

Simultaneous visual events show a long-range spatial interaction

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A stimulus consisting of two brief flashes separated by a short interval appears to flicker, whereas a single brief flash does not. Performance on a task requiring discrimination of double and single stimuli is adversely affected by simultaneous presentation of a second, similar stimulus at a relatively remote position in the visual field. Most errors occur when target and mask follow different time courses, one double and the other single. The results of four experiments studying this interaction are reported. An effect on performance is observed under binocular, monocular, and dichoptic viewing conditions. Performance is affected up to target to mask distances of at least 20 deg of arc. Performance increases as target-to-mask onset asynchrony is increased, reaching asymptote at asynchronies of between 100 and 150 msec. The precise shape of the stimuli does not appear to be important in determining the size of the effect or whether or not an effect occurs. An analogy between this effect and apparent movement is suggested.

A stimulus consisting of two brief flashes separated by a suitably short interval gives the phenomenal impression of flicker. Under appropriate conditions, such a stimulus is quite easily distinguishable from a single brief flash, because the latter does not appear to flicker. If two stimuli are presented simultaneously in different parts of the visual field, the double vs. single discrimination is still quite easy if both stimuli are double or both stimuli are single. If, however, the stimuli are different, one double and the other single, they can look remarkably similar. That is, they may appear to be both flickering or both single. We found this apparent interaction between remote stimuli interesting, particularly because it seemed to be a long-range effect and thus remarkably different from classical masking. However, we could find no reference to such an effect in the literature. The following study was conducted to determine some of the limits of this interaction and to distinguish it from other similar interactions that have been documented. On the basis of the results of this study, we make a suggestion concerning the possible significance of this long-range spatial interaction.

Initially, the effect was arranged as a demonstration. It proved quite difficult to persuade some observers that the stimuli in fact followed different time courses. On the other hand, it became clear that the interaction was more easily seen by some

observers than by others. For systematic study, therefore, a more objective method was thought to be preferable. A forced-choice design was chosen in which judgments were made concerning only one stimulus, called here the *target*. Subjects judged whether this stimulus appeared to be single or flickering. These judgments were made with and without presentation of a second, remote stimulus, designated the *mask*, which itself could be either double or single. The effect of the masking stimulus on judgments concerning the time course of the target could thus be studied as a function of relevant mask parameters.

METHODS

Apparatus

Stimuli were presented on a free-standing white screen by overhead projection from two optical benches. The 12-V dc projection lamps were equipped with 100-W Osram halogen bulbs. Stimulus presentation duration was controlled by silent, electromagnetic shutters with rise times of 5 msec and fall times of 10 msec. Timing of the stimulus sequence was governed by a Hivotronic HG 100 series stimulator programmer. The position of stimuli in the horizontal dimension could be controlled by electromagnetic rotation of triangular prisms mounted on each of the benches. Positioning of the stimuli in the vertical domain was achieved by rotation of the optical benches on their mountings.

Subjects were seated, and a chinrest which fixed the viewing distance of the screen at 67 cm was provided. The screen measured 184 cm vertically \times 185 cm horizontally. A black fixation cross, subtending 1 deg at the viewing distance, was attached to the screen. The luminance of the screen was approximately 2.5 asb ($.8 \text{ cd/m}^2$) as measured by a Schmidt-Haensch spot photometer.

Stimuli

Stimuli were constructed by inking black forms on paper. The photographic negatives of these forms were then mounted in

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slide holders on the optical benches. The stimuli usually employed were circular spots of light with diameters subtending 2.65 deg. For Experiment 4, two further stimuli, with the same area as the circular stimuli, were constructed: a square stimulus with sides subtending 2.4 deg at the viewing distance, and a stimulus consisting of three vertically oriented bars with widths and separations of .8 deg. By placing neutral density filters on one of the benches, the luminances of the stimuli were matched and were equal to approximately 10 asb (3.2 cd/m²).

The general spatial arrangement of target, mask, and fixation cross is shown in Figure 1a. To ensure that the location of the target was unambiguous, a small arrow was located above the point at which the target appeared. The target was always presented 10 deg to the left of the fixation cross. Unless otherwise noted, the mask was presented 10 deg to the right of fixation.

Target and mask consisted either of a single 30-msec flash or of a 30-msec flash followed, after an interval of 35 msec, by a second 30-msec flash. The time courses of single and double pulses are shown in Figure 1b. Phenomenally, the double flashes appeared to produce a flicker rather than two clearly separate flashes. The particular time settings were chosen because they appeared to make discrimination of this feature moderately difficult. In fact, there were considerable individual differences in the ability to discriminate single and double flashes. Three subjects tested in the present series of experiments failed to reach 90% correct judgments for targets presented alone; these subjects were excluded from analysis. It should be noted that single and double flashes probably also differed phenomenally in other, less noticeable ways, such as apparent duration and brightness.

Ordinary binocular viewing was usually employed. Monocular viewing could be achieved by patching one eye with an eye patch. Dichoptic viewing could be arranged by placing a partition between the eyes, which limited the field of binocular vision to a strip approximately 3 deg wide centered on the fixation cross. Using this arrangement, the target was seen only by the left eye and the mask was seen only by the right eye.

Subjects

Subjects were volunteers from the staff of the Max Planck Institute for Psychiatry and paid volunteers from the general

population. The subjects had normal or corrected-to-normal vision.

Procedure

The subjects were allowed at least 10 min of dark adaptation at the commencement of the session. Double and single target stimuli were shown to the subject, and it was pointed out that the double stimuli appeared to flicker while single stimuli did not. The subjects' task was to say "yes" if a target was judged to flicker and "no" if it was judged to be single. A trial consisted of the following sequence: On a signal from the experimenter, the subject fixated the cross and pressed the button to initiate the trial. Target presentation followed 100 msec later. If a mask was being presented, its onset occurred at the same time as the target. After stimulus presentation, the subject responded and this response was recorded by the experimenter. The apparatus was then reset by the experimenter in readiness for the next trial. Each trial lasted approximately 3.5 sec.

Target and mask could both be either double or single. There were thus four target-mask combinations: double-double, single-single, double-single, single-double. Trials were performed in blocks of 40–10 trials with each target-mask combination. Order of trials within each block was determined by random selection without replacement from the total set of trials for that block. The first block of trials was a practice with the target stimulus alone; this block consisted of 20 double-flash and 20 single-flash trials. During the practice, knowledge of results was given. For the subsequent blocks of trials, no knowledge of results was given. A different experimental condition was tested during each block; order of conditions was randomized. Subjects were warned about the presence of the mask and instructed to concentrate only on the target.

RESULTS

Experiment 1

The following experiment had two aims: (1) to verify that a remote masking stimulus would interfere with judgments concerning the time course of a target stimulus, and, if there was such an effect, (2) to determine over what target-to-mask distances it could be obtained. Performance was investigated as a function of presentation of a masking stimulus at eccentricities of 5, 10, 15, 20, and 25 deg on the opposite side of the visual field; additionally, under one condition, the target was presented alone.

Five subjects contributed a total of 200 observations per condition. Inspection of the results indicated that all subjects showed a similar main effect; the individual results were therefore pooled. It should be noted that the size of the effect as well as overall performance varied considerably among the individual subjects. Percentages of correct responses over all subjects as a function of mask eccentricity are shown in Figure 2. Chance performance is 50% correct. Pooled errors under all conditions, except that in which no mask was presented, are shown in Table 1 for different target and mask combinations. As can be seen, 86% of errors were made when the target and mask followed different time courses. A one-way repeated-measures analysis of variance was performed on the number of correct

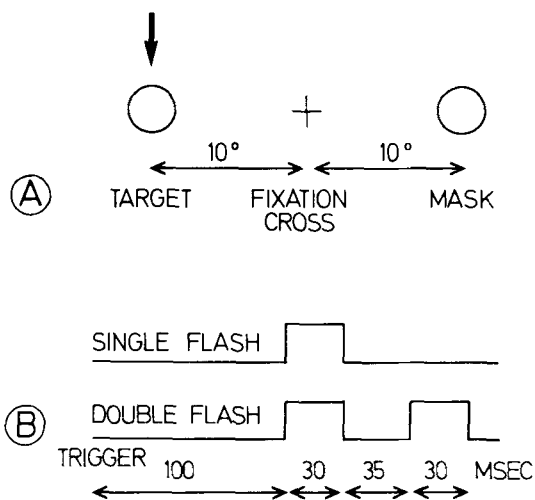


Figure 1. Schematic representation of the general stimulus arrangement. (A) The positions in space of target, fixation cross, and mask. (B) The stimulus sequences for single and double flashes. Both target and mask could be either single or double; there were thus four target-mask combinations.

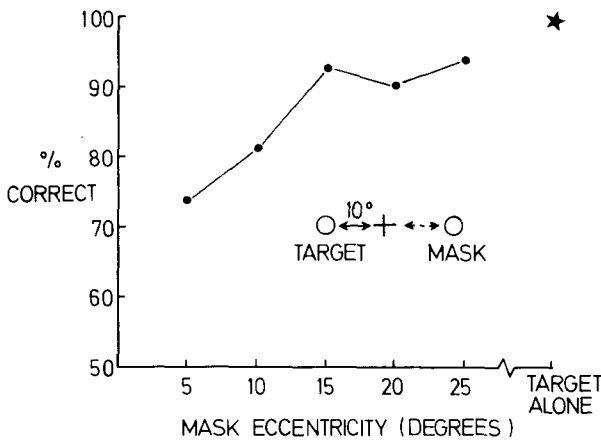


Figure 2. Percentages of correct response for a task requiring judgment of whether a target stimulus flickered or not as a function of the eccentricity of a masking stimulus. Inset is a schematic representation of the spatial arrangement of target, mask, and fixation cross. Ordinary binocular viewing was employed. Chance performance in this and subsequent figures is 50% correct.

Table 1
Percentages of Errors (PE) Made With Different Target and Mask Combinations in Experiment 1

PE	Single Mask		Double Mask	
	Single Target	Double Target	Single Target	Double Target
	2	54	32	12

Note—Total errors = 139.

responses. The analysis indicated that the main effect was highly significant [$F(5,20) = 11.78, p < .001$]. As can be seen from Figure 2, performance increases as mask eccentricity increases. The difference between performance with a mask at 10 deg and performance with the target alone is significant at the .05 level on a post hoc test (Lindquist's d). Thus, performance is affected at target-to-mask distances of at least 20 deg of arc.

It is not clear from the present results whether the function relating mask eccentricity and performance is monotonic or not. In particular, performance with a mask eccentricity of 15 deg appears to deviate from a simple monotonic trend. An eccentricity of 15 deg to the right corresponds closely to the position of the blind spot of the right eye. In fact, when asked to report whether a stimulus at this eccentricity could be seen when viewed monocularly with the right eye, four of the subjects reported that such a stimulus was invisible and one reported that only a small part of it could be seen. The following experiment was therefore performed.

Experiment 2

The present experiment was similar to the previous experiment except that monocular viewing with the left eye was employed rather than binocular viewing. Under these conditions, any effects peculiar to the right eye will disappear.

The subjects employed in this experiment were the same as those used for Experiment 1. Percentages of correct response over all subjects as a function of mask eccentricity are shown in Figure 3. A one-way repeated-measures analysis of variance was performed on the number of correct responses. The effect of mask eccentricity was highly significant [$F(5,20) = 10.54, p < .001$]. As can be seen from Figure 3, the effect of the mask decreases monotonically as distance increases. This finding supports the idea that the scotoma is relevant in determining the size of the effect under binocular viewing conditions. An asymptote in performance appears to be reached at mask eccentricities of between 15 and 20 deg, or target to mask distances of 25 to 30 deg.

Since subjects in the present experiment were the same as those in Experiment 1, an effect of practice might be expected on the present results. In general, practice was found to reduce the magnitude of the masking effect, probably because subjects learned to use secondary cues in making the discrimination between double and single flashes. A comparison of Figures 2 and 3 fails to reveal such an effect. If anything, performance at 5 and 10 deg is poorer in the present experiment than in the previous experiment, but this difference does not reach conventional levels of significance.

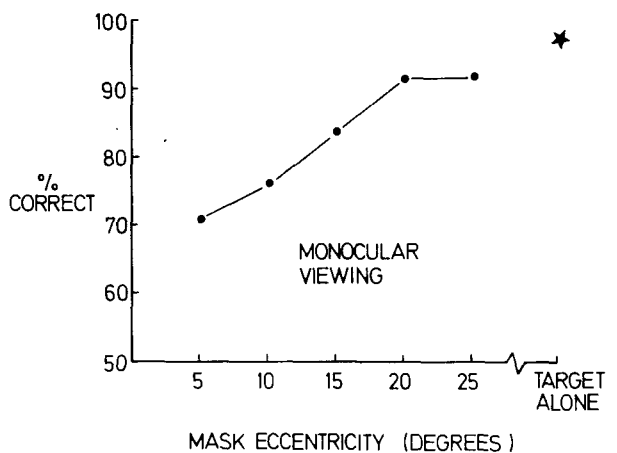


Figure 3. Percentages of correct response as a function of mask eccentricity, as in Experiment 1. Monocular viewing with the left eye was employed. The same subjects served in both experiments.

Experiment 3

The aim of the experiment was to investigate to what extent the present stimuli needed to be simultaneous in order to interact. Performance was investigated at six stimulus onset asynchronies: 0, 50, 100, 150, 250, and 500 msec.

Five subjects contributed a total of 200 observations per condition. Percentages of correct response as a function of the onset asynchrony of target and mask are shown in Figure 4. An analysis of variance performed on the number of correct responses indicated that the effect of stimulus onset asynchrony (SOA) was significant [$F(5,20) = 15.29$, $p < .001$]. As can be seen, performance increases as SOA increases, reaching asymptote between 100 and 150 msec.

The results show a great reduction in the effect of the mask as SOA is increased from 50 to 100 msec. Thus, it appears that target and mask must be simultaneous, or nearly simultaneous, for there to be a sizable interaction between them.

Experiment 4

The final experiment was designed to answer three questions. The questions, together with the comparisons intended to answer them, were as follows: (1) Is there an interaction between stimuli if the stimuli are of different shapes? Performance was compared with a circular target without a mask was compared with performance for the same target with a square mask. (2) Is the effect of the mask greater if it contains more contour? Performance with a mask that was circular was compared with performance with a mask that was composed of three bars totaling the same area. (3) Is there an interaction if target and mask are presented dichoptically? Performance when tar-

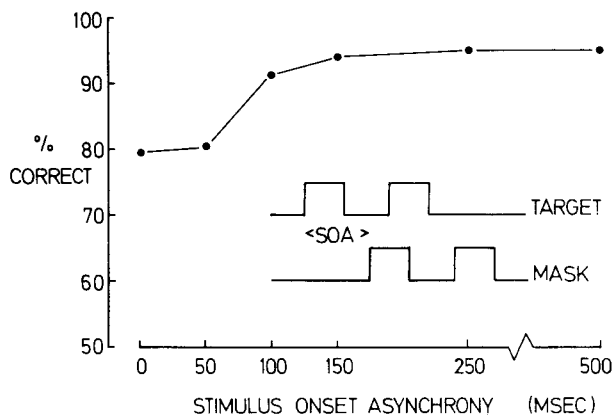


Figure 4. Percentages of correct response as a function of the asynchrony of target and mask. Inset is a schematic diagram of the temporal relationship between target and mask; in the example shown, both target and mask are double and their asynchrony is 50 msec. Ordinary binocular viewing was employed.

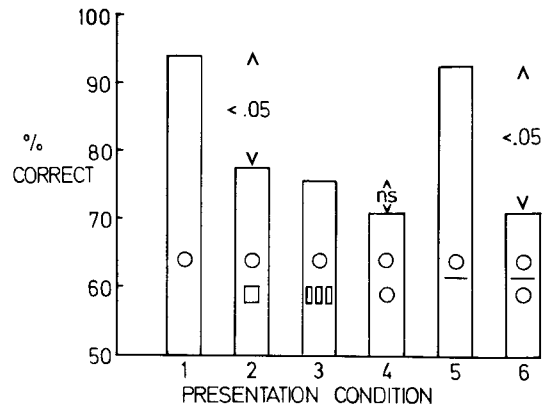


Figure 5. Percentages of correct responses with a variety of arrangements of target and mask. The presentation conditions were: (1) no mask; (2) square mask; (3) bar mask; (4) circular mask; (5) no mask, dichoptic presentation conditions; (6) circular mask, target and mask presented dichoptically. These presentation conditions are shown schematically in the figure, with target indicated above and mask, if present, below. Physically, the target was always presented 10 deg to the left of the fixation cross while the mask was presented the same distance to the right. The probabilities associated with preselected comparisons are also indicated.

get and mask were presented to different eyes was compared with performance when only the target was presented under the same conditions.

Six subjects contributed a total of 240 observations per condition. Percentages of correct response over all subjects under the six presentation conditions are shown in Figure 5. Comparisons between the paired conditions were carried out using t tests for related samples. The difference between performance with the target alone and with a square mask was significant [$t(5) = 2.76$, $p < .05$, two-tailed]. Thus, an interaction occurs when target and mask have different shapes. The difference between performance with a circular mask and performance with a bar mask was not significant [$t(5) = .79$]. Thus, additional contour does not increase the strength of the masking effect; if anything, the bars were slightly less effective than the circle under present conditions of stimulation. Finally, under dichoptic viewing conditions, there was a significant difference between performance with and performance without a mask [$t(5) = 7.38$, $p < .05$, two-tailed]. Thus, an interaction between target and mask occurs under dichoptic viewing conditions also.

DISCUSSION

The study demonstrates the existence of a visual interaction between double and single flashes. The most important characteristics of this interaction appear to be the following. First, it is an effect on the perception of the time course of stimuli. It is

probable that the effect is specific to this dimension of stimuli. An investigation of detection of the present stimuli at threshold failed to reveal any effects of remote stimuli on detectability. Furthermore, the interaction seems to be largely independent of the shape of the stimuli involved. Second, it is a long-range interaction. Stimuli presented in different hemifields interact, and stimuli presented in different hemifields of different eyes interact also. Finally, the interaction requires simultaneous or near-simultaneous presentation of stimuli.

Neurophysiological Substrates

The results described above, together with some additional observations, allow some comment to be made concerning the probable locus of the interaction. The fact that the effect occurs under dichoptic viewing conditions shows that the interaction is taking place after the point of binocular confluence. Thus, the effect is not due to retinal or LGN mechanisms. Furthermore, since the effect occurs when target and mask are presented in different hemifields, the interaction is probably not taking place in striate cortex. Neurons in the striate cortex show a fairly strict mapping into the respective contralateral hemifields: only a narrow strip in the center of the visual field is represented in both hemispheres. Moreover, the callosal connections between the striate visual areas of both hemispheres are restricted essentially to the representation of the vertical meridians (Bilge, Bingle, Seneviratne, & Whitteridge, 1967; Tusa, Palmer, & Rosenquist, 1978; Zeki, 1977). Thus, primary visual cortex can be excluded as a substrate for far-reaching spatial interactions. It appears conceivable, therefore, that the interaction is occurring at the level of the second visual system (Schneider, 1969), in particular along the colliculopulvinar pathway to prestriate visual areas. However, there are reasons for believing that this is not the case either. We had the opportunity to test a patient with hemianopia due to a large brain defect in the left occipital lobe (including cuneus) after removal of a hematogenous brain abscess. The colliculopulvinar pathway for this patient was intact. Presentation of a mask in the blind hemifield had no detectable effect on judgments concerning a target in the sighted hemifield. Although a failure to find an effect is inconclusive evidence, it suggests that the interaction is not taking place in the tectal system, but requires the relay of signals via the geniculostriate cortex loop.

A substrate potentially capable of mediating the effect is the visual area in the superior temporal sulcus. This area contains neurons with large receptive fields which are particularly sensitive to movement and temporal variations in stimulus parameters (van Essen, Maunsell, & Bixby, 1980; Zeki, 1979).

The callosal connections of this area are more diffuse than in primary visual cortex, thus allowing for far-reaching interactions between the hemifields. Some intriguing observations made with a second patient seem to support this notion. This patient had bilateral lesions in prestriate visual cortex which were due to an infarction. As assessed from computer tomography, the lesions were most probably in the region of the superior temporal sulci. A full report concerning this patient is in preparation; however, her most obvious visual deficit was in the ability to perceive motion. She was unable to perceive real motion occurring at velocities of 15 deg/sec or more and seemed virtually unable to perceive apparent motion. When tested in the present paradigm, it was found that she was unable to perform the discrimination task normally: she found the discrimination between double and single stimuli difficult, even at intervals between flashes as long as 250 msec. It should be noted that her flicker fusion threshold for a continuously modulated light had previously been found to be near normal in both the fovea and periphery.

Relation to Other Visual Interactions

A number of different kinds of visual masking have been distinguished (Breitmeyer & Ganz, 1976; Kahnemann, 1968; Michaels & Turvey, 1979; Turvey, 1973). These interactions generally concern the detrimental effects of a mask on detection or recognition of a target rather than judgments concerning the time course of a target. The SOA over which the present effect is obtainable is similar to that for many masking effects. The present effect, however, is unlike conventional masking effects in that it can be obtained over large target-to-mask distances. Although they can be obtained dichoptically, effects of metacontrast disappear at target-to-mask distances of 2 to 3 deg of arc (Gronney, Weisstein, & Cox, 1977; Kolers & Rosner, 1960). It thus seems very unlikely that the present interaction is an extension of conventional masking effects.

Periphery (McIlwain, 1964, 1966) and shift effects (Fischer & Krueger, 1974; Krueger, Fischer, & Barth, 1975) are long-range interactions which have been reported in the neurophysiological literature. McIlwain (1964) demonstrated that a subthreshold spot of light flashed on and off in the receptive field center of cat retinal ganglion or lateral geniculate nucleus neurons could evoke a suprathreshold response when a black disk was moved outside the classical receptive field. The effect could be obtained at distances up to 90 deg. Levick, Oyster, and Davis (1964) have shown that the periphery effect is not due to stray light. Attempts to demonstrate a periphery effect psychophysically were at first unsuccessful (Spillman & Gambone, 1971). However, Sharpe (1972) and, more

recently, Breitmeyer and Valberg (1979) claim to have found psychological correlates of the periphery effect. Breitmeyer and Valberg found that oscillating a peripheral square-wave grating back and forth decreased the detectability of a test flash presented in the foveal region. Does the present effect share the same underlying mechanisms as the periphery effect? The present effect apparently is not the same as that reported by Breitmeyer and Valberg, since they did not find an effect for stimuli presented outside the fovea. Furthermore, the present interaction is unlike McIlwain's effect in the following respects. First, in Experiment 4, the present effect was not increased by increasing the number of contours in the mask; the periphery effect, on the other hand, is dependent on amount of contour (McIlwain, 1966). Second, the periphery effect is an effect on detectability at threshold, whereas the present effect is not. Finally, periphery and shift effects have their origins in the peripheral visual system (Krueger, Fischer, & Barth, 1975; McIlwain, 1964), whereas the site of the present interaction is beyond the point of binocular confluence.

An interaction that occurs between mirror symmetric portions of the peripheral visual field has been reported by Singer, Zihl, and Poeppel (1977). They found that repetitive determination of the increment threshold in a given part of the visual field produced an adaptation effect, resulting in an increase in threshold for that part of the visual field. Threshold normally returned to control levels over a period of approximately 10 min. However, thresholds could be immediately reset to control level by adapting a position in the visual field which was mirror symmetric with respect to the vertical meridian. This interaction occurred up to distances of at least 60 deg. Both adaptation and resetting effects showed interocular transfer. Resetting could be produced by stimulation in the blind hemifield of patients with cortical lesions, but resetting was not observed in patients with optic tract or pulvinar lesions (Singer et al., 1977; Zihl & von Cramon, 1979). The effects reported by Singer et al. are thus associated with subcortical visual centers, and are consistent with previous findings concerning the function of such centers (e.g., Schneider, 1969; Wurtz & Mohler, 1974, 1976a, 1976b). For example, adaptation may play a role in distinguishing new events from repetitive stimulation. These effects differ from the present effect in a number of respects. First, resetting was observed with stimulation only at or near a mirror symmetric position in the visual field; there was no similar restriction on the present effect. Second, both adaptation and resetting required repetitive stimulation, while the present effect does not. Finally, while resetting is subcortical, the available evidence suggests that the present effect is not.

Investigations of central factors in the perception of flicker appear to conflict with the present findings.

In a frequently cited study, Sherrington (1904) investigated the perception of flicker under conditions of binocular fusion of the test stimuli. Sherrington compared critical flicker frequency (CFF) when the eyes were stimulated synchronously and when they were alternately stimulated. If there were perfect binocular fusion in the temporal domain, there should be no perceptible flicker with alternate stimulation. In fact, Sherrington found very similar CFFs under both conditions: the CFF was about 2.5% less when the eyes were stimulated alternately. Later studies have generally revealed a slightly larger effect. However, in 14 studies reviewed by Baker (1970), the mean difference between conditions is only about 6%. These findings have generally been taken to imply that there is very little binocular interaction in the perception of flicker. This conclusion appears to conflict with present findings. The conflict, however, is probably more apparent than real. Clearly, any of a large number of differences between the paradigms could account for the presence of a dichoptic effect under present conditions and its absence, or near absence, under Sherrington's conditions. More generally, the differences between the two paradigms and the results obtained from them suggest that certain aspects of the perception of flicker are determined in the peripheral visual system, while other aspects are determined centrally. It is perhaps not surprising that, under appropriate conditions, both peripheral and central factors in the perception of flicker can be demonstrated. In this context, it should be noted that Cavonius (1979) has recently shown that a larger effect can be demonstrated in Sherrington's paradigm using sensitivity to sinusoidal flicker rather than CFF. Cavonius found that about 40% more modulation was needed to detect flicker when the eyes were stimulated alternately than when they were stimulated synchronously. Thus, even in the Sherrington paradigm, it can be shown that central factors contribute to the perception of flicker.

Analogy with Apparent Movement

The discussion has emphasized the dissimilarity of the present effect from previously documented interactions. While motion between stimuli was not observed in the present paradigm, an interaction with certain points of similarity to the present effect is that involved in apparent motion. Braddick (1974) distinguishes a short- and a long-range process in apparent motion. It is long-range apparent motion which has been studied classically; apparent motion can certainly be observed up to 10 deg (Kolers, 1972) and possibly over distances greater than 20 deg (Anstis, 1978; Teuber, Battersby, & Bender, 1960). Thus, the spatial limits of apparent movement and the present effect are rather similar. Apparent movement can also be observed between stimuli presented dichoptically (Shipley, Kenny, & King, 1945). Furthermore, the shape of stimuli ap-

pears to be largely irrelevant to whether apparent movement is observed (Kolers & Pomerantz, 1971). The present effect thus shares some of the characteristics of this kind of apparent movement. This interpretation is also consistent with the finding that a patient with bilateral lesions in the prestriate visual cortex who was unable to perceive motion was also unable to perform the present task. The main difference between the two phenomena is, however, that the present interaction requires simultaneity, or near simultaneity, while for apparent motion to be observed between brief stimuli the stimuli must be successive (Kahneman & Wolman, 1970).

It is tempting to extend the analogy between the present interaction and apparent movement. The phenomenon of apparent movement indicates that there is a perceptual mechanism which attributes motion to physically independent, successive events. The present observation is that simultaneous events may appear to have similar time courses whether they are physically the same or not. This observation suggests that there is a perceptual mechanism which attributes identity to physically independent simultaneous events. In both cases, connecting independent events represents a simplification of the visual world. The suggested account is thus that simultaneous events tend to be perceived as having a common source and thus a common time course.

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