Vision Research. Vol. 18, pp. 1669–1674
Pergamon Press Ltd 1978. Printed in Great Britain

# METACONTRAST AND PARACONTRAST SUPPRESSION OF A CONTOURLESS AREA[1]

ARNOLD E. STOPER and JAMES G. MANSFIELD[2]
Psychology Department, California State University, Hayward, CA 94542, U.S.A.

(*Received* 28 *November* 1977; *in revised form* 17 *April* 1978)

**Abstract**—Metacontrast is usually explained as a suppression of target contour. Here we demonstrate brightness suppression of a contourless area of a target by an adjacent mask. This "area suppression" cannot be due to contour suppression. Nevertheless, it follows a U-shaped function of time similar to those obtained in traditional metacontrast, except that "forward masking" is equal in strength to backward masking. An explanation in terms of interference with a "filling-in" process is proposed.

*Key Words*—brightness; contrast; masking; metacontrast; spatial frequency; filling in; sustained response; transient response; lateral inhibition.

## INTRODUCTION

In traditional metacontrast the target (T) is a small bounded figure surrounded by a larger mask (M); e.g. a disk surrounded by an annulus. When metacontrast occurs the entire T figure, including its bounding contours, appears dim or even invisible; we refer to this effect as "figure suppression". When T and M are of equal luminance "U-shaped" functions of time are typically obtained; i.e. there is little or no suppression when T and M are simultaneous, and suppression is at its maximum when M follows T with onset asynchrony of from 50 to 100 msec, depending on many factors (Alpern, 1953; Breitmeyer and Ganz, 1976; Lefton, 1973).

The figure suppression of traditional metacontrast is considered here to include two separate effects. These are "contour suppression", i.e. the suppression of the bounding contours of the target, and "area suppression", i.e. the suppression of the bounded area of the target. Metacontrast has long been assumed to be primarily a contour suppression effect (e.g. Werner, 1935) and area suppression has either been ignored or assumed to be a result of contour suppression. There have been some who have questioned this assumption; for example, Kolers (1962) showed that under some circumstances area suppression follows a differently shaped function of time interval than contour suppression. Nevertheless, recent theories of the U-shaped function seem to depend on the assumption that metacontrast is primarily a contour suppression effect (e.g. Breitmeyer and Ganz, 1976). Weisstein, Ozog and Szoc (1975) explicitly attribute suppression of target area to suppression of its bounding edges. In this paper we demonstrate area suppression in the absence of contour suppression. We show that, even though this area suppression cannot be attributed to contour suppression, it nevertheless follows a U-shaped function of time similar in some respects to that of traditional metacontrast.

## METHOD AND PROCEDURE

The visual display shown in Fig. 1 was presented with a three-field Iconix Tachistoscope. T was an evenly illuminated white disc 5° in diameter. M was two white squares 1° on a side, separated by a 1° gap. Luminance was 64 cd/m$^2$. Durations of T and M were 20 msec, and onset asynchrony between them was varied.

A total of nine observers was used. All were naive as to the purposes of the experiment; all had normal or corrected to normal vision, and all were paid.

In Experiment 1, two presentations were made at each asynchrony value, each lasting 2 sec. An 8° square adaptation field of 64 cd/m$^2$ luminance, containing a central fixation spot, was viewed between presentations. This adaptation field was offset 1 sec before onset of the mask in each presentation; this was necessary to prevent interference of the fixation spot with the apparent brightness of the central area of the target disc. We estimate, based on data of Matin, Matin and Pearce (1970), that eye drift during this time was less than 20′ of arc. Nineteen values of onset asynchrony between T and M were used ranging from −400 msec (M preceding T) to +400 msec. Ten trials at each of the nineteen onset asynchronies were run for each of five observers, using a random block design.

Observers were instructed to keep fixation centered and make magnitude estimations of the brightness in one of two areas: (i) the area corresponding to the center of the target disc, or (ii) the area corresponding to the outside edge of the disc. Since these areas varied in apparent brightness from moment to moment it was necessary to specify the time at which the judgement was to be made; thus in Experiment 1 observers were instructed to rate brightness at "the moment the disc flashed." The adaptation field was used as the standard; observers were instructed to rate the area 10 when it looked as white as the adaptation field, and zero when it looked black. In each pair of presentations observers rated center and then edge or vice versa, in random order.

In Experiment 2 T and M were presented in a sequence which was repeated every 250 msec. This 250 msec repetition rate has been shown to produce the appearance of a continuously present (though flickering) figure (Haber

[1] Some of these results were reported at a meeting of the Psychonomic Society, Washington, D.C., 1977. This research was partially supported by the Research Foundation of California State University, Hayward.

[2] Present address: Department of Medical Psychology, University of Oregon Medical School, Portland, OR 97201, U.S.A.

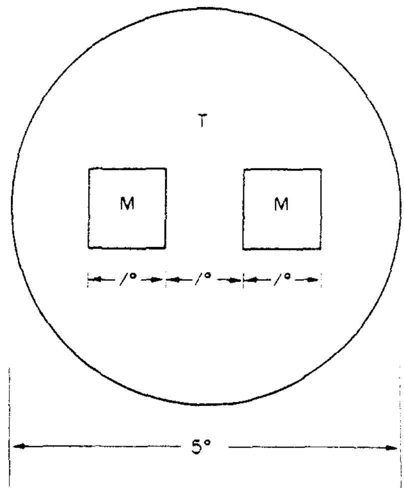


Fig. 1. Display configuration. Both T and M were evenly illuminated white figures against black backgrounds.

and Standing, 1969). Despite this flicker, the apparent brightness of a particular area in the display remained constant over time; thus it was not necessary to specify the "moment" at which ratings were to be made. No adaptation field was used, nor was a fixation point present.

Four observers were used, different from those in Experiment 1. Since no adaptation field was present the disc edge was used as a standard, and observers made magnitude estimations of only the disc center. They were instructed to rate the center 10 if it looked as white as the edge, and zero if it looked black. Since no fixation point was present observers were instructed to fixate the apparent center of the disc while making their judgments.

Onset asynchrony was varied in a modified method of limits to determine the threshold onset asynchrony, i.e. that asynchrony at which the observer first reported the center to be black. Starting from zero, onset asynchrony was increased in either positive or negative direction in increments of 10 msec. (Because of the 250 msec repetition rate any asynchrony could be described as either positive or negative, i.e. a 50 msec positive asynchrony was also a 200 msec negative. The convention here was to use the shorter asynchrony as the descriptive one.) When a zero rating was obtained the direction was reversed, until zero asynchrony was again reached. This procedure was repeated five times for positive and for negative onset asynchronies for each of three luminance values: 16, 32 and 64 cd m$^{-2}$.

## RESULTS

### *Experiment 1*

The mean center and edge brightness judgements made by the five subjects in Experiment 1 are shown in Fig. 2. It can be seen that brightness of both center and edge areas is slightly depressed at short asynchronies relative to long, i.e. the apparent brightness of the entire disc is diminished when the squares are presented close to it in time. (The points at $\pm 400$ msec asynchrony were compared with those at zero asynchrony, for center and edge judgements. Each of these four comparisons was significant by Wilcoxon $T$. $P < 0.01$.) It can also be seen that the center is always judged dimmer than the edge. This difference is more or less constant at asynchronies with absolute values above 160 msec.

Of particular interest here is the shape of the center function between $-160$ and $+160$ msec. It can be described as two U-shaped curves. One curve has a minimum at about $-70$ msec asynchrony; it is a forward masking, or paracontrast curve. The other has a minimum at about $+50$ msec; it is a backward masking, or metacontrast curve. Both minima are significantly below the maximum which occurs at zero onset asynchrony. (For $-60$ msec, $n = 28$, Wilcoxon $T = 9.2$, $P < 0.01$; for $+60$ msec, $n = 26$, Wilcoxon $T = 21.3$, $P < 0.01$.) It is these U-shaped curves which we take to be evidence of area suppression.

The U-shapes of area suppression indicate a backward masking function similar to that of traditional metacontrast. However, the forward masking effect in area suppression is equal in strength to backward; this is not true in traditional metacontrast, where forward masking, or paracontrast, is generally weak or non-existent (Alpern, 1953; Kolers and Rosner, 1960).

### *Experiment 2*

Figure 2 also shows the center brightness judge-

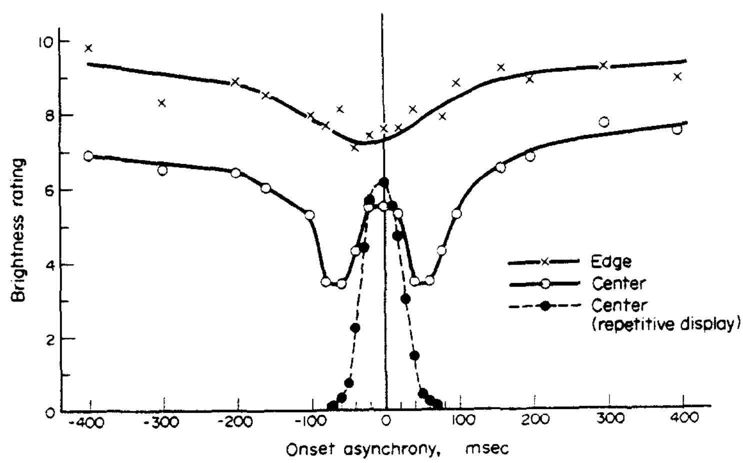


Fig. 2. Brightness ratings as a function of onset asynchrony. ×—ratings of edge, ○—ratings of center, with single presentation of display, Experiment 1. Average of five observers. ●—ratings of center with a 250 msec repetition rate, Experiment 2. Average of four observers. Negative asynchronies indicate that the mask squares preceded the target disc.

ments of Experiment 2 averaged over four subjects and three luminance values. Because of the sequential rating method used, the ratings are not truly independent. Only the values of threshold asynchrony (i.e. the asynchrony at which a zero brightness rating was first given by the subject) were used as a measure of the area suppression effect for the purposes of determining the effect of luminance on suppression. For the 16, 32 and 64 cd/m$^2$ luminance levels the average positive threshold asynchronies were 58, 57.5 and 47.5 msec. The average negative asynchronies were 57, 62 and 61.5 msec. ANOVA showed no significant effect of luminance ($F < 1$).

It can be seen that the apparent brightness of the center has a maximum at zero onset asynchrony, and falls with an increase of asynchrony in either positive or negative direction. This indicates equally strong forward and backward masking, and is essentially similar to the results of Experiment 1. However, in Experiment 2 there is a much steeper drop in brightness than in Experiment 1, with apparent brightness reaching zero between 50 and 60 msec ("threshold asynchrony"). Also, brightness does not increase at longer asynchronies in Experiment 2, and the curve is not, in a strict sense, U-shaped. The lack of brightness increase at long onset asynchronies can be most simply attributed to the fact that, with the 250 msec repetition rate, longer negative asynchronies become shorter positive ones, and vice versa.

Since the edge was used as a standard, no data are available as to its actual apparent brightness change. On the basis of informal observation it can be said that edge brightness was essentially unchanged with variation in asynchrony.

The repetitive display of Experiment 2 produces a considerably stronger masking effect than the longer repetition period of Experiment 1, as can be seen from the amplitude of the brightness function. The presence of strong suppression with a repetitive display of short period is a second departure from traditional metacontrast (the first being strong forward masking). A repetition period in the range of 250 msec destroys tradional metacontrast (Schiller and Smith, 1966); it enhances area suppression.

The increased magnitude of area suppression in Experiment 2 can be attributed to two factors: (1) The summation of forward and backward suppression effects. (2) The lack of the instruction to rate "at the moment when the disc flashed". This instruction could well have served to decrease suppression effects in Experiment 1 by concentrating attention on whatever could be seen of a homogeneous disc.

*Appearance of display*

At very short asynchronies the appearance of the display was of a homogeneous white disc with two luminous white squares superimposed on it. At intermediate asynchronies the appearance of the display was as shown in Fig. 3. The center seemed dark, often black, especially in Experiment 2. The edge of the disc remained evenly bright along its entire length. The sharp discontinuity between black center and bright edge shown in Fig. 3 was in fact not visible; instead there was a gradual, difficult to localize transition.

This appearance of a dark center in conjunction with a bright edge was important in eliciting reports of a dark disc center at "the time the disc flashed". It was particularly dramatic with the display of Experiment 2. Here the brightness of particular areas of the display appeared more or less constant through time as depicted in Fig. 3, even though the display appeared to flicker strongly. Position of fixation did not seem to influence this appearance as long as fixation was left roughly within the area between the squares. Our impression was that, with more eccentric fixation, e.g. outside the disc itself, the suppression effect was diminished. This is in contrast to traditional metacontrast, which is strengthened by eccentric fixation (Alpern, 1953).

A similar "shading" effect occurs in stabilized image experiments where one bounding contour of a figure is stabilized (Gerrits and Vendrik, 1970) and in classical metacontrast displays where the target is only partly bounded by the mask (Stigler, 1910; Werner, 1935). It also occurs in demonstrations of binocular rivalry (Levelt, 1964). In fact, a reasonable approximation of the display appearance can be created without a tachistoscope by simply viewing a large disc with the left eye and smaller squares with the right eye.

Another similarity to binocular rivalry occurred if there were small black markings on the white disc surface. Even if these markings were in the area which had its brightness suppressed, the black markings were clearly visible, surrounded by a white "halo".

Although the backward and forward masking effects in Experiment 1 were measured to be of equal strength, they seemed to differ in appearance. One aspect of this difference is that the black halo around the mask seemed broader with backward than with forward masking.

The mask squares were bright white and highly visible at all asynchrony values. At long asynchronies they appeared white against a black background, as shown in Fig. 3. At short asynchronies the mask squares appeared white against a white background, and thus had a lowered edge contrast, but nevertheless appeared slightly brighter than they did at longer asynchronies. This increase in brightness would be expected from the summation of the luminance of the disc and that of the superimposed squares which would occur at short asynchronies.

No "split motion" accompanied area suppression. This split motion generally accompanies classical metacontrast with viewing conditions similar to those used here (see Stoper and Banffy, 1977). Motion between the outer edge of the disc and the squares did tend to occur at somewhat longer asynchronies—around 200 msec. (It was found in pilot studies that this motion was stronger, and occurred at shorter time intervals, when the shapes of T and M were more similar to each other, and when they were closer together. The presence of this motion indicated poor circumstances for elicitation of area suppression, since it accompanied suppression of the entire T figure, and obscured the appearance of "dark center–bright edge" shown in Fig. 3. The display actually used was designed to minimize T to M motion.)

## DISCUSSION

The result of main concern to us here is that area

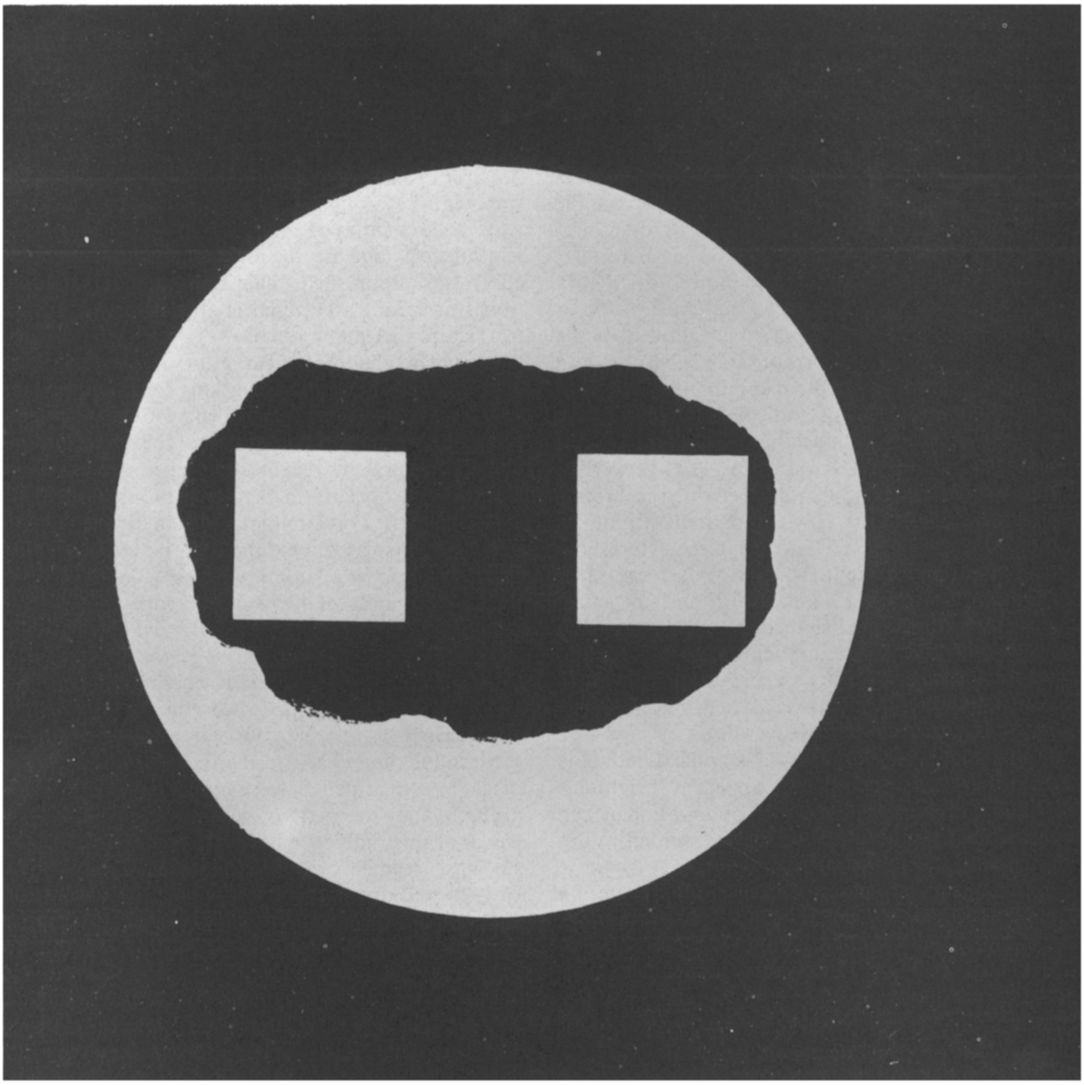

Fig. 3. An impression of the appearance of the display when strong area suppression obtains. The center area of the disc looks black even though it has the same luminance as the edge, which looks white. The transition between the black center and the white edge was not sharp, as drawn here, but was gradual and difficult to localize.

suppression follows a U-shaped backward masking function similar to that of classical metacontrast. Also of concern is the U-shaped forward masking curve, much stronger than is usual in classical metacontrast or paracontrast displays.

The U-shapes of area suppression do not seem explicable by current theories of metacontrast. One explanation of the U-shape of traditional metacontrast is that it is due to apparent motion between T and M (Kahneman, 1967); however, no such apparent motion accompanies area suppression. Another explanation is that of the "sustained–transient" theories (Breitmeyer and Ganz, 1976; Matin, 1975; Weisstein *et al.*, 1975). These theories assume that metacontrast is due to the inhibition of sustained channels, which respond to the target pattern, by transient channels which respond to the mask (or to the combination of target and mask). The U-shape is attributed to the difference in latency between the sustained and transient channels. Necessary to these theories is the assumption that the inhibited "target" channels respond to higher spatial frequencies than the inhibiting "mask" channels. But in the experiments reported here there are no high or intermediate spatial frequencies in the area of the target which is suppressed—certainly none which are higher than those of the mask stimulus. Other theories of metacontrast do not assume inhibition is necessarily of high or intermediate spatial frequencies (Bridgeman, 1971; Bernstein, Proctor, Proctor and Shurman, 1973; Ganz, 1975); they are not subject to the same problems. However, all of these theories are designed to explain the backward masking function of traditional metacontrast; they all fail to explain the strong forward masking shown here.

Area suppression is easier to explain than traditional metacontrast in that it does not require the assumption of a mechanism to suppress contours. The explanation we offer here is roughly along the lines of an explanation offered by Levelt (1964) for binocular rivalry. The essential idea is that the contours present in the display determine its brightness values, with the contours closest to a particular area contributing most heavily to its brightness. We further assume the existence of a "filling in" process by which contours or edges can influence brightness of areas at some distance from themselves. In the case of the time-varying display used here we make the following relatively commonplace assumptions: (i) Brightness signals for local retinal areas are generated at some low level in the visual system. (ii) A contour or edge signal is generated by the difference between adjacent brightness signals. This process would involve lateral inhibition. The edge signals, but not the brightness signals, are transmitted to the next higher level (see Cornsweet, 1970). (iii) A higher level representation of brightness of the visual scene is constructed by a process of "filling in" all areas by using information from the edge signals. This filling in process would work by the simple rule that brightness spreads from an edge through an area until it meets a "change signal", i.e. another edge signal. (See Gerrits and Vendrik, 1970, for a theory of such a filling in process). It is this higher level representation which the observer reports on. (iv) The low-level brightness system has a shorter time constant than the higher, i.e. it is capable of greater temporal resolution.

At long asynchrony values the filling in process would be completed and the disc and squares would be seen as if presented independently, i.e. they would each appear evenly white. At very short asynchrony values the low-level system would fail to resolve brightness in time; the resulting brightness summation would reduce the contrast of the outer edges of the squares. The display would appear as if target and mask were simultaneous, i.e. white squares against a white background. There will be some range of intermediate asynchronies at which the low level system can resolve the display, but the high level system can not. At these intermediate values the high contrast square edge signal would correctly indicate the background to be black, and the disc edge would correctly indicate, at a later (or earlier) time, the same area to be white. However, the more sluggish high level representation would not discriminate the two edge signals in time. These edge signals would thus give information to the effect that the same area is both black and white simultaneously. The appearance of Fig. 3, i.e. area suppression, is one resolution of this contradiction; the apparent brightness of a particular area seems to be determined by the edge closest to that area.

Thus area suppression can be said to result not from inhibition of target excitation by the mask but from an interference by the mask with the process of filling in of target brightness. On this explanation the U-shaped curve occurs because the time interval between T and M must be great enough to allow temporal resolution by the low level brightness system, but not so great as to allow resolution by the higher level filling in system. Since the order of T and M does not matter, two symmetrical U-shaped functions would result—one for T preceding M (backwards masking) and the other for M preceding T (forward masking).

To what extent can this explanation of area suppression be generalized to traditional metacontrast? Area suppression must be involved in some traditional metacontrast displays. Consider a display where the target is a disc of duration 75 msec, the mask is a contiguous annulus of duration 150 msec, and onset asynchrony is zero. In the first 75 msec of this display, disc and annulus are presented together, creating a larger homogeneous disc (if the borders are truly contiguous). The next 75 msec consist of an annulus alone. This sequence is thus identical to that of a large disc followed, at an SOA of 75 msec, by an annulus with its inner contours superimposed on a contourless area of the disc. This is the situation which would be expected, on the explanation offered here, to produce area suppression of the area enclosed by the annulus (informal observations indicate that this display does produce such suppression). Thus, what might seem to be a traditional metacontrast effect can be explained entirely in area suppression terms.

This explanation is not, however, applicable to the metacontrast produced when T and M borders are not contiguous, nor does it apply to the typical situation where duration of T and M are equal and onset asynchrony is 50–100 msec. In these cases the border of T would produce an edge signal; there is no mechanism in the explanation above to suppress such an edge signal once it is produced. The "sustained–transient" theories described above do contain an edge signal suppression mechanism. Perhaps some combination of one of these theories with the area suppression explanation offered here would be desirable. However, on this combination theory the similarity in U-shapes for the two phenomena would be pure coincidence; they would be produced by two totally different processes. We find more attractive the possibility that the same basic process underlies both phenomena. The low-level brightness process assumed here to underly area suppression is one candidate for this basic process. We will present elsewhere a theory which assumes that it is the time constants of this brightness detecting process which controls the time course of not only area suppression, but traditional metacontrast as well.

## REFERENCES

Alpern M. (1953) Metacontrast. *J. opt. Soc. Am.* **43**, 648–657.

Bernstein I. H., Proctor V. D., Proctor R. W. and Schurman D. L. (1973) Metacontrast and brightness discrimination. *Percept. Psychophys.* **14**, 293–297.

Breitmeyer B. and Ganz L. (1976) Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression, and information processing. *Psychol. Rev.* **83**, 1–36.

Bridgeman B. (1971) Metacontrast and lateral inhibition. *Psychol. Rev.* **78**, 528–539.

Cornsweet T. N. (1970) *Visual Perception*. Academic Press. New York.

Ganz L. (1975) Temporal factors in visual perception. In *Handbook of Perception* (edited by Carterette E. C. and Friedman M. P.), chap. 6, Vol. 5. pp. 169–227. Academic Press. New York.

Gerrits J. J. M. and Vendrik A. V. H. (1970) Simultaneous contrast, filling in process and information processing in man's visual system. *Expl Brain Res.* **11**, 411–430.

Haber R. N. and Standing L. G. (1969) Direct measures of short-term visual storage. *Q. Jl exp. Psychol.* **21**, 43–54.

Kahneman D. (1967) An onset–onset law for one case of apparent motion and metacontrast. *Percept. Psychophys.* **2**, 577–584.

Kolers P. A. (1962) Intensity and contour effects in visual masking. *Vision Res.* **2**, 277–294.

Kolers P. A. and Rosner B. S. (1960) On visual masking (metacontrast): dichoptic observation. *Am. J. Psychol.* **73**, 2–21.

Lefton L. A. (1973) Metacontrast: a review. *Percept. Psychophys.* **13**, 161–71.

Levelt W. J. M. (1964) *On Binocular Rivalry*. Institute for Perception, RVO-TNO, Soesterberg (Netherlands).

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

Matin L., Matin E. and Pearce D. G. (1970) Eye movements in the dark during the attempt to maintain a prior fixation position. *Vision Res.* **10**, 837–857.

Schiller R. H. and Smith M. C. (1966) Detection in metacontrast. *J. exp. Psychol.* **71**, 32–39.

Stigler R. (1910) Chronophotische Studien uber den Umgegungskontrast. *Pflügers Arch. ges. Physiol.* **134**, 365–435.

Stoper A. E. and Banffy S. (1977) Relation of split apparent motion to metacontrast. *J. exp. Psychol. Hum. Percept. Perf.* **3**, 258–277.

Weisstein N., Ozog G. and Szoc R. (1975) A comparison and elaboration of two models of metacontrast. *Psychol. Rev.* **82**, 325–43.

Werner H. (1935) Studies on contour: I. Quantitative Analysis. *Am. J. Psychol.* **47**, 40–64.