

ON PERIPHERAL AND CENTRAL PROCESSES  
IN VISION:  
INFERENCES FROM AN INFORMATION-PROCESSING ANALYSIS  
OF MASKING WITH PATTERNED STIMULI<sup>1</sup>

M. T. TURVEY<sup>2</sup>

*Haskins Laboratories, New Haven, Connecticut*

The masking of briefly exposed letter forms by a preceding or succeeding stimulus may originate in either peripheral or central visual mechanisms. The question of how masking varies with origin was examined in a series of experiments which made use of stimuli that masked the target forms only monoptically (or binocularly), or both monoptically and dichoptically. Peripheral forward and backward masking were described by a simple relation between target stimulus energy and the minimal interval between target offset and mask onset permitting evasion of masking: the minimal interval multiplied by the target energy equals a constant. Peripheral forward masking, however, was more sensitive to mask intensity than was peripheral backward masking. On the other hand, central masking, which was primarily backward, was relatively unaffected by stimulus energy and was determined by the interval elapsing between the onsets of the two stimuli. The multiplicative rule and the onset-onset rule characterized, respectively, peripheral and central visual processes. The peripheral processes were viewed as a set of parallel systems or nets signaling crude features of the stimulus and the central processes as a series of decisions conducted, in part, on these features and resulting in stimulus recognition. It was hypothesized that the peripheral and central processes were related in a concurrent and contingent fashion: apparently, the two occur in parallel, with the central decisions contingent on the output of the peripheral systems which signal different features at different rates.

Perceptual interference results when two stimuli are delivered to an observer in rapid succession. The term "forward masking"

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<sup>2</sup> Also at the University of Connecticut, Storrs. Requests for reprints should be sent to M. T. Turvey, Haskins Laboratories, 270 Crown Street, New Haven, Connecticut 06510.

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describes the impairment in the perception of the second stimulus induced by the first, and the term "backward masking" describes the interference on the first induced by the

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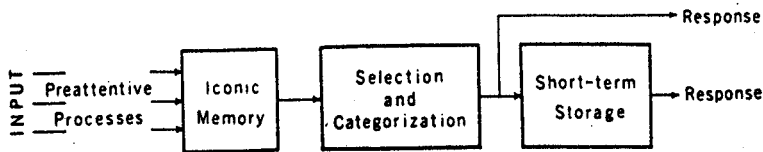


FIG. 1. Schematic representation of the visual information-processing system.

second. The phenomena of forward and backward masking are evident in both aural and visual perception (Elliot, 1971; Kahneman, 1968; Raab, 1963; von Békésy, 1971), and they occur, to varying degrees, under conditions in which the two stimuli are presented to opposite ears (i.e., dichotically) or eyes (i.e., dichoptically) and under conditions where both stimuli are presented to the same ear or eye. Thus the perceptual interference may originate in the peripheral sense organ or in the more complex structures of the brain. Presumably the rules determining masking differ with the origin of the effect. In the present paper, masking in vision is examined for the purpose of isolating these differences.

#### *Backward Masking and Information Processing*

Backward masking of form by visual pattern or visual noise has recently received considerable attention primarily because of the central role it plays in the information-processing approach to visual perception (see Haber, 1969a). In brief, the information-processing analysis represents visual perception as a hierarchically organized temporal sequence of events involving stages of storage and transformation of information. Within this framework, backward masking by pattern or noise is proposed as an analytic tool with which to investigate visual perception (Haber, 1969b; Sperling, 1963). The principal argument behind that proposition is that if a pattern mask follows a target stimulus after some delay, processing is assumed to have occurred during that delay but is terminated or interfered with by the mask. This argument is, essentially, the interpretation forwarded by Baxt (1871) for backward masking and, following Kahneman (1968), will be called an interruption hypothesis.

An alternative interpretation of masking by pattern is also emphasized in the literature. This interpretation, referred to as an integration hypothesis (Kahneman, 1968), stresses the effect that a visual pattern has on the sensory character of the target stimulus representation rather than on the extraction of information from the target representation. The idea is that two stimuli which follow one another in rapid succession are effectively simultaneous within a single "frame" of psychological time, analogous to a double exposure of a photographic plate. In masking by homogeneous flash of light, for example, the outcome of such a process of summation will be a reduced level of contrast between figure and ground (Eriksen & Hoffman, 1963). As Kahneman (1968) has pointed out, this position views masking by pattern as just a special case of temporal summation of heterogeneous stimuli.

Figure 1 summarizes the essential features of a visual-information-processing system appropriate to the description of performance in tachistoscopic experiments. It contrasts the interruption and integration hypotheses.

Iconic storage (Neisser, 1967) is seen as a buffer memory system in which the input can be held in a literal form for several hundred milliseconds during the course of conversion to response and/or short-term categorical storage. Although the information in iconic storage is considered to be relatively unanalyzed, preattentive mechanisms have, perhaps, already extracted certain global features of the input (Neisser, 1967). These would include, for example, figure-ground relationships which provide the raw material for subsequent selective processing of the iconic representation. This selective processing or recoding is demanded by the brevity of the iconic representation (Averbach & Coriell, 1961) and

by the limited channel, or processing, capacity of subsequent mechanisms. At all events, the assumption is that the material in iconic storage is, in due course, recoded into categorical form for representation in response and/or short-term storage and that this recoding involves the processes of pattern recognition.

The interruption hypothesis localizes the effect of backward masking by pattern subsequent to iconic storage. It is assumed that a clear icon is established and that an "after-coming" pattern interferes with the translation into categorical form. The time needed to effect that translation is cut short by the after-coming stimulus. The integration hypothesis, on the other hand, proposes that target material and mask are dealt with as a composite, resulting in an unintelligible icon. For the integration hypothesis, the effect of an after-coming pattern is on the formation of the target iconic representation so that it never achieves the acuity, contrast, or clarity that it would have attained in the absence of the mask.

#### *Integration and Interruption as Non-exclusive Hypotheses*

Comparisons between an integration and interruption hypothesis of backward masking are usually made to decide which one is correct. It is, of course, not inconceivable that both are in fact true; they may be descriptions of two different stages in the flow of visual information. This possibility is suggested by the fact that two sorts of independent variables have been used in backward masking experiments. On the one hand, there are the energy properties of target and mask, that is, duration and intensity; on the other, there is the time elapsing between onset of target and onset of mask. Sometimes backward masking has shown strict dependence on target duration or target-mask intensity (e.g., Eriksen, 1966; Kinsbourne & Warrington, 1962a; Thompson, 1966), yet at others it has shown strict dependence on onset-onset time with stimulus variables such as target duration proving irrelevant (e.g., Haber & Nathanson, 1969; Mewhort, Merikle, & Bryden, 1969). It is possible that when target

energy (and/or mask energy for that matter) is the relevant independent variable, mechanisms underscored by the integration hypothesis are prevailing, but when onset-onset time is the determining variable and target energy properties are irrelevant, interruption is perhaps the more appropriate theory.

The above ideas guided the present series of experiments, for which the experiments of Kinsbourne and Warrington (1962a, 1962b) provided a departure point. Their experiments were interesting in several important respects. First, with a paradigm fundamentally similar to that used, originally, by Sperling (1963), Kinsbourne and Warrington (1962a) found no evidence that in the backward masking situation the number of items reported is a linear function of onset-onset time. That result reported by Sperling (1963) and Allport (1968), among others, may be viewed as evidence for a process of sequential readout from an intact iconic representation and as support for the interruption hypothesis. Kinsbourne and Warrington by contrast reported that not only did three letters become available at approximately the same onset-onset time as one letter but also that there was a simple relation between target duration and the minimal interstimulus interval which permitted evasion of the masking action: target duration  $\times$  interstimulus interval = a constant. That result, as Kahneman (1968) has pointed out, has not subsequently been investigated. It is an important result because it argues that masking is determined by energy properties of the stimuli, not by the time elapsing between the onsets of the stimuli. The present series of experiments began, therefore, with a partial replication of the experiments of Kinsbourne and Warrington (1962a).

#### GENERAL METHOD

What follows is a brief description of some of the terms used in the present communication and some general comments on procedure, apparatus, stimulus materials, and subjects.

#### *Terms*

(a) Target refers to the stimulus which the subject is required to identify. (b) Random noise



FIG. 2. Examples of masking and target stimuli.

refers to a masking stimulus such as that shown in Figure 2. A mask of this sort had been used in the Kinsbourne and Warrington experiments (1962a, 1962b). Described by Kinsbourne and Warrington as a noninformational stimulus, the mask reproduced in Figure 2 is a section of the random pattern (visual noise) described by Laner, Morris, and Oldfield (1957)—type 80 units per square centimeter. In the present experiments, the size of the visual field subtended by random noise was 3.5 degrees vertical by 6.5 degrees horizontal. (c) The term "pattern mask" was reserved for masks other than random noise.<sup>3</sup> An example of a pattern mask is given in Figure 2. An essential feature of the pattern mask reproduced in Figure 2 is that the lines comprising the mask were approximately of the same thickness as the target letters. All masks classified as pattern masks shared this characteristic with the target material. (d) Time elapsing between *offset* of target and *onset* of mask field is referred to as interstimulus interval. (e) The minimum interstimulus interval at which a masking field no longer affects the target according to a predetermined performance criterion is referred to as the critical interstimulus interval. (f) The time elapsing between the *onset* of the target and the *onset* of the masking field is referred to as stimulus onset asynchrony; see Kahneman, 1968. (g) The minimum duration of the target that permits evasion of masking (at an interstimulus interval equal to 0 milliseconds), according to some criterion, is defined as the critical target duration.

### Procedure

The procedure which was used for most of the present series of experiments *mutatis mutandis* is spelled out below in some detail. It is essentially the procedure used by Kinsbourne and Warrington (1962a, 1962b).

A target stimulus was presented to the subject for a brief period of time followed at varying intervals by the mask stimulus. The task of the subject was to identify the target stimulus. The duration of the target stimulus and the duration of the mask stimulus were held constant and interstimulus interval was increased from zero in steps of 2 milliseconds to some value at which the sub-

ject correctly identified a target stimulus. At each interstimulus interval step, the target stimulus was changed whether the subject was correct or incorrect. The interstimulus interval value at which the subject correctly identified a target stimulus was left unchanged for the next target stimulus. If, however, the subject was incorrect, the interstimulus interval was increased by one millisecond for the following target presentation. This procedure was continued until the subject correctly identified four target stimuli in succession. The interstimulus interval value at which the subject identified four target stimuli in succession was designated as the critical interstimulus interval. Kinsbourne and Warrington had defined the critical interstimulus interval as that interstimulus interval at which a subject first reported one target stimulus correctly.

A number of different target durations were employed, and for each, the critical interstimulus interval was determined at several values of mask duration. In the course of determining the critical interstimulus intervals, several orderings of the target stimuli were used. In all experiments, for all target durations, identification was 100% accurate in the absence of the mask.

Generally speaking, in the present series of experiments where the critical interstimulus interval, or identification performance, was estimated for more than two values of target or mask duration, these values were examined for each subject in ascending order from the lowest to highest value. In those experiments in which two masks, or monoptic and dichoptic viewing, or forward and backward masking, or two energy ratios were compared, the order of conditions was counterbalanced across subjects so that each condition occurred with the same frequency in each test-order position.

### Apparatus

A six-channel tachistoscope (Scientific Prototype, Model GB) with automatic stimulus changers was used for the present series of experiments. The two three-channel optical units of the tachistoscope permitted monoptic and dichoptic presentation of stimuli, and one unit could be readily modified for binocular presentation. One of the two separate units was adjustable for interocular distance and convergence angle. The apparent viewing distance was 36 feet and the field of the tachistoscope subtended 3.5 degrees vertical by 6.5 degrees horizontal. Coarse intensity controls were available, but nonlinearities required the use

<sup>3</sup> The use here of the term "pattern" is, of course, arbitrary; pattern mask like random noise is essentially a random arrangement.

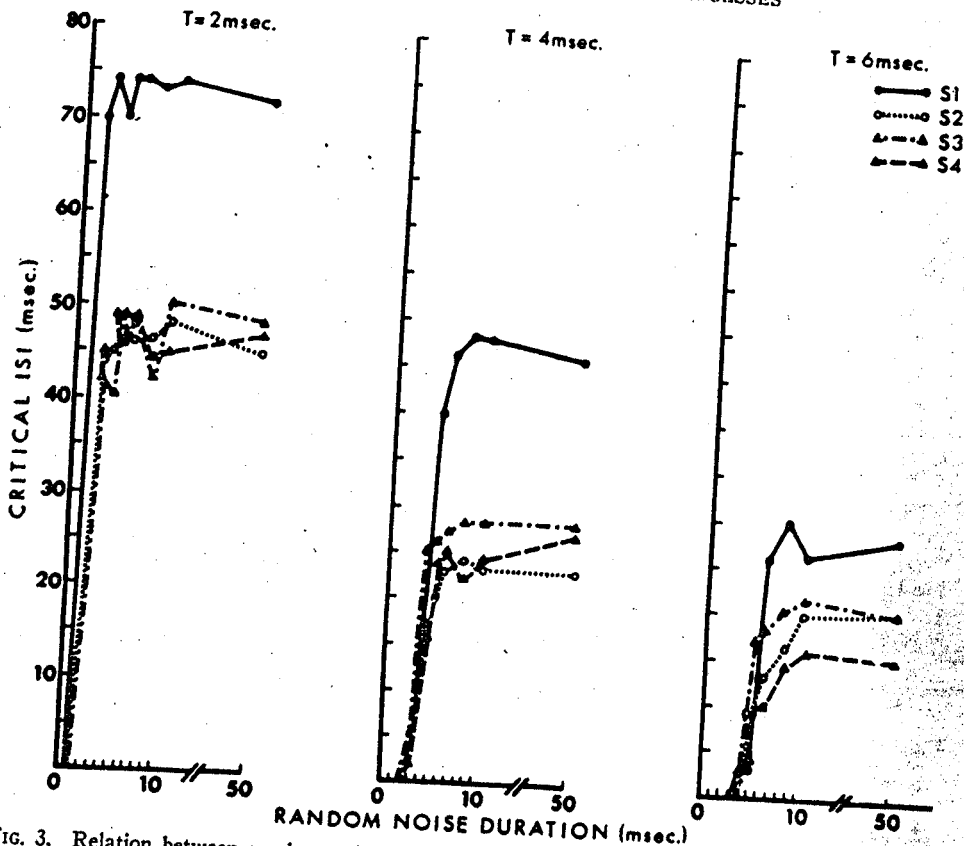


FIG. 3. Relation between random noise duration and the critical interstimulus interval for binocular masking at three values of target duration for each subject in Experiment I.

of Kodak neutral density filters for accurate variation of stimulus luminance. Luminance was measured at the eyepiece by a spectra brightness spotmeter (Photo Research).

*Stimulus Material*

Three 100-slide sets of letter stimuli were constructed. The stimuli were in all cases positives of Stenro Gothic capitals. The positives, which were transparent, were held in 2 x 2 inch, 35-millimeter slide mounts. In one set the letters were located singly at the center of the slides. Those letters were the symmetrical letters of the alphabet (A, H, I, M, O, T, U, V, W, X, and Y). In a second set those same letters were located singly to the side of the center. A third set consisted of consonant trigrams, that is, three letters to a slide, selected from all the consonants. No consonant was repeated within a slide.

The letters in all sets subtended .67 degrees vertical by an average .36 degrees horizontal. The thickness of the letters subtended .13 degrees visual angle. In the set of single letters displaced off center, the angular distance between the center of the slide (or fixation point) and the center of a

letter was 1.37 degrees. For the consonant trigrams, the separation between the letter edges was on the order of .40 degrees.

*Subjects*

For the most part, the subjects were Yale University students who were paid for their services. University of Connecticut graduate students and members of Haskins Laboratories also served as subjects in several experiments. All subjects had normal or corrected to normal vision.

EXPERIMENT I

*Method*

In Experiment I, the target material was the set of centrally located symmetrical letters and the after-coming mask random noise. Three durations of target were employed, 2, 4, and 6 milliseconds, which were presented in this order for each subject. For each target duration, critical interstimulus interval was determined at random noise durations of 1, 2, 3, 4, 5, 6, 8, 10, and 50 milliseconds. The luminance of the target and that of random noise was 15 footlamberts and the

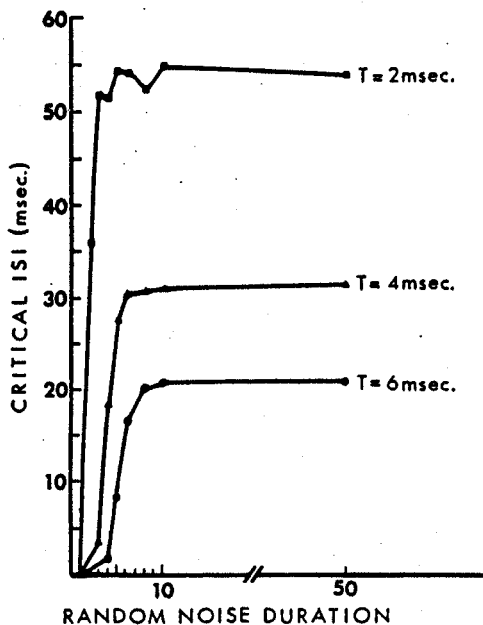


FIG. 4. Relation between random noise duration and the mean critical interstimulus interval for binocular masking at three values of target duration in Experiment I.

fixation field was .02 footlamberts.<sup>4</sup> The stimuli were delivered binocularly. Four subjects participated in the experiment; one subject was not naive to masking phenomena.

### Results and Discussion

The data of the four subjects are shown in Figures 3 and 4. Figure 3 shows the plot of the critical interstimulus interval as a function of random noise duration for each subject. Figure 4 shows the critical interstimulus interval by random noise duration functions averaged across subjects with target duration as the curve parameter.

As can be seen on inspection of the figures, the masking effect of random noise varies in a discontinuous fashion with its exposure duration. The effect of varying duration of random noise achieves its maximum sharply. Increasing the random noise duration beyond some value does not augment the masking effect; that is, it does not extend the interval over which masking can

be obtained. All of this concurs with the original observations of Kinsbourne and Warrington (1962a). Inspection of Figure 4 yields further corroboration of Kinsbourne and Warrington in that there exists a simple relation between target duration and the critical interstimulus interval at asymptote: target duration  $\times$  critical interstimulus interval = a constant. The picture is not as tidy as it might be; target duration  $\times$  critical interstimulus interval does not yield exactly the same value at 2 milliseconds as it does at 4 and 6 milliseconds, yet the values are close enough to favor the Kinsbourne and Warrington conclusion.

Kinsbourne and Warrington (1962b) interpreted this result as reflecting the fact that the critical interstimulus interval is "the time which permits the perceptual process to deal with the two stimuli separately in succession, rather than simultaneously as a composite, and therefore unintelligible stimulus [p. 235]." It is quite evident that the formulation target duration  $\times$  critical interstimulus interval = a constant argues strongly against onset-onset time and for target duration as the relevant parameter in masking by noise. There is, of course, the question of whether it is target exposure duration per se or the quantity of light in the stimulus that is important. The second experiment examined this question.

### EXPERIMENT II

The time-intensity reciprocity law, known for human vision as Bloch's law, says that a given effect can be achieved by the reciprocal manipulation of luminance and duration of a light flash. In the second experiment, luminance of target was manipulated so as to produce a constant energy value for different exposure durations. If target energy rather than target duration is the important independent variable, then varying target exposure duration with energy held constant should not produce the inverse relation between target duration and the critical interstimulus interval obtained in Experiment I; rather, the critical interstimulus interval should remain constant. Such an outcome would indicate that the formulation target duration  $\times$  the critical in-

<sup>4</sup>The fixation field against which the target and mask fields were exposed was at this level of luminance for each experiment in the present series.

terstimulus intervals = a constant should be written target energy  $\times$  critical interstimulus interval = a constant.

### Method

Experiment II was conducted in two parts. In Part 1, stimulus presentation was binocular. Two naive subjects were tested in the paradigm described in Experiment I. For both subjects, the critical interstimulus interval was determined at several values of random noise duration for two duration-intensity values of the target: 2 milliseconds, 20 footlamberts and 8 milliseconds, 5 footlamberts. The target stimuli were the set of centrally located symmetrical letters. The luminance of the random noise was 15 footlamberts. In Part 2, presentation of stimuli was monocular. The stimuli were presented at the right eye. Two different naive subjects were tested in the manner described in Experiment I and Part 1 above. The values of the target were: 2 milliseconds, 4 footlamberts and 4 milliseconds, 2 footlamberts. The stimuli were the set of consonant trigrams. The definition of the critical interstimulus interval in this case was four trigrams reported correctly in succession. The subject had to report all three letters to be correct; correct order of letters, however, was not required. The intensity of the random noise was 15 footlamberts.

### Results and Discussion

The data of the two subjects in Part 1 are given in the upper panels of Figure 5. The data of the two subjects in Part 2 are given in the lower panels of the same figure.

Comparison of the functions reproduced in Figure 5 with those in Figure 3, which give the data of Experiment I, suggests that target energy, not target duration, is the proper independent variable. In the upper panels of Figure 5, for example, the critical interstimulus interval for both subjects was unchanged from a 2-millisecond to an 8-millisecond exposure duration of target. As Figure 3 from Experiment I shows, the critical interstimulus interval for the exposure duration of 6 milliseconds is significantly lower than the critical interstimulus interval for the exposure duration of 2 milliseconds. In Experiment I energy increased with increase in exposure duration; in Experiment II total quantity of light was held constant across the exposure durations. Masking by random noise, therefore, seemed to be very much a matter of stimulus energies. Further evidence to this effect was

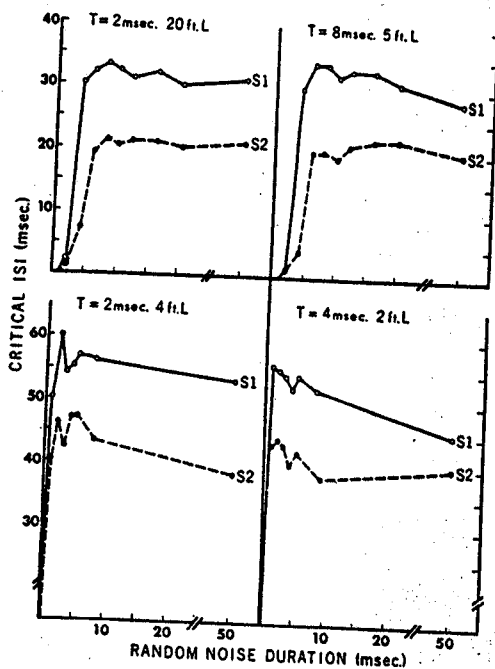


FIG. 5. Relation between random noise duration and the critical interstimulus interval at various target duration-intensity combinations in Experiment II. (Upper panel shows functions of the two subjects in Part 1; lower panel shows functions of the two subjects in Part 2.)

given in the observation that the minimal random noise energy needed to mask a target stimulus was directly related to the target energy, as can be seen by inspection of Figure 4.

The masking reported in Experiments I and II is, perhaps, explicable in terms of the lack of fine temporal resolution in the visual system. That is to say, stimuli presented in succession with too brief an interval elapsing between them are perceived as essentially simultaneous, an interpretation of masking proposed by Kinsbourne and Warrington and championed in a multitude of articles by Eriksen (e.g., Eriksen, 1966; Eriksen & Collins, 1965; Eriksen & Hoffman, 1963). The best known example of this lack of temporal resolution is Bloch's law: within some critical period, usually of the order of 100 milliseconds, time and intensity of stimulation can be reciprocally interchanged without changing the visual effect. Research by Davy (1952) has

shown, at least for the periphery of the retina, that such integration of energy over time by the visual system is independent of the distribution of energy within this period. The reciprocity between luminance and duration in the rule  $\text{target energy} \times \text{critical interstimulus interval} = \text{a constant}$  suggests that the masking demonstrated in Experiments I and II may be another manifestation of the visual processes underlying Bloch's law.

The explanation of masking by random noise as due to the lack of fine temporal resolution in the visual system implies that target and random noise are treated as a single package presumably at some later stage in the processing of visual information. The impairment in the perception of the target may be attributed to a confusion of features or contours or to a change in the minimum acuity requirements (Eriksen & Collins, 1965; Purcell, Stewart, & Dember, 1968). It may also be due to summation of target luminance with random noise luminance. Luminance summation would reduce the contrast between the target form and its background, thereby impairing detection and identification (e.g., Thompson, 1966). In any event, the argument is that the resulting representation of the target is degraded.

An explanation closely related to the integration hypothesis described above may also account for the masking observed in Experiments I and II. This explanation assumes that the masking stimulus impedes the perception of the target by overtaking the target somewhere in the visual system (Crawford, 1947; Fry, 1934; Leibovic, 1968; Stigler, 1910). It has sometimes been proposed that for "overtake" to occur the masker must be more intense than the target stimulus (e.g., Kinsbourne & Warrington, 1962a), a view which is based on the well-documented observation that the latency of retinal and cortical responses to stimulation is inversely related to stimulus intensity (e.g., Monnier, 1952). However, visual-response latency is also determined by duration (cf. Cone, 1964), and thus the requirement for overtake is, more accurately, greater mask energy rather than greater mask intensity.

Elegant data favoring an overtake hypothesis for backward masking by a flash of light have been reported recently by Schiller (1968). In single-cell recordings in the lateral geniculate nucleus of the cat, Schiller observed that cells which respond at their maximal level to the mask stimulus fail to register the earlier display of the target stimulus. In certain ways, as pointed out by Kahneman (1968), the overtake concept may be described as an integration theory: it assumes a nonlinear summation of response rather than a linear summation of stimuli.

### EXPERIMENT III

The third experiment primarily compares the severity of backward masking by random noise under monoptic and dichoptic presentation. It also looks for differences in the critical interstimulus interval as a function of the hemisphere receiving the stimuli. In the monoptic conditions, the target and random noise were delivered to the same hemiretina. In the dichoptic conditions, the target and random noise were presented to different hemiretinas but to the same hemisphere.

#### *Method*

The procedure was identical in most respects to that described in Experiment I. For monoptic and dichoptic delivery of inputs, both of the three-channel units of the tachistoscope were used. The two fields of view, one for each eye, both contained a centrally located fixation point and were set at the same luminance, .02 footlamberts.<sup>5</sup> Whether the subject was receiving a monoptic or dichoptic sequence, he was required to view with both eyes. Both the target and random noise appeared on the same side of the fixation point: in the monoptic condition, they came to the same eye, and in the dichoptic, to different eyes. The target stimuli were the set of the symmetrical letters displaced off center 1.37 degrees. The random noise subtended 2.25 degrees horizontal by 1.5 degrees vertical, with its inner edge bisecting vertically the fixation point.

Four subjects, two naive and two experienced, participated in the experiment. Stimuli presentations were not mixed; the subject always knew that within a monoptic or dichoptic condition, the target and random noise would always appear in the same half of the visual field, say the left. For each subject, the interocular distance of the two eye-pieces was adjusted to facilitate convergence of

<sup>5</sup> This was the case for each dichoptic presentation condition described in the present paper.



the two fixation points. The subjects were required to converge the two fixation points prior to presentation of stimuli. (The subjects were told to indicate to the experimenter any occasion on which they were aware of their eyes moving off the converged fixation point prior to stimulus presentation. Involuntary eye movements do occur during fixation; however, the work of Riggs, Armington, and Ratliff (1954) indicates that during a 10-millisecond exposure the typical excursion is less than 5 seconds of arc.)

For all conditions, the exposure duration of the target was 4 milliseconds. The exposure durations of random noise were 1, 2, 3, 4, 5, 6, 8, 10, and 50 milliseconds. The critical interstimulus interval was determined by the usual procedure at each random noise duration in the order shown. Throughout, the target and random noise were of equal luminance, 10 footlamberts.

### Results and Discussion

The most important feature of Experiment III was the failure to obtain masking in any of the dichoptic conditions. In all the dichoptic conditions, the subject was able to identify the target letters at any interstimulus interval value in the range 0–300 milliseconds, at stimulus onset asynchrony equal to 0 milliseconds, and at any exposure duration of random noise ranging from 1 to 500 milliseconds. (All of these results were confirmed subsequently with several other subjects.) The data for monoptic presentation are given in Figure 6. All functions are in accord with that observed in Experiment I for a target equal to 4 milliseconds.

The mean of the critical interstimulus intervals at random noise durations of 5, 6, 8, 10, and 50 milliseconds were computed for each subject in each of the four conditions. These means were submitted to a Treatment  $\times$  Subjects analysis of variance. The main effect of hemiretina was significant,  $F = 6.39$ ,  $df = 3/9$ ,  $p < .05$ .

Although subjects in the dichoptic conditions of the present experiment could identify target stimuli without difficulty, the target was not completely unaffected by random noise. Further investigation revealed that at exposure duration and luminance close to threshold, identification and/or appearance of target stimuli could be impaired by random noise especially at a stimulus onset asynchrony equal to zero milli-

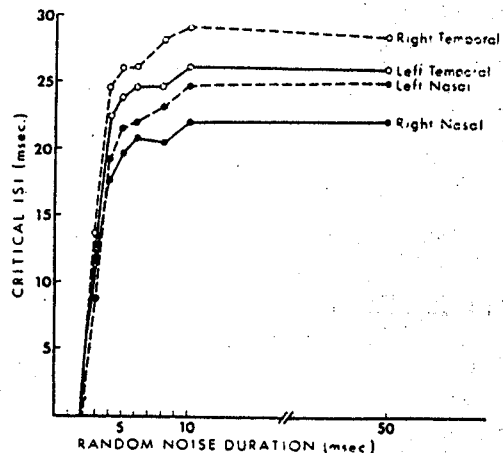


FIG. 6. Relation between random noise duration and the mean critical interstimulus interval as a function of the hemiretina receiving the stimuli in Experiment III.

seconds. An increase in target duration or interstimulus interval of the order of several milliseconds would be enough, however, to overcome any effect of random noise. The effect of random noise in the dichoptic mode was at best a very modest one. Since in dichoptic presentation target and random noise can only interact centrally, the conclusion must be drawn that the locus of masking by random noise as observed in Experiments I and II was primarily, if not solely, in the peripheral visual system.

Backward masking of forms in the dichoptic mode has been reported in the literature (e.g., Schiller, 1965; Schiller & Wiener, 1963; Smith & Schiller, 1966). The effect, however, is restricted to masks which contain contours; a homogeneous flash of light does not mask forms dichoptically (e.g., Mowbray & Durr, 1964; Schiller & Wiener, 1963; Smith & Schiller, 1966).<sup>6</sup> Thus, in the present experiments random noise is operating like a homogeneous field of light. A first guess, therefore, was that failure to confirm masking in dichoptic presentation in the present experiment was in some part due to the relation between the target and

<sup>6</sup> Flashes of light may yield slight dichoptic effects, but they depend for the most part on the use of near-threshold target stimuli and the relatively close proximity of target and mask borders. (Battersby & Wagman, 1962; Boynton, 1961).

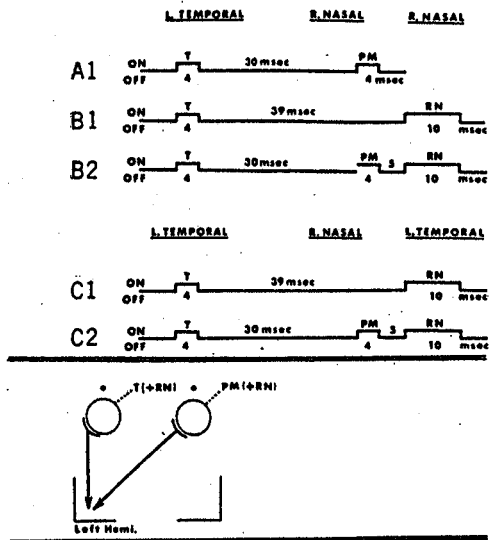


FIG. 7. Order and mode of stimulus presentation in Experiment IV.

random noise. Several investigators have commented on the fact that in many instances masking is highly form-specific (e.g., Buchsbaum & Mayzner, 1968; Houlihan & Sekuler, 1968; Parlee, 1969; Schiller, 1965; Sekuler, 1965). There was little, if any, formal similarity between the target and random noise in the present experiment. It is, however, important to note that with almost the same type of stimuli (target and random noise), Kinsbourne and Warrington (1962b) did obtain masking with dichoptic presentation. For these reasons, various stimuli were examined in the dichoptic mode, including other random noise displays. An initial observation was that the inverse of the random noise mask did produce a fairly significant effect dichoptically (cf. Fitzgerald & Kirkham, 1966). However, the inverse of random noise was not considered to be as effective a mask as some other stimulus patterns. A pattern of lines of approximately the same thickness as the target letters located only in region of the display field occupied by a target letter was eventually selected for further investigation of masking in dichoptic regard. The pattern mask is shown in Figure 2. Casual investigation revealed that such a pattern was an effective dichoptic mask.

## EXPERIMENT IV

Experiment IV looked at the relation between random noise and pattern mask. Specifically it asked whether it was correct to assume that the random noise influenced a stimulus only if it followed on the same peripheral route and, therefore, differed from the pattern mask, which could have a central influence.

### Method

As in Experiment III, the target and mask stimuli were presented to hemiretinas. The target stimuli were presented in the right visual field of the left eye, that is, on the left temporal hemiretina. The random noise and pattern mask stimuli described above were used as masks. The random noise stimulus was presented in either the right visual field of the right eye or the right visual field of the left eye, that is, to the right nasal or left temporal hemiretina. The pattern mask stimulus was presented in the right visual field of the right eye (see Figure 7).

Exposure durations of target, pattern mask, and random noise were 4 milliseconds, 4 milliseconds, and 10 milliseconds, respectively. Pilot work had shown that a 4-millisecond exposure of the pattern mask could effectively mask dichoptically a 4-millisecond exposure of the target within a relatively large interstimulus interval range. Previous experiments, Experiments I and III for example, had already shown that random noise of 10-milliseconds duration effectively masked a preceding 4-milliseconds exposure of the same intensity on the same transmission line if the two stimuli were separated by an interstimulus interval of less than about 30 milliseconds. The intensities of target, pattern mask, and random noise were equal at 15 footlamberts. The pattern of lines constituting the pattern mask was displaced off center on a slide so as to cover the area in the field occupied by the set of off-center symmetrical letters which were the target stimuli.

There were five conditions, which are reproduced in Figure 7.

Each of six subjects was tested in all five conditions with 20 stimuli presented for identification in each condition. All six subjects went through the five conditions in sequence (i.e., A1, B1, B2, C1, and C2) four times, with five observations made each time in each condition. Predictions based on the assumption that random noise operated only peripherally were as follows: (a) In Condition A1, the target would be masked by pattern mask. (b) In Conditions B1 and C1, the target would be seen and identified against random noise as background. Note that in B1 the relation between the target and random noise was dichoptic; in C1 both stimuli were presented at the left temporal hemiretina. The particular interstimulus interval value was chosen to insure that random noise would

not monoptically mask the target in Condition C1. (c) In Condition B2, the target would be seen and identified against random noise as background because random noise would mask the pattern mask in the periphery, thereby preventing the central interference of the target by the pattern mask. On the other hand, in Condition C2, the target would still be masked by the pattern mask. Note that the only difference between B2 and C2 was that in the former random noise was on the same transmission line as the pattern mask.

### *Results and Discussion*

The data of all six subjects conformed to the predictions. All six subjects failed to identify any of the 20 letters in Conditions A1 and C2; since subjects were not told to guess their typical response was "nothing." All six subjects identified every letter in Condition B2. As a check on the phenomenon, to see if asynchrony of the three stimuli was essential to the effect (cf. Robinson, 1968), each subject was tested in Conditions A1, B1, and B2 with the three stimuli delivered simultaneously (i.e., stimulus onset asynchrony = 0 milliseconds). The results of simultaneous presentation were identical to those of successive presentation: no masking in Conditions B1 and B2, complete masking (i.e., no identification of the target letters) in Condition A1. Temporal separation of stimuli was therefore not necessary for the effect. Further investigation also showed that this "recovery of target effect" could be obtained with the target and masks presented to the entire retina rather than hemiretinas. The phenomenon was easily demonstrated informally many times subsequent to the experiment.<sup>7</sup>

Demonstrations of an increase in the perceptibility of a masked target as the result of a second mask are not uncommon in the literature (e.g., Dember & Purcell, 1967; Purcell & Dember, 1968; Robinson, 1966, 1968; Schiller & Greenfield, 1969), and while an interpretation of the phenomenon has not been agreed upon, it has been suggested that lateral inhibition is probably the likely mechanism (e.g., Robinson, 1968; Weisstein, 1968). Although a lateral-inhibition orientation is well suited to some

demonstrations of target recovery (e.g., Schiller & Greenfield, 1969), it is ill suited to the present demonstration because of the stimulus configurations used and the different loci of the two masking effects.

A preferred approach to the data of Experiment IV and to those of the experiments which follow is given in an analogy proposed by Kolers (1968):

A customer who enters a store is usually treated as fully as the attending clerk can treat him; a second customer then entering, the clerk tends to shorten the amount of time he spends with the first. In a store whose customers enter aperiodically, the amount of treatment given to anyone depends upon whether a second enters; if he does, treatment of the first is usually shortened. In this analogy, the visual inputs are the "customers" and the central processor the "clerk" [p. 38].

The analogy is revealing. It would suggest that in the present experiment the loss in perceptibility of the target when a pattern mask is presented cannot be because the target is "erased." On the contrary, the target may persist but what is known of the target is limited. The clerk can find out a great deal from his customer: how he feels today, how the wife is, whether he wants Brand X or Brand Y, etc. With the appearance of another customer, however, much of this is left undone. If the second customer is particularly compelling and close on the heels of the preceding customer, the clerk may come to know very little, if anything, of his first customer's dispositions and wants. The analogy is further illuminating in that it implies that random noise prevented the pattern mask (Condition B2) from gaining access to the store housing the clerk or central processor. For the analogy, the impairment in the perception of the target by the pattern mask was not due to interference between the inputs, or customers; rather it was the result of their effect upon the central device, or clerk. On the other hand, the loss of perceptibility of the pattern mask, and consequently, the loss of its masking effect on the target, might have been due to degradation by random noise with this interference taking place in the transmission channel itself.

It is evident that random noise must gain access to a central processor. In the present experiment in Conditions B1 and B2, for

<sup>7</sup> A homogeneous light flash of energy greater than the target produced the same effect when substituted for random noise.

example, the target and random noise were seen clearly by the subject; in Condition C2, the subject saw the pattern mask and random noise clearly. Introspective accounts were that the target or the pattern mask appeared "through" random noise or "on top of" random noise. This would suggest that figural analysis or synthesis (depending on one's predilections) of the target (or pattern mask) and random noise were accomplished in parallel by different processors or neural systems (cf. Liss, 1968) or concurrently by the same processor. Indeed, random noise should function as a central mask for some stimuli. All this implies that masking with dichoptic presentation occurs whenever the analyses of both the target and the mask require the use of the same central mechanism, or the same components of a single central mechanism, and not otherwise. On the other hand, binocular and monocular masking, where peripheral interaction can occur, may not be so dependent on formal similarity between the target and the mask.

#### EXPERIMENT V

Kinsbourne and Warrington (1962b) reported that the relation target duration  $\times$  critical interstimulus interval = a constant, described masking functions for dichoptic, as well as monoptic, presentation. Experiments I and II of the present series taken together imply that the proper independent variable for masking by random noise was not duration of target but rather the total quantity of light in the target exposure. The Kinsbourne and Warrington relation was therefore rewritten: target energy  $\times$  critical interstimulus interval = a constant. We can hypothesize on the basis of Experiments III and IV, however, that the interfering effect of random noise on the perceptibility of target was mainly of peripheral origin. Perhaps, then, the relation target energy  $\times$  critical interstimulus interval = a constant speaks only to peripheral interaction, contrary to the report of Kinsbourne and Warrington. The variation of Kolers' (1968) clerk-and-customer analogy described above hints at a difference between masking originating outside the store (peripherally) and masking originating inside the store (cen-

trally). There are also several sources of data which suggest that masking under conditions of dichoptic presentation differs in a fundamental and interesting way from monoptic masking. Boynton (1961) and Schiller (1969) reported experiments showing that dichoptic masking is relatively independent of stimulus intensity.

#### Method

The design of Experiment V was comparable to that of Experiment I, but stimulus presentation was dichoptic and the pattern mask was the after-coming mask. The configuration of lines used for the pattern mask was centrally located in the mask field, the target material was the set of centrally located symmetrical letters, and both their luminances were 4 footlamberts. (Thus, the present experiment contrasts with the preceding two in that presentation was to retinas rather than to hemiretinas.) Four naive subjects were presented with the target to the left eye and the pattern mask to the right eye. For two durations of the target, 4 milliseconds and 10 milliseconds, the critical interstimulus interval was determined for the following exposure durations of pattern mask: .5, 1, 2, 3, 4, 5, 6, 8, 10, 25, and 50 milliseconds.

#### Results and Discussion

The functions relating the critical interstimulus interval to pattern mask exposure duration for the two durations of target are reproduced in Figure 8. Each data point represents the average of the four subjects.

The most important aspect of Figure 8 is the absence of any dramatic separation between the critical interstimulus interval for the two exposure durations of the target. Compare this figure with the data of Experiment I, in which stimulus presentation was binocular and the after-coming mask was random noise; there the critical interstimulus interval separation between a target equal to 2 milliseconds and a target equal to 6 milliseconds in Figure 4 was about 35 milliseconds.

The data reproduced in Figure 8 show that the relation target duration  $\times$  critical interstimulus interval = a constant does not describe dichoptic masking by pattern mask. If that relation was in effect, then the critical interstimulus interval for a target equal to 10 milliseconds should have been on the order of, at most, 14 to 16 milliseconds, given that the mean critical interstimulus interval for a target = 4 milliseconds was about 36 milliseconds. Again it should be noted that Kinsbourne and Warrington (1962b) *did* find that the relation target duration  $\times$  critical interstimulus interval = a constant held for dichoptic masking. The reason for the disparity between the data of the present experiment and those of Kinsbourne and Warrington is unclear.

Two other aspects of Figure 8 deserve comment.

First, the critical interstimulus interval tends for both target exposure durations to decrease with an increase in pattern mask duration beyond 10 milliseconds, an effect which proved to be consistent on further examination. At the longer exposures of pattern mask, subjects reported that the field surrounding the configuration of lines (see Figure 2) appeared brighter and that the pattern itself looked degraded. It seems, therefore, that as exposure duration increases and intensity is held constant, a display such as the pattern mask may partially mask itself in the sense that the surrounding white area may degrade the contours of the central dark area. This effect may be related to the Broca-Sulzer effect on the one hand (see Raab, 1963) and possibly to the observations of Purcell, Stewart, and Dember (1969) on the other. Essentially, the Broca-Sulzer effect is that the brightness of a flash is nonmonotonically related to its duration. As exposure duration is increased, brightness first increases and then decreases, with the point of maximum brightness shifting to longer durations as the luminance level is reduced (see Stevens, 1966). The observations of Purcell et al. are that at relatively high luminance levels, increasing either the luminance or the duration of a target field consisting of a black form on a white surround results in an increased susceptibility to masking. Their interpretation of this phenomenon is that increasing either intensity or duration amplifies the lateral-inhibitory effect of the bright surround on the dim target form.

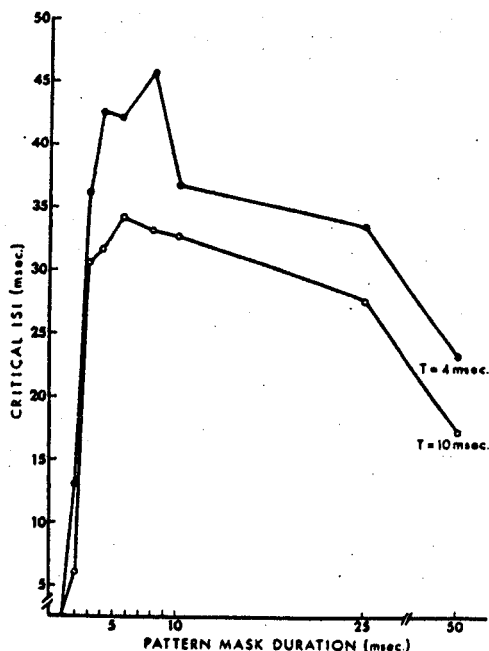


FIG. 8. Relation between the pattern mask duration and the mean critical interstimulus interval for dichoptic presentation of stimuli in Experiment V.

Second, and more important, comparison of Figure 8 with Figure 4 of Experiment I indicates that for a given target duration, dichoptic masking was obtained with mask exposure durations of less than the minimal duration found to be effective in binocular (and monocular, e.g., Experiment II) conditions. Moreover, the minimal duration of the after-coming pattern mask, which substantially masked the target in the present experiment, was not contingent on the duration of the target itself. A 3-millisecond duration of pattern mask was as effective a mask for a target equal to 10 milliseconds as it was for a target equal to 4 milliseconds. This is in sharp contrast to the results obtained binocularly and monocularly with random noise, where the minimal duration of the mask which impaired the perception of the target was a direct function of target duration.

A further point needs to be added. It was frequently observed in pilot work and subsequent experiments that with dichoptic presentation the severity of masking was not equivalent for the two eyes. cursory examination indicated that the severity of dichoptic masking was very much a matter of which eye received the target stimulus and which eye received the mask. This suggests that factors related to ocular dominance and binocular rivalry are probably involved in the dichoptic paradigm.

## EXPERIMENT VI

Experiment VI was conducted to compare monoptic masking by random noise and pattern mask, with dichoptic masking by pattern mask. A conclusion of Experiment V was that mask durations which fail in the monoptic and binocular situations to mask a target of a given duration do function effectively under conditions of dichoptic presentation. That conclusion, however, had to be accepted with some reservations since the functions under comparison were obtained with different masks. The monocular and binocular data were obtained with random noise as mask; the dichoptic data were obtained with pattern mask.

### Method

Four naive subjects participated in the experiment over 2 days. Two subjects were tested dichoptically on Day 1 and monoptically on Day 2. The other two subjects received the reverse order. In the monoptic condition for two subjects, masking was examined first with pattern mask and then with random noise as the after-coming stimulus; the other two subjects were tested in the reverse order. The target stimuli were presented to the left eye.

The exposure duration of the target was 4 milliseconds for both monoptic and dichoptic conditions.

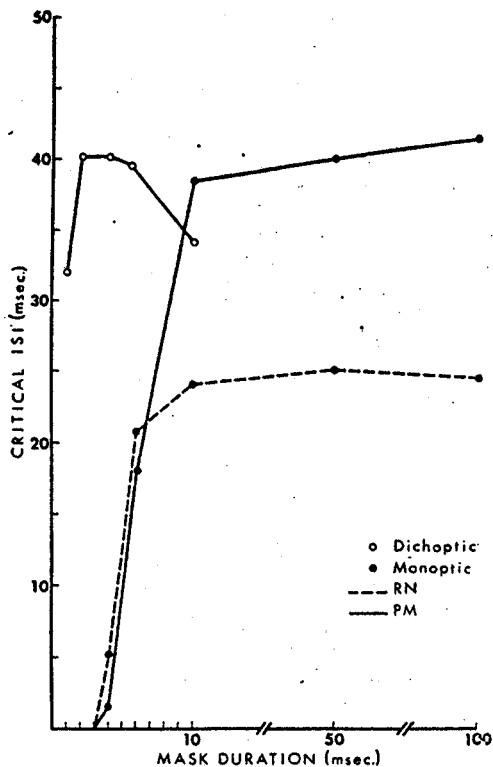


FIG. 9. Relation between mask duration and the mean critical interstimulus interval for monoptic masking by random noise, and monoptic and dichoptic masking by pattern mask, in Experiment VI.

The luminances of the target, the pattern mask, and random noise were each 10 footlamberts. The set of centrally located symmetrical letters was the target stimuli. For each subject in the monoptic conditions, the critical interstimulus interval was determined by the usual procedure for the following mask durations in the order shown: 1, 2, 4, 6, 10, 50, and 100 milliseconds. In the dichoptic conditions, the critical interstimulus interval was determined at pattern mask exposure durations of 1, 2, 4, 6, and 10 milliseconds.

### Results and Discussion

The results for both monoptic and dichoptic presentation are given in Figure 9. Each data point represents the average critical interstimulus interval of the four subjects.

First, inspection of Figure 9 shows that masking in the dichoptic mode can be produced by mask exposure durations which are ineffective in monoptic presentation. In the monoptic condition, masking by pattern

mask at durations of 1, 2, or 4 milliseconds was practically nonexistent. Figure 9 also shows that masking in the monoptic mode by pattern mask was more severe than masking by random noise.

For the present, what is important about Experiment VI is that it adds to the suspicions aroused in Experiment V that dichoptic masking is governed by somewhat different principles than monoptic masking. In dichoptic presentation, central devices receive "clean" stimuli, that is, inputs that are free from the possible confounding effects of the between-stimulus interference introduced when both stimuli have come to the central device by a common peripheral route. The between-stimulus interference which results when the stimuli travel on a common transmission line appears to be due, in part, to the comparative strengths of the stimuli. A 1-millisecond duration of pattern mask failed to mask monoptically a 4-millisecond duration of a target of the same luminance because the target had more energy than the pattern mask. Stimulus strength, however, was not a prominent factor in central processes. In dichoptic presentation, a 1-millisecond duration of pattern mask masked a preceding 4-millisecond duration of target of the same luminance *in spite of the fact* that the target was the stronger signal.

### EXPERIMENT VII

A tentative conclusion drawn from Experiment V was that the relation target duration  $\times$  critical interstimulus interval = a constant did not hold true for dichoptic viewing. That experiment seriously questioned the status of target duration as a determining temporal variable in dichoptic masking. Furthermore, in Experiments V and VI mask exposure duration was not as important a variable in dichoptic presentation as it was in monocular or binocular presentation. The relevant temporal parameter in dichoptic masking is suggested in the masking functions of Experiment V (Figure 8). The average separation between the critical interstimulus interval for targets of 4 and 10 milliseconds was approximately 7 milliseconds, which is roughly the difference between the two durations. That coinci-

TABLE 1

EXPERIMENT VII: CRITICAL INTERSTIMULUS INTERVAL, CRITICAL TARGET DURATION, AND STIMULUS ONSET ASYNCHRONY FOR DICHOPTIC PRESENTATION

S <sub>s</sub>	Critical ISI and estimated SOA (T + ISI <sub>c</sub> )						Critical T duration and SOA (critical T duration)		
	T = 8 msec. PM = 2 msec.	SOA	T = 20 msec. PM = 10 msec.	SOA	T = 5 msec. PM = 5 msec.	SOA	PM = 2 msec.	PM = 10 msec.	PM = 5 msec.
S 1	31	39	18	38	35	40	40	42	43
S 2	59	67	50	70	65	70	78	70	73
S 3	50	58	48	68	54	59	59	64	64

Note. T = target; PM = pattern mask; SOA = stimulus onset asynchrony; ISI = interstimulus interval.

dence implicates stimulus onset asynchrony as the likely candidate for the role of determining temporal variable in dichoptic masking. Kahneman (1968) and Haber (1969b) advocate stimulus onset asynchrony as the important temporal variable in masking rather than stimulus duration or interstimulus interval. However, the data of Experiment I, and of Kinsbourne and Warrington (1962a), are compelling evidence against the theory that stimulus onset asynchrony is the only relevant variable. Clearly, the conditions under which stimulus onset asynchrony, rather than interstimulus interval and/or stimulus duration, determines the masking function have to be delineated.

Experiment VII was conducted to examine the hypothesis that stimulus onset asynchrony was the proper temporal variable for dichoptic masking. The logic of the experiment was simple. If stimulus onset asynchrony was the relevant variable, then the following relation should hold: critical target duration = target duration + critical interstimulus interval = a constant, where critical target duration is the minimal duration of the target which permits evasion of masking when the interstimulus interval is 0 milliseconds.

### Method

The procedure of the experiment was as follows. There were two general conditions. In Condition A, target and pattern mask duration were held constant and the critical interstimulus interval was determined in the usual manner. In Condition B, pattern mask duration was held constant, the interstimulus interval was 0 milliseconds, and critical target duration was determined. In Condition A there were three target duration-pattern mask

duration combinations: target = 8 milliseconds, pattern mask = 2 milliseconds; target = 20 milliseconds, pattern mask = 10 milliseconds, target = 5 milliseconds, pattern mask = 5 milliseconds. For each target-pattern mask combination the critical interstimulus interval was determined. The pattern mask exposure durations for Conditions A and B were the same. For each pattern mask duration in Condition B, both critical target duration and the critical interstimulus interval were determined as that value at which the subject correctly identified four consecutive target letters.

The target stimuli were the set of centrally located symmetrical letters. Luminances of the target and pattern mask were equal at 10 footlamberts. Three subjects participated in the experiment. One subject (S<sub>1</sub>) had had considerable experience with tachistoscopic presentations; the other two subjects were naive. The subjects were tested in a partially counterbalanced design. For a given pattern mask duration, each subject received Condition A first and then Condition B. Across the three subjects, each pattern mask duration appeared once in each test-order position.

### Results and Discussion

Table 1 gives the data for the three subjects. A Treatment × Subjects analysis of the stimulus onset asynchronies revealed that the six treatments did not differ,  $F = 2.44$ ,  $df = 5/10$ ,  $p > .05$ , which suggests that under conditions of dichoptic presentation stimulus onset asynchrony rather than target duration or pattern mask duration is the relevant variable.

Inspection of Table 1 shows no profound differences in the estimates of stimulus onset asynchrony for the subject whether stimulus onset asynchrony is computed from Condition A, in which the target duration was held constant and the critical interstimulus interval is determined, or from Condition B, in which

TABLE 2  
EXPERIMENT VIII: MEAN CRITICAL TARGET  
DURATIONS FOR PART A

T intensity	Monoptic PM intensity		Dichoptic PM intensity	
	5 ftL.	10 ftL.	5 ftL.	10 ftL.
5 ftL.	24.5	46.5	56.0	40.5
10 ftL.	9.5	33.5	67.0	67.0

Note. T = target; PM = pattern mask.

the interstimulus interval was set at 0 milliseconds and the critical target duration was determined. In any event, the picture is obviously quite different from that of Experiment I. The data of the present experiment show a complementarity between target duration and the critical interstimulus interval implying that dichoptic masking by pattern mask is best described as target duration + critical interstimulus interval = a constant.

#### EXPERIMENT VIII AND EXPERIMENT IX

The thrust of Experiments V, VI, and VII was that dichoptic masking by pattern mask was fundamentally different from monoptic masking by random noise. The earlier experiments in the present series showed that stimulus energy was important in determining the interference between stimuli traveling the same peripheral route. There was little, if anything, in Experiments V, VI, and VII which suggested that energy was similarly important in determining the perceptual impairment resulting from two stimuli arriving over separate channels.

Experiments VIII and IX compared monoptic masking by pattern mask with dichoptic masking by pattern mask. Experiment VIII varied target and pattern mask intensity, and Experiment IX varied pattern mask duration. Four subjects participated in Experiment VIII, two subjects in each of two parts. In Part A the target stimuli were the centrally located symmetrical letters presented to the left eye and in Part B the target stimuli were the trigrams presented to the right eye. The mask in Part B was the pattern mask and in Part A a mask was used which was the line configuration of the

pattern mask reproduced in triplicate, once at each of the locations of the consonant letters in the target displays. For future reference, this mask will be referred to as Pattern Mask 3. In both Parts A and B, the mask duration was 10 milliseconds and the measure of masking was critical target duration.

Three subjects participated in Experiment IX which used the trigram stimuli presented to the right eye and Pattern Mask 3 as the mask. The luminances of target and Pattern Mask 3 were both 2.5 footlamberts. Again critical target duration was estimated monoptically and dichoptically. The results of the two experiments are given in Tables 2, 3, and 4. Inspection of these tables reveals that while monoptic masking was significantly influenced by the energy relation between target and mask, dichoptic masking was relatively unaffected. We should also note that in both experiments critical target duration was considerably larger for dichoptic presentation than for monoptic presentation than for monoptic presentation (see Experiment XIX).

The dichoptic data of Table 2 are a little untidy which may be attributable in part to the phenomenon reported in Experiment V which was that a loss in clarity may accompany the increase in duration of stimuli which are of the dark figure-light background type and which are exposed at particular luminance levels. It was suggested above that this phenomenal decrease in form clarity may be due to a combination of both the Broca-Sulzer and lateral-inhibition effects. And both of these effects are probably more evident in those experiments of

TABLE 3  
EXPERIMENT VIII: MEAN CRITICAL TARGET  
DURATIONS FOR PART B

T intensity	Monoptic PM3 intensity		Dichoptic PM3 intensity	
	1.25 ftL.	2.5 ftL.	1.25 ftL.	2.5 ftL.
1.25 ftL.	19.0	40.5	73.5	71.0
2.5 ftL.	7.0	15.0	81.0	75.5

Note. T = target; PM = pattern mask.



TABLE 4

EXPERIMENT IX: CRITICAL TARGET DURATION AS A FUNCTION OF PATTERN MASK 3  
DURATION FOR MONOPTIC AND DICHOPTIC PRESENTATION

Pattern Mask 3 duration (in msec.)	S <sub>s</sub>					
	S 1		S 2		S 3	
	Monoptic	Dichoptic	Monoptic	Dichoptic	Monoptic	Dichoptic
4	6	50	10	152	6	90
10	20	50	34	156	14	95
20	38	48	38	161	28	91

the present series which use critical target duration as the measure of masking.

#### GENERAL DISCUSSION OF EXPERIMENTS I-IX

##### *"Peripheral" and "Central" Defined*

The terms peripheral (or transmission line) and central as used in the present communication have served as convenient ways of talking about the loci of particular effects. They are, however, loaded terms because they imply two distinct and separable anatomic regions. In reality, the interface between the sensory pathways and cortical structures is not at all a sharp boundary but rather a gradual merger. In addition, the term "transmission line" connotes a passive conduit via which exact images of physical stimuli are conveyed from the peripheral receptor to the brain. To the contrary, the electrophysiological evidence available thus far (see Chung, 1968) indicates that visual information is subject to drastic recoding as it proceeds along the pathways of the nervous system, with the degree of recoding and modification increasing as the input proceeds further centrally. In other words, enroute to the cortex operations occur which give rise in output to something other than a mere relaying of the input array.

The definition of peripheral that has been implicit in the preceding discussions is one which includes retina, lateral geniculate nucleus, and striate cortex as its components. Preference is given to a view of the transmission line as a collection of devices signaling properties of the stimulus, and on this view the interface between peripheral and

central is intentionally vague. Some cells of the striate cortex are seen as terminals of peripheral systems extracting basic stimulus parameters, while others are seen as enlisted in central processes that derive an identification of the stimulus from the data set so provided. A recent, relevant discussion of the functional organization of the striate cortex with respect to form perception is that of Pollen, Lee, and Taylor (1971).

The earliest point in the nervous system at which dichoptic masking may originate is probably in the region of the peripheral-central interface, although the question of whether the two eyes interact earlier, at the level of the lateral geniculate nucleus, has not gone unheeded. For the cat visual system, at least, there is some reason to believe that the two eyes might interact at the geniculate. Dichoptic interactions have been observed by Fillenz (1961) and by Lindsley, Chow, and Gollender (1967), and Bishop and his co-workers (Bishop, Burke, & Davis, 1959) have reported activation of geniculate cells by stimulation of either optic nerve. However, against this evidence is the work of Hubel and Wiesel (1961) and Sturr and Battersby (1966) which implies that interactions at the level of the geniculate are minimal at best. Furthermore, it has been reported (Jung, 1961) that at the level of the primary visual projection in the cortex, true binocular convergence is comparatively rare and most cells respond only to afferents from the ipsilateral or the contralateral retina. The implication of this is that dichoptic masking may arise at a relatively late stage in the cortical processing of visual data.

### *Two Loci for Backward Masking*

In short, there are two possible loci for the perceptual impairment resulting when two visual stimuli follow in rapid succession. The impairment may have its locus in the transmission channel or in a central processor. Impairment localized in the transmission channel is best viewed as the effect one stimulus exerts on the other. Impairment localized in a central processor can be of two sorts: an interaction between the stimuli, similar in kind to that occurring in the transmission channel, or a distortion induced in the operation of a central processing mechanism (see Kolers, 1968). The proposition that backward masking reflects a disturbance in the proper functioning of a central device is to emphasize that the masking is not due to the effects exerted by stimuli on each other. With reference to the clerk-customer analogy, the second customer does not have a direct effect on the fate of the first; rather, he exerts an indirect effect by causing the clerk to be hurried and less thorough in his treatment of the first.

Masking by random noise under conditions of monocular and binocular presentation was an instance of interference in the transmission channel. That the effect random noise exerted upon the target was probably not central in its locus was revealed by the absence of any serious dichoptic masking by random noise. Between-stimulus interference arising peripherally was defined by the following relation: target energy  $\times$  critical interstimulus interval = a constant. Masking by pattern mask, on the other hand, could have a central locus. The data suggested that the relevant independent variable for dichoptic masking by pattern mask was stimulus onset asynchrony. Moreover, the nature of dichoptic masking by pattern mask was not significantly affected by energy properties of the stimuli. Those two observations, the relevance of stimulus onset asynchrony and the comparative irrelevance of energy variables, may be interpreted as support for the view that dichoptic masking by pattern mask represents an interruption in the normal functioning of a central mechanism rather than the effects of serial stimuli upon each other. However, the irrelevance

of energy variables should be treated with caution since central interactions between target and mask could be occurring through transients, or on-off signals, scaled for luminance and contrast.

### *The Peripheral Operation*

What does the relation target energy  $\times$  critical interstimulus interval = a constant tell us about the peripheral visual system? The answer seems to be this: whatever the operations performed by the peripheral visual system on an incoming stimulus, the rate at which those operations are conducted is directly related to the energy of the stimulus. It must be assumed that masking by random noise at some interstimulus interval means that the peripheral processing of the target stimulus has not been completed by the time random noise occurs. The minimal time between target and random noise at which the target evades the masking action of the after-coming event, that is, the critical interstimulus interval, is inversely related to the target stimulus energy. Therefore, suffice it to say that peripheral processing time is inversely proportional to the energy of the stimulus. A possible constraint on this conclusion is Purcell, Stewart, and Dember's (1969) finding that at relatively high luminance levels (e.g., 30-60 footlamberts) an increase in either duration or luminance may reduce rather than enhance target perception at a given interstimulus interval. In any event, we can infer from the foregoing that peripheral processing may be completed within the duration of a stimulus, given the right order of stimulus intensity. Support for that conclusion is found in the experiments of Kinsbourne and Warrington (1962a, 1962b).

### *The Role of Mask Energy in Peripheral Masking*

The energy of the mask (random noise) in monoptic or binocular presentation had to be equal to or greater than that of the target in order to impair the identification of the target. But once random noise energy was just slightly greater than the target energy as inspection of Figure 4 clearly shows, further increases did not extend the inter-

stimulus interval over which masking could be obtained. A useful general conclusion follows from this fact. When backward masking does occur in monoptic and binocular conditions where the energy of the mask is less than that of the target stimulus, it is unlikely that the masking originates peripherally. Rather, we ought to conclude that the masking is of central origin. This conclusion may only apply to masking of form where the subject's task is to identify the form, that is, the masking of interest to the present communication.

To clarify the potential importance of this conclusion, consider two instances of masking: masking by a contourless light flash and dichoptic masking by pattern. When the mask is a homogeneous flash of light of energy less than or the same as that of the target stimulus, masking is generally not obtained (Sehiller, 1969). It is also known that masking of a form by a contourless light flash of greater energy does not have any appreciable central component (e.g., Schiller, 1965). Therefore, we may conclude that if the flash energy is not greater than the target energy and if the two stimuli are not on the same transmission line, then masking of a form by a flash of light cannot occur. In contrast, when the mask is a pattern (say, the pattern mask) and the stimulus presentation is dichoptic, masking does occur, and the condition that mask energy be greater than target energy is not a necessary condition for such masking. Presumably, therefore, monoptic or binocular masking by pattern could occur centrally rather than peripherally, and that means, of course, that monoptic or binocular masking could occur in conditions where the energy of the pattern mask is less than that of the target stimulus.

### *The Central Operation*

An important distinction between peripheral and central processes was demonstrated in Experiments VI, VIII, and IX. Whereas the parameters of duration and intensity significantly affected masking of peripheral origin, their effect centrally was negligible. This distinction is put into relief by electrophysiological data which show that the further centrally a neuron lies, the more

complex and specific become the stimulus parameters to which the cell responds. Thus, the more centrally a cell is located, the more likely it is that the cell will be affected by informational rather than energy characteristics of stimuli.

The relevance of stimulus onset asynchrony to masking of central origin suggests that the constraint on central processes is simply time elapsed since stimulus onset. We will presume, and not without reason, that the central machinery assumes the major burden of pattern recognition and that it uses as its raw material the visual data provided by the peripheral mechanisms.

We may assume for the present that the relation between the peripheral and central processes is that they are successive and additive. That is to say, the peripheral operation must be complete before the central operation can begin, and therefore, the time needed to identify a tachistoscopically presented letter would be the total time of the two operations combined. It will be part of the task of the experiments that follow to assess the validity of this hypothesis.

### *Backward Masking by Pattern Mask*

There is now the question of the nature of masking by pattern mask under conditions of monocular or binocular presentation. As noted in the introduction to the present paper, it is not inconceivable that the masking effect of a particular stimulus could be exerted prior to the establishment of the target representation or subsequent to the establishment of the target representation. Therefore, when the target and the pattern mask are transmitted on the same channel, the resulting perceptual interference could reflect effects at either, or both, loci. However, the impression gained from Experiments I-IX was that interference in the transmission channel and interference with the operation of a central processor were two very distinct phenomena such that any masking that might be observed reflected either one or the other, but probably not both.

Consider the target and the pattern mask presented monocularly. If the target and the pattern mask fuse in the transmission channel, as suggested by the integration hypothe-

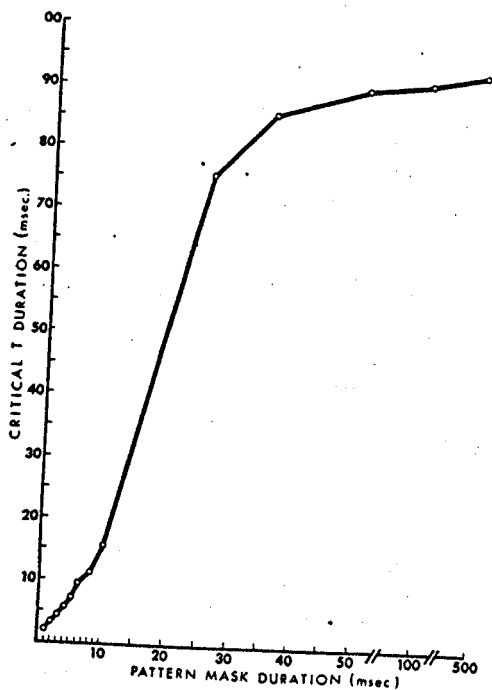


FIG. 10. Relation between Pattern Mask 3 duration and mean critical target duration for monoptic stimulus presentation in Experiment X.

sis, the task of the central processor would be rather like that of trying to make sense of a photograph produced by a double exposure. What is important here is the fact that if the stimuli superimpose in the peripheral channel, then what the central device receives effectively is but *one* stimulus for analysis, *not two*. If, however, the two stimuli do not interact in the transmission channel, for whatever reason, then the central processor receives two stimuli in succession and the task now is that of trying to make sense of the first before the second arrives.

In the experiments that follow, an attempt is made to separate the peripheral and central components in monoptic masking by pattern mask (Pattern Mask 3). More generally, the experiments are directed at the question of how the two operations, peripheral and central, relate.

### EXPERIMENT X

The essence of the concluding comments on Experiments I-IX was that at some point

a masking function for monoptic presentation, of the sort generated by the procedure of Experiment IX, must assume the characteristics of dichoptic presentation. What Experiment IX (and for that matter Experiments VI and VII) had shown was that central processes were unaffected by the exposure duration of a lagging mask stimulus. Presumably, therefore, in monoptic presentation a measure of masking, such as critical target duration, should asymptote at some value of pattern mask duration. Such an outcome, perhaps, would be expected regardless of any theory. Yet, pilot work prompted this experiment in that subjects reported an interesting shift in their phenomenological description of the stimuli as the duration of pattern mask (actually Pattern Mask 3), and accordingly, the duration of the target, increased. At brief durations, pilot subjects reported a relatively unclear, degraded stimulus. The experience was that of target and pattern mask "mixed." At longer durations, subjects reported seeing a "clear" target followed by a "clear" pattern mask, the experience being that of "not having sufficient time to read the target." The latter description had been used occasionally by subjects in the previous dichoptic conditions.

### Method

Six subjects participated in the experiment. Two of the subjects were highly experienced in tachistoscopic experiments; they were members of the staff of Haskins Laboratories and had served as pilot subjects for a number of the preceding experiments. The remaining four subjects were naive to the apparatus and to the experiment.

For each subject, critical target durations were determined in the given order for the following values of Pattern Mask 3 duration: 2, 3, 4, 5, 6, 8, 10, 25, 35, 50, 100, and 500 milliseconds. Presentation was monoptic at the right eye. The target stimuli were the set of trigrams and the luminance of target and Pattern Mask 3 was 2.5 footlamberts. Following each stimulus presentation and report, the subject was required to describe his experience of the stimuli. The subjects were not told what to expect.

### Results and Discussion

The averaged data are represented graphically in Figure 10. The individual subject data are given in Table 5. Inspection of

Figure 10 suggests a linear relation between critical target duration and Pattern Mask 3 duration up to a Pattern Mask 3 duration equal to 10 milliseconds, followed by what appears to be a relatively abrupt transition to asymptote. Individual subject data shown in Table 5; Subjects 2 and 6, for example, demonstrate this transition most vividly. In the region of this transition, subjects shifted in their description of what they were seeing as the target duration approached the critical value. Up to the transition region, subjects described the target stimulus as "messy," "mixed up," "hard to make out," and "unclear." Subsequent to the transition region, subjects gave the following descriptions: "pattern replaced letters"; "image of letters shortened by pattern"; "pattern stopped me reading the letters." The principal phenomenological difference between the phase prior to and that subsequent to the transition region was that subjects described a shift from seeing one event to seeing two events in succession.

Further indication that masking in the Pattern Mask 3 duration range 1-10 milliseconds was fundamentally different from that observed in the Pattern Mask 3 duration range 25-500 milliseconds was provided by subject errors and by between-subject differences. A coarse examination revealed a fairly consistent pattern. For the mask range 1-10 milliseconds, errors seemed to be evenly distributed across position: for example, subjects tended to commit as many errors in reporting the first letter of the trigram as they did in reporting the third letter. Moreover, all three letters became available at very much the same critical target duration (cf. Kinsbourne & Warrington, 1962a). In contrast, errors committed in the mask range 25-500 milliseconds tended to relate to position in the trigram array. As the target duration increased, the subject was more likely to report the first letter correctly, less likely to report the second letter, and least likely to report the third. Omitting the third item of a trigram was common in the Pattern Mask 3 range 25-500 milliseconds, the subjects frequently responding that they did not have time to read it.

Between-subject comparisons were also

TABLE 5  
EXPERIMENT X: CRITICAL TARGET DURATION  
AS A FUNCTION OF PATTERN MASK 3  
DURATION FOR MONOPTIC  
PRESENTATION

PM 3 duration (in msec.)	S <sub>s</sub>					
	S 1	S 2	S 3	S 4	S 5	S 6
1	1.5	1.5	1.5	2.5	2.5	2.5
2	3.0	3.5	2.5	3.5	3.5	3.5
3	4.0	4.5	3.0	5.5	5.0	5.0
4	5.0	6.0	4.0	6.0	6.0	6.0
5	6.0	7.0	7.0	8.0	7.5	8.0
6	8.0	8.5	8.0	12.5	10.0	10.0
8	9.0	10.5	10.5	14.5	11.5	10.5
10	12.5	15.0	13.5	21.0	20.0	12.0
25	21.5	130.0	25.0	84.0	42.5	150.0
35	28.0	145.0	26.0	110.0	48.0	157.0
50	37.0	145.0	28.5	112.0	62.0	156.0
100	34.0	150.0	31.5	113.0	63.0	157.0
500	37.0	150.0	31.5	113.0	66.0	162.0

Note. PM = pattern mask.

illuminating. Two subjects, Subject 1 and Subject 3, as noted above, were highly experienced in the task of reading material from a masked display. Inspection of Table 5 reveals a considerable difference between the performance of Subjects 1 and 3 and the remaining subjects across the Pattern Mask 3 durations of 25-500 milliseconds, yet little, if any, difference in the range 1-8 milliseconds. Admittedly, the possibility of large differences in critical target duration across Pattern Mask 3 exposure durations 1-8 milliseconds was limited; this, however, does not detract from the fact that the increase in mask duration from 10 to 25 milliseconds resulted in a clean separation of the sophisticated from the naive subjects. Moreover, errors committed by Subjects 1 and 3 in the asymptotic part of the function were more evenly distributed across the trigram-letter positions.

#### EXPERIMENT XI

Experiment X reinforced the impression that two quite different processes could be isolated in monoptic masking by Pattern Mask 3. It was inferred that at briefer durations of the target and Pattern Mask 3, the masking was similar to masking by random noise, and at the longer durations, the

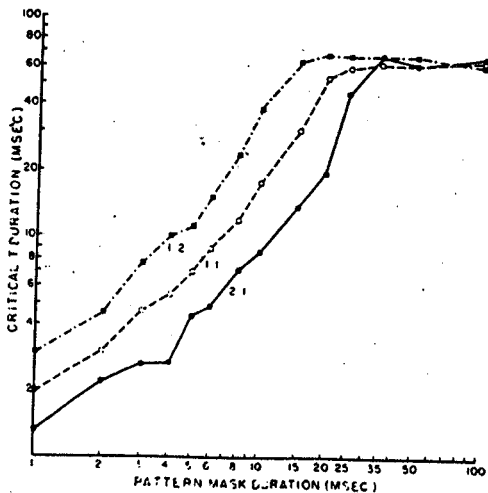


FIG. 11. Log-log relation between Pattern Mask 3 duration and mean critical target duration for monoptic stimulus presentation at three intensity ratios in Experiment XI.

perceptual interference was more like that seen dichoptically. The correctness of this inference could be tested on the basis of the data of Experiment VIII: manipulating luminance should affect the initial rising part, if that mirrored peripheral masking, but not the subsequent asymptotic part of the function relating critical target duration to Pattern Mask 3 duration. Experiment XI was designed to perform this test.

#### Method

The procedure of Experiment XI was similar to that of Experiment X. Critical target duration was estimated at the following durations of Pattern Mask 3: 1, 2, 3, 4, 5, 6, 8, 10, 15, 20, 25, 35, 50, and 100 milliseconds. The principal feature of Experiment XI was that across the exposure durations of the after-coming stimulus, critical target duration was determined for three target stimulus-mask stimulus luminance ratios. The three ratios were: 1:1 (target = 2.5 footlamberts, Pattern Mask 3 = 2.5 footlamberts); 2:1 (target = 5.0 footlamberts, Pattern Mask 3 = 2.5 footlamberts); 1:2 (target = 2.5 footlamberts, Pattern Mask 3 = 5.0 footlamberts). In a partially counterbalanced design, each ratio condition appeared twice across the six naive subjects at each of the three possible test-order positions. The stimuli, trigrams, and Pattern Mask 3 were viewed with the right eye.

#### Results and Discussion

The average critical target durations for each of the three intensity ratios are shown

in Figure 11. The family of curves are reproduced in a log-log plot in order to give a clearer picture of the initial rising component of the functions. The hypothesis under test was that the ascending component of the function relating critical target duration to pattern mask duration would be affected by the ratio of stimulus intensities but the asymptotic component would not, the idea being that the ascending and asymptotic phases reflected masking of two different origins. Inspection of Figure 11 shows, in accord with this hypothesis, that the ascending components of the three curves differed, while the asymptotic components did not.

#### EXPERIMENT XII

The data of Experiments X and XI invite the following hypothesis: the duration (energy) of the target stimulus determines whether the upper limit on monoptic masking by pattern mask (or Pattern Mask 3) will reflect peripheral or central processes. Inspection of Figure 11 suggests that for all three ratios, the masking, for example, of a 3-millisecond exposure of target by a 5-millisecond exposure of Pattern Mask 3 was localized in the transmission line; on the other hand, the masking of a 60-millisecond target by a 50-millisecond Pattern Mask 3 was central in origin. The data of Experiment XI further imply that the origin of interference with a 3-millisecond target by a 50-millisecond exposure of Pattern Mask 3 should be one and the same. That is, in both of these instances in which mask energy is greater than target energy and target energy is comparatively weak, the locus of masking should be peripheral. The upshot of all this is that the locus of the interference induced by a Pattern Mask 3 of 50-millisecond exposure should shift from peripheral to central as target exposure duration increases.

The design of Experiment XII involved estimating the critical interstimulus interval for eleven values of target duration, ranging from 2 to 64 milliseconds, with mask duration held constant at 50 milliseconds. Assuming the validity of the above reasoning, it was expected that at brief values of the target, masking would display characteristics of

TABLE 6

EXPERIMENT XII: MONOPTIC CRITICAL INTERSTIMULUS INTERVAL AS A FUNCTION OF TARGET DURATION WITH RANDOM NOISE AND PATTERN MASK 3 AS MASKS

Target duration (in msec.)	Random noise							Pattern Mask 3						
	Ss						Mean ISI <sub>c</sub>	Ss						Mean ISI <sub>c</sub>
	S 1	S 2	S 3	S 4	S 5	S 6		S 1	S 2	S 3	S 4	S 5	S 6	
2	58	63	45	63	46	70	57.50	96	89	72	73	75	135	90.00
3	40	45	32	48	35	45	40.83	66	61	51	50	66	80	62.33
4	29	32	23	35	26	32	29.50	51	40	44	38	68	79	53.33
6	21	22	15	25	19	24	21.00	44	46	41	35	49	78	48.83
8	15	18	12	16	15	18	15.67	67	37	40	33	49	68	49.00
16	2	8	1	3	3	3	3.33	59	33	20	24	52	54	40.33
24	0	0	0	0	1	1	.33	53	25	23	18	40	45	34.00
32	0	0	0	0	0	0	0	54	13	12	6	38	39	27.00
40	0	0	0	0	0	0	0	44	7	5	2	27	29	19.00
48	0	0	0	0	0	0	0	37	1	0	0	14	25	12.83
64	0	0	0	0	0	0	0	12	0	0	0	0	3	2.50

Note. ISI<sub>c</sub> = critical interstimulus interval.

between-stimuli interference in the transmission line; at longer durations of the target, the masking would fit the central mold, that is, complementarity would be observed between the target duration and the critical interstimulus interval. To provide a yardstick for interference in the transmission channel, the critical interstimulus interval was determined across the eleven target durations, with random noise as the after-coming mask. At the briefer durations of the target, the function relating target duration to the critical interstimulus interval with Pattern Mask 3 lagging should look similar to that with random noise lagging. However, at the longer exposures of the target, the two functions should assume very different characteristics.

### Method

At each target duration, the critical interstimulus interval was determined in the usual manner for both masks before testing at the next duration. Three of the six naive subjects were given random noise first and the remaining three were given Pattern Mask 3 first. The luminances of the target (trigrams), Pattern Mask 3, and random noise were equal at 5 footlamberts, and stimuli were viewed with the right eye.

### Results and Discussion

The data averaged across the six subjects for Pattern Mask 3 and random noise as the

masking stimuli are plotted in Figure 12. Individual data are given in Table 6.

As before, masking by random noise pro-

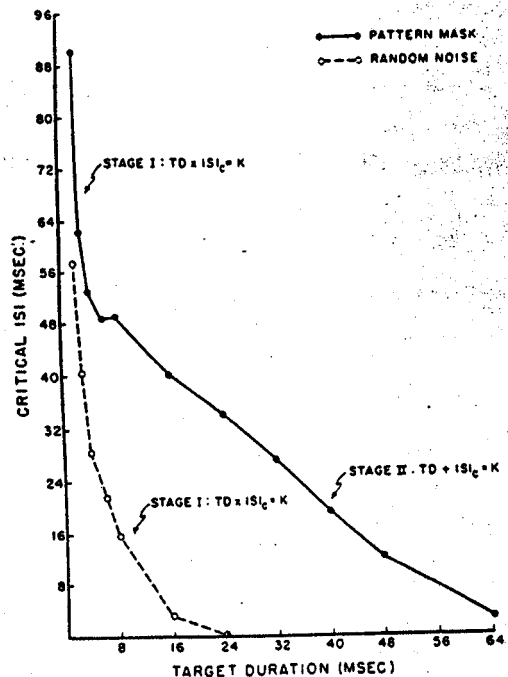


FIG. 12. Relation between target duration and the mean critical interstimulus interval for monoptic masking by random noise and Pattern Mask 3 in Experiment XII.

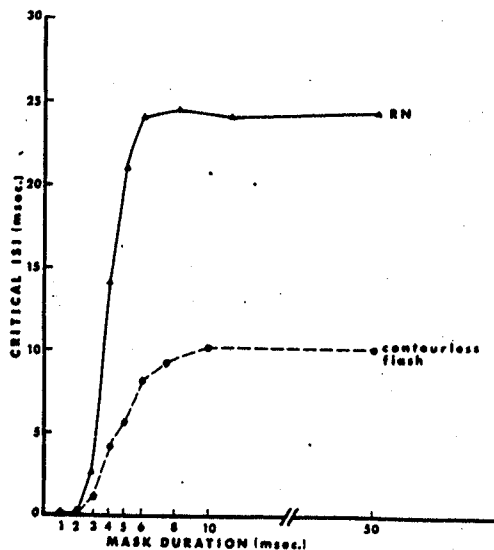


FIG. 13. Relation between mask duration and the mean critical interstimulus interval for monoptic masking by random noise and a contourless light flash of the same intensity.

duced a simple relation between the exposure duration of the target event and the minimal time required to evade masking, that is, target duration  $\times$  critical interstimulus interval = a constant. The present random noise function if plotted on log-log paper is virtually a straight line, and compares favorably with a log-log plotting of the random noise function by Kinsbourne and Warrington (1962a). The only serious departure from the multiplicative relation occurs at a target equal to 16 milliseconds. At that exposure duration, some subjects were still masked by the lagging random noise, as inspection of Table 6 shows, but the multiplicative rule was obviously not in effect.

Masking by Pattern Mask 3, in sharp contrast to masking by random noise, yielded a complex relation between target duration and the critical interstimulus interval. At the very brief durations of 2 and 3 milliseconds (and perhaps 4 milliseconds), the Pattern Mask 3 function paralleled the random noise function, that is, the relation between exposure duration and the critical interstimulus interval appeared to be multiplicative. For targets equal to 2 and 3 milliseconds the critical interstimulus intervals

were 90 milliseconds and 62 milliseconds, respectively. Multiplying duration by critical interstimulus interval in these two cases yields very much the same values, 180 in the 2-millisecond case and 186 in the 3-millisecond case. In contrast, taking the next four values of the target—4, 6, 8, and 16 milliseconds—and multiplying them by their appropriate critical interstimulus intervals yields unequal products of approximately 208, 288, 384, and 1280, respectively. Thus, at the longer exposures of the target, the Pattern Mask 3 function does not fit the multiplicative rule, and the relation between target duration and the critical interstimulus interval is best described as target duration + critical interstimulus interval = a constant.

The conclusion of Experiments I-IX was that the multiplicative rule characterized peripheral and the additive rule characterized central processes. Indeed, the additive relation between target duration and the critical interstimulus interval had been detected in dichoptic presentation. Thus, the present experiment may be viewed as a demonstration that peripheral and central masking are isolable and separable in conditions of monoptic (or binocular) presentation of stimuli. In Figure 12, the multiplicative and additive relations are referred to as Stage I and Stage II, respectively.

It is evident from Figure 12 that the critical interstimulus interval was greater with Pattern Mask 3 than with random noise as mask at the very brief target durations, that is, durations at which, on the present hypothesis, peripheral processes were setting the upper limit on masking.

Figure 13 shows a comparison between monoptic masking by random noise and by a homogeneous flash of light of the same intensity. The data are from two subjects the duration of the target was 4 millisecond and its intensity was the same as that of the two masks. The experiment was conducted in the manner of Experiment I. Perception of target was more impaired by random noise than by a contourless flash of light of the same intensity. It is known that masking of a form by a light flash does not take place dichoptically (e.g., Mowbray & Durr, 1964; Schiller & Wiener, 1963); its effect, like



TABLE 7

EXPERIMENT XIII: COMPARISON OF MONOPTIC AND DICHOPTIC STIMULUS ONSET ASYNCHRONY MEAN CRITICAL INTERSTIMULUS INTERVAL AS A FUNCTION OF TARGET DURATION

Ss	Monoptic target duration				Dichoptic target duration			
	10	20	30	40	10	20	30	40
S 1	99.0	86.0	68.5	63.0	87.0	74.5	69.5	66.5
S 2	105.0	87.5	83.0	86.5	96.5	93.0	76.5	76.5
S 3	67.0	69.5	59.5	44.0	75.5	65.0	64.0	51.0
S 4	212.0	213.0	197.5	186.5	225.0	190.0	197.5	182.5
Mean ISI <sub>c</sub>	120.75	114.00	102.13	94.88	121.00	105.63	101.88	94.13
Mean SOA	130.75	134.00	132.13	134.88	131.00	125.63	131.88	134.13

Note. ISI<sub>c</sub> = critical interstimulus interval; SOA = stimulus onset asynchrony.

that of random noise, is restricted to the transmission channel. Comparison of Figure 13 with Figure 9 and with Figure 12 suggests that masking in the transmission line owes allegiance to variables other than energy variables. Evidently, the similarity between the target and the mask is a determinant of the degree of between-stimulus interference in the transmission channel. However, for any given target and mask the degree and direction of interference in the transmission line vary as a function of their respective energies.

### EXPERIMENT XIII

The hypothesis that Experiment XII had isolated peripheral and central masking effects in monoptic viewing prompted the question: Is the central effect in monoptic presentation the same as that in the "clean signals" case of dichoptic presentation? That is, would the minimal stimulus onset asynchrony for criterion performance be the same regardless of whether the two stimuli traveled to the central processor by the same route or by separate routes? Experiment XIII answers this question.

#### Method

At four values of target duration, 10, 20, 30, and 40 milliseconds, four naive subjects were examined both monoptically and dichoptically. For each target duration in each mode, two estimates of the critical interstimulus interval were made. Two subjects were given the following order of conditions: dichoptic, monoptic, rest (approximately 10 minutes), monoptic, dichoptic. The other two subjects were given: monoptic, dichoptic,

rest, dichoptic, monoptic. The target stimuli were the consonant trigrams and Pattern Mask 3 was the mask held constant at 50-millisecond duration and at 2.5 footlamberts, the intensity of the target stimuli. Presentation of the target stimuli was to the right eye.

#### Results and Discussion

The average of the two estimates of the critical interstimulus interval made at each target duration for each subject for both modes of presentation is given in Table 7. The data are unequivocal. The minimal stimulus onset asynchrony for criterion performance was constant for monoptic and dichoptic masking. This suggests that the additive component isolated monoptically is the same as that isolated by the dichoptic procedure. In addition, the present data, taken together with those of Experiment VII, imply that central processing time is not influenced by peripheral processing time.

#### APPROXIMATIONS TO A MODEL FOR MASKING

##### *Another Look at the Relation between the Two Processes*

In the general discussion of Experiments I-IX, the rudiments were spelled out for a theory of the recognition of visual stimuli. It was proposed that visual pattern recognition involves at least two distinct stages and that these two stages are successive and additive, the two stages in question corresponding to the processes represented by the multiplicative and additive rules. Several current theories of pattern recognition take

the same form. Neisser (1967), for example, has proposed that an initial preattentive process which segregates objects in the optical array, and which may signal the presence of easily discriminable physical features, precedes a second stage of focal attentive processing which makes extensive contact with long-term storage and is essential for stimulus recognition. Sternberg (1967) has similarly argued for a successive-additive model of stimulus classification. We should not assume, however, that the stages described in the theories of Neisser and Sternberg are identical to those described here. In any event, while the present research may be viewed as substantiating one aspect of such theories, which is that there are several distinct processes underlying pattern recognition, the results of Experiment XII raise serious doubts about the postulation that the two processes of interest to the present paper are successive and additive.

Figure 12 shows two functions relating the target duration to the critical interstimulus interval. One of these functions was generated by random noise as mask and the other by Pattern Mask 3, and as noted above, these functions are fundamentally different. For present purposes what is important about the Pattern Mask 3 function is the invariance of target duration + critical interstimulus interval in the target duration range from 4 to 64 milliseconds. What this means essentially is that the central process as identified by the additive rule was requiring a certain amount of time between stimuli onsets to identify the target stimulus and that this amount of time was constant and unaffected by the duration of the target stimulus. Inspection of the random noise function, on the other hand, tells us that the time needed to complete peripheral processing varied with the duration of the target stimulus. This is how the critical interstimulus interval in the multiplicative rule has been interpreted; it identifies the minimal time needed by peripheral processes to signal the features of the stimulus. The problem for the successive-additive postulation lies in this fact: while the peripheral processing time varied with target duration, the central processing time was constant.

But if the processes or stages are sequential and the central processing time is measured as the elapsed time between onsets, then central processing time must include peripheral processing time as well. The implication is that the two processes are not conducted in sequence but instead overlap in time.

What is needed on the evidence of Experiment XII is a restatement of the relation between peripheral and central processes, or more precisely, between the processes symbolized by the multiplicative and additive rules. Two criteria must be met. First, any proposed relation must account for the invariance in the central processing time with varying peripheral processing time as evident in the range of 4 to 64 milliseconds of the Pattern Mask 3 function of Figure 12. Second, it must account for why the upper limit on the masking range of Pattern Mask 3 for the brief target durations of 2 and 3 milliseconds is apparently set by peripheral processing time and not by central processing time.

Two possible hypotheses present themselves. One is that the processes symbolized by the multiplicative and additive rules are not allied at all; they are operationally parallel. The other is that the two processes overlap in time, but one is contingent on the other.

The first hypothesis requires discarding the notion that the multiplicative rule speaks to peripheral events and the additive rule to central. To say that the processes are operationally parallel is to say that they work independently of one another, and given the earlier anatomical localization of these rules, this is tantamount to saying that central processes are not contingent on the output of peripheral processes, which is nonsensical. On this view, the two principles, target duration  $\times$  critical interstimulus interval = a constant, and target duration + critical interstimulus interval = a constant, are seen as representing simply two operations in vision rather than as indicants of peripheral and central processes.

To meet the criteria posed above, an operationally parallel view of the two processes must carry the rider that the rule

describing the minimal time needed to evade masking by a pattern (such as Pattern Mask 3) must depend, for any circumscribed range of energy values of the target stimuli, on which of the two processes takes longer. In the Pattern Mask 3 function of Figure 12 masking at the target exposures of 2 and 3 milliseconds is best described by the multiplicative relation, while at the longer exposures, the additive relation is more suited. From the data illustrated in Figure 12, it may be concluded that at the exposures of 2 and 3 milliseconds the processing symbolized by the multiplicative rule took longer, and at the exposure durations of 4 to 64 milliseconds it was the processing described by the additive rule which was more durable. Thus, for the exposures of 2 and 3 milliseconds it may be inferred that the operation characterized by the additive rule was complete by a stimulus onset asynchrony of approximately 58 milliseconds, while the operation characterized by the multiplicative rule was still in progress. Therefore, up to an stimulus onset asynchrony of 58 milliseconds or so, Pattern Mask 3 could interfere with either or both processes; beyond that stimulus onset asynchrony, however, the after-coming stimulus could only interfere with the process characterized by the multiplicative rule. Since the dependent variable was the minimal time needed to evade masking, the obtained estimate of that minimal time would, on this view, mirror the properties of the process underlying the multiplicative relation between target duration and critical interstimulus interval. This would hold only for those durations of target exposure at which the process underlying the multiplicative relation took more time than that underlying the additive relation. Where this criterion is no longer met, the estimate of minimal time needed to evade masking would mirror the properties of the process described by the additive rule.

In order for the operationally parallel view to account for the Pattern Mask 3 function, the assertion has had to be made that both operations must be concluded in order for the target stimulus to evade masking by Pattern Mask 3. This is equivalent to saying that for identification to occur, both

operations must be complete, which implies perhaps that they cannot be orthogonal. On the other hand, it may imply only that some subsequent decision mechanism cannot output an identification until inputs from both processes are available.

Perhaps the strongest argument against the operationally parallel view is that the data of the present research point to a distinction between the two processes that is, in a nontrivial sense, anatomical. The multiplicative relation was most surely grounded in those circumstances which allowed for peripheral interaction, that is, in conditions of monoptic and binocular presentation. Indeed, the multiplicative relation was realized only in these conditions, Kinsbourne and Warrington (1962a, 1962b) to the contrary. In addition, only the multiplicative rule was engendered across target durations by random noise, a mask which failed to impede letter perception in dichoptic presentation. Furthermore, the stimulus parameters of duration and intensity, immaterial to dichoptic masking by pattern mask or Pattern Mask 3, were the determinants of monoptic and binocular masking by random noise. In short, an anatomical distinction between the two processes along the lines peripheral-central is strongly demanded by the data.

#### *A Concurrent and Contingent Model of the Peripheral-Central Relation*

An alternative to the successive-additive and the operationally parallel interpretations is that the processes overlap temporally and that one process, the central, is contingent on the output of the other. This approach preserves the central/peripheral distinction nurtured in the earlier arguments of the present paper.

The essence of such a view is that the central process receives data intermittently from the periphery. This implies two things: there are a number of different peripheral systems or neural nets, and these peripheral systems may output data at different rates.

The form that such peripheral nets might take is suggested by a consideration of the selectivity manifested by individual cells in the visual systems of vertebrates such as cat

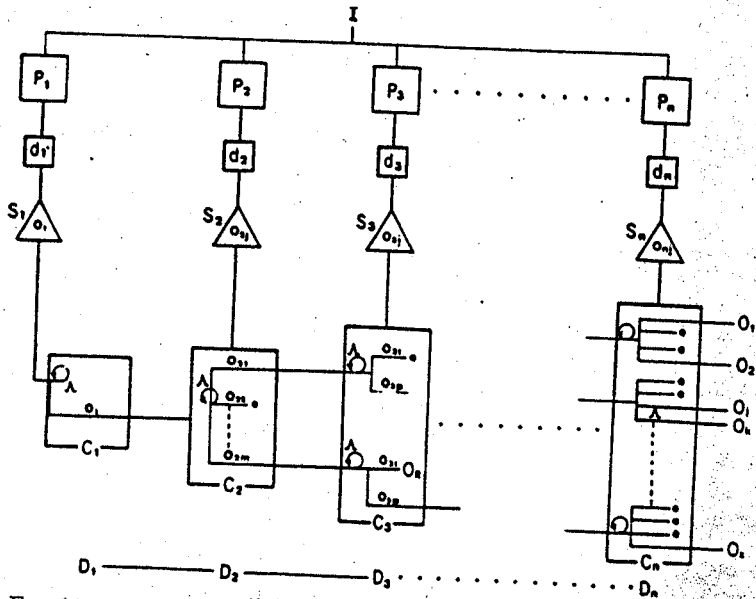


FIG. 14. Schematic representation of the concurrent-contingent model.

and monkey. We know, for example, that certain neurons respond only if the input to the retina has a particular size, shape, or orientation or moves in a certain direction (Hubel & Wiesel, 1962, 1965, 1968). However, what is important to note here is that this selectivity is the result of an operation performed by a fairly large neural system, served in part by spatial summation and lateral inhibition and including many receptor units and intermediate neurons in addition to the cell in question. Neural systems of this sort exhibit certain features which are important to the present discussion (see Thomas, 1970). First, each is selectively responsive to a certain characteristic of stimulation. Second, although the different systems may have receptors and intermediate neurons in common, they are for the most part independent. Third, an input to the retina will affect several or all systems simultaneously, but only some will respond to it; that is, only some systems can output a characteristic of the input. And fourth, each system has a "preferred feature condition," that is, it responds best when the feature to which it is selective is present in a particular way. With straight-line contour detectors, for example, the strongest

response is given when the line is in a particular orientation. The strength of a system's output varies inversely with the degree of difference between the preferred condition of the feature and the actual condition. Thus, the output from these systems is graduated.

Evidence for parallel perceptual systems of this sort in the human has been accumulating. (See Weisstein, 1969, for a recent review.) The explanation of hue perception by reference to separate, parallel systems is of course, not new. Recently, several experiments have argued for the existence of systems which are both selectively sensitive to color and tuned to a narrow range of edge orientations (Held & Shattuck, 1971; McCollough, 1965). Sekuler and his colleague (Pantle & Sekuler, 1968; Sekuler, Rubin & Cushman, 1968) have proposed that mechanisms exist which are sensitive to the direction of movement and contour orientation. In addition, several papers by Thomas (e.g. Thomas & Kerr, 1971) have argued that stimulus detection is mediated by mechanisms which are at least crudely size tuned. There is also some evidence favoring the view that different properties of stimulation are ascertained at different rates. Kahn-

man (1967a), for example, has shown that brightness and contour data have different rates of formation. The experiments of Fehrer and Raab (1962) and Fehrer and Biederman (1962) revealed that information about stimulus onset is available well in advance of data on contour and that the former may be available in the phenomenal absence of the latter. And Cheatham (1952) has reported, albeit contrary to intuition, that the perception of contour precedes the perception of hue. In sum, there is reason to believe that different operations may be going on simultaneously at different rates (Kolars, 1967; Weisstein, 1971).

The following sketches the details of a concurrent-contingent model which relates the peripheral and central processes. The model is illustrated in Figure 14:

- (a) I is an input to a particular retinal location from the set of all possible inputs to either or both eyes. For present purposes, we will talk only about input to one eye.
  - (b) The multiplicative rule characterizes the workings of the peripheral mechanisms,  $P = [P_1, P_2, \dots, P_n]$ , a set of "neural nets" or "logical units" which all have the same input I but which give rise to different outputs. The assumption is made that each peripheral net consists of several stages and that the peripheral nets are operationally parallel. We will presume that the two sets of peripheral systems,  $P_{right}$  and  $P_{left}$  are functionally equivalent. Only one P set will be discussed for simplicity.
  - (c)  $O_{ij}$  is an output of a peripheral net  $P_i$ , where  $O_{ij}$  belongs to the set  $[O_{i1}, O_{i2}, \dots, O_{in}]$  and  $n$ , the number of outputs for each  $P_i$  is finite and varies for different  $P_i$ .
  - (d) Peripheral net outputs are realized at different times after I onset. Operating times for peripheral nets are symbolized  $d_1, d_2, \dots, d_1, \dots, d_n$ , such that, in general,  $d_1 < d_2 < \dots < d_n$ .
  - (e) For any peripheral net  $P_i$ , operating time varies as follows: (a) When I energy  $<$  the minimal energy,  $E_{min}$ , required to elicit a terminal response in a peripheral net, there is no new output; (b) When  $E_{min} <$  I energy  $<$  maximum energy,  $E_{max}$ , operating time varies inversely with energy; (c) When I energy  $>$   $E_{max}$ , operating time is at some fixed minimum.
  - (f) Peripheral net outputs are stored in central storage units, (S) for use by the central decision process. The base state of any storage unit,  $S_i$ , is  $\Lambda$ , the null state. This state can be changed only by the entry of real data,  $O_{ij}$ , from the peripheral net,  $P_i$ .
- The record of  $O_{ij}$  either decays with time, returning  $S_i$  to state  $\Lambda$ , or is replaced by the record of another  $O_{ij}$ .
- (g) Reduced sensitivity occurs in peripheral nets following the processing of I. The nets recover in sensitivity with time, and it is proposed that the efficacy with which they can process a subsequent stimulus is a direct function of the energy of that stimulus and the time since I offset. Depending on the pattern of I, lowered sensitivity exists throughout in some peripheral nets while in others it may be limited to the early stages. Peripheral nets recover at different times following I offset.
  - (h) We will presume that there is only one set of stores,  $S = [S_1, S_2, \dots, S_i, \dots, S_n]$ , for the outputs of the two peripheral systems,  $P_{right}$  and  $P_{left}$ . In other words, for a corresponding region of the two retinas, the outputs from right-eye nets and left-eye nets are entered into the same storage units.
  - (i) The central process (C) is also a set of nets,  $[C_1, C_2, \dots, C_i, \dots, C_n]$ , whose serial operations can be conveniently represented as a decision tree in which each  $C_i$  consists of a set of nodes on the tree. The additive rule characterizes the workings of the central process.
  - (j) For any central net,  $C_i$ , two sources of data are necessary for a decision: an input from the appropriate  $P_i$  and a decision from the preceding central net,  $C_{i-1}$ .
  - (k) The final output of the central process is  $O_n$ , belonging to the set  $[e, O_1, O_2, \dots, O_n]$ , where  $e$  is the null element.
  - (l) For any given input branch, a decision by  $C_i$  will be made depending on the output  $O_{ij}$  (other than  $\Lambda$ ) in  $S_i$ . Either a branch of the tree will continue to  $C_{i+1}$ , or it will terminate in a final output  $O_n$ , or it will terminate in the null output  $e$ , meaning no output possible. Thus we say that C is a pruned tree.
  - (m) If a decision branch from  $C_{i-1}$  finds  $\Lambda$  as the record in  $S_i$ , then two possibilities arise, since  $\Lambda$  means that no particular output,  $O_{ij}$ , has been made by the peripheral net,  $P_i$ . In general we would expect  $C_i$  to wait for some output,  $O_{ij}$ , by looping at the input (symbolized  $\hookrightarrow$ ). This looping would have an upper time limit greater than that of the slowest operating time of  $P_i$ , at which point the decision branch would terminate in the final  $e$  state. Sometimes, however,  $\Lambda$  in  $S_i$  would be a permissible output from  $P_i$ , and  $C_i$  would compute its decision in the normal way.
  - (n)  $D_1, D_2, \dots, D_i, \dots, D_n$  are the operating times for the central nets. For any  $C_i$ , the operating time,  $D_i$ , is constant across input branches from  $C_{i-1}$  and outputs  $O_{ij}$  from  $P_i$ . Thus, as long as all central nets receive their inputs from their respective

peripheral nets simultaneous with, or prior to, the input branches from the preceding nets,  $D_1 + D_2 + \dots + D_n$  is a constant.

- (o)  $P_1$  and  $C_1$  are, respectively, the peripheral and central nets detecting and identifying onset or change of stimulation.

Peripheral processing time refers to the time needed to complete a subset, or the complete, set, of peripheral net operations, and central processing time refers to the time needed to reach a particular decision. It is assumed that both peripheral processing time and central processing time have varying upper limits determined by the characteristics of  $I$  and that the upper limit on central processing time is also determined by the task, for example, detection, identification. To be more precise, the subset of peripheral nets which will output data on  $I$ , that is, the number and type of nets engaged, is constrained by the nature of  $I$ . A contourless flash of light will not occupy the same number or type of peripheral nets as would be occupied by a contoured flash; obviously, networks determining intensity, duration, and size are involved in both, but networks determining inhomogeneities in the input array are needed only for the latter. Also, the full complement of central decision nets needed to identify an input as the letter  $A$  would not be needed to identify the occurrence of a stimulus (cf. Fehrer & Raab, 1962) or the presence of a vertical (versus a horizontal) line.

Based on the data of Experiment XII, illustrated in Figure 12, the following statements can be made on the relation between peripheral processing time and central processing time: (a) when peripheral processing time < central processing time, the upper limit on masking is central processing time; (b) when peripheral processing time < central processing time, central processing time is constant and does not vary with peripheral processing time; and (c) when peripheral processing time > the constant central processing time identified in (b), the upper limit on masking is peripheral processing time.

The model rationalizes (a), (b), and (c) as follows: when peripheral processing time < central processing time (a condition which is met when  $I$  energy is "substantial" as in

the Region 4 to 64 milliseconds of Fig. 12) outputs from peripheral nets are run ahead of decisions by the central decision nets to a degree depending on the energy  $I$ . Thus for  $C_i$ ,  $O_{ij}$  is stored in  $S_i$  await the decision of the preceding stage,  $C_{i-1}$ . The decision process of  $C_i$  begins only when both  $O_{ij}$  and the decision of the preceding central net are available (see  $j$  and  $m$  above). Since the decision time for  $C_i$  is constant ( $n$  above), the decision of  $C_i$  is received  $C_{i+1}$  after a constant delay; therefore,  $C_i$  cannot benefit from the earlier arrival  $O_{(i+1)j}$ . In short, when peripheral processing time < central processing time, reducing peripheral processing time by increasing energy will not decrease central processing time; the constraint on central processing time is the time constants of the individual decision stages. Under these conditions, then, central processing time sets the upper limit on masking by Pattern Mask 3. However, decreasing  $I$  energy retards peripheral processing time to a point where, for (other than  $C_1$ ), the decision from  $C_{i-1}$  is received prior to  $O_{ij}$ . In this case, the  $C_i$  decision is delayed (see  $m$  above), and the constraint on central processing time would no longer be solely the time constants of the individual central nets but also the delay time for peripheral net outputs. In this instance the upper limit on backward masking by Pattern Mask 3 would be determined by peripheral processing time.

We may now reexamine the issue of peripheral and central backward masking. The term "peripheral" has emerged in the present context as a rubric for systems which extend from receptor surface to cortex and which underlie the extraction of properties of visual stimulation.

Given the principles above, the second and invariably stronger, stimulus in the present series of experiments would be processed by the peripheral systems more rapidly than the first. A situation, therefore, can exist in which a peripheral net is simultaneously occupied by two events presented in close succession. Under this condition of double occupancy, the output of peripheral net will depend on two things: whether both stimuli elicit terminal output

from the net in question and the order of time elapsing between the two stimuli.

Consider the case where the net gives a terminal response only to the target stimulus. Since the mask covers the same receptor surface as the target, the peripheral systems which will eventually output properties of the target will at some early stage be affected by the mask. An early stage in a peripheral system may be so occupied by a response to the masking event that there is no room left for a response to the first stimulus. Or the response at an early stage may be to the combination of the target and mask and thus the input to later stages of the peripheral net is distorted. The probability of perturbations of this sort occurring drops off sharply as the time elapsing between the two stimuli increases.

Both of the above means of affecting the peripheral net function are included in the condition in which the peripheral net can give a terminal response to either the target or the mask. However, since all stages of this peripheral net respond to the mask, the temporal range over which the mask may impair or occlude a terminal response to the target is extended. In brief, the greater energy mask may in this case "overtake" the target stimulus at any stage in the peripheral net.

The implication is that when masking is peripheral in origin, the upper limit on the critical interstimulus interval for a target of given energy is set by the slowest operating peripheral nets outputting data on the target. The extent to which this upper limit is realized depends on the extent to which the second stimulus, the mask, elicits terminal responses from the same set of peripheral nets. Therefore, we should expect the severity of peripheral masking to vary as a function of the relation between the target and mask. The earlier discussion on the differences between pattern mask, random noise, and a contourless light flash as masks is relevant to this point.

A purchase on masking of central origin may be gained by speculating on differences between masks which function only monoptically and masks which function either monoptically or dichoptically for a given set

of target stimuli. In the context of the present series of experiments, this reduces to speculating on the differences between random noise and pattern mask.

It may be argued that the identification of random noise for the most part is not based on outputs from the peripheral systems required for the identification of the target stimuli. Pursuing this further, it may be argued that if data on the target have been laid down in a subset of the central stores (S) most of these data cannot be replaced by data on random noise since data on random noise are entered into a relatively non-overlapping subset of S stores by virtue of the fact that different peripheral systems have extracted them. On this reasoning, random noise can impede the identification of the target only when it has the opportunity to affect the peripheral systems responding to properties of target. This impedance arises, as described above, by occluding outputs at early stages in a system, or by degrading outputs.

Consider random noise and the target presented dichoptically. In this situation random noise obviously cannot occupy the peripheral systems abstracting properties of the target. Thus at brief stimulus onset asynchronies what is represented in the set, S, of central stores are most of the properties of the target and most of the properties of random noise, represented respectively in relatively independent subsets of S. What is perceived are both target and random noise.

In some circumstances it is conceivable that properties of two successively presented stimuli may be represented simultaneously in relatively independent subsets of S, and yet confusion, that is, failure to identify the target stimulus, may occur. An example may be found in experiments using computer-generated dot stimuli, in which patterns are masked by nonoverlapping dynamic visual noise (Uttal, 1970, 1971b). The central decision process does not yield a distinction between the two dot stimuli; both are "perceived" and the masking results from failure to segregate the signal from the noise. A similar situation could also lead to fusion in which the two stimuli

are integrated to yield a single identifiable form (e.g., Eriksen & Collins, 1967). In either of these cases, however, the degree to which masking or fusion occurs is dependent on the time elapsing between the two stimuli and the extent to which data on the first have decayed, that is, the extent to which the central stores have returned to the null state.

In contrast to the argument on the identification of random noise, it may be argued that the identification of the pattern mask does rely on outputs from some peripheral systems in common with those underlying the identification of the target. Peripheral masking by pattern mask should occur for the reasons cited above, and we should expect such masking to extend over greater intervals than the corresponding masking by random noise. On the other hand, central masking by pattern mask arises from the fact that data on pattern mask can replace data on the target in the set of central stores. Assume that a complete peripheral description of the target is available in the central stores before the input of the pattern mask. The processing of the mask by the peripheral nets leads to a change in some of the stores,  $S_1, S_2 \dots S_n$ . The number of stores that change depends on the number of peripheral nets common to the processing of the target and the pattern mask. During the peripheral processing of the pattern mask, the central mechanisms have been making decisions on the nature of the target. At some point in the decision series, however, data on the mask will enter into the ongoing decision on the target. The point at which pattern mask data enter into this decision process is determined, in part, by how soon data on pattern mask replace data on the target in the set of central stores. If replacement occurs before the decision process has progressed very far, the central mechanisms may fail to architect any perception of the target whatsoever. In this circumstance the  $C_i$  decision may have specified a different branch in the subsequent stage,  $C_{i+1}$ , from that which would have been taken if mask data had not replaced the target data in  $S_i$ , or  $C_i$  may have reached a null decision. The

latter is unlikely if only low-level decisions had preceded  $C_i$ .

With increasing time before replacement the central decision may have proceeded to the point where substantial data on the target and the pattern mask are incorporated into the decision process. The result is composite perception, but one which does not allow for a segregation of the target from the pattern mask.

Quite obviously masking does not originate at the level of the central decision process described by the model when entries in  $S_1, S_2 \dots S_n$  are changed after completion of  $C_n$  or when entries in earlier stores, for example,  $S_3, S_4$ , are changed as the decision process is reaching the later stages, for example,  $C_{n-1}, C_n$ .

In the model, the peripheral nets and central decision nets have been described for a single item input to one retinal location. Simultaneous presentation of several items to several locations would be represented by a simple replication of the basic model. With several spatially separated objects or figures present at input, the peripheral-central net complexes serving the items, or complex to each, would yield a number of final outputs, one to each of the corresponding  $C_n$  decision nets. Thus peripheral central net complexes operate in parallel over the visual field.

The concurrent-contingent model as described is not so much a formal theory as is an example of a particular class of theories of visual masking. In its emphasis on stimulus-analyzing mechanisms, on selective interference with stimulus attributes, and on central decision mechanisms, it contrasts with theories of the integration and interruption type which view masking in terms of relatively global processes. Because the model is intended mainly to exemplify an approach, certain details have been left unspecified (for example, the identity of the peripheral nets' output, that is, the kind of features represented; the relation of the concept of central stores to the concept of icon memory; the form of the  $C_n$  net output; and the decision processes, if any, beyond  $C_n$ ). The issues involved in making explicit these aspects of the model will be taken up in



subsequent discussion. For the present, attention is directed to an examination of forward masking of peripheral and central origin.

#### EXPERIMENT XIV

Kolers (1968) proposed the clerk-customer analogy in response to the question: Why is greater interference exerted on the preceding rather than on the subsequent presentation, that is, why are masking effects primarily backward? However, Kolers' analogy as it stands does not rule out forward masking. When two customers enter a store the later arriving customer usually has to queue while the clerk takes care of the earlier customer. An implication of queueing is that central forward masking should occur. Yet, since queueing is not the same as receiving insufficient service, we should not expect, on the analogy, forward and backward masking to give rise to the same type of perceptual interference.

To pursue Kolers' reasoning a little further: "The phenomenon of backward masking itself identifies a 'formation time' and a perceptual 'refractory period' in the nervous system governing the construction of a perceptual representation [p. 38]." The lagging mask stimulus, therefore, disturbs that process identifying (constructing) the earlier target input. With the mask leading, this disturbance in the identification of the target is absent; at worst, the target is denied immediate access to the central process.

The concurrent and contingent model does provide for the occurrence of a mild, central forward masking effect of a somewhat different nature than that implied by queueing. If data on the mask have already been entered into the central stores, *S*, and data on an after-coming target are now entered, the target data will replace some, but not all, of the mask data. This is so because the mask tends to cover a slightly larger retinal area than the target, and, thus, while the two stimuli have some peripheral nets—and, therefore, central stores—in common, other nets, and their stores, are only responding to, and storing, data on the mask.

A situation may, therefore, exist in which the central stores contain data on both

stimuli. The decision process in this circumstance may yield a composite perception in which the target is inseparable from the mask. The probability of failing to identify the target in this circumstance, however, should extend over a relatively small range of delays between the two stimuli. On the concurrent and contingent model forward masking of central origin must, by necessity, be a rare event; the later arriving stimulus always overrides the earlier stimulus in the set of stores which they share. Thus, data sufficient for identifying the target are always available to the central decision process in central forward masking, which is not true of central backward masking. The model predicts peripheral forward masking on the assumption (*g*, in the description of the model) that processing a stimulus raises the threshold in the peripheral nets, thus suppressing subsequent lower-energy stimuli. Peripheral forward masking is to be expected even if central is not; a survey of the literature (Kahneman, 1968) shows substantial evidence for monoptic forward masking in contrast to the sparse evidence for dichoptic forward masking.

The present experiment compares forward and backward masking by Pattern Mask 3 under conditions of monoptic presentation. The procedure follows, *mutatis mutandis*, that of Experiment XII. The expected outcome was as follows: at brief durations of the target, masking should be severe for Pattern Mask 3 leading and lagging; at the longer durations, the lagging function should match the additive rule, the leading function should not, and only in the lagging case should the masking be pronounced.

#### Method

Four subjects, three naive and one experienced, participated in the experiment. The target material was the set of consonant trigrams. The luminances of target and Pattern Mask 3 were 2.5 footlamberts and the exposure duration of Pattern Mask 3 was 50 milliseconds. For these durations of the target—2, 3, 6, 8, 24, 40, and 56 milliseconds—the critical interstimulus interval was determined in the usual manner. Forward and backward critical interstimulus intervals were determined in succession at any particular target duration. Thus, Subjects 1 and 3 at each target duration were given the forward arrangement first,

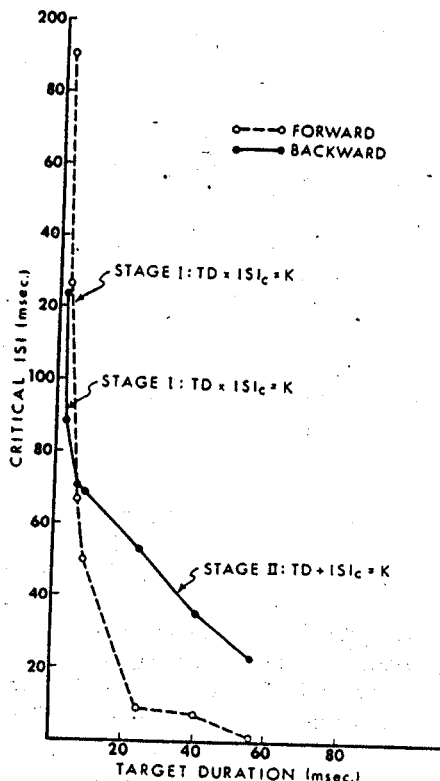


FIG. 15. Relation between target duration and the mean critical interstimulus interval for monoptic forward and backward masking by Pattern Mask 3 in Experiment XIV.

and Subjects 2 and 4 were given the backward arrangement first. The target durations were examined in the order shown. Stimuli were presented to the right eye.

### Results and Discussion

Graphic representation of the averaged data is given in Figure 15.

An important feature of Figure 15 is the resemblance that forward masking by Pattern Mask 3 bears to backward masking by random noise shown in Figure 12 of Experiment XII. The forward masking function, up to and including a target equal to 8 milliseconds, fits the multiplicative relation reasonably well. This suggests that Pattern Mask 3 forward masking was very much a peripheral event, a suggestion further advanced by the dissimilarity between backward and forward masking at the longer target durations. Here, the backward mask-

ing function was clearly of the central type with the appropriate description being, before, target duration + critical interstimulus interval = a constant. There is nothing in the forward masking function at the longer durations to suggest a similar central effect although there does appear to be some central forward masking. The fact that forward masking by Pattern Mask 3 still occurs at the target duration of 40 milliseconds well beyond the duration at which random noise became ineffective in Experiment XI means, perhaps, that a leading Pattern Mask 3 can exert some influence centrally.<sup>3</sup>

Another important feature of the data is the considerably greater critical interstimulus interval needed in the forward case at the brief target durations. If only the brief durations of the target had been investigated the conclusion would have been that monoptic forward masking by pattern was more severe than monoptic backward masking by pattern. Such a conclusion was reached by Smith and Schiller (1966), who used a target duration of 2 milliseconds. However, what is suggested by inspection of Figure 15, given the hypothesis that the multiplicative and additive rules identify, respectively, peripheral and central processes, is that whether forward masking is more severe than backward depends on whether the phenomenon is of peripheral or central origin. Indeed, it was abundantly clear to Smith and Schiller that although monoptic masking of a 2-millisecond stimulus was more severe when the mask led, dichoptic masking was more severe when the mask lagged.

Smith and Schiller (1966) concluded that "forward masking [by pattern] seems to be mainly a monoptic phenomenon [p. 196], a conclusion substantiated by Greenspoon and Eriksen (1968), who noted that dichoptic forward masking by pattern was quite weak. This conclusion, given the present data, can be stated more usefully: forward and backward masking can both occur peripherally, but only backward masking occurs to any appreciable degree centrally.

<sup>3</sup> Observation of dichoptic forward masking by Pattern Mask 3 confirmed this: forward masking occurred but over a much smaller range than backward masking.

Therefore, when two stimuli are in competition for the services of the central decision process, it is the later arriving one which is most completely identified. On the other hand, when two stimuli compete for the same peripheral nets, order of arrival is less important than energy. The stimulus of greater energy, whether it leads or lags, will be the one whose properties are likely to be output by peripheral nets.

### EXPERIMENT XV

The data of Experiment XIV suggested that a leading mask may be more disruptive peripherally than a lagging mask. The purpose of Experiment XV was to verify that this was the case, and for this reason the experiment used random noise as the masking stimulus instead of Pattern Mask 3. Also, the experiment looked at the possibility implied by Experiment XIV and the experiments of Kinsbourne and Warrington (1962b) that the same rule, target duration  $\times$  critical interstimulus interval = a constant, applies to both forward and backward masking by random noise. The idea that peripheral forward masking obeys the multiplicative rule is expressed in assumption *g* of the concurrent-contingent model.

#### Method

The duration of random noise was 50 milliseconds and its luminance was 2.5 footlamberts, equal to the luminance of the trigram target stimuli. The critical interstimulus interval was estimated for each of two experienced subjects in both forward and backward masking conditions at each of these target durations: 2, 4, 6, 8, 10, 12, 16, and 20 milliseconds. Stimulus presentation was to the right eye.

#### Results and Discussion

The relation between target duration and the critical interstimulus interval for both forward and backward masking is illustrated in the log-log plot of Figure 16. The log-log plot facilitates comparison with Figure 3 of Kinsbourne and Warrington (1962b). Both figures demonstrate that the forward and backward masking curves relating target duration to the critical interstimulus interval are of identical slope and that the relation target duration  $\times$  critical interstimulus interval = a constant holds whether random

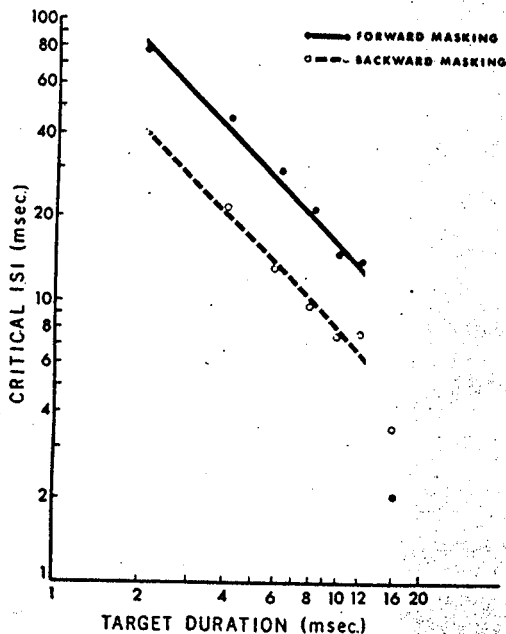


FIG. 16. Log-log relation between target duration and the mean critical interstimulus interval for monoptic forward and backward masking by random noise in Experiment XV.

noise leads or lags. Furthermore, the absolute value of the critical interstimulus interval is greater at any given duration of the target when random noise leads. In the present experiment the ratio of the critical interstimulus interval in forward masking to that in backward masking at any target duration was approximately 2:1.

The inference to be made, therefore, is that the temporal range of forward masking of peripheral origin is greater than that of backward masking of the same origin. A difference in this direction between forward and backward masking has been demonstrated several times by Schiller and his associates (Schiller, 1966; Schiller & Smith, 1965; Smith & Schiller, 1966) and others (e.g., Kietzman, Boyle, & Lindsley, 1971; Sperling, 1960b, 1965). What the data of Experiments XIV and XV do is to point to the transmission line as the locus of this difference.

### EXPERIMENT XVI

Although some authors (e.g., Eriksen & Lappin, 1964) have argued that both for-

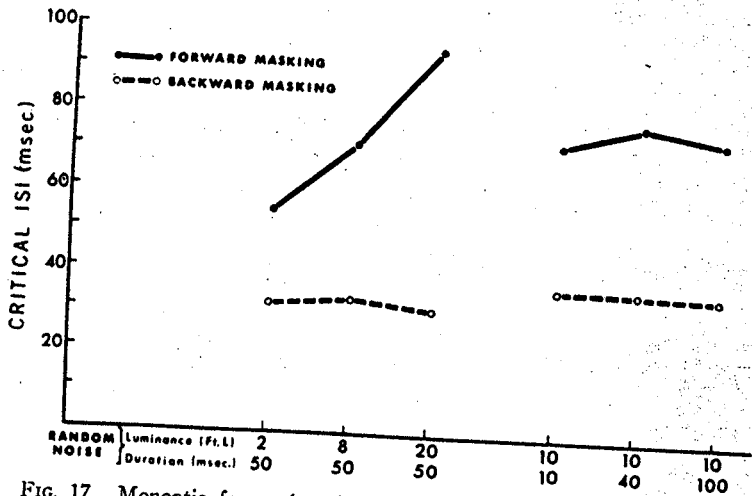


FIG. 17. Monoptic forward and backward masking by random noise as a function of random noise intensity (left panel) and random noise duration (right panel) in Experiment XVI.

ward and backward masking reflect a single underlying process, the data of the preceding experiments and others (e.g., Kinsbourne & Warrington, 1962b; Schiller & Smith, 1965; Smith & Schiller, 1966) suggest the contrary. The present communication has argued, and demonstrated, that backward and forward masking of central origin are fundamentally different processes, and that central forward masking is rather modest at best. At the peripheral level, there is some support for the notion of a common process. Both forward and backward masking occur substantially and they seemingly obey the same rule but they do differ; forward masking as we have seen is more pronounced.

Experiment XVI looks for further evidence of dissimilarity between forward and backward masking of peripheral origin. The point has been made above that masking originating in the transmission line requires that the mask stimulus be of greater energy than the target stimulus. Yet, as was determined in Experiments I and III on backward masking by random noise, once this criterion was met, further increase in mask duration with luminance held constant did not amplify the masking effect, that is, the critical interstimulus interval was unchanged. The present experiment compares forward and backward masking by random noise as

a function of mask intensity and mask duration to determine whether the two mask arrangements are differentially affected by these variables. There is some research (Schiller (1966) which has pointed to greater sensitivity of forward masking mask intensity.

#### Method

The target stimuli, the trigram set, always appeared at the same level of illumination, 2 foot lamberts, and the same exposure duration, 5 milliseconds. In one condition the mask stimulus, random noise, was always presented at the same exposure duration of 50 milliseconds, but its level of illumination was 2, 8, or 20 foot lamberts. In the other condition random noise was always present at the same level of illumination, 10 foot lambert but its exposure duration was 10, 40, or 100 milliseconds. Thus, in both conditions the target random noise energy ratios were the same. For subjects, two of whom had served in a previous experiment, were given both conditions in a partially counterbalanced design. The usual procedure was used for estimating the critical interstimulus interval, and presentation of stimuli was monocular to the right eye.

#### Results and Discussion

The critical interstimulus intervals averaged across the four subjects for forward and backward masking by random noise in each condition are shown in Figure 17.

Since each duration had not been paired with each intensity, a single Treatment X

Treatment  $\times$  Subjects analysis of variance could not be performed on the present data. Instead, a separate Treatment  $\times$  Subjects analysis was conducted, in turn, on the intensity-varying and duration-varying conditions. These analyses revealed that for both conditions, the difference between forward and backward masking was highly significant: for the intensity condition,  $F = 130.66$ ,  $df = 1/3$ ,  $p < .001$ , and for the duration condition,  $F = 44.23$ ,  $df = 1/3$ ,  $p < .001$ . The effect of random noise luminance on the critical interstimulus interval was significant,  $F = 19.19$ ,  $df = 2/2$ ,  $p < .05$ . However, the significant interaction between stimulus order (forward or backward masking) and intensity,  $F = 7.66$ ,  $df = 2/6$ ,  $p < .05$ , coupled with inspection of the left panel of Figure 17, suggests that only forward masking was affected by intensity. The duration-varying condition revealed no significant effect of duration ( $F < 1$ ) on either forward or backward masking.

In sum, the critical interstimulus interval in backward masking was invariant with respect to increase in random noise intensity or random noise duration. On the other hand, the critical interstimulus interval in forward masking varied directly with increase in random noise intensity, but like the critical interstimulus interval in backward masking, it was unaffected by increases in random noise duration.

The data are in complete agreement with those of Schiller (1966) and Kinsbourne and Warrington (1962b, Experiment I.). Schiller showed that once mask energy was greater than target energy, increases in mask intensity were not accompanied by increases in interference in backward masking but were accompanied by increases in interference in forward masking. Kinsbourne and Warrington observed that given a mask of energy greater than target energy, increases in mask duration with luminance held constant did not extend the temporal range over which forward masking was obtained.

## EXPERIMENT XVII

Forward masking of central origin is slight. The interpretation proposed above

for the small effect generally found (e.g., Greenspoon & Eriksen, 1968; Smith & Schiller, 1966; and see also Experiment XIV) was that for a fairly limited range of delays between the two stimuli, mask data and target data are treated as a composite by the central decision process, resulting in a failure to detect and identify the target. Another view of central forward interference is suggested by Kolers' clerk-customer analogy. The idea is that a later arriving event may have to queue to gain access to a central decision process. On the perspective of the concurrent-contingent model, queueing might be interpreted as a delay in the replacement time in the set of central stores; for example, replacing mask data by target data takes longer than replacing the null state by target data. At all events, the forward interference implied by queueing would be manifest more as a delay in perception than as an impairment in perception, such as failure to identify.

The paradigm developed to examine this possibility had the following form. To one eye is presented a pair of contoured stimuli,  $t_1$  and  $t_2$ , the second lagging the first by  $x$  milliseconds, where  $x$  is greater than the peripheral processing time of  $t_1$ . To the other eye is presented a patterned mask,  $m$ , which follows  $t_2$  after a delay of  $y$  milliseconds. The delay of  $y$  milliseconds is just sufficient for  $t_2$  in the absence of  $t_1$  to evade the dichoptic masking action of  $m$ . Thus, when  $t_1$  and  $t_2$  are presented alone,  $t_2$  is readily identified. When  $t_2$  and  $m$  are presented alone,  $t_2$  is again readily identified.

Now, if  $t_1$  does in fact retard the entry of  $t_2$  into the central decision process, then when  $t_1$  precedes  $t_2$ , and  $t_2$  is followed by  $m$  after  $y$  milliseconds, failure of  $t_2$  to gain immediate access to that process should make it susceptible to masking by  $m$ .

Experiment XVII was conducted as a demonstration of queueing rather than as a formal experiment. The stimuli chosen were as follows. The first stimulus,  $t_1$ , was the letter U located centrally;  $t_2$  was two H's located on a slide such that if superimposed on the  $t_1$  slide, they flanked the U. The separation between the arms of the U and the inner vertical components of the left and

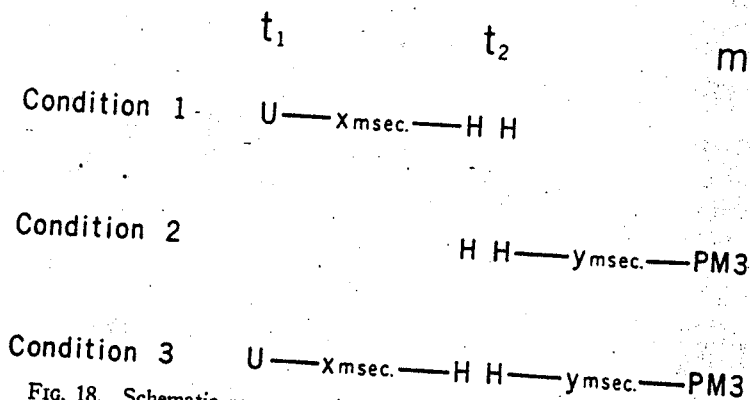


Fig. 18. Schematic representation of conditions in Experiment XVII.

right H's was  $.18^\circ$ . The  $m$  stimulus was Pattern Mask 3. The first and third line-configuration of Pattern Mask 3 overlapped the two H's and the middle line-configuration overlapped the U, if superimposed.

The three conditions described above and depicted in Figure 18 were examined. Three naive and one experienced subjects participated. First, for each subject an interstimulus interval was determined between  $t_1$  and  $t_2$  which yielded a fairly good and consistent metacontrast effect, that is, the subject reported either that he failed to see U (only one subject reported such a failure) or that the U was of "ghost-like" character and apparent movement was strongly present. For three subjects this interstimulus interval value was approximately 100 milliseconds; for the remaining subject it was 80 milliseconds. Second, the minimal interstimulus interval between  $t_2$  and  $m$  at which  $t_2$  could always be seen and identified was determined for each subject. This value,  $y$ , varied between 50 and 70 milliseconds across the four subjects. Third, the three stimuli were presented in succession at the determined  $x$  and  $y$  values. Throughout,  $t_1$  and  $t_2$  and  $m$  were all exposed at 10 milliseconds and 8 footlamberts. The right eye received  $t_1$  and  $t_2$ , and the left eye received  $m$ .

### Results and Discussion

The results of this demonstration were as follows. For each subject in Condition 3, U was clearly seen with Pattern Mask 3 as background, and the pair of H's was not. Switching back and forth between Condi-

tions 2 and 3, that is, simply turning U on and off, revealed that whereas the pair of H's followed by Pattern Mask 3 were clearly seen in the absence of U, they were not seen in its presence.<sup>9</sup> And, of course, the fact that U was more identifiable in Condition 3 than in Condition 1 is further evidence of the effect observed in Experiment IV, which is that an after-coming mask (Pattern Mask 3) may reduce or eliminate the interfering effect of a preceding mask (the pair of H's) on the perception of an earlier-presented target (in this case, U). The present experiment stands in contrast to Experiment IV in that here the "disinhibiting" effect is purely of central origin.

Three further experiments/demonstrations were conducted with the same subjects. One showed that the queuing effect could be obtained with an overlapping U and H centrally located in their fields and with the pattern mask as the third stimulus. These  $x$  and  $y$  values were not identical to those of the main experiment. For expository purposes, these stimuli did not provide as good a demonstration as those described above. This experiment showed, however, that metacontrast conditions were not essential to the demonstration of queuing.

A second experiment showed that the queuing effect, that is, the effect of  $t_1$  upon

<sup>9</sup> In retrospect, the phenomenon under discussion here is the same as that reported by Uttal (1969) in what he has called "the character in the hole experiment." The "hole" is the temporal interval elapsing between the first and third stimulus into which the second stimulus, the character, is inserted.

the susceptibility of  $t_2$  to  $m$ , could be obtained just as well when U was presented to one eye and the flanking H's and Pattern Mask 3 were presented, at the same  $x$  and  $y$  values as before, to the other. This rules out the notion that U retards the processing of the H's by lowering the sensitivity of peripheral nets, a possible interpretation of the queueing effect described in the main experiment.

A third and final experiment provided further corroboration of the queueing hypothesis. A prediction from this hypothesis is that in Condition 3 the likelihood of  $m$  masking  $t_2$  at an interstimulus interval equal to  $y$  milliseconds should decrease with increases in  $x$ . This prediction was demonstrated for all four subjects by holding  $y$  constant and increasing the value of  $x$ . What was surprising, however, was that for the four subjects the value of  $x$  at which the flanking Hs became visible was fairly substantial, of the order of 200 + milliseconds. This implies that the locus of queueing was probably beyond the level of the central stores. If replacement time were of this order of magnitude, it would be difficult to account for most central backward masking.

### EXPERIMENT XVIII

A shorthand account of the preceding research is that when two successive stimuli compete for the services of peripheral systems, the greater energy event wins; on the other hand, when two stimuli compete for the services of the central decision process, the victor is likely to be the one that arrives second.

Consider a target stimulus of relatively low energy, so that its peripheral processing time is longer than its duration. A mask event which follows immediately on the same eye will occupy the same peripheral nets as the target. Whether the peripheral nets output data on the target or not is very much dependent on whether the target stimulus has more or less energy than the mask. If the target stimulus has the greater energy, then the peripheral nets will, in the main, output data on the target. On the other hand, if the mask has the greater energy,

then what is represented in the set, S, of central stores is primarily data on the mask.

Let us now look at the case in which target energy is greater than mask energy and the mask is Pattern Mask 3. The temporal variable is stimulus onset asynchrony. At brief stimulus onset asynchronies the target and Pattern Mask 3 will occupy common peripheral nets but since the target is of greater energy, target data, rather than mask data, will be output, that is, Pattern Mask 3 will fail to mask the target. At longer stimulus onset asynchronies, however, peripheral processing of the target is close to completion, or is in fact completed, prior to Pattern Mask 3 onset. As a consequence, the central decision process now receives in succession two sets of data. The central decision process is not affected by stimulus energy, and therefore, the energy superiority of the target over Pattern Mask 3 is no longer relevant; what does matter is which data set arrives second. In this circumstance, Pattern Mask 3 can now successfully mask the target. In short, for the condition in which target energy > Pattern Mask 3 energy, masking should vary nonmonotonically with stimulus onset asynchrony and a U-shaped function should be obtained.

Quite to the contrary is the case in which target energy < Pattern Mask 3 energy. At brief stimulus onset asynchrony, Pattern Mask 3 masks the target because of its energy superiority. At longer stimulus onset asynchronies, Pattern Mask 3 masks the target not because of the energy difference, but because data on Pattern Mask 3 replace, or are interwoven with, data on the target in the central stores, thus distorting the central decision process. Hence, when the target energy < Pattern Mask 3 energy, masking should be a monotonic function of stimulus onset asynchrony. Experiment XVIII tests these predictions.

#### Method

There were two conditions with four naive subjects receiving both. In one condition, the luminance of the target stimuli, the set of trigrams, was twice that of Pattern Mask 3 (Condition 2:1); in the other, the luminance of the target was half that of Pattern Mask 3 (Condition 1:2). The luminance values were 5 footlamberts:2.5 foot-

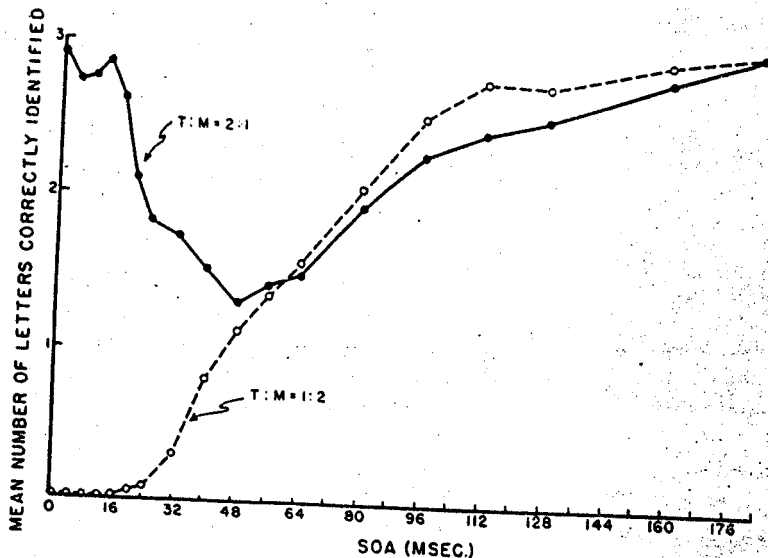


FIG. 19. Relation between stimulus onset asynchrony and mean number of correct identifications for monoptic masking under two target-Pattern Mask 3 energy ratios in Experiment XVIII.

lamberts and 2.5 footlamberts:5 footlamberts, respectively, and both the target and Pattern Mask 3 were exposed for 10 milliseconds.

At each of eighteen stimulus onset asynchronies ranging from 0 to 184 milliseconds, all four subjects in both conditions viewed twenty trigrams followed by Pattern Mask 3, with a different set of twenty trigrams given at each stimulus onset asynchrony. The number of consonants correctly identified was recorded for each trigram presentation. All stimuli were presented monocularly to the right eye.

### Results and Discussion

The mean number of letters correctly identified (without respect to position in the trigram) at each stimulus onset asynchrony value is shown in Figure 19. The expected nonmonotonic and monotonic functions were obtained.

With very few exceptions, U-shaped masking functions have been observed only under conditions of metacontrast, that is, conditions in which the contours of the mask do not overlap spatially with those of the target stimulus. Thus, a common sentiment has been that U-shaped functions are unique to metacontrast paradigms (e.g., Bridgeman, 1971) and that metacontrast is therefore a very special type of visual masking. Although the present data do not necessarily

refute the latter view, they do show that U-shaped functions can be obtained with target and mask overlapping, an observation buttressed by recent experiments of Purcell and Stewart (1970) and Weisstein (1971).

The interpretation proposed for the U-shaped function of the present experiment is that it resulted from the differential effect of stimulus energy on peripheral and central processes, coupled with the privileged nature of a stimulus arriving centrally as the second of a pair. It is quite unlikely however that peripheral-central differences are similarly responsible for the U-shaped metacontrast functions obtained monoptically. Several sources of evidence strongly imply that these functions are purely of central origin. In the first place, an important requirement for the nonmonotonic, metacontrast effect is that the subject uses a high criterion to determine his response (see Kahneman, 1967b, 1968; Schiller, 1969) which may be interpreted to mean that fairly complex, central processes underlie the effect. Second, Schiller's (1969) microelectrode recordings from the lateral geniculate nucleus of the cat show that there is no physiological evidence of response depression in metacontrast-like stimulus conditions. Depression or suppres-



sion in neural response (Fehmi, Adkins, & Lindsley, 1969; Schiller, 1969) or in evoked potential (Donchin, Wickes, & Lindsley, 1963) are usually found only in situations in which the two stimuli overlap in receptive fields.<sup>10</sup> Third, U-shaped metacontrast functions can be obtained dichoptically (e.g., Kolers, 1962; Kolers & Rosner, 1960; Weistein & Growney, 1969). Fourth, there is some evidence which implies that metacontrast effects are not only central but indeed arise at a very late phase of the central decision or construction process. Werner (1935) showed that metacontrast effects rapidly diminish when the similarity between the contours of the two stimuli decrease. More recent evidence suggests that the effect is most pronounced when the two stimuli, such as a form as target and two flanking forms as mask, are identical (Parlee, 1969; Uttal, 1970). The implication is that metacontrast masking may depend in some circumstances on the achievement of a central state approximating the identification of the form and not simply upon an interaction between contour-forming processes (see Uttal, 1970, 1971a).

It is hypothesized that the U-shaped metacontrast effect is due, in part, to decision processes beyond the level of the concurrent-contingent model described above. What the model needs, perhaps, is the notion that decisions on proximate objects in the visual field enter into the decision process on a particular object, with this convergence occurring at a relatively late stage, at least beyond the point at which the property data from the relevant subset of central stores has been used. Moreover, this relatively late stage might be one in which the decisions make contact with the structures of long-

<sup>10</sup> Recent experiments on visual evoked-potential correlates of sequential blanking by Andreassi, Mayzner, Beyda, and Davidovics (1971) are relevant both to this point and to the general thesis of the present paper. In conditions where all the stimuli are of equal intensity, subjects, while not perceiving and recognizing blanked stimuli, do give a visual evoked potential to blanked stimuli. On the other hand, when the blanking stimuli are of greater intensity than the blanked stimuli, both perceptual and evoked-potential suppression occur.

term storage to achieve identification of the form in question.<sup>11</sup>

### EXPERIMENT XIX

Basically, Experiment XVIII showed that a stimulus which may escape monoptic masking at some relatively brief delay of mask may suffer masking at a longer delay. This result, besides implicating the interplay between peripheral and central processes in determining the shape of some masking functions, suggests caution in assigning an upper temporal limit to the masking effect of a particular pattern on a given target form. This point is put into relief by considering the data of Experiment IX given in Table 4. There it can be seen that the monoptic critical target duration for various durations of Pattern Mask 3 was relatively brief in comparison to the dichoptic critical target duration for the same Pattern Mask 3 values. An interpretation of this result might say that the minimal duration of the target at which a particular duration of Pattern Mask 3 (at an interstimulus interval of 0 milliseconds) failed to mask monoptically defines the upper boundary on the monoptic influence of that Pattern Mask 3 on the perception of the target.

The hindsight afforded by subsequent experiments, and in particular Experiment XVIII, says that this minimal duration of the target at which criterion performance has been attained does not define an upper limit for monoptic masking. Rather it simply reflects the basic peripheral rule, which is that when two stimuli occupy com-

<sup>11</sup> A number of geometric illusions, for example, the Ebbinghaus and Ponzo illusions, are not too dissimilar from metacontrast. In both metacontrast and the illusions, a distortion in the perception of one element is induced by surrounding, or flanking, elements. Schiller and Weiner (1962) have shown with brief, dichoptic presentation of the test and inducing elements that these illusions are of central origin. This, of course, questions the notion that these illusions arise from recurrent lateral-inhibitory processes in the retina; other lines of evidence question any form of lateral-inhibition explanation (see Coren, 1970). An alternative view is that these illusions occur because the visual system is misled into entertaining incorrect hypotheses about the test element (cf. Gregory, 1970). Presumably these hypotheses would be generated at a relatively late stage in the central decision process.

TABLE 8  
EXPERIMENT XIX: MEAN NUMBER OF LETTERS REPORTED AS A  
FUNCTION OF INTERSTIMULUS INTERVAL

Ss	Critical target duration (in msec.)	ISI (in msec.)									
		0	10	20	30	40	50	60	70	80	90
S 1	16	3.0	2.4	2.8	1.8	1.8	1.0	2.0	2.6	2.6	3.0
S 2	12	3.0	2.6	2.6	2.4	3.0	2.8	2.6	3.0	3.0	3.0
S 3	14	3.0	2.6	2.2	1.4	1.8	2.4	2.6	2.2	2.6	3.0
S 4	16	3.0	2.6	1.6	2.0	2.2	3.0	2.8	3.0	2.8	3.0

Note. ISI = interstimulus interval.

mon peripheral nets, the more energetic one is favored. Presumably if the target stimuli were presented for this duration and an interstimulus interval were introduced between the target and mask, as the interstimulus interval increased, identification accuracy should first decrease and then increase, gradually returning to the original criterion level. The reason for this see-saw effect would be the transition from masking originating peripherally to masking originating centrally as witnessed in Experiment XVIII.

Experiment XIX was conducted to verify these assertions. The procedure used was essentially that of Experiment IX grafted onto that of Experiment XVIII.

#### Method

Critical target duration was first determined for each of four naive subjects with the set of trigrams at 2.5 footlamberts followed at an interstimulus interval of 0 milliseconds by a Pattern Mask 3 of 10 milliseconds  $\times$  2.5 footlamberts. The usual criterion of four correct in succession was used. When this critical target duration had been determined, 10 interstimulus intervals were introduced between the target and Pattern Mask 3 in 10-millisecond steps from 0 to 90 milliseconds, with the target duration held constant at this critical value. At each interstimulus interval, the subject was presented with five different trigrams, and the number of letters correctly identified at each was recorded. Stimuli were presented to the right eye.

#### Results and Discussion

Each subject's critical target duration and the mean number of letters correctly reported at each interstimulus interval are given in Table 8. Inspection of Table 8 shows that mean identification performance declined from a maximum of three letters to approxi-

mately two letters at an intermediate interstimulus interval and then recovered to the original level. The interstimulus interval means were cast into a repeated-measures analysis which showed a significant difference in identification performance as a function of interstimulus interval,  $F = 4.75$ ,  $df = 9/27$ ,  $p < .001$ . In short, identification accuracy varied nonmonotonically with interstimulus interval, and critical target duration was obviously not the upper limit on monoptic masking by Pattern Mask 3.

#### CONCLUDING DISCUSSION

The theoretical persuasion of this paper has been a view of perception as a temporal sequence of events involving stages of storage and transformation (Posner, 1969). Accordingly, the broad conclusions from the preceding research and speculations on these conclusions are drawn within the general context of the information-processing approach described at the outset. Figure 1 will serve as a useful reference.

Visual pattern recognition at some point involves contact between a representation of the visual input and long-term storage. On current theorizing, the contact between input and memory may be described as a feature match or, alternatively, as an analysis-by-synthesis operation (MacKay, 1967; Neisser, 1967). In either case the question "What (kind of) object is this?" is answered by first extracting certain properties or features, which in turn raises the question "What kinds of features are suitable?"

It is quite unlikely that an inventory of straight lines, curved lines, verticals, horizontals, diagonals, edges, colors, etc., present

in the retinal input could provide a sufficient data set for stimulus identification.<sup>12</sup> Rather, what would seem to be essential for recognizing a visual object or figure is the existence at some neural level of a description of the input which embodies, but does not necessarily list, all the potential relations between the parts of the object. We must suppose that knowledge of what kind of object or figure something is relies very heavily on "features," which exist only as relations among the parts. In short, the prerequisite for answering the question "What object is this?" is a global representation of the input, since it is only in the context of the whole that certain "features" can be specified and that things such as lines and curves are useful to pattern recognition devices. As Neisser (1967) observed: "In terms of information processing the whole is prior to its parts [p. 91]."

Yet, paradoxically, it has to be argued on the basis of the single-cell recordings of Hubel and Wiesel (1959, 1962, 1965) that any wholistic representation must be derived originally from an inventory of features much like that described above. We may have to distinguish between two kinds of "features": those *detected* by feature-detecting systems and used to reconstitute the global character of the input and those *abstracted* from the global representation and used to recognize it. Let us call features of the first kind context independent and features of the second kind context dependent.

In light of the foregoing, the outputs of peripheral nets in the concurrent-contingent model, that is, the content of the model's set of central stores, can be viewed in either one of two ways: either the content of the stores is a list of context-independent features or it is a wholistic representation from which relational properties can be abstracted.

Let us suppose that the data in the set of central stores are context-independent

<sup>12</sup> Recently several authors have argued quite vigorously against the claim that feature-detectors can account for how things are recognized or why things should look as they do (Pribram, 1971; Rock, 1970; Uttal, Bunnell, & Corwin, 1970). Others have been less vigorous, but equally poignant (Gregory, 1970; Neisser, 1967).

features. The central decision process in the concurrent-contingent model must be, therefore, at least in part, a series of operations by which a wholistic representation of the visual input is assembled, or "reconstructed." Thus, paraphrasing Neisser, preliminary decisions emphasize the global rather than the particular in the figure they construct. Assuming, therefore, two fairly broad stages in pattern recognition (Neisser, 1967), the central decision process must first establish figural unity—which is Neisser's term for wholistic representation—and then make decisions on the nature of this segregated object. The first stage works with the data set provided by the peripheral nets; the second stage, with the figural unit afforded by the first. Thus in Figure 14 which illustrates the concurrent-contingent model, the figural unit is represented by the output of  $C_n$ ; decision nets beyond  $C_n$  are needed for the further elaboration and classification of the stimulus.

If, on the other hand, we suppose that figural unity is represented at the level of the central stores, then the central decisions,  $C_1$  to  $C_n$ , illustrated in Figure 14 are those which determine the proper classification of the stimulus by means of context-dependent features abstracted from the wholistic representation. On this view, however, it would be difficult to account for the relation between peripheral processing time and central processing time described earlier. As was noted, in conditions of relatively low target energy, the upper limit on masking (by a pattern mask, Pattern Mask 3) can be set by peripheral processing time, which implies that, to some extent, the peripheral and central processes overlap in time. If central decisions beyond figural unity are decisions which make use of properties abstracted from, and therefore determined by, the context of the whole, then it is impossible on this view of peripheral net output for peripheral and central processes to occur concurrently. The latter must await the completion of the former. Thus, of the two views, the one which more easily accommodates the data is that which describes the total output of peripheral nets as a list of context-independent features from which the

object form is reconstructed. We may now address the question of whether the postulated set of central stores in the concurrent-contingent model and the concept of iconic storage (Neisser, 1967) are identical.

In the main, the characteristics of iconic, or brief, visual storage have been isolated via the delayed partial-sampling procedure of Sperling (1960a) and Averbach and Coriell (1961). Essentially, this procedure involves presenting simultaneously an overload of items, usually letters or digits, in a brief tachistoscopic exposure, which is followed by an indicator designating which element or subset of elements the subject has to report. If the indicator is given soon enough after the stimulus, the subject can report proportionately more with partial report than if asked for a report of the whole stimulus. This superiority permits the inference of a large capacity store; the sharp decline in partial-report superiority with indicator delay permits the inference of rapid decay. Estimates of the decay time of iconic storage vary from 250 milliseconds to several seconds after the end of the stimulus (Averbach & Coriell, 1961; Averbach & Sperling, 1961; Keele & Chase, 1967).

It is proposed that iconic storage is literal, or precategorical (Broadbent, 1971; Neisser, 1967), a proposition supported, in part, by the kinds of selection criteria which yield efficient performance in the delayed partial-sampling task. Generally superior partial report can be demonstrated when the selection criterion is brightness (von Wright, 1968), size (von Wright, 1968, 1970), color (Clark, 1969; Turvey, 1972; von Wright, 1968, 1970), shape (Turvey & Kravetz, 1970), or location (e.g., Sperling, 1969a). Partial report performance, however, is notably poorer when the letter-digit distinction is the basis for selection (Sperling, 1960; von Wright, 1970). These data demonstrate that we are able to select or ignore items in iconic storage on the basis of their general physical characteristics. We cannot, however, with the same efficiency select or ignore items on the basis of their derived properties. In terms of the distinctions recently made by Broadbent (1971), we can select efficiently on the basis of stimu-

lus set, but not on the basis of response set. All this speaks to the precategorical nature of iconic storage.

Several other lines of evidence point to a difference between iconic storage and the immediately subsequent store for categorized data, generally referred to as short-term storage or primary memory (Atkinson & Shiffrin, 1968; Broadbent, 1971). Wickelgren and Whitman (1970) have argued that unlike short-term storage, iconic memory is nonassociative. Memory for the position of the elements is by an ordered two-dimensional array of locations, not by associations between the representatives of the elements. This conclusion is buttressed by Rudov's (1966) close examination of error production in the iconic memory task. Several studies (Glucksburg & Balagura, 1965; Standing & DaPolito, 1968; Turvey, 1967) have indicated that iconic memory is not affected by repetition although repetition does significantly influence the memory of material at the level of short-term or primary storage (Hebb, 1961; Melton, 1963). In addition, experiments by Turvey (1966) and Doost and Turvey (1971) suggest that iconic storage does not require central processing capacity for its maintenance, in contrast to short-term storage which does rely on the availability of central attentive processes (see Broadbent, 1971; Posner, 1966).

There are two interpretations of the experiments which show efficient partial report under stimulus set instructions. One is that the properties of the stimulus on which stimulus set selection is based are present in the iconic store; the other is that they are not present but they can be rapidly ascertained, more rapidly, that is, than the properties which allow for a response-set selection, say, between letters and digits. Take as an example selection on the basis of size or shape. On the first view these global properties of the stimulus would be "known" at the level of iconic storage; on the second they would not. On the second view these global characteristics of the stimulus would have to be derived from a data set consisting, presumably, of context-independent features.

In theory, the content of iconic storage

could be either a description of a visual object or objects, suitable for subsequent operations of pattern recognition, or a conglomerate of "crude," context-independent features which requires some further operations before it is rendered into a form suitable for classification. On the basis of perceptual reports of subjects in the delayed partial-sampling paradigm, the second of the two views of iconic content seems unlikely. Generally, subjects' descriptions imply that they see far more items than they can report (e.g., Sperling, 1960a), and indeed, they may know how many items were presented although they may not know what the items were (see Eriksen & Rohrbaugh, 1970). In other words, at the level of visual information processing isolated by the delayed partial-sampling paradigm, something is known about the gross form of the input, and it is the persistence of this knowledge which has been called iconic memory.

The description of what is known at the level of iconic storage, provided in the main by selection criteria which yield efficient partial report and by the perceptual reports of subjects, contrasts with the data set postulated for the central stores in the concurrent-contingent model. The argument made was that the outputs of peripheral nets are context-independent features and that it is via means of a central decision process that the visual object is "assembled" and identification of that object eventually achieved. Perceptual reports of the subjects, in those situations of the present series of experiments in which masking was described by the additive rule, shifted with increasing interstimulus interval from reporting little or no evidence of the presence of the target letter to an intermediary state of noting its presence, and finally to reporting not only that it was present but that its form was clear and that the problem was to identify it before it was replaced by pattern mask (cf. Haber & Standing, 1968; Liss, 1968). In other words, the perceptual report which defines the iconic memory experience, that of an image in which the global characteristics are clearly defined, emerges at a relatively late stage in the process embraced by the additive rule. The conclusion we would like to draw

from this is that iconic storage and the central set of stores on peripheral nets output are not identical. Iconic storage for a single item is perhaps better viewed as a storage of a decision *on* peripheral data as opposed to a storage *of* peripheral data. The decision represented at the level of iconic storage is an intermediary decision relating to the global properties of the stimulus object; the final category state (Broadbent, 1971) has not yet been achieved at this point in the flow of visual information. For example, what is stored for an input to a certain region of the visual field is the decision that the input in this region has this size, this brightness, this color, this general shape, etc., but whether the input was the letter F or one's loved one is not yet known. Thus, in the central decision process, iconic storage represents an interface between decisions based on context-independent features and decisions based on context-dependent features.

Given the foregoing, the "read in" to and "read out" from, iconic storage may be described briefly as follows. First, a set of operationally parallel, peripheral visual systems which have the retina as starting point and the cortex as end point, signal fundamental, but context-independent, properties of the stimulus at a rate which varies directly with the energy of the stimulus up to some limiting energy value. These properties are entered asynchronously into a set of central stores by virtue of the different processing rates of the different systems. In parallel with the peripheral signaling of properties, central decisions about the stimulus based on these properties are being made. At some point, and here we can talk only vaguely, a decision is reached which corresponds to a convenient description of the stimulus from the vantage point of the subsequent categorization process (Broadbent, 1971; Neisser, 1967). This decision state can persist for a relatively prolonged period, probably because the decisions which now occur (in read-out) are based on relational features which have to be abstracted (and abstracting the "right" features may on occasion require several attempts), and probably because these subsequent decisions tax the limited

capacity of the information-processing mechanisms and thus, in the face of concurrent demands, cannot always be conducted as efficiently, and as swiftly, as is ideally possible. This decision state is iconic storage, and we may conjecture that when peripheral processing time < central processing time, the read-in to iconic storage is relatively constant for varying energy values of the stimulus.

It will be recalled that this paper began with the adoption of a particular view on two theories of masking—the integration and interruption theories. This view proposed that integration localized masking by pattern in the read-in to iconic storage and interruption placed the effect of a patterned mask on read-out; moreover, in the visual information-processing framework, both theories could, indeed, be true. An extension of this view, implicit in the general discussion of Experiments I-IX, was that “integration” described masking originating peripherally while “interruption” was a more appropriate description of central masking. These notions, especially the peripheral-central one, served to guide the design and interpretation of many of the experiments reported. However, we must now emphasize what is already manifestly apparent in the reported data and the description of the concurrent-contingent model and that is that neither integration, nor interruption, nor both theories combined can substantially accommodate the phenomena of masking. The point to be made is, perhaps, an obvious one: there are many ways in which one stimulus may impair the perception of another.

But let us pursue for a moment, in the context of the concurrent-contingent model, the general approach of pinpointing the masking effects of a pattern prior to, and subsequent to, the attainment of the iconic representation. The read-in to iconic storage consists of a number of operations which may be affected in several ways by an after-coming event. Outputs from early stages of peripheral nets may be occluded and/or terminal outputs may be distorted. Data on both stimuli may exist in the set of central stores leading to an iconic state which would, in effect, be a mixture of both. Or

data on the leading stimulus in the central stores may be replaced almost entirely, and immediately, by data on the following stimulus so that no iconic representation of the first is achieved.

A preceding mask can similarly influence the read-in by temporarily prohibiting peripheral net outputs or by mixing with the target stimulus data in the central stores, thus giving rise to a blemished iconic representation of the target. The temporal range over which impairment of the latter kind can occur is limited by virtue of the fact that data on a later arriving stimulus event will always replace data on an earlier event in any central stores that the two have in common. Quite obviously, in this perspective the effect of a leading or lagging patterned mask on read-in to iconic storage could not be classified exclusively as either integration or interruption or as any simple combination of the two.

The position taken in this final section is that the decision nets illustrated in Figure 14 represent the process by which the iconic, or wholistic, representation is established. Thus, as we have noted, the output of  $C_n$  represents the iconic form. The hypothesis with which we began proposed, in part, that interruption theory spoke specifically to the effects of a mask on read-out, which here is viewed as a series of decisions. Usually the interruption theory has been interpreted as saying that an after-coming stimulus erases or replaces the icon of an earlier stimulus, thus curtailing the time available for processing (Haber, 1969b; Scharf & Lefton, 1970; Spencer & Shuntich, 1970; Sperling, 1963). In the concurrent-contingent model, therefore, the notion of replacement can be translated into “a change in the decision state of  $C_n$ .” Presuming that subsequent central decision nets use the  $C_n$  output as their data base, changing  $C_n$  output on a first stimulus would cut short the time available for these decisions on that stimulus. This interpretation, of course, is similar to that suggested in the clerk-customer analogy. Moreover, it implies that the minimal stimulus onset asynchrony needed to evade a central mask defines the minimal time needed for read-in and for read-out from iconic store.

But a fundamental<sup>13</sup> assumption of the information-processing approach is that the flow of information on the nervous system is characterized by successive changes over time in the content of the information (Haber, 1969a). The idea that the output from each central decision net is, in essence, a new form of the stimulus information and a further step on the way to answering the question of what kind of object the stimulus is, suggests a very different view of how iconic read-out might be disturbed.

One prediction of the theory that backward masking by pattern interrupts the processing of the icon by replacing the target icon is that all pattern masks that can mask a given type of target stimulus centrally should mask over the same temporal range. Thus, for example, the minimal stimulus onset asynchrony needed by a set of target letters, say the trigrams, to evade masking by Pattern Mask 3 should be the same as that needed to evade, say, a mask which is either another configuration of lines different from Pattern Mask 3, or three letters, or a word. In all these cases we must suppose that the time needed to process the target letters from the icon is constant and, therefore, that the upper limit on central masking is set by this processing time. Replacing the target icon by any one of the masking forms cited before processing is complete should yield masking, but the interval at which no masking occurs should be identical for all.

Quite to the contrary are some informal observations we have made which imply that the upper limit on central masking for a given target stimulus set depends on the form of the mask. For example, following the trigrams by a trigram mask, that is, three letters overlapping the three letters of the target stimulus, requires a longer minimal stimulus onset asynchrony for evasion of masking than following the trigram by Pattern Mask 3. In addition, in a variation of the situation described in Experiment XVII, a letter U followed by a pair of flanking H's gives a maximum metacontrast effect at an interval in excess of that at which pattern mask fails to mask the U. What these observations imply is that the minimal stimulus onset asynchrony needed by a stimulus to

evade masking does not necessarily define the minimal time needed to process that stimulus; rather it defines the maximal time in which this particular mask can interfere with the processing of this particular stimulus. In other words, the time to process an item may well extend beyond the temporal interval in which a given mask can impede perception.<sup>13</sup> Essentially, this theme is expressed in the contrast between random noise and pattern mask.

We may therefore entertain an alternative to the icon-replacement notion. To begin with, perception is, as we have noted earlier, a sequence of operations in time in which the iconic stage, we might now add, is a convenient point to introduce a delay if such a need arises (see Posner, 1963). But in most circumstances perception proceeds uninterrupted with the output of each decision net representing a further gain in knowledge about the stimulus. Masking arises subsequent to the  $C_n$  output, that is, posticonically, not because of icon replacement, although that may occasionally be true, but because discovering what kind of object the mask is may require the services of decision nets beyond  $C_n$  which are presently engaged in discovering what kind of object the target is. The implication of this view is that the more similarities between the target and mask, and this similarity is not restricted to the physical dimensions, the greater the opportunity for masking and the greater the temporal range over which the mask may influence the processing of the target.

In this respect a most instructive observation on sequential blanking or masking has been reported by Mayzner and Tresselt (1970): if a nonword mask of five letters follows a nonword, five-letter target, masking occurs; on the other hand, masking does not occur if the nonword mask follows a five-letter word. This means, perhaps, that semantic similarity as well as geometric similarity may be grounds for central masking (cf. Uttal, 1971b).

<sup>13</sup> The same argument has been made by Walsh (1971): "It is quite an arbitrary assumption that a stimulus has been identified at that moment when the presentation of a mask ceases to have any effect on the overt response to the stimulus [p. 265]."

## SUMMARY

A series of experiments were conducted which explored visual masking of peripheral and central origin through the use of mask stimuli which masked either both monoptically and dichoptically or only monoptically. The major observations are summarized below.

1. Backward masking of peripheral origin was characterized by a multiplicative rule relating the energy of the target stimulus to the minimal interstimulus interval needed to evade masking; thus, target energy  $\times$  minimal interstimulus interval = a constant.

2. Backward masking of central origin was characterized by an additive rule relating the duration of the target stimulus to the minimal interstimulus interval needed to evade masking: target duration + minimal interstimulus interval = a constant. This complementarity between target duration and interstimulus interval implicates onset-onset time as the relevant temporal variable in central masking.

3. While energy variables significantly affected the degree and direction of peripheral masking, they were relatively immaterial to masking arising centrally.

4. Forward masking of peripheral origin was more pronounced than backward masking of peripheral origin; moreover, the severity of peripheral forward masking increased with increases in mask intensity, the severity of peripheral backward masking did not. Peripheral forward masking, like peripheral backward masking, was characterized by the multiplicative rule.

5. In comparison to central backward masking, central forward masking was relatively weak and did not appear to obey the additive rule. In addition, a central forward masking effect was observed which delayed, rather than impaired, target stimulus perception.

6. When two stimuli, target and mask, were presented monoptically in a backward masking arrangement, the upper limit on masking was set by either peripheral or central processes depending on the energy of the target and the relation between the target and mask patterns.

7. A nonmonotonic U-shaped function was

obtained monoptically with overlapping target and mask, where target energy was greater than mask energy. It was hypothesized that this function reflected the transition from peripheral to central masking with increasing delay between the two stimuli.

8. Individual differences were more obvious in central than in peripheral masking.<sup>14</sup>

9. It was proposed that the peripheral and central processes, symbolized respectively by the multiplicative and additive rules, did not function in a sequential and additive fashion. Rather, the relation between the two was that they overlapped in time, with the central processes contingent on the outputs of the peripheral processes. A model was developed which expressed this concurrent-contingent relation and rationalized the data of the present series of experiments.

<sup>14</sup> Two observations by Schiller (Schiller, 1965; Schiller & Weiner, 1963) speak to this point: monoptic and dichoptic masking by pattern declines with practice, more so for dichoptic than monoptic presentation, but practice does not significantly influence masking by a homogeneous flash. Both of these results would be expected on the principle that dichoptic masking by pattern reflects distortions in the central decision process while monoptic masking by a light flash reflects disturbances in peripheral nets. The central process should be more susceptible to practice (experience), and a more significant source of individual differences. There is also some evidence to suggest that individual differences in masking may be quite stable (Dember & Neiberg, 1966).

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