McFadden and Gummerman (1973). This, according to the conventional view (Gazzaniga, 1967; Sperry, 1974) could be interpreted to mean that the present effects are due to interhemispheric interactions, since according to that view stimuli presented to the left and right of fixation are processed by the right and left hemispheres, respectively. However, such conclusions may be premature. Recent neurophysiological studies in the monkey (Rocha-Miranda, Bender, Gross, & Mishkin, 1975) indicate that the right and left visual hemifields are not represented exclusively in the left and right hemispheres, respectively. Rather there is a narrow strip of visual space, 2°–3° wide and straddling the vertical meridian, which is represented in both hemispheres. Moreover, this dual cortical representation of the central visual field exists in the absence of an intact corpus callosum and anterior commissure (Rocha-Miranda et al., 1975), indicating that its origin is subcortical (Stone, 1966; Stone, Leicester, & Sherman, 1973) and, contrary to views like those expressed by Mitchell and Blakemore (1970), does not require interhemispheric communication.

REFERENCE NOTES

1. Biederman, I. Personal communication, March 1974.
2. Stoper, A. Personal communication, July 1975.

REFERENCES

Alpern, M. Metacontrast. *Journal of the Optical Society of America*, 1953, *43*, 648–657.

Breitmeyer, B. Simple reaction time as a measure of the temporal response properties of transient and sustained channels. *Vision Research*, 1975, *15*, 1411–1412. (a)

Breitmeyer, B. Predictions of U-shaped visual backward pattern masking from considerations of the spatio-temporal frequency response. *Perception*, 1975, 4, 297–304. (b)

Breitmeyer, B., & Ganz, L. Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychological Review*, 1976, *83*, 1–36.

Breitmeyer, B., Love, R., & Wepman, B. Contour suppression during stroboscopic motion and metacontrast. *Vision Research*, 1974, *14*, 1451–1456.

Burchard, S., & Lawson, R. B. A U-shaped detection function for backward masking of similar contours. *Journal of Experimental Psychology*, 1973, *99*, 35–41.

Dow, B. M. Functional classes of cells and their laminar distribution in monkey visual cortex. *Journal of Neurophysiology*, 1974, *37*, 927–946.

Eriksen, C. W. Temporal luminance summation effects in backward and forward masking. *Perception & Psychophysics*, 1966, *1*, 87–92.

Eriksen, C. W., & Colgate, R. L. Identification of forms at brief durations when seen in apparent motion. *Journal of Experimental Psychology*, 1970, *84*, 137–140.

Gazzaniga, M. S. The split brain in man. *Scientific American*, 1967, *217*, 24–29.

Harmon, L. D., & Julesz, B. Masking in visual recognition: Effects of two-dimensional filtered noise. *Science*, 1973, *180*, 1194–1197.

Hess, R., Negishi, K., & Creutzfeldt, O. The horizontal spread of intracontical inhibition in the visual cortex. *Experimental Brain Research*, 1975, *22*, 415–419.

Hubel, D. H., & Wiesel, T. N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology, London*, 1962, *160*, 106–154.

Hubel, D. H., & Wiesel, T. N. Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology*, 1968, *195*, 215–243.

Kahneman, D. An onset-onset law for one case of apparent motion and metacontrast. *Perception & Psychophysics*, 1967, *2*, 577–584.

Kolers, P. A., & Rosner, B. S. On visual masking (metacontrast): Dichoptic observations. *American Journal of Psychology*, 1960, *73*, 2–21.

Matin, E. Saccadic suppression: A review and analysis. *Psychological Bulletin*, 1974, *81*, 899–917.

Matin, E. The two transient (masking) paradigm. *Psychological Review*, 1975, *82*, 451–461.

McFadden, D., & Gummerman, K. Monoptic and dichoptic metacontrast across the vertical meridian. *Vision Research*, 1973, *13*, 185–196.

Mitchell, D. E., & Blakemore, C. Binocular depth perception and the corpus callosum. *Vision Research*, 1970, *10*, 49–54.

Rocha-Miranda, C. E., Bender, D. B., Gross, C. G., & Mishkin, M. Visual activation of neurons in the inferotemporal cortex depends on striate cortex and forebrain commissures. *Journal of Neurophysiology*, 1975, *38*, 475–491.

Singer, W., & Bedworth, N. Inhibitory interaction between X and Y units in the cat lateral geniculate nucleus. *Brain Research*, 1973, *49*, 291–307.

Sperry, R. W. Lateral specialization in the surgically separated hemispheres. In F. O. Schmitt & F. G. Worden (Eds.), *The neurosciences third study program*. Cambridge, Mass.: MIT Press, 1974.

Stone, J. The naso-temporal division of the cat's retina. *Journal of Comparative Neurology*, 1966, *126*, 585–600.

Stone, J., Leicester, J., & Sherman, S. M. The nasotemporal division in the monkey's retina. *Journal of Comparative Neurology*, 1973, *150*, 333–348.

Sukale-Wolf, S. U. *Prediction of the metacontrast phenomenon from simultaneous brightness contrast.* Unpublished doctoral dissertation, Stanford University, 1971.

Turvey, M. T. On peripheral and central processes in vision: Inferences from an information-processing analysis of masking with patterned stimuli. *Psychological Review*, 1973, *80*, 1–52.

Uttal, W. R. On the physiological basis of masking with dotted visual noise. *Perception & Psychophysics*, 1970, *7*, 321–327.

Uttal, W. R. The psychobiological silly season—or—what happens when neurophysiological data become psychological theories. *Journal of General Psychology*, 1971, *84*, 151–166.

Weisstein, N. Metacontrast. In D. Jameson & L. M. Hurvich (Eds.), *Handbook of sensory physiology* (Vol. 7, Part 4: *Visual psychophysics*). Berlin: Springer-Verlag, 1972.

Weisstein, N., & Growney, R. Apparent movement and metacontrast: A note on Kahneman's formulation. *Perception & Psychophysics*, 1969, *5*, 321–328.

Weisstein, N., Ozog, & Szoc, R. A comparison and elaboration of two models of metacontrast. *Psychological Review*, 1975, *82*, 325–343.

Wertheimer, M. Experimentalle Studien über das Sehen von Bewegung. *Zeitschrift für Psychologie*, 1912, *61*, 161–265.

(Received July 28, 1975)