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CONTOUR SUPPRESSION DURING STROBOSCOPIC MOTION AND METACONTRAST

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Abstract—Findings of visual contour masking obtained when two stationary and spatially separated stimuli are presented briefly and successively in time indicate that the contour masking typically observed while viewing a stimulus in real movement also occurs while viewing a stimulus in stroboscopic movement. Additional results indicate that the loss of detailed contour information attending stroboscopic movement may contribute to, though not constitute, the contour suppression effects observed in metacontrast.

INTRODUCTION

The edge or contour information in a visual stimulus can be suppressed perceptually in several ways. For instance, studies of metacontrast show that the information in a briefly presented test stimulus is suppressed when the test stimulus is followed at short temporal intervals by a brief and spatially contiguous (i.e. non-overlapping) masking stimulus (Weisstein and Haber, 1965; Sukale-Wolf, 1971).

Loss of contour information or acuity also occurs when a test stimulus moves rapidly across the visual field (Smith and Gulick, 1957; Mackworth and Kaplan, 1962). Since the edge or contour information of a visual stimulus is comprised of high spatial frequency components (Campbell and Robson, 1968; Carpenter and Ganz, 1972), this loss of contour information may be a consequence of the fact that channels in the visual system which respond selectively to high spatial frequencies respond much less effectively to rapid stimulus motion than do low spatial frequency channels which are known to prefer relatively high velocity motion (Pantle, 1970; Breitmeyer, 1973; Tolhurst, 1973).

Insofar as the visual mechanisms underlying the perception of continuous movement overlap with those underlying the perception of stroboscopic movement (Wertheimer, 1912; Frisby, 1972), it is reasonable to expect contour suppression when two spatially separated stimuli presented briefly and successively in time produce a strong stroboscopic movement effect in a direction from the first to the second.

That stroboscopic motion may contribute to contour suppression also has been suggested on theoretical grounds by Kahneman (1967). Kahneman (1967) noted several investigations (Fehrer and Biederman, 1962; Schiller and Smith, 1966) which report the observation of stroboscopic motion in a metacontrast situation. In fact, Kahneman (1967) argues that metacontrast suppression is simply an anomalous type of stroboscopic movement. For instance, if a disk-like test stimulus is followed by an annular or ring-like masking stimulus, the test stimulus is suppressed by the perceptual system because it cannot accommodate simultaneously the perception of an expanding disk and a subsequent nonexistent disk as marked by the "hole" of the ring.

Kahneman's (1967) theoretical account of metacontrast has been challenged recently by Weisstein and Growney (1969). While stroboscopic motion is clearly and effectively obtainable when two successively presented stimuli are separated spatially by two or more degrees, the latter investigators also demonstrated, as Alpern (1953) did previously, that the metacontrast effect diminishes substantially or entirely when the test and masking stimuli have similar, large spatial separations. Although metacontrast effects have not yet been demonstrated over large spatial separations, contour suppression in stroboscopic motion over similarly large spatial separations remains a possibility in light of the preceding discussions.

METHODS

Apparatus and stimuli

The apparatus used in the three experiments to be reported in this paper consisted of a three-channel Scientific Prototype tachistoscope. The stimuli used (Fig. 1) were drawn with black India ink on 5 × 7 in. white index cards and were front-illuminated yielding a luminance of 18 mL and a contrast of 0·9. In Figs. 1(a),(b), and (c) the spatial arrangements of the stimuli used in Experiments 1, 2 and 3, respectively, are shown. Although all the stimuli in fact had a contrast of 0·9, the lighter shading of the stimuli illustrated in Fig. 1 is used simply to designate those stimuli presented first in the stimulus sequence. It should be noted that all stimuli had sharp edges or contours. The first stimulus was

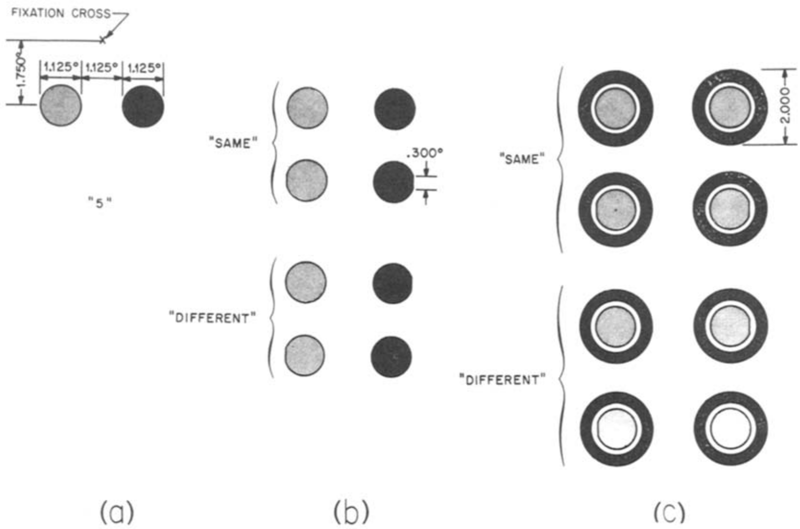

Fig. 1. Spatial arrangement of stimuli used in experiments 1–3. Although all stimuli were of the same contrast, in these illustrations the lighter stimulus denotes one presented first in the total stimulus sequence; the darker stimulus denotes one presented second in the sequence. (a) Stimuli used in experiment 1 to obtain ratings of the degree of apparent movement as a function of onset-onset interval. Subject, for instance, would respond by saying "five", which indicates a very clear percept of stroboscopic movement. (b) The four possible pairs of stimuli, one pair of which was presented (left stimulus followed by the right one) on any given trial of experiment 2. Responses to be assigned to each pair ("same" or "different") are indicated. (c) The four possible pairs of stimuli, any one pair of which was presented simultaneously and followed by annular masks, on any given trial of experiment 3. Again, responses to be assigned to each pair ("same" or "different") are indicated. The inside diameter of the annular masks was 1·250°.

located in Field 1 of the tachistoscope; Field 2 was blank except for a fixation point as shown in Fig. 1(a); and Field 3 contained the second stimulus. The viewing distance was 125 cm. At that viewing distance each of the fields was 8·000 wide and 5·75° high, and the stimuli had dimensions as shown in Fig. 1.

Subjects

Two subjects, graduate students at the University of Houston, were used. Both subjects had uncorrected, normal vision and although they were familiar with stroboscopic motion and metacontrast phenomena, neither one of them was aware of the purpose of the experiments.

Procedure

Experiment 1. Experiment 1 was designed to measure the magnitude of stroboscopic motion experienced as a function of the temporal interval separating the onsets of the two disk stimuli shown in Fig. 1(a). By throwing a switch on a given trial, the subject initiated the stimulus sequence which consisted of a 15 msec presentation of Field 1 containing the first (left) stimulus, followed by a Field 2 presentation (blank except for fixation point) of variable duration, in turn followed by a 15 msec presentation of Field 3 containing the second (right) stimulus, 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 one trial one of the following 10 intervals separating the onsets of the two stimuli: 15, 35, 55, 75, 95, 115, 135, 155, 195 and 265 msec. After such a stimulus sequence, the subject rated the degree of observed stroboscopic motion according to a category rating technique employed in similar studies by Kahneman (1967). A rating of five indicated optimal stroboscopic motion; a rating of zero indicated no stroboscopic movement (clear simultaneity or clear successiveness of the two stimuli); and ratings of intermediate value indicated corresponding intermediate degrees of observed stroboscopic motion.

Two 40-trial sessions per subject were run each day for six consecutive days. In each session, four trials were devoted to each of the 10 onset–onset intervals. The interval used in any trial was determined by a pseudo-random sequence. Prior to each experimental session, the subject was given a 5-min practice session of 20 trials. This served the double purpose of familiarizing the subject with the upcoming task and attaining a relatively stable light adaptation level. All viewing was binocular.

Experiment 2. Experiment 2 was designed to measure the contour masking effects attending stroboscopic motion. Except for modifications listed below, the procedure used in this experiment was essentially the same as used in experiment 1. In experiment 2 any one of the four stimulus pairs shown in Fig. 1(b) could be presented sequentially on any trial; and the subject, instead of rating the degree of observed stroboscopic movement, judged verbally whether or not the two stimuli were of the same or different type. Each of the stimulus pairs was presented equally often in a given experimental session. Correct responses are shown in Fig. 1(b). The response "same" was assigned to stimulus pairs of which both members either had or did not have a contour deletion; the response "different" was assigned to stimulus pairs of which one member had a contour deletion while the other did not. When uncertain subjects were forced to guess. Subjects were not given any response feedback. It should be noted that each stimulus of a stimulus pair, besides having sharp contours, was spatially separated from the other stimulus such that the critical contour information in either stimulus (a) was not spatially adjacent to any contour of the other stimulus and (b) was removed from the nearest contour of the other stimulus by greater than 2° visual angle. This procedure was used to minimize metacontrast effects which are known to depend critically on close contour adjacency of the test and mask stimuli (Alpern, 1953; Weisstein and Growney, 1969).

Experiment 3. In a design similar to that used in experiment 2, experiment 3 measured the contour masking effects due to metacontrast produced when two annular masks followed at variable onset–onset intervals the presentation of any of the four pairs of test stimuli as shown in Fig. 1(c). Again the subject was asked to indicate whether or not the two stimuli in a stimulus pair were of the same or different type. As in experiment 2, there was no response feedback. In this experiment, as in experiment 2, a higher response error rate was an indication of a greater contour masking effect. It should also be noted that in experiment 3, any contour of the test stimulus pairs (the disk-like stimuli) was separated only by 9′ of visual angle from the inside contour of the pair of annular masking stimuli. This arrangement normally provides for strong metacontrast contour suppression.

RESULTS

The results of all experiments are shown for each subject in Fig. 2. Each point is based on 48 observations. The results of experiment 1 (curve 1) show, as previously reported by Kahneman (1967), a curvilinear, inverted U-shaped function relating degree of stroboscopic motion to onset–onset interval. Both subjects attained an optimal rating at a 95-msec interval. This corresponds, nominally, to a velocity of 24°/sec. The decreases in rating at progressively lower and higher onset–onset intervals reflect the changes in the subjects' perception from clear stroboscopic motion to clear simultaneity and successiveness of the two stimuli, respectively. For both subjects, the results of experiment 2 (curve 2) also show an inverted, somewhat broader, U-shaped function relating proportion of incorrect responses to onset–onset interval; and peak error rates occur at an interval of 95 msec. One can conclude that suppression of contour information is an increasing function of the degree of stroboscopic motion experienced by the subjects. Finally, the results of experiment 3 (curve 3) also yield a relatively broad, inverted U-shaped metacontrast function relating proportion of incorrect responses to onset–onset interval separating the test stimuli from the annular masks; again the peak contour suppression effect occurred at an onset–onset interval of 95 msec. For all experiments, within-subject trend analysis of variance over the initial eight onset–onset intervals (15–155 msec) yielded highly significant quadratic components ($P < 0.001$).

DISCUSSION

The combined results of experiments 1 and 2 strongly indicate that detailed contour information is suppressed during stroboscopic motion and that the degree of suppression is directly related to the degree of stroboscopic motion. In this regard, it is interesting

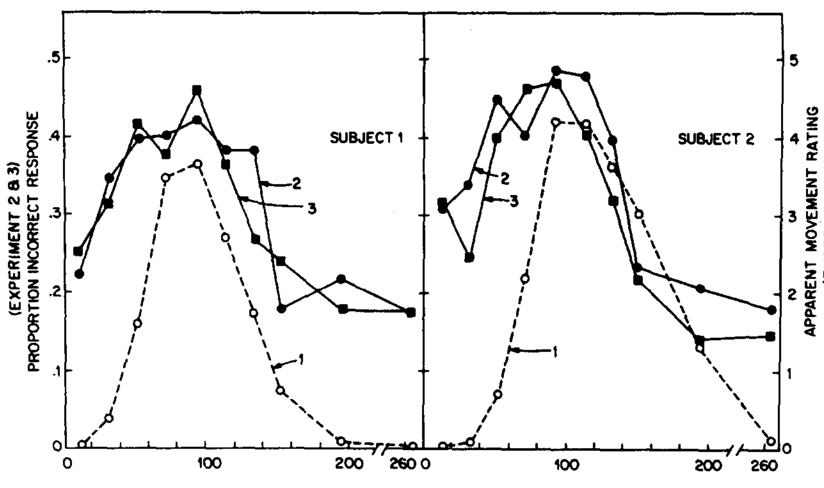

Fig. 2. Results of Experiments 1–3 plotted separately for each subject. Right ordinate indicates the stroboscopic movement ratings obtained in experiment 1; left ordinate, the proportion incorrect response obtained in experiments 2 and 3. Individual data curves are numbered according to the number of the Experiment which yielded them.

to note that Eriksen and Colgate (1970) obtained no decrement in recognition of letters presented sequentially in a stroboscopic motion situation. This in no way contradicts the present results, since sharp edges or contours are not prerequisites for pattern recognition (Kabriskey *et al.*, 1970; Ginsburg, 1973): in fact, blurring or deletion of detailed contour information at times may facilitate pattern recognition (Harmon and Julesz, 1973).

Recent psychophysical findings have shown that visual analyzers selectively sensitive to temporally transient stimulation produced by rapidly moving patterns (Pantle, 1970; Breitmeyer, 1973; Tolhurst, 1973) or by high frequency flicker (Kulikowski and Tolhurst, 1973) are also selectively sensitive to low spatial frequencies. On the other hand, high spatial frequency analyzers, responsible for the discrimination of detailed spatial structure, e.g. a sharp contour, respond best to low temporal frequencies of stimulation or to sustained stimulation (Tulunay-Keesey, 1972; Kulikowski and Tolhurst, 1973). The picture which seems to emerge is that the visual system can be divided roughly into two subsystems one of which is composed of low spatial frequency analyzers highly responsive to rapid motion and temporally transient stimulation, the other of which is composed of high spatial frequency analyzers characterized by high spatial resolution but low temporal resolution. A similar distinction between motion analyzers and analyzers of detailed spatial structure has been made previously by Saucer (1954). On the assumption that the mechanisms for detecting continuous and stroboscopic motion are alike, and on the basis of the above discussions, it is possible that the contour suppression effect is related to the strong activation of low spatial frequency channels and the relatively weak response of the high spatial frequency channels.

While a comparison of the results of experiments 1 and 2 show a strong positive relation between degree of observed stroboscopic motion and contour suppression, comparison of the results of experiments 2 and 3 in turn show a close functional similarity between contour suppression during stroboscopic motion and metacontrast—this, despite the divergent contour separations used in these two experiments which are known also to produce *differences* in the stroboscopic motion and metacontrast effects (see below). These facts, as discussed below, are of theoretical importance and suggest that metacontrast and stroboscopic motion may share some but not all mechanisms in common.

As mentioned in the introduction, Kahneman (1967) proposed a theory in which metacontrast and stroboscopic motion are intimately linked; in particular, metacontrast is identified with paradoxical or perceptually impossible stroboscopic motion. The current results show that contour suppression is obtainable under highly apparent and possible stroboscopic motion. Insofar as stroboscopic motion is observed in typical metacontrast situations (Fehrer and Raab, 1962; Fehrer and Biederman, 1962; Schiller and Smith, 1966), a more tenable theoretical position than Kahneman's would be (a) that contour suppression attends stroboscopic motion, (b) that stroboscopic motion is observed in metacontrast and consequently (c) that contour suppression is expected in metacontrast.

However, the above reformulation of Kahneman's theory does not mean that one can now identify metacontrast with perceptually possible stroboscopic motion. Metacontrast and stroboscopic motion contour suppression may share common mechanisms; but, as Weisstein and Growney (1969) demonstrated, the mechanisms mediating other perceptual effects of metacontrast such as *brightness* suppression need not be identical to mechanisms mediating the perception of stroboscopic motion. In particular, Weisstein and Growney showed that while rating of stroboscopic motion does not change at progressively larger contour separations, metacontrast brightness suppression, as previously shown by Alpern (1953), decreases considerably as contour separation increases.

The above discussions imply that metacontrast and stroboscopic motion may share some, but not all, mechanisms in common. The common mechanisms, as suggested by the present results, are those by which contour information is suppressed. It was noted earlier that the visual system is composed of two subsystems: (1) a transient response system which is selectively sensitive to low spatial frequencies but to high temporal frequencies of stimulation such as produced by flicker or rapid motion; and (2) a sustained response system which is selectively sensitive to high spatial frequencies or detailed spatial structure and to sustained or low temporal frequency stimulation. In this regard, Breitmeyer (1974) has shown that the simple reaction time to a 50 msec presentation of low spatial frequency (0·5 or 1·0 cycles/deg.) gratings is approximately 100–150 msec faster than the reaction time to a high spatial frequency (11·0 c/deg.) grating. This suggests that low spatial frequency channels respond faster by about 100 msec than do the high spatial frequency channels. With the assumption, based on recent electrophysiological results reported by Singer and Bedworth (1973), that the transient channels inhibit the activity of sustained channels, the contour suppression effects observed during stroboscopic motion and metacontrast are readily explainable. A stimulus onset delay of roughly 100 msec required to obtain optimal stroboscopic motion and metacontrast coincides with the temporal interval separating the response of the high spatial frequency channels activated by the first stimulus in the total stimulus sequence from the response of the low spatial frequency channels activated by the second stimulus. Consequently, the inhibitory effect of the low spatial frequency channels activated by the second stimulus would be optimally superimposed on the excitatory activity of the high spatial frequency channels activated by the *first* stimulus. This would result in maximal suppression of the latter channel's activity which in a nonsuppressed state signals the presence of detailed spatial structure. At progressively higher or lower values of the stimulus onset delay, the inhibitory effect of the low spatial frequency channels activated by the second stimulus on the excitatory response of the high spatial frequency channels activated by the first stimulus becomes progressively less effective. This explanation implies among other things, that, as a function of onset–onset interval, the inverted U-shaped contour suppression effect attending stroboscopic motion (as well as metacontrast) is particularly apparent in the first of the two sequentially presented stimuli. Since the subjects in experiment 2 of the present study made their response on the basis of a "same-different" comparison between the first and the second stimuli rather than on a classification of each of the stimuli separately as to the presence or absence of a contour deletion, the current results do not bear on this implication and others which await further investigation.

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Résumé—Les résultats du masquage d'un contour visuel obtenus par présentation brève et successive dans le temps de deux stimulus stationnaires et séparés spatialement indiquent que le masquage de contour observé typiquement en regardant un stimulus en mouvement réel se produit aussi avec un stimulus en mouvement stroboscopique. Des résultats supplémentaires indiquent que la perte d'information sur les détails du contour par suite du mouvement stroboscopique peuvent contribuer, sans en être la seule cause, aux effets de suppression de contours observés dans le métacontraste.

Zusammenfassung—Wenn zwei stationäre und räumlich getrennte Reize kurz und zeitlich aufeinanderfolgend dargeboten werden, zeigt sich, dass typisches Konturenmasking, wie es bei wirklicher Bewegung beobachtet wird, auch bei stroboskopisch erzeugter Bewegung beobachtet wird. Zusätzliche Ergebnisse zeigen, dass der Verlust an genauer Intureninformation, der die stroboskopische Bewegung begleitet, zu derKonturenunterdrückung, die bei Metakontrast auftritt, beitragen, wenn auch nicht voll erklären kann.

Резюме—Результаты маскировки зрительно воспринимаемого контура, получаемые в том случае, когда два стагионарных и пространственнр раздельных стимула представляются на короткое время последовательно, показывают, что маскировка контура типически наблюдаемая если рассматриваемый стимул находится в реальном движении, происходит также и при рассматривании стимула в стробоскопическом движении. Дополнительно получены результаты, которые показывают, что утрата детальной информации о контуре, сопутствующая стробоскопическому движению, может участвовать, хотя и не быть основой, подавления контура наблюдаемого при метаконтрасте.