# ABSTRACT

## "CROSS-FIELD" VISUAL MASKING BY TACHISTOSCOPIC PRESENTATION OF TARGET AND NOISE PATTERNS TO OPPOSITE CEREBRAL HEMISPHERES

By

David P. Goff

Methods for studying hemispheric asymmetry in the processing of sensory information by normal human subjects involve unilateral presentation of stimuli which then project to the opposite hemisphere. In the employment of these techniques, detection of laterality differences is often difficult. A reason for this is that several milliseconds after initial projection to one hemisphere, information becomes available for processing by the other hemisphere due to transfer across the commissures.

The goals of this study were to develop a new technique for increasing observed laterality differences in the visual modality and test the underlying explanatory constructs. The procedure employed tachistoscopic presentation of target information to one hemisphere and a pattern "mask" to the other. Although target <u>and</u> mask information then transfer to opposite hemispheres, it was predicted that the mask would produce less interference in one hemisphere than in the other due to attenuation through the corpus callosum. Consequently, a greater laterality difference would be observed under masking than with conventional procedures.

Target stimuli were single alphabetic letters, and recognition accuracy was the dependent variable. When the pattern was projected initially to the left (language) hemisphere, masking should have been greater than when mask was projected to the right hemisphere.

Findings indicated that the predicted phenomenon was: statistically confirmed, not influenced by differences in energy levels between mask and target stimuli, significantly affected by stimulus onset asynchrony between target and mask, dependent on size of the mask, and not reproducible when diffuse light was substituted for the pattern. Various aspects of these results supported the theory that the cross-field masking effect resulted from interaction of central (hemispheric) rather than peripheral neural mechanisms. Methods of improving the paradigm and for testing related theoretical issues were discussed.

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By

David P. O'Goff

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# DEDICATION

To Dr. Charles Hanley

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# Chapter 1: INTRODUCTION

Over the past 50 years a large volume of evidence has accrued in support of the concept of lateral specialization of functioning in the two cerebral hemispheres of humans. This evidence has derived from a variety of sources which include: direct cortical stimulation, study of patients with unilateral brain damage, postoperative case studies, gross evoked potential recordings, sodium amytal anesthetization of one or the other of the hemispheres as a preoperative investigation technique, unilateral presentation of visual, auditory, and tactile stimuli to normal human subjects, and most dramatic, the recent work of Sperry and associates with "split-brain" epileptic patients. Among the most consistent generalizations made are that the left (language) hemisphere in most right-handers specializes in symbolic and analytic functions while the right (mute) hemisphere demonstrates a superiority in Gestalt-type processing of spatial information (Hecaen, 1962; Gazzaniga et al., 1965; Geschwind, 1965; Levy, 1969; Levy-Agresti & Sperry, 1968; Sperry & Levy, 1970).

Most of the above methods for investigating asymmetry of hemispheric functioning comprise the drawback that few brain-damaged or surgical patients are available to the <u>general</u> scientific community. Furthermore, the conditions leading to the use of such surgical procedures involve pre-existing structural damage to the normal central nervous system of a rather critical nature. The choice, therefore, of some supplementary paradigms that permit the study of "normal" subjects seems desirable. The most popular methods which fall in this category are the dichotic listening paradigm for the auditory mode and tachistoscopic presentation of visual stimuli to the right or left hemisphere for the visual mode. Kimura (1961) showed a left hemisphere superiority for verbal stimuli via the right ear, and a right hemisphere superiority for the perception of melodies (1964). Although the hemisphere contralateral to the stimulated ear is favored for receiving the stimulus, each ear nevertheless has a direct cochleo-cortical projection route to both hemispheres (Davis, 1951), a "disadvantage" not shared by the visual system. For higher mammals, the two right hemiretinae (left visual field) contain direct retino-cortical projections to the right hemisphere only while the two left hemiretinae project directly to the left visual cortex (see Thompson, 1967, p. 250). Thus visual stimuli can be projected, <u>at least initially</u>, to only one hemisphere by tachistoscopic exposure to the contralateral (opposite) visual field.

The vision literature on laterality is extensive and not without controversy (see review by White, 1969). The general findings, however, support a left hemisphere superiority for verbal and a right hemisphere superiority for spatial processing as indicated by more accurate recognition or shorter reaction times to tachistoscopic presentation of the appropriate material in the appropriate visual half-field (Kimura, 1966; White, 1969; Rizzolatti et al., 1971)[1].

While some of these vision studies show significant differences in support of the lateralization of function hypothesis, the differences are nevertheless quite small and many of the studies are either contradictory or totally inconclusive. The most outstanding difficulty in this approach with normal subjects is, of course, the fact that 6-10 ms (Efron, 1963a;

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[1] This literature has been reviewed and the troublesome issues discussed in Appendix A.

Jeeves & Dickson, 1970) after one hemisphere has been stimulated, the information has become available for processing by the opposite hemisphere via the corpus callosum. The function of the callosum in this transfer of visual information has been demonstrated with commissurotomized animal and human patients (Sperry, 1961; Geschwind, 1965). Electrophysiological evidence has been provided by Berlucchi et al. (1967). Hence, either or some combination of both hemispheres may still do the processing.

Clearly, if one is to investigate more complex modes of unilateral "information processing" in "normal" human subjects, a method is needed for isolating, as much as possible, the processing of specific information to a given hemisphere. One means by which this may be possible would be to present target information to one hemisphere while presenting "conflicting" or noise pattern stimuli to the contralateral side and perhaps interfere with its processing. The specific aim of this project has been to develop and test the feasibility of such a model for the visual system. The empirical data will provide some tests of the hypothetico-deductive assumptions on which the model is based. Following is a detailed description of the model along with the behavioral, anatomical, and neurophysiological evidence which seem to support its tenability.

## Brief anatomy

Figure 1 is a block diagram of the afferent pathways of the visual system of the rhesus monkey which relate specifically to the processing of patterned stimuli. For simplicity, only the pathways from right hemiretinae corresponding to the left field of vision have been depicted. In primates, the retino-cortical projection (for the contralateral half-field of vision) goes exclusively to area 17 (Wilson & Cragg, 1967) of the visual cortex. Area 17 then projects to 18 and 19 on both sides (Cragg et al., 1969; Zeki, 1969; Zeki, 1970); 18 and 19 from both sides then project to the

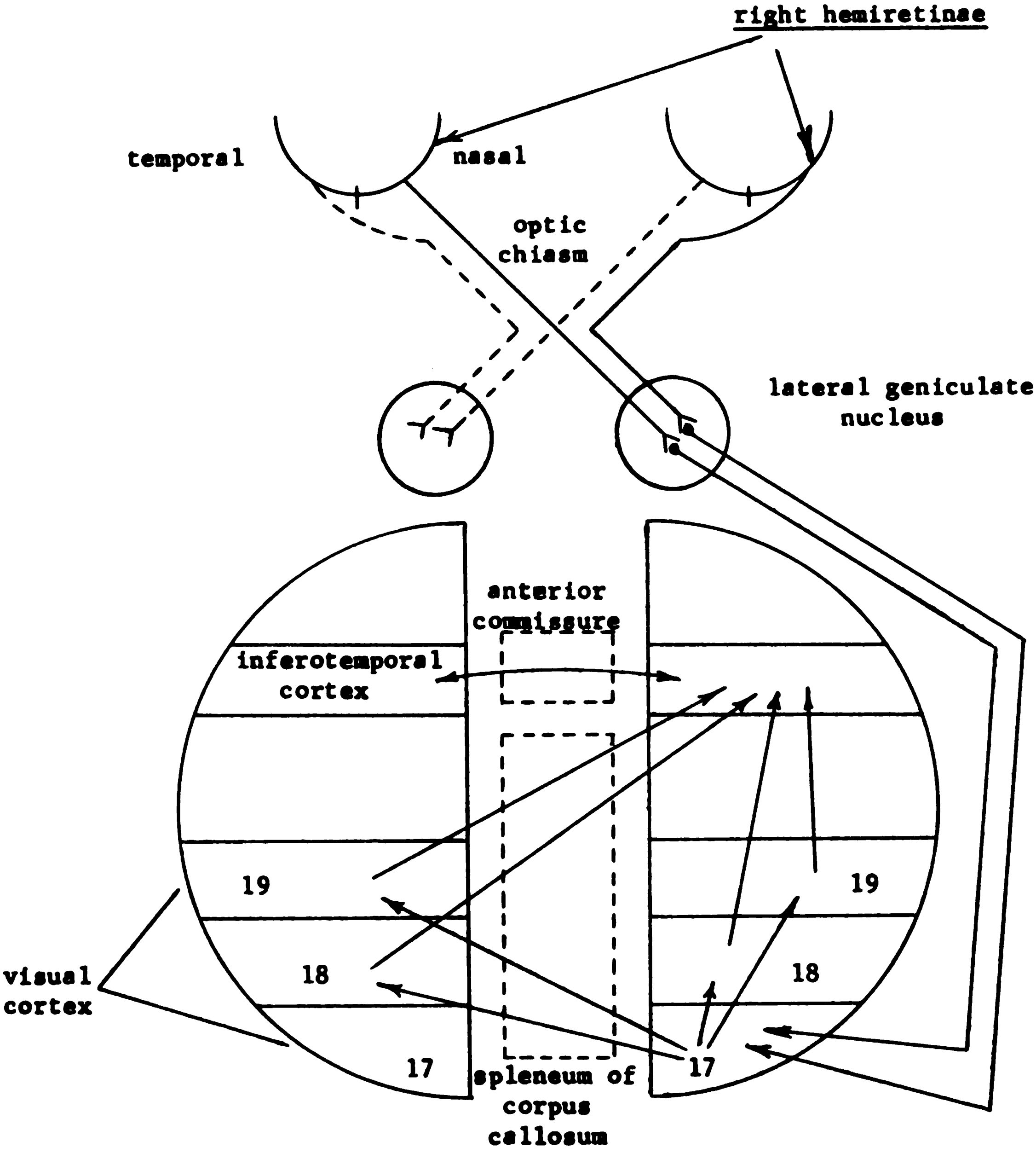

Figure 1. Afferent pathways of the visual system of the rhesus monkey (most like man). Connections to structures (e.g. pulvinar and superior colliculus) not related to pattern processing are excluded. (Drawn from a description by Gross, et. al., 1972)

inferotemporal cortex (Cragg et al., 1969). All the cortico-cortical pathways just described go through the spleneum of the corpus callosum. The two inferotemporal cortices connect through the anterior commissure (Fox et al., 1948). Present evidence suggests that these pathways from area to area of a given side represent successive stages of pattern processing (Hubel & Wiesel, 1965; Gross et al., 1972).

## The model

Given that the two eyes are focused on a fixation point, a "target" stimulus tachistoscopically flashed - for a time shorter than the 200 ms central reaction time for saccadic eye movements (Robinson, 1968) - to, say, the left half-field of vision, will go to area 17, the "primary" receiving area, in the right visual cortex (refer to Figure 1). The information will then go to the "secondary" receiving areas 18 and 19 on the ipsilateral side and to the secondary areas via the longer transcallosal pathway on the contralateral side. The writer proposes that the "raw" stimulus information, coded in electrophysiological form, will be more attenuated when it arrives at the contralateral as compared to the ipsilateral secondary receiving area as a result of the longer transcallosal pathway. (These assumptions will be discussed below.) Considering, now, the other half of the system, a visual "noise" pattern simultaneously flashed in the right visual field will arrive in the secondary areas with greater intensity in the left as compared to the right hemisphere. The result, for this particular example, would be that the right hemisphere receives a strong target signal (compared to the left) and a weak noise pattern (compared to the left). Correspondingly, the left side receives a weaker target signal and a stronger noise pattern (see Figure 2). Coined in different terms a high "signal-to-noise" ratio is obtained on the right side, and a low signal-to-noise ratio on the left. If the target and visual noise pattern are located in corresponding heteronymous (mirror symmetric) areas of the half visual fields, and not too far from the vertical meridian (less than $7^{\circ}$ visual angle), they should project to a common location in visual area 18 (see for example Berlucchi & Rizzolatti, 1968; and Blakemore, 1970). It is proposed that the noise pattern will interfere with (mask) the target stimulus in such a way as to decrease recognition accuracy for the target. This "masking" effect should occur on both sides (since both stimuli go to both sides), but it should be greater on the side with the lowest signal-to-noise ratio, i.e. the left hemisphere for this particular example.

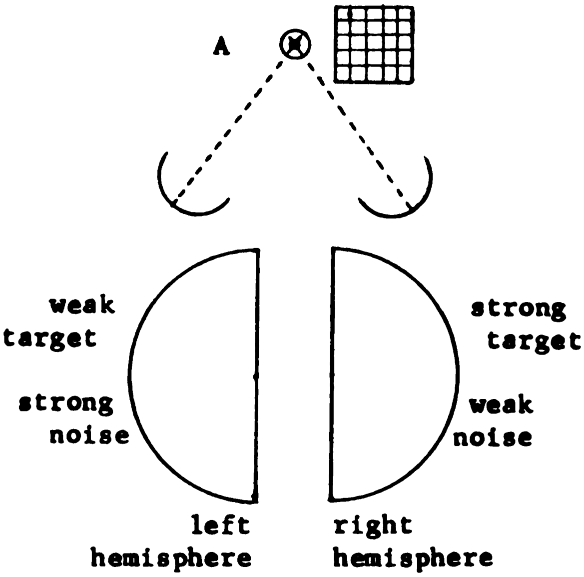

Figure 2. Relative strength of target and noise information arriving in the respective hemispheres as predicted by the model.

Employing, now, the previously described concepts of lateral specialization of function of the two hemispheres, it should be a simple matter to derive the behavioral predictions generated by the model. Take, for example, the left (language) hemisphere as the required processor. It is a given at this point that a verbally coded response to verbal stimulus material requires that the information reach the left hemisphere.

A stimulus (letter or word) flashed to the right hemisphere must cross the transcallosal pathway, and the signal attenuation hypothesis predicts that recognition accuracy should be less than when the stimulus is flashed directly to the left hemisphere (see Figure 3, no mask condition). These are the standard observations as described in the above studies. With the

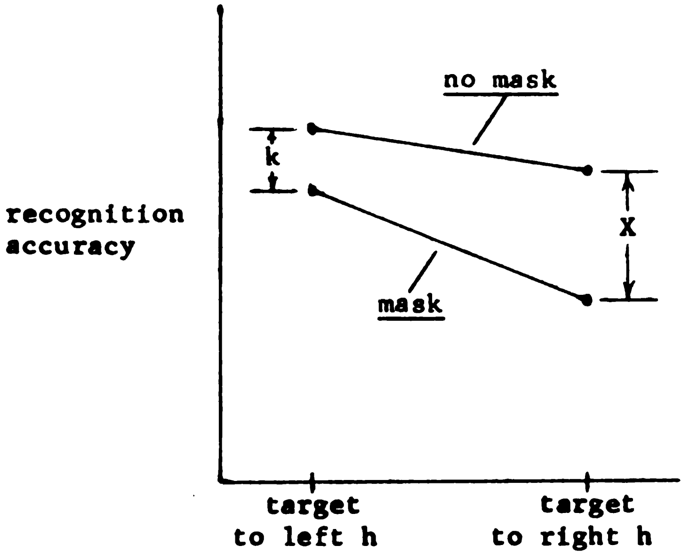

Figure 3. Predicted changes in recognition accuracy for verbal target stimuli resulting from projection of the mask pattern to the hemisphere opposite that of the target. (The finding X>k would satisfy the model)

target flashed to the right and noise pattern now flashed to the left hemisphere, recognition accuracy should decrease by some amount X, as compared to the right hemispher "<u>no mask</u>" condition (Figure 3). The <u>responding</u> hemisphere now has the low signal-to-noise ratio. To assess the undesirable (for present purposes) effect of the mask projecting to the opposite hemisphere via the cortico-cortical pathway, we reverse (laterally) the above stimuli and flash the target to the left hemisphere and the noise pattern to the right. Recognition accuracy should now decrease by some smaller amount k (from left hemisphere - no mask condition), since the left or responding hemisphere now has the larger signal/noise ratio. Thus, if the $X > k$ prediction is the empirical finding, then the data will support the model. Secondly, and as an algebraic consequence of the above statements, the difference in recognition accuracy between left and right hemisphere presentations should increase under the masking condition, and the magnitude of that increase will determine the utility of the paradigm as a research tool.

## Dichoptic visual masking

That interference between a target and noise pattern projected by separate pathways can be produced at the cortical level receives strong support from the dichoptic visual masking studies. Schiller (1965) flashed a letter to one eye and either a flash of light or a visual noise pattern to the other at corresponding retinal areas (foveally) and found a significant increase in recognition threshold (in ms exposure time) above the no-masking condition for the noise pattern - but not the diffuse light. These results indicate an interaction between stimuli presented to the two eyes at some central location subserving a binocular interaction between the two eyes. Area 17, which receives a direct retino-cortical projection from both eyes, serves as a good candidate.[1] Hubel and Wiesel (1965, cat; 1968, monkey) find that many "simple" cells in area 17 can be binocularly driven from corresponding homonymous points of the two retinae and that they respond only to lines and edges (pattern fragments), not diffuse light.

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[1] In their spatial vision review article, Bishop and Henry (1971, p. 145) state: "Relatively little interaction between the pathways from the two eyes takes place below the level of the striate cortex (Sanderson et al., 1969; Singer, 1970)." The authors they cite, of whom Bishop is one, found that some inhibitory binocular interaction does occur in the lateral geniculate body of the cat. The relevant pathways are unknown and no speculation has been made concerning their purpose. It should also be noted that the interaction is (a) extremely small and (b) exists only for corresponding homonymous points.

Referring to Figure 1, we see that the difference between the dichoptic and "cross-field" masking paradigms is as follows: in the dichoptic case, the stimuli may interact in area 17 which receives *direct* retino-cortical projections from homonymous retinal areas; in the "cross-field" case interaction cannot occur until area 18 which receives projections from ipsilateral 17 (right hemiretinae in the diagram) and contralateral 17 (left hemiretinae) via the transcallosal route. In the latter instance, individual cells in area 18 would have to be driven from corresponding *heteronymous* points in the two half-fields of vision. Direct evidence for this latter possibility has recently been obtained by Berlucchi & Rizzolatti (1968) who found neurons in area 18 that could be binocularly driven from corresponding heteronymous areas in the split-chiasm cat (Figure 5).

## Some functions of the corpus callosum

This area is too extensive to receive a detailed review here (see Ettlinger, 1965; Bishop & Henry, 1971); however, a few points relevant to the theoretical development of the above model require discussion. They concern the nature of information transfer between the visual cortices of the two hemispheres and its relation to the issues of interhemispheric masking. The following introductory paragraph will facilitate the discussion of these points.

Hubel and Wiesel (1965), using the retrograde degeneration technique, found that fibers going from area 17 to ipsilateral and contralateral 18 and 19 projected to very specific areas; the area in 18 immediately adjacent to the 17-18 border, and the area in 19 immediately adjacent to the 18-19 border. The retinotopic projection to these areas represents the areas adjacent to the vertical midline of the field of vision. For example, they found (by microelectrode recording; Hubel & Wiesel, 1967) that the "receptive fields" of all cells on the 18 side of the 17-18 border extended to the vertical meridian. Secondly, Berlucchi and Rizzolatti (1968) found, as mentioned previously, that cortical cells in this same section of area 18 could be binocularly driven from corresponding heteronymous retinal areas adjacent to the vertical midline. This evidence suggests that two of the "natural" functions of this callosal crossover network may be to (a) provide continuity between the two half-fields of vision (Hubel & Wiesel, 1967; Berlucchi & Rizzolatti, 1967) and (b) provide a stereoptic mechanism for making depth judgments about objects falling on the vertical meridian and thus projecting to opposite hemispheres (see discussion and review by Bishop & Henry, 1971). It is by this particular crossover network through the spleneum of the corpus callosum that the proposed interference phenomenon between the hemispheres might occur.

One feature of the cross-field masking model described above was the proposal that interference might be produced in the 18-19 areas by a visual noise pattern. This presupposes that, since a noise pattern is to be the effective masking stimulus, it must be interfering with "basic sensory data" (e.g. pattern fragments) of the target stimulus projecting from contralateral 17 rather than some more highly processed code for the stimulus (e.g. in engram form). Is there any evidence to support the contention that the spleneum transmits basic sensory data as opposed to more complex codes? Myers (1962) and Sperry (1964) argue that this is, in fact, the case but their support is based on some rather indirect inferences deriving from the interhemispheric transfer of pattern discrimination learning in chiasm-sectioned animals. Far more direct evidence was provided by

Berlucchi and Rizzolatti (1967). In an effort to specifically answer the above question they conducted a microelectrode recording analysis of the receptive fields of the *axon fibers* in the spleneum (posterior third) of the corpus callosum of the cat. They found *all* the fields to have properties identical to those of the simple, complex, and hypercomplex cells found by Hubel and Wiesel (1965) in areas 17, 18, and 19 of the cat. The fields extended from the vertical midline to as far as 20° into the periphery.

While the above obviously supports the hypothesis that the spleneum may be specialized for the interhemispheric transfer of sensory-type visual information, it does not exclude the possibility that yet another commissural structure may transmit more highly coded information between "higher" visual centers of the two hemispheres - in particular, the anterior commissure which links the two temporal lobes. The evidence on this point is short but rather dramatic. Gorden, Bogen, and Sperry (1971) describe the testing of two human patients having received *partial* commissurotomy operations for the control of epilepsy. Both had only the anterior commissure sectioned with all other structures remaining intact. These patients could easily give a verbal description of visual stimuli flashed to the right hemisphere. However, a third patient (described in the same report) who had received only a sectioning of the spleneum - all other structures remaining intact - was totally *unable* to describe any visual material flashed to the right hemisphere. In sum, it appears that interhemispheric communication of visual information *depends on* the existence of an intact spleneum which has been shown, at least in a lower species, to carry only sensory-type codes.

The last events in the processing chain that would lead to the observation of a cross-field masking phenomenon have involved the implicit assumption that interference with the processing of target information in areas 18 and 19 would necessarily disrupt "higher" processing in the visual centers of the temporal lobe and therefore the *output in response form* produced by the responding hemisphere. Support for this contention derives from a series of cross-lesion experiments on monkeys performed by Mishken (1966). He demonstrated rather conclusively that the contribution of the inferotemporal cortex to the pattern recognition process *depends on* the neural processing that occurs in areas 18 and 19 (see also Stone & Freeman, 1973).

While the above argument makes a case for the hypothesis that masking in *areas 18 and 19* could disrupt processing and output by higher centers, it does not exclude the mutually *inc*lusive possibility that yet another pathway, the projection of 18 and 19 to the inferotemporal cortex via the spleneum could provide the target information for continued processing by the "masked hemisphere" (refer to Figure 1). Although the visual noise pattern also projects to this site from the ipsilateral side, the above suggests that masking, in a sense, "engram with engram" could yet be a more effective procedure than masking "engram" with "noise."[1] If this were tenable, then masking, for example, a target letter or word with a matrix of random *letters* would have relatively *more* effect than masking with a visual noise pattern. A testable hypothesis.

Finally, it was mentioned previously that a "natural" callosal function which could potentially account for an interhemispheric interaction

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[1] For lack of a better word, the term "engram" is used, not in its strictly conventional meaning as a *stored* bit as a result of learning, but to mean the *terminal stage* to which a given pattern is processed by the *visual* system. The word "code" also seems inappropriate since the "basic sensory information" is obviously in coded form even in the peripheral energy transducers.

between target and mask, was the mechanism providing for a stereoptic interaction for stimuli that projected binocularly to opposite hemispheres (a situation that is identically simulated by the cross-field visual masking paradigm). As much of the above data are based on cats and monkeys, and since, as we ascend the phylogenetic scale, the visual system becomes more precise (e.g. receptive fields and nasotemporal overlap are smaller for monkey than for cat etc.), the question arises as to how far into the periphery, on opposite sides of the fixation point, can we safely assume a binocular interaction from heteronymous points in the human subject. The data are provided by the unfortunate case of a 14-year-old boy who fell off his bike and split his optic chiasm (Blakemore, 1970). The subject was able to make depth judgments when a slit was briefly exposed in front of his fixation point although its images projected to the temporal retinae of both eyes and therefore projected separately to the two hemispheres (see Figure 4). The amount of disparity that could be tolerated and still give the stereoscopic effect was 6°, i.e. 3° to the temporal side of each fovea. This study provides not only behavioral evidence for an interhemispheric pathway for binocular interaction in man (which correlates with the electrophysiological findings of Berlucchi and Rizzolatti, 1968), but an assessment of the spatial parameters relevant to the present project.[1]

## The signal attenuation hypothesis

Attenuation of signal and mask due to the longer transcallosal route is perhaps the most critical assumption on which this model is based. Three

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[1] The question arises as to the possible contribution of the "nasotemporal overlap" (the small band at the fovea from which fibers might pass to either optic tract) which was found to be 0.9° wide in the cat (Stone, 1966). In man and monkey it is purported to be considerable smaller (van Buren, 1963). Functionally, it does not seem to be an important factor in man since Mitchell and Blakemore (1970) found that section of the corpus callosum in man (chiasm intact), "disrupts depth perception entirely in the middle of the visual field."

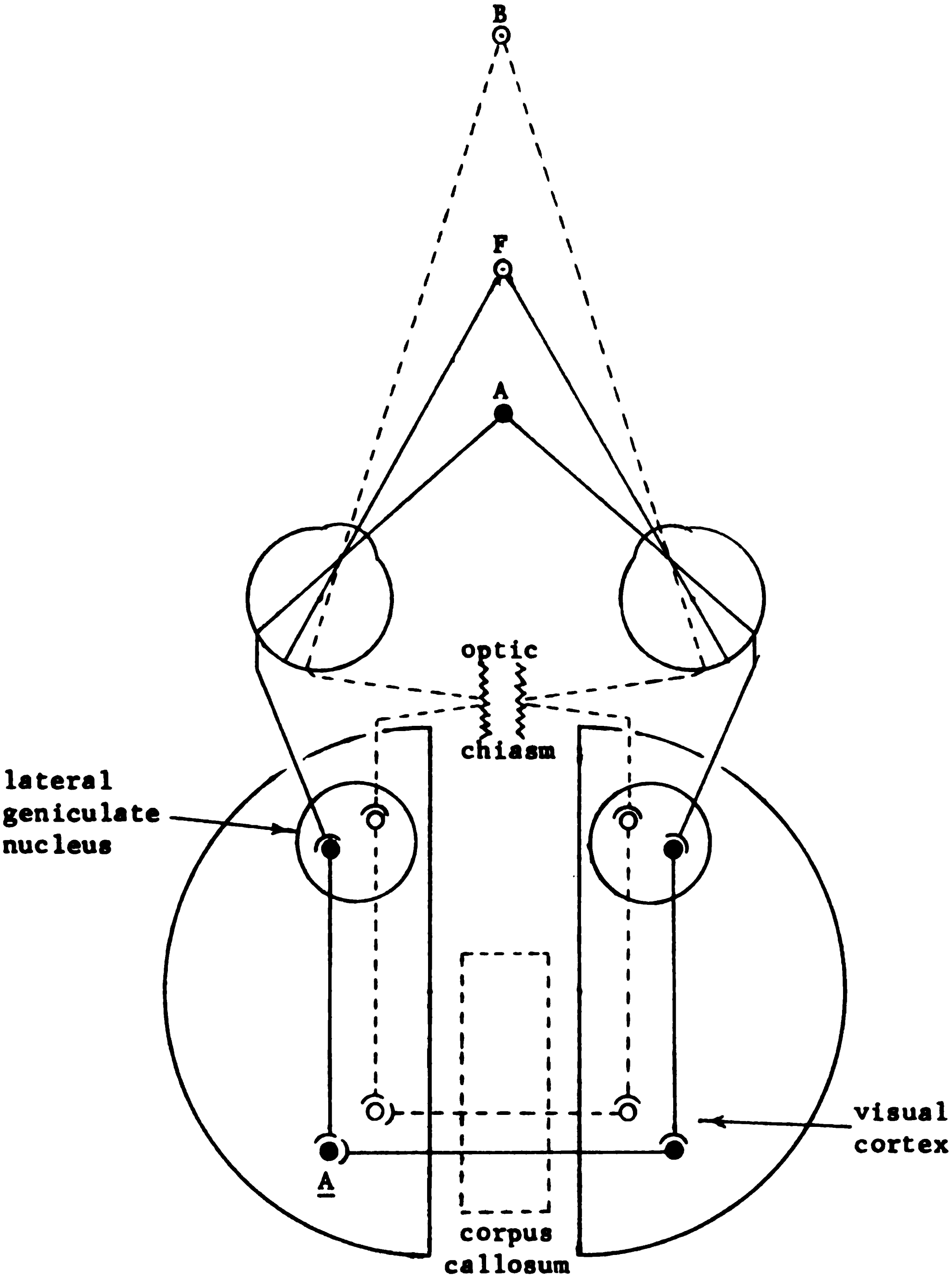


Figure 4. Pathways in the visual system of the retinal images of two objects falling on the vertical meridian, one in front of and one behind the fixation point, for a human with sagittal section of the optic chiasm. The object at A, directly in front of fixation point F, projects to the two temporal hemiretinae and drive the neurons indicated by the solid circles. The neuron at A, left hemisphere, receives an input from corresponding heteronymous areas of the two eyes, one input deriving from the corpus callosum. Object B cannot be seen due to interruption of decussating fibers at the optic chiasm. (figure redrawn from Blakemore, 1970)

kinds of evidence will be offered for its support.

Bremer (1965) electrically stimulated the <u>left</u> lateral geniculate body (see Figure 1) of the brain of a cat and measured the gross evoked potential responses from symmetrical areas of the left and right visual cortex. The oscilloscope traces obtained from the <u>left</u> hemisphere represented the direct geniculo-cortical pathway while those obtained from the <u>right</u> hemisphere represented the geniculo-cortico-cortical pathway via the corpus callosum (Ibid. 1965, p. 286). The two wave forms were not only similar, as might be expected, but the amplitude of the signal from the <u>right</u> hemisphere (longer pathway) had decreased by a factor of about five when compared to the left hemisphere (direct pathway).

Behavioral evidence of the "inefficiency" of the callosal transfer mechanism comes from studies by Myers (1962). He found that split-chiasm animals could learn a pattern discrimination task through one eye (while the other is occluded) and then perform the learned task using the opposite eye even after post-training sectioning of the corpus callosum. In other words, both hemispheres learned the discrimination, one of them through the callosum. However, the "untrained hemisphere" always performed more poorly than the one which had received the discriminanda via the direct retino-cortical route.

At the single cell level, Berlucchi and Rizzolatti (1968) provide the most dramatic evidence. These researchers found that cells in area 18 of the chiasm-sectioned cat (see Figure 5) could be binocularly driven from corresponding heteronymous retinal areas (as previously described). Furthermore, a cell when stimulated (by <u>natural</u> visual stimuli) via the callosal pathway gave responses that "were in general less brisk and more fatigable" than when stimulated <u>by equal stimuli</u> via the direct retino-cortical path.

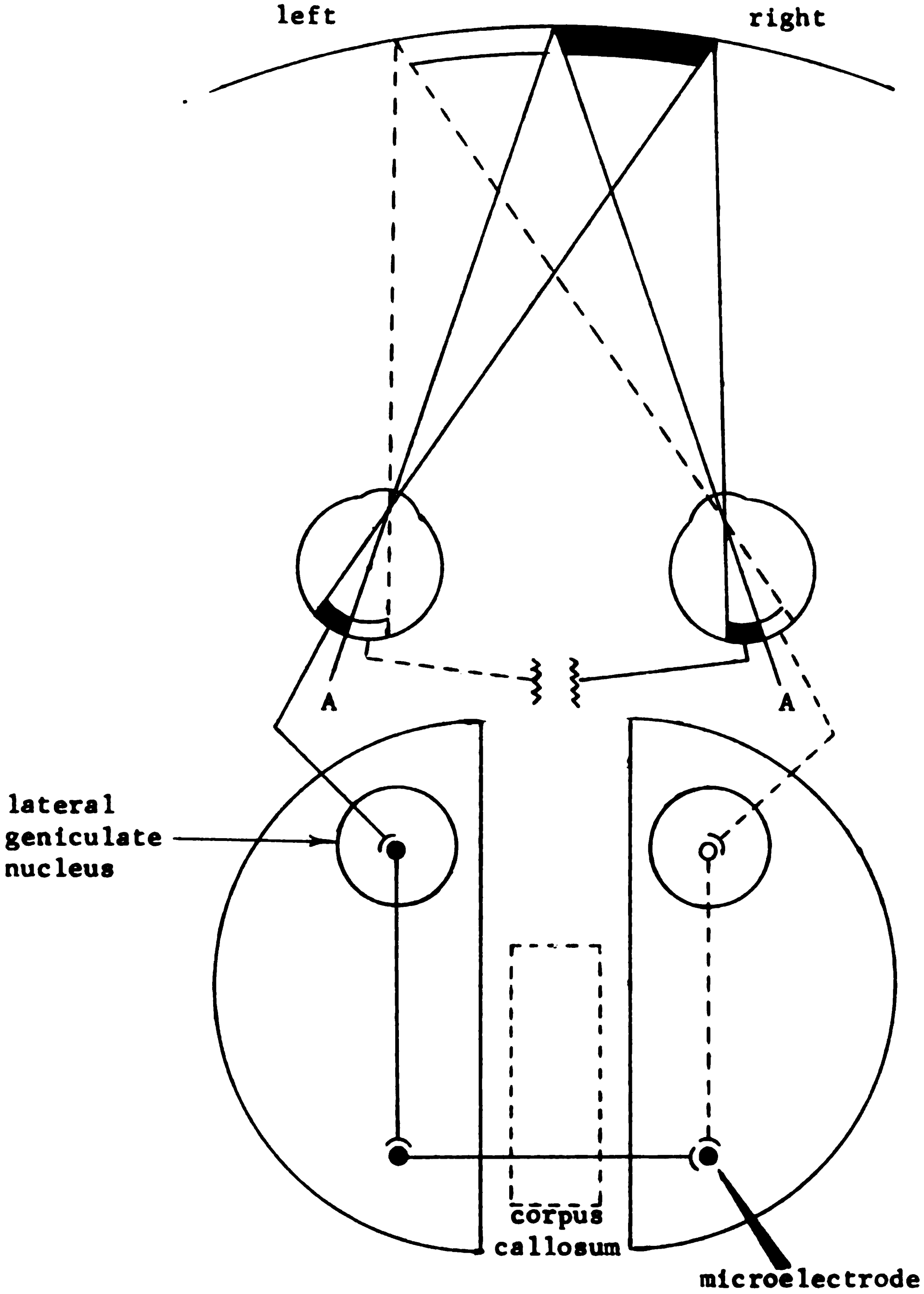


Figure 5. Example of a single neuron in the right visual cortex which was driven (Berlucchi & Rizzolatti, 1968) by a stimulus crossing the vertical meridian for a cat with sagittal section of the optic chiasm. The recorded cell could be driven either by the part of the stimulus falling in the left visual field (white area) and projecting to the right temporal hemiretina or by the stimulus in the right visual field projecting to the left temporal hemiretina (black area) and across the corpus callosum. The line at A indicates the division between the nasal and temporal hemiretina of each eye. (figure redrawn from Berlucchi and Rizzolatti, 1968)

Compare Figures 4 and 5 and note that similar events in the visual system are produced by two different stimulus configurations. Figure 4 applies to the case that would represent binocular stereopsis and Figure 5 represents the situation encountered in the cross-field visual masking paradigm.

# Chapter 2: EXPERIMENT I

For all studies reported in this paper, the "target" stimuli employed were single capital letters for which the left (language) hemisphere is presumed to be the primary, or final, processor for naming the letters and initiating a verbal response. To briefly reiterate the basic paradigm, single letters are to be flashed unilaterally and in random sequence to both left and right visual hemifields under both no-mask and mask (noise pattern in hemifield opposite the letter) conditions. The main prediction is that with target letter projected to the right and noise pattern to the left hemisphere, decrement in response accuracy should be greater - compared to the no-mask condition - than when the situation is reversed, i.e. letter to left and mask to right hemisphere (Figure 3). The former is purported to represent the low "signal-to-noise" and the latter the high "signal-to-noise" stimulus conditions for the left hemisphere.

The results of exploratory pilot work supported, though not conclusive statistically, the above predictions and provided information for establishing the base-line parameters to be used for the present studies. The goals of the experiments reported here were (a) to establish, if possible, statistical confirmation of the predicted "effect," (b) to provide a systematic investigation of some stimulus parameters which may be relevant to increasing or decreasing the "effect," and (c) to test some related theoretical assumptions about the neural mechanisms potentially involved.

The purposes of Experiment I were (1) to accumulate sufficient data to make a statistical determination of the tenability of the "effect" and (2) to investigate the possible effects of varying brightness relationships between target and noise pattern. Brightness was varied by holding target intensity constant for different noise-pattern intensities and by holding noise intensity constant while varying target intensity. The preliminary supposition was that, as with other masking paradigms, the greater the brightness difference between target and mask, the greater would be the masking effect. In the present case, however, the issue becomes considerably complicated by the fact that the (presumed) masking site is exclusively cortical. The present goal was to find a set of relative brightness parameters which might suggest the existence of an optimum set for obtaining the *differential* effect.

## METHOD

### Subjects

The subjects were 16 paid volunteers from two undergraduate psychology classes at Michigan State University. All were males, right-handed, as determined by the Crovitz and Zener (1962) questionnaire for hand dominance, and naive to the purpose of the experiment.

### Apparatus

A three-channel Scientific Prototype (Model GB) Auto-Tachistoscope was used. Each field was back-lit through the diffusion screen (with color-matching filters) by the standard fluorescent bulbs (GE-FT4-5 with painted silver stripe between the electrodes). Although not measured, the rise and decay times are claimed to be considerably less than 1 ms each. Each of the two "stimulus" fields were modified to obtain more equal left-right half-field brightness by repositioning the right member of the vertically mounted pair of bulbs and by inserting a mat white strip of cardboard behind each bulb pair. Maximum and minimum stimulus field brightnesses, measured through the split-beam binocular eyepiece with a Salford Electrical Instruments Company spot-photometer, were 2.50 footlamberts (ft.l.)

and 0.40 ft.l. respectively. For two of the fields, stimuli were presented on 24x36 mm slide transparencies automatically fed from 100-slide "rototrays."

Stimulus materials

The fixation stimulus viewed by the subject was a dark field, and a lighted circle in the center (0.44° visual angle in diameter) within which was an "x" containing a "dot" (0.088° visual angle) in its center (Figure 6). The subject also saw a small lighted bracket in each of the four corners of the rectangular field. The area within the brackets represents the unoccluded portion of any stimulus field as seen through the binocular eyepiece and permitted the subject to make minor self-centering head adjustments before each exposure sequence. The magnified (through the scope optical system) portion of this unoccluded viewing area had an "apparent" viewing distance of 30 inches and projected a visual angle of 2.9°x5.25° (laterally) at the retina. The lighted areas (center circle and brackets) of the fixation field measured 0.40 ft.l. while the "black" area of the transparency (found under higher luminance conditions to transmit 0.8% of the back light) was 0.0032 ft.l.

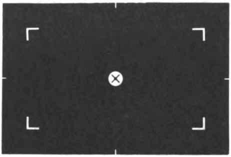
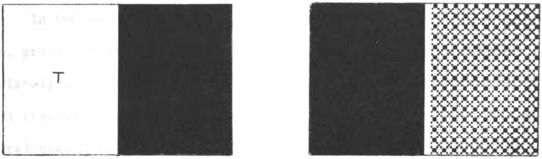


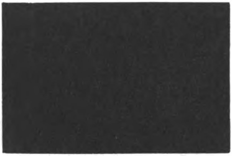
Figure 6. Fixation stimulus with brackets for parallax adjustment.

The target stimuli (see example in Figure 7) consisted of a rototray of 100 slide transparencies, each with a single black letter of the alphabet against a "white" background on the left or right half of the slide while the half-side opposite the letter was "black". The center point of each letter was 1.7° to the left or right of fixation as viewed through the scope. The letters subtended an angle of 0.34° in height and a maximum of 0.34° in width. Thickness of the letter features was 0.03° visual angle.



target stimulus

mask stimulus



no-mask stimulus

Figure 7. Example of the target, mask, and no-mask stimuli.

A second rototray, for the remaining stimulus channel, contained a set of 50 blank slides, blank the entire area, and a set of 50 masking stimuli (Figure 7) which were black on either the left or right side and contained a visual noise pattern, the area of which was 50% white and 50% black, on the opposite side. This pattern is identical to that used by Schiller (1965) for dichoptic masking of single letters. A third rototray identical to the second except for a one to one reversal in order of mask and blank stimuli was also used.

All stimuli were prepared in black-white reverse on mat white paper with black marking pen and photographed with Kodak High Contrast Copy Film 5069. The negatives then comprised the stimulus material. The black areas of the mask and blank slides were exposed and developed to the same density so that they would pass an equal amount of light from the rear diffusion screen in their specific channel.[1]

In the center of the target and masking fields, a black vertical strip, projecting a visual angle of $1.0^{\circ}$ at the eyepiece, was mounted immediately in front of the stimulus position. This strip was to block foveal transmission from either half-field resulting from whatever naso-temporal overlap exists in man (estimated to be considerably less than the $0.9^{\circ}$ found in the cat; van Buren, 1963), or from microsaccadic eye movements, 7 to 10 minutes to either side of fixation (Ditchborn & Ginsburg, 1953; St. Cyr & Fender, 1969). The resultant composite viewed by the subject on a "mask" trial and target presentation on, say, the left side is illustrated in Figure 8. The remaining unoccluded portions of the

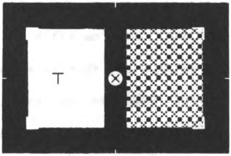


Figure 8. Composite view of the stimuli as seen through the tachistoscope on a "masked" trial with target projecting to the right hemisphere.

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[1] This was crucial for the purpose of maintaining a constant background illumination in the half-field of the superimposed target letter for both mask and no-mask trials.

mask projected a visual angle of $2.13^{\circ}$ in width and $2.90^{\circ}$ in height. A no-mask trial appears identical except for replacement of the noise pattern by a "black" half-field.

## Procedure

As the subject sat in a chair facing the tachistoscope, a head rest, chin rest, and the interocular separation of the eyepieces were all adjusted so that the subject, by occluding first one eye, then the other, could see all four brackets of the fixation field with each eye separately. The room lights were then turned off and the subject was given a brief period to dark-adapt to the brightness level of the fixation field.

At the beginning of each trial, the subject binocularly viewed the fixation slide. At the signal "ready", the subject made minor head adjustments (if necessary) to insure a clear view of all four reference brackets. About 1½ seconds after the ready signal, the subject was signalled to "focus" on the center dot, and within another second the stimulus fields were fired by the experimenter.

On a "masking" trial, the noise pattern fired on one side for a total duration of 200 ms. Fifty ms after onset of the noise pattern the target flashed on the opposite side for a duration of 3.5 to 9.0 ms depending on brightness conditions and threshold level for a particular subject. On a "no mask" trial, all conditions were the same except for replacement of the noise pattern with an all "black" slide (i.e. the masking field still fired for the same time duration to maintain constant target background for <u>both</u> "mask" and "no mask" trials). The fixation stimulus remained continuously lit. At the termination of a 750 ms interval (from trial onset), the slide changers automatically advanced the target and mask - no-mask stimuli for the next trial. The subject's task was to call out a letter as quickly as possible and within the 750 ms interval, i.e. before he heard the slide changers advance. The subject's response was manually recorded during an intertrial interval of approximately 4 seconds. Three aspects of the experiment were emphasized to the subject as having the following order of importance: (1) he must constantly maintain the fixation point for the period beginning with the "focus" command and ending with the sound of the slide changers, (2) for each trial, he was to make his best guess as to what the letter might have been, regardless of the stimulus conditions and regardless of whether or not he actually "saw" a letter, and (3) he was to call out his best guess <u>before</u> he heard the changers advance.

The target set of stimuli contained 25 letters of the alphabet (excluding Q), each letter appearing 4 times, twice on the right and twice on the left. The order of the letters and their right-left position was randomized with the restriction that the same letter did not appear more than twice in succession, and not more than three right or three left presentations occured in succession. The "mask - no mask" stimulus set was randomly arranged with the restrictions that (a) each letter was "masked" once on each side, and (b) no more than three mask or three no-mask conditions occurred in succession. The second "mask - no mask" set (100) was identical to the first except for a one to one reversal of the 50 noise and 50 blank stimuli. In other words, a letter in a given serial position that was masked on the first set of 100 trials, was not masked the second time around. In sum, the right-left, mask - no mask, and serial position of the mask - no mask conditions were counterbalanced for each letter, with conditions and letters otherwise occurring in random sequence.

At the beginning of the first session, 50 to 75 practice trials were given to acclimate the subject and to determine the target exposure time which elicited a probability of correct responding at approximately 0.5 averaged across all conditions. After a brief rest period, 100 test trials were administered with the first set of "mask - no mask" stimuli. Occasionally, the exposure times were varied by 5% increments to maintain the threshold responding level. Following a 5-10 minute rest period, another 100 trials were given with the second set of "mask - no mask" stimuli and rototrays operating in the reverse direction. This ended the first session of 200 test trials. A second session was given within 3-4 days (but never on the same day) with the direction of the rototray for a particular set of "mask - no mask" stimuli reversed from what it was the first testing day. A 30-40 trial warm-up was required to obtain a threshold level of responding at the previously determined target exposure time. For <u>each</u> of the four 100 trial sets, the stimulus rototray was started from a random position. Each of the two daily sessions lasted approximately 1½ hours.

The 16 subjects were randomly assigned to four groups with 4 subjects in each group. The groups (conditions) varied with respect to the relative brightness difference between the noise pattern and target stimulus fields as follows. Group I: masking field - 2.50 ft.l., target field - 0.40 ft.l.; Group II: mask - 1.05 ft.l., target - 0.40 ft.l.; Group III: mask - 2.50 ft.l., target - 0.20 ft.l.; Group IV: mask - 2.50 ft.l., target - 0.10 ft.l. For Groups I and II, target brightness was held constant while mask brightness was decreased by 50% of the difference between the two. For conditions I, III, and IV mask brightness was held constant while target brightness was decreased in 50% increments from 0.40 to 0.10 ft.l. by Kodak neutral density filters 0.30 (50% transmission) and 0.60 (25% transmission) respectively.

## RESULTS AND DISCUSSION

Percent correct, based on 100 observations per condition per subject, was averaged across the four subjects in each group. These data are tabulated for each of the four groups in Table 1 (within the rectangles). A comparison of the mask versus no-mask conditions averaged across hemispheres is made in column 3. For each group, the third row in the table shows the percentage decrement in responding level produced by masking - using the no-mask condition as <u>baseline</u> responding level. The fourth column shows the difference in percent decrement, right minus

**Table 1. Percentage of correct responses for left versus right hemisphere and mask versus no-mask conditions for Groups I-IV, percentage decrement produced by the mask, average across hemisphere conditions, difference in percentage decrement, and mean target exposure time at threshold.**

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| <u>Group I</u> | no-mask | 63.8 | 59.0 | 61.4 | | |
| M=2.50 ft.l. | mask | 43.3 | 34.3 | 38.8 | 9.7 | 4.9 |
| T=0.40 ft.l. | % decr. | 32.2 | 41.9 | 37.0 | | |
| <u>Group II</u> | no-mask | 56.8 | 55.8 | 56.3 | | |
| M=1.05 ft.l. | mask | 46.8 | 40.8 | 43.8 | 9.3 | 4.4 |
| T=0.40 ft.l. | % decr. | 17.6 | 26.9 | 22.3 | | |
| <u>Group III</u> | no-mask | 67.5 | 57.0 | 62.3 | | |
| M=2.50 ft.l. | mask | 47.0 | 34.8 | 40.9 | 8.6 | 8.3 |
| T=0.20 ft.l. | % decr. | 30.4 | 39.0 | 34.7 | | |
| <u>Group IV</u> | no-mask | 64.5 | 53.0 | 58.8 | | |
| M=2.50 ft.l. | mask | 49.0 | 34.8 | 41.9 | 10.4 | 10.6 |
| T=0.10 ft.l. | % decr. | 24.0 | 34.4 | 29.2 | | |
| <u>Groups I-IV</u> | no-mask | 63.1 | 56.2 | 59.7 | | |
| average | mask | 46.5 | 36.1 | 41.3 | 9.4 | |
| | % decr. | 26.4 | 35.8 | 31.1 | | |

Note. M=mask; T=target; H=hemisphere; R=right; L=left; %decr.=percentage decrement produced by mask left hemisphere, and the fifth column shows the average target exposure time required to maintain threshold level of responding. A "one between - and two within - subjects variables" analysis of variance (see Myers, 1967, pp. 198-209) is summarized in Table 2.

Across hemispheres and groups, the average percent correct for the no-mask condition was 59.7% and for the mask condition 41.3%, a decrement from the no-mask baseline of 31.1% ($p < 0.0005$). The non-significant AC interaction term indicates that the magnitude of the over-all masking effect did not differ for Groups I-IV, the different mask-to-target brightness ratios. This point will be discussed subsequently.

Although not of primary interest to the purpose of this study, the usual left hemisphere (right field) superiority for recognition of alphabetic material was observed ($p < 0.005$). The non-significant AB interaction term indicates that this effect did not differ for Groups I-IV. Normally, such simple alphabetic material as single alphabetic letters presented over periods of time which afford extended practice (as in this study) shows considerably smaller left-right effects than more complex stimuli such as words (left hemisphere) and spatial stimuli (right hemisphere) presented less frequently. Some of the pilot subjects receiving 400-800 presentations and following experiments employing a smaller number of subjects did not show a <u>significant</u> over-all left hemisphere superiority.

The crucial interaction, BC (Table 2), hypothesized from the model, was significant in the direction predicted ($p < 0.05$). The masking decrement, averaged across groups, for the left hemisphere (target to left h, mask to right h) was 26.4% below the no-mask baseline while a 35.8% decrease was obtained for the right hemisphere (target to right h, mask to left h). The former represents the high and the latter the low

Table 2. Analysis of variance summary based on percentage correct scores[1], [2] for Experiment I

| Source | df | SS | MS | F | t |
|---|---|---|---|---|---|
| Total | 63 | 9257.980 | | | |
| Between subjects (S) | 15 | 541.230 | | | |
| Groups (A) | 3 | 25.668 | 8.556 | 0.119 (ns) | |
| S/A | 12 | 515.563 | 42.964 | | |
| Within subjects | 48 | 8716.750 | | | |
| Hemispheres (B) | 1 | 1198.886 | 1198.886 | 16.507 | $4.063^{**}$ |
| AB | 3 | 219.801 | 73.267 | 1.009 (ns) | |
| SB/A | 12 | 871.563 | 72.630 | | |
| Mask conditions (C) | 1 | 5383.886 | 5383.886 | 113.333 | $10.646^{***}$ |
| AC | 3 | 255.301 | 85.100 | 1.791 (ns) | |
| SC/A | 12 | 570.063 | 47.505 | | |
| BC | 1 | 47.270 | 47.270 | 3.468 | $1.862^{*}$ |
| ABC | 3 | 6.418 | 2.139 | 0.157 (ns) | |
| SBC/A | 12 | 163.563 | 13.630 | | |

$^{*}p<0.05$ (one-tailed); $^{**}p<0.005$ (one-tailed); $^{***}p<0.0005$ (one-tailed)

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[1] Since variances decrease as proportions deviate from 0.5, the analysis should more appropriately be made on the arc sin transforms of the observed proportions (tabulated here as percentages). Such analyses were conducted on the transformed data for this and succeeding experiments and led to no difference in conclusions drawn or significance levels reported herein. For ease of interpretation, then, all statistical analyses reported are based on the data in their originally observed form.

[2] The one-tailed t tests are reported for the following reason: all hypotheses tested in this analysis are based on "one-tailed" (a priori) predictions derived from the model, e.g. targets projected initially to the left hemisphere should be more accurately reported than when projected to the right, and masking should produce a decrement. Most important, one and only one of all possible within-subjects interactions had been predicted, i.e. that masking should be greater when targets are projected to the right hemisphere as compared to the left. The appropriate analysis of this interaction for this model (Myers, pp. 337-345) is a one-tailed test of the appropriate orthogonal comparison of the four interaction means. Since that test as well as the preceding two are based on one degree of freedom, they should be algebraically identical to taking the square root of F and doing a one-tailed t test. This was confirmed for these data by doing both the anova and the orthogonal comparisons and producing identical results. (See Hays, 1963, Ch. 14, for a more thorough discussion of orthogonal comparisons for interaction terms.)

"signal-to-noise conditions" for the left hemisphere. The average difference in percent decrement, right minus left hemisphere, was 9.4%. This difference, a single index of the direction and magnitude of the interaction, is tabulated in column 4, Table 1, for each of the groups. This column, and the non-significant interaction between groups (A) and the within-subjects (BC) interaction, i.e. A(BC), shows that the hemisphere X mask interaction did not differ with varying target-to-mask brightness ratios.

The significant hemispheres X masking interaction effect, and its prediction in advance of the empirical observation, supports the major contention of the model developed herein, that visual masking may occur interhemispherically as well as intrahemispherically (the dichoptic paradigm). However, the small magnitude of the effect, as observed so far, would seem to preclude its utility as a general research tool for the investigation of unilateral information processing. Each group taken separately (n=4) and all but two individual subjects[1] failed to produce a statistically significant interaction. It should also be noted here that two of the 16 subjects in this sample (12.5%) produced a non-significant interaction in the direction opposite to that predicted by the model. This is in close agreement with the observation (Milner, et al., 1964; Kimura, 1961) that approximately 10% of right-handed males have the language center in the right hemisphere as determined by unilateral sodium amytal injection into the left or right carotid artery.

The failure to find that varying mask-to-target brightness ratios had an influence on the hemispheres X mask interaction (column 4, Table 1)

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[1] For individual subjects, the orthogonal comparison was made on the arc sin transform of the observed proportions. In this situation, analysis based on single data points (angles) is made possible by the fact that the error variance is known to be 821/n where n=number of observations making up each proportion (100 in this case).

as well as on the over-all masking effect (column 3, Table 1) was initially disappointing in light of the original goal to find a relevant stimulus parameter for controlling or increasing the magnitude of the effect. However, some work by Schiller (1969 - unknown to this writer at the time of this research) and a 19-experiment report by Turvey (1973) established rather conclusively that relative energy level between mask and target is a totally irrelevant dimension for "central" (cortical) visual masking - via the dichoptic procedure. The parameters that do influence cortical masking will be discussed in later sections. On the other hand, they find that "peripheral" (retina and neural pathways leading to the visual cortex) visual masking is most dependent on the relative energy level between mask and target - via the monoptic paradigm (the brighter the mask in relation to the target, the stronger the effect). The failure to find group differences in this experiment supports, in view of the above findings, the thesis that the observed masking was central (and therefore <u>inter</u>hemispheric in this case) rather than peripheral.

Briefly, two additional aspects of the between-groups comparison deserve mention. For Groups I, III, and IV, mask intensity was held constant while target intensity was decreased by 50% increments. One might predict that the effect of halving target intensity might simply be that of requiring a doubling of the target exposure time required to maintain threshold responding levels. This statement is a parallel to Block's law which states that the time and intensity of a <u>light flash</u> required to produce a constant visual effect are reciprocally related. What was not known, of course, was whether the same relationship would apply to the <u>detection of information</u> from briefly exposed targets. If the law does hold, then the total stimulus energy of the target would remain constant as well as the mask-to-target ratio for Groups III and IV when compared to I. Examination of the mean target exposure time required to maintain threshold for Groups I, III, and IV (column 5, Table 1) reveals that for Groups I and III the law holds approximately; but not so well for the I and IV or the III and IV comparisons. A possible explanation for this could be that if the light intensity of the bulbs was still rising over the time intervals used, then a longer exposure would also be a more intense one.[1]

For Groups I and II, target brightness was held constant while mask brightness was decreased by 50% of the mask - target difference. The numbers in column 3 (Table 1) show that over-all masking was somewhat less for Group II (not significant) than for any other group which suggests, according to the findings of Schiller (1968) and Turvey (1973), that some small percentage of the variance attributable to masking may have been "peripheral." The most plausible peripheral effect in this experiment would be that due to stray illumination within the eyeball. (Lateral inhibition is discarded because of the large separation retinally between mask and target.) Nevertheless, target exposure time to maintain threshold remained unchanged, and more important, the differential effect between hemispheres (column 4, Table 1) did not change. Obviously, it is difficult to account for the differential masking effect with a peripheral hypothesis.

## Error analysis 1

Central neurophysiological or parallel "cognitive" mechanisms that might account for "how" the masking effect is accomplished has not

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[1] Brightness levels of the stimulus fields were measured with bulbs constantly lit.

been a major (though admittedly important) theoretical issue of this paper except for the following implicit assumptions which determined the choice of the masking pattern itself. It was assumed that "cross-field" visual masking could occur relatively early in the succession of central processing stations, that is in the areas immediately succeeding the primary (17) visual projection area (18 and possibly 19). It follows, if we may project Hubel and Wiesel's (1968) findings on the monkey to man, that these areas are still involved in processing the pattern elements of a visual stimulus[1]. Consequently, the selected mask contained pattern elements whose size and density, when superimposed on the target, effectively "broke up" the raw stimulus elements of the target. Alternative masks would, when coded, be those which would produce confusability of sounds, for example, or of meanings, for instance a matrix composed of random alphabetic letters.

From the above, then, it was supposed that "masking" would somehow degrade or decrease the amount of physical stimulus information available from the target pattern. If that is the case, it might be expected that the "quality" of a subject's forced guess when an error is committed might depend on the amount of physical stimulus information available to him, and therefore on whether a particular trial was a mask or no-mask condition. Specifically, it could be hypothesized that of the total number of errors made, the percentage of errors that appear to be dependent on physical stimulus information (report of letters with similar shape

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[1] Not until the infero-temporal cortex has been reached (in monkey), has it been found that receptive fields of individual neurons attain a specificity for stimuli more complex than single lines, bars, and edges. For example, the silhouette of a hand - more specifically, a monkey hand (Gross et al., 1972).

but actually different from the target letters) might be higher under the no-mask as compared to the mask conditions. On the other hand, if masking affected primarily a distraction of attention, say, then errors related to the similarity-in-shape dimension might distribute randomly across mask conditions. It should, however, be emphasized that such an analysis based on confusability of <u>shapes per se</u> does not permit discrimination between central versus peripheral mechanisms as explanatory constructs. It can be argued for example that a perceived decrease in contrast between target and "ground" produced by stray illumination within the eye could account for a decrease in information about target features. Rather, it should support or reject the notion that <u>some</u> process degraded the content of <u>physical stimulus</u> information contained in the target.

For present purposes, then, all errors were divided into two categories: (a) those in which there appeared to be a basis for physical similarity between the letter guessed and the actual target, the stimulus-dependent category; and (b) all others, the stimulus-independent category. The letters classified as stimulus dependent (listed in Appendix B) were selected without prior knowledge of experimental conditions into which they fell[1] and by the following criteria: similarities (judged by the experimenter) based on addition or subtraction of a small number of fragments, e.g. E and B, C and G and O, F and P, etc.; similarities based on "almost alike shapes," e.g. A and H, K and X, U and V; mirror image reversals, e.g. A and V, M and W, S and Z, J and L; and letter pairs which <u>upon examination of the response data</u> showed a high frequency of

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[1] The raw data sheets contained only the target letters, the response letter for each target, and a "right" or "wrong" code for template scoring.

confusability but could also be justified on the basis of some physical similarity between these particular hand-drawn letters, e.g. H and M or W, S and B, R and H, O and U, etc.

For each subject and each "within-subjects" condition the percentage of total errors falling into the stimulus-dependent category were computed. These data averaged across subjects and groups are presented in Table 3. To reiterate, the larger the percentage of stimulus-dependent errors, the greater the stimulus (target) information is presumed to have been received by the subject. Employing this new index as dependent variable, an analysis of variance, identical to that reported earlier in this section, was performed.

Table 3. Percentage of stimulus-dependent errors for left versus right hemisphere and mask versus no-mask conditions averaged for Groups I-IV, percentage decrement produced by the mask, average across hemisphere conditions, and difference in percentage decrement (Error analysis 1)

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) |
|---|---|---|---|---|---|
| Groups I-IV average | no-mask | 50.0 | 42.6 | 46.3 | |
| | mask | 39.4 | 33.4 | 36.4 | 0.4 |
| | % decr. | 21.2 | 21.6 | 21.8 | |

Note. T=target; H=hemisphere; R=right; L=left; % decr.=percentage decrement produced by mask

The results showed that masking produced a 21.8% decrease ($p < 0.001$)[1] in stimulus-dependent errors, and a left hemisphere superiority was obtained ($p < 0.0005$). It was not expected that this index would prove sensitive to left-right field differences. The within-subjects hemispheres X mask conditions interaction term was not significant, but the triple interaction was ($p < 0.005$). All other terms were not significant.

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[1] All significance levels reported for the error analyses are based on the directly obtained F ratios.

The significant triple interaction showed that the hemispheres X masking interaction differed for the varying mask-to-target brightness ratios. Examination of this variation and also the over-all masking effect for the different groups revealed no monotonic changes with increasing or decreasing mask-target brightness ratios.[1]

The above finding that masking produces a significant decrement in the percentage of stimulus-dependent errors supports the hypothesis that the neuronal representation of the visual stimulus elements of the target pattern has been degraded by the mask. Further support for the contention that the present index reflects changes in stimulus degradation derives from the finding that the condition requiring the longer callosal transfer route of target information to the left hemisphere also produced a significantly lower percentage of stimulus-dependent errors.

Error analysis 2

Even though the main effects variables were significant in error analysis 1, the between-groups comparisons made no particular sense, and consistency between subjects was quite poor. Although it is perhaps unreasonable to expect an alternate dependent variable to behave as nicely as the original, it was thought, after reexamination of the original criteria for defining stimulus-dependent errors, that the index might be improved. It was noticed that many letter pairs which were similar on the shape dimension afforded a great deal of confusability on the auditory dimension as well, for example E and B, P and B, M and N, and C and G. A second set of error categories was constructed (Appendix B) in which auditorily confusable letter pairs were eliminated as well as

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[1] Summary tables and the analysis of variance are available in Appendix C.

mirror image reversals and any others which seemed to have a more tenuous shape relationship. The final set of errors that could be classified as stimulus-dependent guesses was reduced from the original 72 to 28 in number.

The results, averaged across subjects and groups appear in Table 4. An analysis of variance[1] identical to the previous one was performed. The findings were, in essence, identical to those of the first error analysis. The masking effect was significant ($p < 0.001$), the left hemisphere superiority was even more significant ($p < 0.001$ compared to the previous 0.005), and the triple interaction remained significant ($p < 0.05$), though less so. The fourth column of Table 4 shows that the difference in percent decrement, right minus left hemisphere, was in the direction that would be predicted by the model and was as large in magnitude, 9.7%, as that obtained with the original dependent variable, probability correct. Nevertheless, the hemispheres X masking conditions interaction was non-significant, and the between-subjects variation was much larger for this index as compared with the original dependent variable.

Table 4. Percentage of stimulus-dependent errors for left versus right hemisphere and mask versus no-mask conditions averaged for Groups I-IV, percentage decrement produced by the mask, average across hemisphere conditions, and difference in percentage decrement. (Error analysis 2)

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) |
|---|---|---|---|---|---|
| Groups I-IV | no-mask | 29.8 | 26.2 | 28.0 | |
| average | mask | 23.7 | 18.3 | 21.0 | 9.7 |
| | % decr. | 20.5 | 30.2 | 25.4 | |

Note. T=target; H=hemisphere; R=right; L=left; % decr.= percentage decrement produced by mask

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[1] available in Appendix D

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Recent writers have offered some interesting speculations about the nature of the visual masking process. Turvey (1973) reviews two kinds of masking processes originally elucidated by Kahneman (1968), both of which have received wide support. The first view is that the mask mixes with the "sensory" information of the target stimulus. "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" (Turvey, 1973). This is the integration hypothesis. The second, or interruption hypothesis, states that the (usually aftercoming) mask simply terminates central processing of the target by occupying, so to speak, the same processors. In essence, the time needed to completely process the target has been cut short. While Turvey stipulates that these hypotheses need not be mutually exclusive, he views the integration process as being primarily a function of "peripheral" mechanisms and interruption as a function of "central" processes. He supports these views by the following argument: masking by interruption should depend primarily on stimulus onset asynchrony (SOA) or the onset-onset time relationship between target and mask, whereas integration should more likely be controlled by relative stimulus energies of target and mask. He then proceeded to demonstrate that SOA primarily affected central masking (via the dichoptic paradigm) and that relative mask-target energy levels affected only peripheral masking (via the monoptic procedure). Neither variable was effective with the alternate procedure (within the range of time and energy relationships employed).

Though relevant to the question of masking <u>mechanism</u> introduced earlier, the basic model with which the above issues are concerned is backward masking - a paradigm most useful for the study of information processing. The model of this paper (as presented so far) differs slightly in that it is concerned only with the limiting case of backward masking, that is, simultaneous or overlapping coexistence of target and mask representation in the central processors. The question of interruption in central mechanisms presently gives way to one of integration, and it is now obvious that the position taken for the present model (and supported by the error analysis) is an integration hypothesis. The concept of masking by integration requires that the iconic storage of the target be contaminated at the input stage by sensory information from the mask (Turvey, 1973) and, in the present case, it must be effected centrally by separate neural input pathways. Can such a position be rationalized on the basis of present neurophysiological knowledge of the visual system?

Recent work by Schiller (1968) provides a plausible explanation. In this study, he attempted to find electrophysiological correlates to the visual masking process by measuring responses of single neurons in the lateral geniculate nucleus and of binocularly driven cells in area 17 of the cat's visual cortex. After plotting the receptive fields of individual neurons and studying their response to the target and then target plus mask, he found that by making the contours of the pattern mask more and more similar to those of the target, the cells failed to respond differentially to the two stimuli in combination. In other words, the target lost its separate "identity" in terms of the response characteristics of the cell. His conclusion: "Pattern masking is brought about primarily by a failure of units, whose receptive fields lie near the contours of the figure, to respond differentially to target plus mask and mask alone. It appears that this effect may take place either cortically or at earlier levels in the visual pathway depending on the mode of stimulus presentation. Under dichoptic conditions, the effect occurs at the cortical level, while under monoptic or binocular conditions it may take place earlier." (Schiller, 1968, p. 162.)

Behavioral evidence supporting a central (cortical) masking-by-integration hypothesis comes from this experiment, of course, and the studies by Schiller (1965) and Turvey (1973). As discussed earlier, Schiller found that dichoptic masking, while successful with a pattern stimulus, was ineffective when a bright flash of light was used as mask. Further, Turvey (1973) was unable to obtain a dichoptic effect with a random dot noise pattern. Only when the contours of the mask were redesigned to simulate the contours of his target letters (a random array of short straight lines with approximately the same thickness as the target letter features), was he able to obtain a dichoptic effect. These observations, then, that structural stimulus similarity between mask and target are critical for dichoptic masking, support the concept of "sensory" integration of stimulus elements at the cortical level.

# Chapter 3: EXPERIMENT II

The results of Experiment I failed to satisfy one of the goals set for this series of experiments, that was to find a physical stimulus parameter that would control the magnitude of the differential cross-field masking effect. While the differences in mask-target energy levels failed to influence masking, this finding ironically (on the basis of unknown, Schiller, 1968, or unavailable, Turvey, 1973, research) supported the hypothesis that the obtained effects were central rather than peripheral. The purpose of Experiment II was to investigate the stimulus onset asynchrony (SOA) variable, i. e. the onset-onset relationship between target and mask, as being possibly relevant to the control of the differential cross-field masking effect.[1]

The new model is basically simple in concept. Suppose, for purposes of illustration, that the target and mask intensities to be used are equal and that the callosal transfer time between hemispheres for stimuli of the particular intensity is known to be 8 ms. If the onset of a target in the left visual field precedes the onset of the mask in the right half-field by 8 ms, then their arrival in the left hemisphere should be simultaneous (see Figure 9) due to the additional 8 ms required for the target to transfer from the right to the left hemisphere. For present purposes, the term stimulus arrival asynchrony (SAA) will refer

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[1] The finding of Turvey (1973) that central effects depended only on SOA values (and not on relative energy levels) was not available at the time this experiment was conducted.

to the relative arrival times between two stimuli for a given hemisphere. In the preceding illustration SAA for the left hemisphere is zero. Proceeding now to the right hemisphere, the mask arrives 16 ms after the target (Figure 9) because (a) mask onset was 8 ms later than that of the target and (b) it takes the mask an additional 8 ms to cross from left to right hemisphere. Consequently, the condition that obtains for the left hemisphere is one that simulates the limiting case (maximum effect) for backward masking with a noise pattern (Kahneman, 1968), i.e. simultaneity of target and mask. SAA for the right hemisphere now corresponds to the backward masking paradigm which is known to produce a smaller effect than when SAA is zero (Schiller, 1965; Kahneman, 1968; Turvey, 1973). Backward

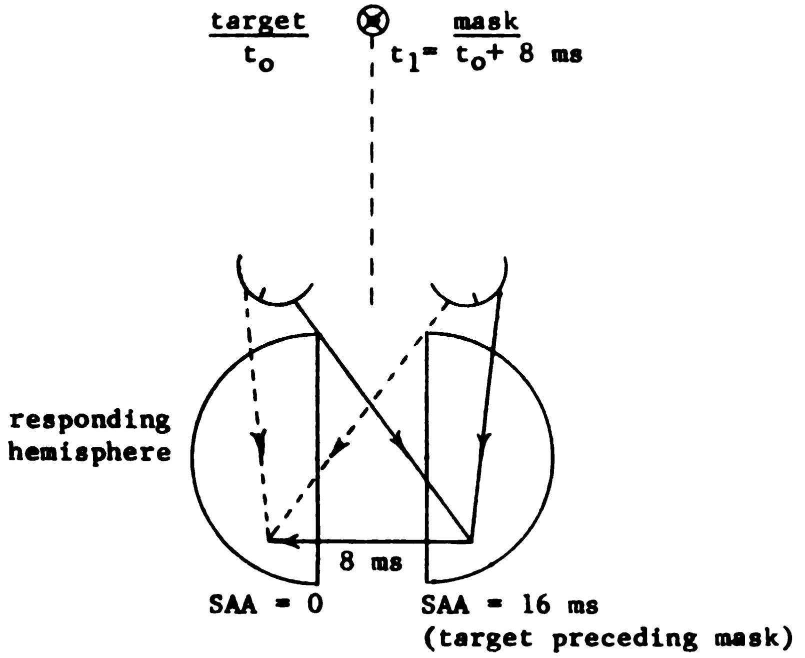

Figure 9. Expected stimulus arrival asynchrony of target and mask stimuli at the two hemispheres for onset of a left-field target preceding onset of a right-field mask by 8 ms with an assumed callosal transmission time of 8 ms. Note. $t_o$ = arbitrary onset time of first (target) stimulus; $t_1$ = onset time of mask; SAA = stimulus arrival asynchrony

masking with noise pattern is a monotonically decreasing function of SOA[1] (Kahneman, 1968).

To follow the same reasoning as with the first model, we also wish to directly assess the relative effect of the 16 ms SAA condition. This is accomplished by reversing the target and mask positions of the above example and maintaining the same target-mask onset-onset relationships (Figure 10). Now, SAA=0 for the right hemisphere, but more important, the mask follows the target by 16 ms in the left or responding

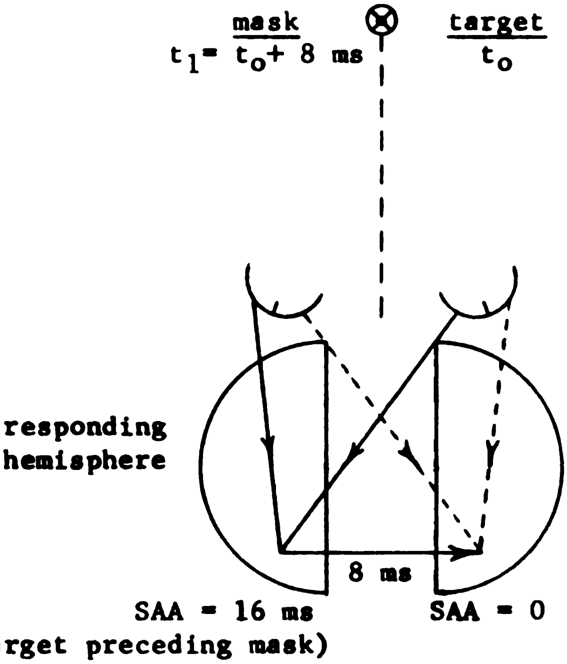

Figure 10. Expected stimulus arrival asynchrony of target and mask stimuli at the two hemispheres for onset of a right-field target preceding onset of a left-field mask by 8 ms with an assumed callosal transmission time of 8 ms.
Note. $t_o$= arbitrary onset time of first (target) stimulus; $t_1$= onset time of mask; SAA = stimulus arrival asynchrony

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[1] In the dichoptic paradigm SOA is considered equal to SAA, as defined here, for stimuli of equal intensities because the pathways are of equivalent length.

hemisphere.[1] The *decrement* in responding accuracy (no mask to mask) should now be less than when SAA=0 for the *responding* hemisphere.

It follows that the conditions of Experiment II should be superior to those of Experiment I for producing the desired differential masking effect. SOA for Experiment I was 50 ms, *mask leading target*. This value is so much greater than any estimates of callosal crossover time (6-10 ms, Efron, 1963; Jeeves & Dickson, 1970) that in effect mask should *overlap* the target timewise in both hemispheres. That is, the mask arrives before, is "on" during, and is present after the brief target representation in both hemispheres. Hence, the only differential advantage would be that due to the predicted difference in signal-to-noise ratios. It is proposed that the conditions of Experiment II superimpose a second advantage over that of Experiment I. With target in the left and mask in the right fields, the low signal-to-noise ratio for the left hemisphere is now combined with the simultaneity of arrival condition for that hemisphere. This pair of conditions (for the left hemisphere) is expected to produce little difference compared to Experiment I since simultaneity is little different from overlap. (Forward masking produces relatively small effects centrally, Kahneman, 1968; Turvey, 1973.) On the other hand, the *high* signal-to-noise condition for the right hemisphere (or for left hemisphere with mask and target positions reversed) is combined with the *asynchrony* in target-mask arrival time, and the combination should produce a smaller masking effect than for Experiment I. The predicted result is a larger *differential* masking effect between hemisphere conditions.

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[1] This hypothesis includes the implicit assumption that transmission time of target information from right to left hemisphere is the same as from left to right - and similarly for the mask.

The strategy for Experiment II was to select what appeared to be the best of the four groups in Experiment I on the basis of differential masking effect, determine the appropriate SOA (to produce simultaneity in arrival at the left hemisphere) for the exact mask-target brightness levels employed for that group, run a new group of four subjects with the new SOA value, and compare the two groups. All conditions for the two groups would be identical except for the different target-mask SOA values. Group III from Experiment I was selected for comparison purposes.[1] All that remained was to determine the appropriate SOA value. The report by Efron (1963a) provided the theory and methodology.

### Determination of SOA value to produce left-hemisphere simultaneity

Efron (1963a) proposes that for two stimuli traversing different neural pathways to be judged as simultaneous in occurrence, they must meet at some common point in the central nervous system. He reviews the research of various investigators dating back to 1912 which shows that (a) estimates of callosal transmission time deriving from various reaction time experiments (stimulus to one hemisphere requiring response of either the ipsilateral or contralateral hand) appear to be on the order of 2-6 ms and (b) when bilaterally symmetrical points of the body are stimulated, the left must precede the right by 2-6 ms in order to be judged as simultaneous for most people. He suggests therefore that the location for the judgment of simultaneity must be the hemisphere that is dominant for

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[1] Time and subject scheduling required that this selection be made prior to the detailed statistical and error analyses. Although the four groups did not differ statistically, it turned out that Group II would have been a slightly better choice. Group II came closest to producing a significant hemispheres X mask conditions interaction term when the groups were analyzed separately, and it produced a larger differential effect under error analysis scrutiny than any other group. However, the overall analysis suggests that for practical purposes, any of the four groups would have sufficed.

speech (the left) since the left-right SOA corresponds to the time required for stimulus information to travel from the right to the left hemisphere. He supported these contentions by showing in his own series of experiments that for right-handers (presumed left hemisphere speech dominant) a visual stimulus flashed to the left field had to precede a stimulus flashed to the right field to be judged simultaneous. But for left-handers (30-40% presumed right hemisphere speech dominant) the right-field stimulus had to precede the left. In a companion paper (Efron, 1963b) he determined that visual stimuli of lower intensity required a longer callosal transmission time than for higher intensity and that for left-right field stimulus pairs of unequal intensity, the SOA requiring a simultaneity judgment could be predicted by algebraic summation (or subtraction) of callosal transmission times for the respective stimuli.

To determine the appropriate SOA value required for Experiment II, Efron's (1963a, pp. 264-265) procedure was replicated on two graduate students - but employing the brightness values used for Group III, Experiment I. The average SOA value obtained would be used as a constant best estimate value for all subjects of Experiment II. It should be noted that for present purposes it is not necessary to obtain the callosal transmission time for the less intense versus the more intense stimulus and then calculate the exact SAA time for the right hemisphere. Rather, it is only required to find the SOA value for the two stimuli to produce simultaneity at the left hemisphere.

Method and results. Two right-handed male graduate students with 20-20 corrected vision and who were experienced at making delicate psychophysical judgments were run as subjects. Both were naive to the purpose of the experiment. The apparatus was that used for Experiment I. The stimuli consisted of two small back-lit circles, one in each visual half-field. The diameter of each circle (prepared by cutting a hole in black light-impervious paper) was identical to the height of the target letters; and their location, equidistant from the fixation point, was identical to that of the target letters which appeared (Experiment I) in the left and right visual fields. The brightness of the left-field circle was always 0.20 ft.l. and of the right was 2.50 ft.l. (the brightness of target and mask respectively of Group III, Experiment I). Each circle would be flashed for a duration of 7 ms.

The procedure employed was (after Efron, 1963a, pp. 264-265) the method of decending limits from alternative directions, i.e. left on first, then right on first. The subject while viewing the fixation point decided which circle came on first by responding "left-first," "right-first," or "same." Each run started with, say, the left preceding the right by 100 ms. For each succeeding trial, the interval was reduced by 5 ms steps until a simultaneity judgment was made. Following this, a new run was started with the opposite stimulus appearing first. For any interval setting, the subject could view the stimuli as many times as he wished before making a judgment. After four practice runs, two from each direction, each left-right descending series was repeated ten times. The starting points were random so as to vary the length of each series.

The average results for the two subjects were 11.5 ms and 9.25 ms respectively - the left coming on before the right to obtain a judgment of simultaneity. The between-subjects mean value of 10.38 ms was the SOA value, target preceding mask, to be used for the four subjects of Experiment II. The SAA value for the right hemisphere must be somewhat less than 2x10.38 ms or 20.76 ms because the two stimuli are of unequal intensity. A reasonable estimate based on Efron's work would place it somewhere between 15 and 20.76 ms.

## METHOD

### Subjects

The subjects were four paid volunteers from the same two undergraduate psychology classes from which the subjects in Experiment I were drawn. All were males, right-handed, as determined by the Crovitz and Zener (1962) questionnaire, and naive to the purpose of the experiment.

### Apparatus

Same as Experiment I.

### Stimulus materials

Same as Experiment I.

### Procedure

The procedure was identical to that of Experiment I except for the following: all subjects obtained the mask-target brightness condition as for Group III of Experiment I, i.e. target=0.20 ft.l.; mask=2.50 ft.l.; onset of the target field preceded onset of the mask field by 10.38 ms for all four stimulus conditions. Consequently, for the "right hemisphere-mask" condition (target to right hemisphere - mask to left), SAA for the left (responding) hemisphere is estimated to be zero, and for the "left hemisphere-mask" condition (target to left hemisphere - mask to right), SAA for the left hemisphere is estimated to be between 15 and 20.76 ms.[1]

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[1] As a limiting condition, it must be greater than 10.38 ms by the amount of time it takes for the high intensity stimulus information to cross the corpus callosum.

## RESULTS AND DISCUSSION

The results for this experiment (Group V) as well as those for Group III, Experiment I, are summarized in Table 5 and the "one between-two within subjects" analysis of variance in Table 6. The nested between-groups factor now represents the different SOA values.[1]

Table 5. Percentage of correct responses for left versus right hemisphere and mask versus no-mask conditions for Groups III and V, percentage decrement produced by the mask, average across hemisphere conditions, difference in percentage decrement, and mean target exposure time at threshold.

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| Group III | no-mask | 67.5 | 57.0 | 62.3 | | |
| SOA=50 ms | mask | 47.0 | 34.8 | 40.9 | 8.6 | 8.3 |
| M before T | % decr. | 30.4 | 39.0 | 34.7 | | |
| Group V | no-mask | 53.3 | 57.3 | 55.3 | | |
| SOA=10.38 ms | mask | 48.8 | 41.8 | 45.3 | 18.6 | 5.0 |
| T before M | % decr. | 8.5 | 27.1 | 17.8 | | |

Note. M=mask; T=target; H=hemisphere; R=right; L=left; SOA=stimulus onset asynchrony; % decr.=percentage decrement produced by mask

Considering first the results of Group V alone (anova not tabled), the difference in percent correct between hemispheres was not significant, the masking effect was significant ($p < 0.025$), and the hemispheres x mask conditions interaction was significant ($p < 0.01$) in the direction predicted by the model. It is noteworthy that this is the only one of the five groups

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[1] Strictly speaking, the design requirements of this analysis were not fully met, i.e. subjects were not randomly assigned to the nested groups. However, since the subjects were drawn from the same classes during the same term, it was not felt that there was any systematic factor that could have influenced the content of the two groups. A better procedure, had it been practical, would have been to include four additional subjects under replicated Group III conditions.

Table 6. Analysis of variance summary based on percentage correct scores for Experiment II (Groups III and V)

| Source | df | SS | MS | F | t |
|---|---|---|---|---|---|
| Total | 31 | 4014.719 | | | |
| Between subjects (S) | 7 | 288.469 | | | |
| Groups (A) | 1 | 13.781 | 13.781 | 0.301 (ns) | |
| S/A | 6 | 274.688 | 45.781 | | |
| Within subjects | 24 | 3726.250 | | | |
| Hemispheres (B) | 1 | 331.531 | 331.531 | 3.303 (ns) | |
| AB | 1 | 195.031 | 195.031 | 1.943 (ns) | |
| SB/A | 6 | 602.188 | 100.365 | | |
| Mask conditions (C) | 1 | 1968.781 | 1968.781 | 57.291 | 7.569*** |
| AC | 1 | 258.781 | 258.781 | 7.531° | |
| SC/A | 6 | 206.188 | 34.365 | | |
| BC | 1 | 81.281 | 81.281 | 12.288 | 3.506** |
| ABC | 1 | 42.781 | 42.781 | 6.468 | 2.543* |
| SBC/A | 6 | 39.688 | 6.615 | | |

°$p < 0.05$ (two-tailed)
*$p < 0.025$ (one-tailed); **$p < 0.01$ (one-tailed); ***$p < 0.0005$ (one-tailed)

which produced a significant hemispheres X mask conditions interaction when analyzed separately (on the basis of four subjects).

The most important comparison for the issues of Experiment II is made in column 4, Table 5. It is seen that the difference in percentage decrement right minus left hemisphere increases from 8.6 to 18.6 with the change in the SOA parameter. To reiterate, the above index is a summary number which expresses the magnitude and direction of the double interaction (hemispheres X mask conditions). The significance of the change in that index between groups is therefore expressed by the triple interaction term of Table 6 which is significant at the 0.025 level (one-tailed).

However, the manner in which the change in the double interaction (i.e. the triple interaction) occurs is also important for present issues.

It was predicted that the primary change would be produced by a smaller masking effect resulting from the SAA of 15 - 20.76 ms or backward masking condition at the left hemisphere for the target-to-left h. mask-to-right h. condition. The third row for each group (Table 5) shows that this was the case.

Perhaps a more lucid picture of this change, and the nature of this one-tailed test of the triple interaction term can be given in the following manner: for each subject we can find the difference between his "no mask" and "mask" percent correct score for each hemisphere (the larger the difference, the larger the masking effect). The average of those differences, across subjects, appears in Table 7 (these values can also be obtained by direct subtraction of the means in Table 5). A decrease from 22.3% to 15.5% is obtained for the "right hemisphere" condition, while a much larger decrease in masking effect, from 20.5% to 4.5%, is observed for the "left hemisphere" condition. The triple interaction has now been reduced "in form" to a double interaction. The one-tailed test of the orthogonal comparison of these four means, based on the a priori

Table 7. Average difference in percentage correct scores, between no-mask and mask conditions, for left and right hemisphere versus two "stimulus-onset-asynchrony" conditions

| | T to left H | T to right H |
|---|---|---|
| Group III<br>SOA=50 ms<br>M before T | 20.5 | 22.3 |
| Group V<br>SOA=10.38 ms<br>T before M | 4.5 | 15.5 |

Note. M=mask; T=target; H=hemisphere; SOA=stimulus onset asynchrony prediction that the largest change in masking occurs in the "left hemisphere - mask" condition, is made in Table 8 (after Myers, 1967, p. 344). Note that the F and t values in Table 8 are identical to those for the triple interaction term in Table 6.

Table 8. One-tailed orthogonal comparison test of the interaction between hemisphere and stimulus-onset-asynchrony conditions based on the average difference in percent correct scores (no-mask minus mask conditions)

| Source | df | SS | MS | F | t |
|---|---|---|---|---|---|
| p(A) x q(B) | 1 | 85.563 | 85.563 | 6.468 | 2.543* |
| S x q(B)/A | 6 | 79.375 | 13.229 | | |

*$p < 0.025$

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Note. A=groups; B=hemispheres; S=subjects

From Table 6 a significant groups X masking (AC) condition interaction effect was also obtained. Columns 3 and 5 of Table 5 show that this interaction is due to a decrease in the overall masking effect from a 34.7% decrement to a 17.8% decrement with a change in the SOA parameter. Also, the average target exposure time required to maintain threshold decreased from 8.3 to 5.0 ms. Clearly, the targets were more detectable with target preceding mask by 10.38 ms. While most of this change is reflected by the predicted decrease in masking for the left hemisphere condition, a notable but smaller decrease from 22.3% to 15.5% (Table 7) was obtained for the right hemisphere condition as well. This result could possibly be accounted for by the elimination of the forward masking component of the total masking effect when the mask-target overlap condition of Group III is changed to the SAA=0 condition in Group V (for the right hemisphere condition). While a central forward masking effect does exist (Turvey, 1973), it is probably too small to totally account for the above change.

What would seem to be a more likely hypothesis is that a possible alteration in peripheral phenomena produced a small but equal decrease in masking effect for both hemisphere conditions. As mentioned previously, stray illumination within the eyeball is, for this paradigm, the most likely source of peripheral interference between mask and target. (See Bartley & Fry, 1934; Bartley, 1935; Boynton et al., 1954, for a discussion of stray illumination phenomena.) This possibility seems especially likely in the context of present experiments because of the semi-dark adapted state of the eyes. However, the effect, whatever its magnitude, is expected to be equal with regard to the left or right hemisphere conditions described here.[1] If we now compare the stimulus conditions of Group III with those of Group V, it can be seen that they differ greatly with respect to possible stray illumination effects. For Group III, the onset of the 200 ms mask preceded that of the target by 50 ms so that for both eyes, stray light was physically present during target exposure. For Group V, however, target onset preceded mask onset by 10.38 ms and the average target exposure time was 5.0 ± 1.3 ms. Consequently, stray illumination from the mask could not have become physically present until approximately 5 ms after offset of the target. In effect, whatever consequence that could have resulted from stray light would have had to be due to "backward masking" by stray illumination with an interstimulus

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[1] The only laterality difference known to exist in the visual system prior to the cerebral cortex is the difference in transmission efficiency of the nasal versus the temporal hemi-retina of each eye. This variable is, of course, held constant in the experiments reported here because both eyes are stimulated at the same time during any one stimulus condition. A stimulus appearing in the left visual field, for example, stimulates the temporal hemi-retina of the right eye and the nasal hemi-retina of the left.

interval of 5 ms. In sum, it is proposed that for Groups I to IV, a percentage of the total masking variance may have been due to stray illumination and that it made an equal contribution to both left and right hemisphere conditions. Thus stimulus conditions for Group V were such as to considerably reduce the magnitude of a possible stray illumination effect while producing an increase in the central differential effect by controlling the SAA intervals for the two hemispheres.

The general goals of the first two experiments were to establish the tenability of the predicted left-right hemisphere differential masking effect and to identify the stimulus parameters that might be relevant to increasing that effect. Both experiments provided statistical confirmation of the effect although its magnitude must, admittedly, be considered "small." Experiment I failed to show that mask-target brightness relationships influenced either the overall or the differential masking effect. The results of Experiment II established that the desired differential effect could be increased by manipulation of the SOA parameter and therefore the arrival-arrival intervals of target and mask information at the two hemispheres. If it is assumed that the effects observed in these experiments are "central" in origin, then the above findings are in total agreement with Turvey's (1973) extensive analysis of peripheral and central masking processes. Turvey found that masking via presumed peripheral mechanisms was very insensitive to the SOA parameter while for "central" masking, via the dichoptic paradigm, it was most crucial. Experiment II is in agreement with those findings. On the other hand, his finding that relative mask-target energy levels influenced only "peripheral" but not "central" masking is in agreement with the results of Experiment I.

While Experiments I and II were concerned with attempts to increase the magnitude of the phenomenon, the remaining experiments deal in a more direct manner with some theoretical issues about the neural mechanisms involved. Experiment III tests the assumption about interaction between mirror-symmetric heteronymous areas of the visual half-fields, and Experiment IV assumptions about single cell properties of the neural substrate (and therefore the stimulus characteristics of the mask), potentially responsible for the central masking effect.

# Chapter 4: EXPERIMENT III

In the general introduction to this study it was proposed that the potential mechanism responsible for producing a masking effect between the hemispheres was that which provided for continuity between the left and right half-fields of vision and which also may be responsible for stereoscopic vision along the vertical meridian, i.e. the interhemispheric connections through the spleneum of the callosum from areas 17 to 18 and 19. One of the features of this system as described by Bishop and Henry (1971) and Blakemore (1970) is that the hemispheric (stereoscopic) interaction depends on stimulation of corresponding heteronymous retinal areas. The rationale for this requirement can easily be seen by the following example. For a human fixating on some object in his environment, objects which fall in front of or behind his point of fixation but to his left or right side project either to his left or right hemisphere. Information from the disparate images of the two eyes have a common meeting point (i.e. can fire a common cell) in area 17 of the contralateral hemisphere. (See Bishop, et al., 1971, for a discussion of how binocular interaction is coded by these units.) On the other hand, objects which lie immediately in front of or behind the fixation point along the vertical meridian stimulate corresponding heteronymous areas of the two retinae and hence project to separate hemispheres (refer to Figure 4). A stereopsis effect resulting from this particular kind of interocular disparity would, so the argument goes, have to result from a combining of coded information from both hemispheres via the corpus callosum. The earliest possible site for such an interaction is, of course, the 18 side of the 17-18 border. As discussed in the general introduction, the behavioral support for this contention was provided by Blakemore's (1970) study of a patient with a sagittal section of his optic chiasm, and neurophysiological evidence came from Berlucchi and Rizzolatti's (1968) demonstration that cells in the appropriate part of area 18 could only be binocularly driven from corresponding heteronymous areas (see Figure 5).

If this mechanism is responsible, at least in part, for the cross-field visual masking phenomenon (which artificially simulates the above stimulus conditions), it ought to be possible to show a difference in masking effect produced by masks which are presented in corresponding versus non-corresponding heteronymous areas in relation to the target stimulus. This was the goal of Experiment III.

In order to define corresponding versus non-corresponding visual areas within the confines of the maximum stimulus field dimensions available in the tachistoscope used (2.13° wide x 2.90° high per visual half-field after central occlusion for possible naso-temporal overlap), it was necessary to substantially reduce the area of the noise pattern used to about 1/10th the original size so that mask location could be varied. The scheme for varying the location is depicted in Figure 11 for the right field mask conditions. The geometric center of each mask is the same distance from fixation as is the target on the opposite side. The mask in position M-2 is considered the corresponding heteronymous location while those in positions M-1 and M-3 are defined as falling in non-corresponding heteronymous locations. The large mask (M-L), comprising the entire visual half-field on either side, as well as the no-mask conditions were retained for control purposes.

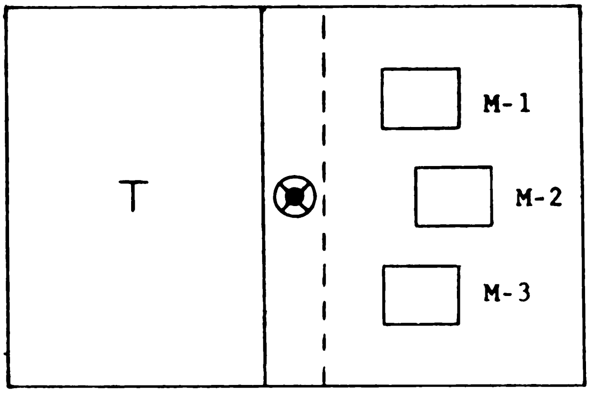

Figure 11. Corresponding and non-corresponding heteronymous mask locations for the right-field (left hemisphere) mask conditions.
Note. M-2 = corresponding; M-1 & M-3 = non-corresponding

The predictions are that the small M-2 mask will produce the same differential masking effect obtained in the earlier experiments but that the "overall" effect (across left-right conditions) will be smaller than that produced by the large mask due to a decrease in stray illumination or possibly due to a decrease in total retinotopic projection area represented in the visual cortex. Masks M-1 and M-3, while providing equivalent extrafoveal stimulation, should produce a much smaller or no effect compared to mask M-2 because they project to non-corresponding heteronymous areas.

## METHOD

### Subjects

The subjects were four paid graduate students in non-perception areas of experimental psychology at Michigan State University. All were right-handed males with 20-20 or better corrected vision in each eye and naive to the purpose of the experiment.

## Apparatus

Same as for previous experiments.

## Stimulus materials

The set of 100 target letters used in the previous experiments were retained unaltered as well as the no-mask and large mask stimuli. The small masks were prepared by photographing a cropped version of the original noise pattern so that the entire stimulus slide was "black" except for the mask appearing in its appropriate location. Six sets of the new mask stimuli were prepared, three with masks appearing in the M-1, M-2, or M-3 positions in the right visual field (see Figure 11), and three for the same positions in the left field. The dimensions of each small mask were $0.85^{\circ}$ in width by $0.74^{\circ}$ in height - a little more than twice the height and width dimensions of the target letters and approximately 1/10th the visible area of the large (M-L) masks. The geometric center of these masks fell on an imaginary circle with a radius of $1.7^{\circ}$ measured from the fixation point (the same distance as the target centers from the fixation point). The angular elevation of the M-1 masks (left or right field) was $38.2^{\circ}$ from the horizontal and depression of the M-3 masks from horizontal was of the same magnitude.

The masks M-1 and M-3 together comprise the stimuli for the non-corresponding mask condition. Consequently, there were half as many M-1 or M-3 slides (25 each for each field) as there were M-2 slides (50 for each field). As a result, the total number of stimuli for each condition (non-corresponding, corresponding, no mask, and large mask) was the same.

## Procedure

The general procedure was the same as that for the preceding experiments except as noted below. The mask-target brightness ratios and the controlled SAA conditions were the same as for Group V (that group having produced the best results) except that the appropriate SOA value was independently determined for each subject by the psychophysical procedures described in Experiment II.

The four within-subjects conditions defining the previous experiments have here been expanded to eight. They included the no-mask, large mask, non-corresponding small mask, and corresponding small mask conditions for both the left and right visual half-fields. The randomizing and counterbalancing procedures for presentation of target and mask stimuli were the same as described earlier. Any one of the (now 4) 100-slide rototrays (for masking) contained either 12 or 13 stimuli for each of the eight conditions. Administration of two 100 trial sets gave the subject 25 trials for each of the eight conditions with each of the 25 target letters appearing once per condition. Excluding Day 1, which was used for the psychophysical determination of a subject's SOA value, a subject received 200 trials per day on each of four separate days (usually within one calendar week). Consequently, the four different sets of 100 masking stimuli were administered twice but in reverse order. In sum, each unfortunate subject received a total of 100 trials for each of the eight conditions.

## RESULTS AND DISCUSSION

The percentage of correct responses averaged across subjects for each of the eight conditions appear in the first two columns of Table 9. The averages across hemispheres for each of the masking conditions are tabulated in column 3. Results of the 2 x 4 within-subjects analysis of variance are summarized in Table 10.

Table 9. Percentage of correct responses for left and right hemisphere conditions as a function of the no-mask, large mask, small corresponding, and small non-corresponding mask conditions of Experiment III (Group VI)

| | T to left H | T to right H | average across H |
|---|---|---|---|
| no mask | 49.5 | 53.0 | 51.3 |
| large mask (M-L) | 38.8 | 37.0 | 37.9 |
| small mask (M-2) | 48.3 | 50.3 | 49.3 |
| small mask (M-1-3) | 47.5 | 54.8 | 51.1 |

Note. T=target; H=hemisphere; M-2=corresponding; M-1 and M-3=non-corresponding

Table 10. Analysis of variance summary based on percentage correct scores for Experiment III

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 31 | 1377.500 | | |
| Hemispheres (A) | 1 | 60.500 | 60.500 | 3.924 (ns) |
| Mask conditions (B) | 3 | 982.750 | 327.580 | 26.568 ($p < 0.001$) |
| Subjects (S) | 3 | 40.750 | | |
| AB | 3 | 83.250 | 27.750 | 4.711 ($p < 0.05$) |
| AS | 3 | 46.250 | 15.420 | |
| BS | 9 | 111.000 | 12.330 | |
| ABS | 9 | 53.000 | 5.890 | |

A difference between masking conditions (averaged across hemispheres) was obtained ($p < 0.001$), but examination of column 3, Table 9, reveals that the effect was attributable entirely to the effect of the original "large" mask. Percentage correct for the no-mask, small corresponding, and small non-corresponding mask conditions was 51.3%, 49.3%, and 51.1% respectively, while for the "large" mask it was 37.9%. Table 11 shows the result of all possible multiple comparisons between masking conditions (by the method of Scheffé). All paired comparisons of each condition with the large mask condition proved significant, while comparisons of the other conditions with each other were not. Clearly, in terms of "overall" masking effect, the small corresponding and non-corresponding mask conditions did not differ, and in fact neither of the "small" mask conditions produced any effect at all.

Table 11. Statistical tests of the paired comparisons of all possible combinations of masking conditions (averaged across hemispheres) for Experiment III by the method of Scheffé

| | | | | |
|---|---|---|---|---|
| no mask | -- | | | |
| M-L | $p < 0.05$ | -- | | |
| M-2 | ns | $p < 0.05$ | -- | |
| M-1-3 | ns | $p < 0.05$ | ns | -- |
| | no mask | M-L | M-2 | M-1-3 |

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Note. M-L=large mask; M-2=small corresponding mask; M-1-3=small non-corresponding masks

The results in terms of the differential masking effect (hemispheres X mask conditions interaction) were similar. Although the overall hemispheres X mask conditions interaction term was significant ($p < 0.05$), examination of any two rows (within the rectangle) in

Table 9 or of the breakdown in Table 12 showing all possible interactions, reveals that none of the interactions of interest were significant. The no-mask versus large mask interaction was in the direction predicted by the model but non-significant, and the non-significant no-mask versus the M-2 mask interaction was in the direction predicted by the model, but so small in magnitude (2.7% difference in percent decrement) as to be totally inconsequential. The only interaction proving significant, the large versus small non-corresponding mask conditions, is both unexplainable and unimportant in terms of present considerations.[1] In sum, the hypothesis of "no difference" between corresponding and non-corresponding heteronymous mask locations (as here defined) cannot be rejected, and some aspect of the *size* difference between these particular "large" and "small" masks seems to have been crucial for obtaining the cross-field masking effect.

Table 12. Statistical tests of the two-way interaction effects between left-right hemisphere conditions and all possible pairs of mask conditions for Experiment III by the method of Scheffé

| | no mask | M-L | M-2 | M-1-3 |
|---|---|---|---|---|
| no mask | -- | | | |
| M-L | ns | -- | | |
| M-2 | ns | ns | -- | |
| M-1-3 | ns | $p < 0.05$ | ns | -- |

Note. M-L=large mask; M-2=small corresponding mask; M-1-3=small non-corresponding masks

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[1] A comparison of rows 1,2, and 4 of Table 9 shows that the M-1-3 mask condition deviated "away from" the large mask condition in the same direction as did the no-mask condition - only *slightly more so* for some reason. The fact that the small M-1-3 masks did not differ from the *no-mask condition*, either in term of the overall or the differential interaction effect (as neither did the large mask condition), renders the obtained "significant" interaction to a position of little theoretical importance.

Before discussing the implications of these findings, it is important to note the result of some methodological differences between this and the previous experiments. The effects obtained for the control (no mask and large mask) conditions were considerably different from those obtained for Group V, Experiment II, even though the stimulus parameters and mask sizes were the same. Principally, the magnitude of the differential masking effect, right minus left hemisphere, was much smaller at 8.6% than the 18.6% value obtained for Group V. The only controlled difference between the two situations is that for Experiment III the no-mask and large mask conditions were "imbedded" within the two additional within-subjects conditions. The writer speculates that the above result is due to the effect of more extended "practice" made possible by Experiment III. The comparison between any subset of four conditions, based on x number of trials per condition, involves the administration of twice the total number of trials under the conditions of Experiment III as compared with Experiment II. The first point is that, as mentioned earlier, left-right field differences obtained for many repeated exposures of single alphabetic letters under the no-mask condition are not especially reliable.[1] This was observed during pilot work for those studies which involved administration of 400 - 1,000 trials to some subjects. More significant support, however, stems from Schiller's (1965) research which systematically investigated the effects of practice on masking. He found that the effect of central masking by noise pattern (via the dichoptic procedure) considerably decreased with practice over

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[1] The reasons for this may involve a possible shift in the mode of processing these highly overlearned pattern stimuli under conditions of extended practice. Such shifts are known to occur (Grill, 1971) under practice and they may relate to hemispheric differences in the pre-verbal pattern recognition stages of processing.

trials and days. On the other hand, masking by the monoptic procedure, which favors interaction by peripheral mechanism, was most insensitive to practice effects. It would seem that as we go from peripheral to more central neural mechanisms, there is an increased "adaptability" to adverse stimulus conditions.

Having employed the control conditions as "yardstick," it would seem, then, that Experiment III was not optimally designed to measure small changes. Spreading a given number of observations too thinly over so many within-subjects conditions seems to have favored a greater influence by unwanted (for present purposes) practice effects. Employment of more complex stimuli (e.g. words) would, of course, help alleviate this problem since the larger field differences obtained (Kimura, 1973) can be reliably measured with a smaller number of observations.

In light of the above, it was decided to substantiate or recheck the unexpected finding that the small mask (M-2), in the corresponding heteronymous location, has no effect by replicating part of Experiment III under conditions identical to the preceding experiments. Three additional subjects were run under the same conditions as Experiment V (four within-subjects conditions at 100 observations per condition, mask = 2.40 ft.l., target = 0.20 ft.l., SOA = a constant 10.38 ms for all subjects) except for replacement of the large mask by the small M-2 mask. The results for each subject are shown in Table 13. Subject J.B. showed no masking effect at all. The remaining two subjects produced a miniscule effect but in both cases the effect obtained resulted from their performance on the first 100 trials only. No effect was produced on the last 300 trials by any subject. Though a small practice effect is in evidence here, the inescapable conclusion is that the "small area" M-2 pattern is an ineffective cross-field masking stimulus.

Table 13. Percent correct responses for left-right and mask - no-mask conditions for three individual subjects receiving only the small "corresponding" mask stimulus, percentage decrement produced by the mask, average across hemisphere conditions, difference in percent decrement, and mean target exposure time at threshold

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| Subject J.B. | no-mask | 55.0 | 40.0 | 47.5 | | |
| | mask (M-2) | 56.0 | 41.0 | 48.5 | -0.007 | 5.1 |
| | % decr. | -0.018 | -0.025 | -0.022 | | |
| Subject J.E. | no-mask | 42.0 | 53.0 | 47.5 | | |
| | mask (M-2) | 38.0 | 48.0 | 43.0 | -0.1 | 5.7 |
| | % decr. | 9.5 | 9.4 | 9.5 | | |
| Subject J.H. | no-mask | 50.0 | 54.0 | 52.0 | | |
| | mask (M-2) | 48.0 | 46.0 | 47.0 | 10.8 | 3.5 |
| | % decr. | 4.0 | 14.8 | 9.4 | | |

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Note. All other stimulus conditions the same as for Group V. M-2=small mask in corresponding heteronymous location; T=target; H=hemisphere; R=right; L=left; % decr.=percentage decrement produced by mask

Failure to find a difference between corresponding versus non-corresponding heteronymous mask locations for these particular stimuli has two possible explanations. Either there <u>are</u> no "true" differences or the hypothesis was not adequately tested by Experiment III due to the fact that mask M-2 was ineffective. The test of the above hypothesis was, of course, predicated on the assumption that simply reducing the area of the "large" corresponding heteronymous mask would not have the effect of erasing the phenomenon. Obviously there must be a phenomenon before <u>differences</u> can be measured. Consequently, the position taken here is that the corresponding versus non-corresponding issue has not been adequately tested.

The question of central importance now becomes: "Why did reduction in area eliminate a measurable effect?" Reduction in total <u>energy level</u>

per se (i.e. reduction of the total light flux - not flux density) by reducing the area of the large mask does not seem a plausible explanation for elimination of the effect. The findings of Experiments I and II which are in agreement with those of Turvey (1973) simply do not support such a contention. Experiment I showed that varying the energy level by controlling brightness had negligible effects on the phenomenon; and Experiment II showed that, although the "overall" effect could be lessened by a set of timing conditions which substantially reduced the potential interplay by peripheral mechanisms, the basic phenomenon remained intact and even improved in terms of the "differential" criterion. In consequence, it seems that alteration in total area of retinotopic projection (of the mask) to the visual cortex would be a more likely accounting.

Upon reconsidering the work of Berlucchi and Rizzolatti (1968) and Hubel and Wiesel (1965), it was realized that a serious error may have been committed by trying to imitate one feature of Schiller's dichoptic masking experiments. The size of his masking pattern was about 1½ times the size of his single target letters, and so it was assumed that for Experiment III masking patterns a little more than twice the length and width dimensions of the targets would be adequate. However, there is a very important difference between the dichoptic and cross-field visual masking paradigms: the probable masking sites within the visual cortex and the response characteristics of the cells populating those sites. It will be remembered that for the dichoptic procedure corresponding homonymous areas of the two retinae are stimulated and the first central location where the interocular information can meet at a common point is area 17 (where single cells can be binocularly activated or inhibited). Area 17 is most densely populated with "simple" cells which have the characteristic of being, for all practical purposes, "point specific;" that is the width of the receptive field sizes is on the order of ½° or less (rhesus monkey, Hubel & Wiesel, 1968). This means that if the edge, bar, or line is moved by more than, say, ½° in a direction orthogonal to the preferred stimulus orientation, the cell ceases to be activated. In light of this, it is easy to see why a mask pattern only 1½ times the size of the target is a more than adequate interference stimulus in area 17 (in terms of optimally stimulating the relevant projection area).

For the "cross-field" paradigm, on the other hand, area 18 is the first possible meeting site for stimulus information deriving from corresponding heteronymous areas (see Figure I). Area 18 is most densely populated with "complex" cells, and their receptive fields are many times larger. In Berlucchi and Rizzolatti's (1968) split-chiasm cat experiment all cells in area 18 that could be binocularly driven through the corpus callosum (from corresponding heteronymous retinal areas) (a) were "complex," (b) had receptive fields which always extended to the vertical meridian, and (c) had receptive field sizes which ranged from 1 x 2° to 9 x 9°. The properties of a complex cell are briefly as follows: a line of proper orientation with length x (where x is smaller than the length or width dimension of the receptive field) will fire the cell when moved anywhere within the receptive field of that cell.[1] Furthermore, Hubel and Wiesel (1965) observe that increasing the length of the line up to the boundaries of the receptive field continuously increases the response of the cell. Increasing the length beyond the receptive field boundary has no additional effect.

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[1] Hubel and Wiesel speculate that this characteristic of complex cells may be a means of providing a stable image representation from eyes that are continuously in motion.

Based on these facts, it is quite plausible that a mask pattern whose area is considerably smaller than the receptive fields of the cells occupying the presumed masking site will stimulate those cells less than would a pattern of larger area. Receptive field sizes of complex cells in man can, at present, only be estimated from data on the rhesus monkey. Hubel and Wiesel (1968) find those sizes to be about 1/4th the size (in linear dimensions) of those of the cat which would make them on the order of about 2 1/4° x 2 1/4° for the larger ones. The dimensions of the small mask used in Experiment III were 0.85° x 0.74° while dimensions of the larger one were (quite fortuitously) 2.125° x 2.9°. Also, the small masks did not extend as close to the vertical meridian as did the large ones - another receptive field property of the binocularly driven complex cells found by Berlucchi and Rizzolatti (1968). The above contentions could at least be supported by conducting an experiment which systematically varied mask area while holding total brightness level constant. If the above is tenable, then masking effect should be found to be an increasing monotonic function of increasing mask area up to some optimal point and then asymotote for larger sizes. The "near zero" point on the curve has obviously been demonstrated by Experiment III.

Before concluding, we must return briefly to the corresponding versus non-corresponding areas issue. If in fact the receptive field sizes of the binocularly driven complex cells in area 18 are on the order of 2° x 2° or greater, then the masks M-1-2-3 each stimulated a part of the same corresponding heteronymous area, neurologically speaking. In other words, the "geometric" definition of corresponding versus non-corresponding for these particular masks and their relative locations may have been irrelevant to the neural processors. If it should turn out that the minimal-sized mask pattern required for producing an effect should extend close to the vertical meridian, then it will be most difficult to directly test the corresponding versus non-corresponding issue. The reason is that it would be impossible to define, within the two-dimensional space of a visual half-field, non-corresponding areas that would provide equal retinal stimulation with respect to their distance from the fovea.

The preceding line of reasoning regarding the role of receptive field sizes of complex cells in area 18 leads to predictions about what might have happened had certain conditions of Experiment III been set up differently. For example, in Experiment III the "white" field area surrounding the target might have been decreased to match the area of the "small" mask. Alternatively, a "white" background surrounding the "small" mask and equal in size to that of the target field could have been used. By the arguments developed above, no masking should occur, because the critical feature in both situations should be the proportion of the receptive field area (for cells in area 18) stimulated by pattern features, not the relative background dimensions of target and mask stimuli. As these combinations have not been tried, future research will have to resolve the validity of these predictions.

Finally, how do these notions stand with the theory of binocular stereopsis for viewing objects along the vertical meridian? What of the concept of corresponding heteronymous points when we are dealing with cells whose receptive field dimensions are sometimes as large as $2^o \times 2^o$? Several comments on this line are in order. First of all, it should be recognized that a $2^o \times 2^o$ area is a very small portion of the total visual field. Secondly, real life objects that may fall along the vertical meridian defined by the fixation point are not themselves dimensionless points but occupy some space across the meridian. Thirdly, such objects may deviate slightly to the left or right of vertical as a result of being in motion, and fourth, the vertical meridian itself is constantly being re-defined by involuntary saccadic eye-movements. To derive order from such chaos, the requirement of receptive fields which permit cross-field interaction anywhere within a $2^{o}$ x $2^{o}$ space, does not seem extravagant.

The final experiment provides a direct test of the stray illumination hypothesis and of yet another assumption about the properties of the cells involved in the masking interaction.

# Chapter 5: EXPERIMENT IV

Aside from establishing the existence of the cross-field visual masking phenomenon and determining the stimulus parameters which influence its magnitude, a central concern of this paper has been to establish the tenability that the observed "effect" is a result of what the model says it is instead of the result of something else. Specifically, the model predicts a differential masking effect that results from a "central" interaction between hemispheres on the feature content of visual stimuli. The "something else" says that the effect is somehow due to peripheral mechanisms (or from some "higher order" process such as distraction of attention). The peripheral mechanism of greatest concern has been the known existence of stray illumination resulting from the flash of a bright masking pattern. While it has been conceded that stray illumination may play a role in contributing to the "overall" masking effect (which was actually supported by Experiment II), it has been argued that it cannot account for the differential effect. Although various kinds of evidence from Experiments I and II strongly supported the operation of "central" as opposed to "peripheral" mechanisms, the peripheral (or stray light) hypothesis has not been tested directly. It may be that the peripheral mechanism could produce the differential effect in some manner unanticipated by the experimenter. The purpose of Experiment IV was to test the stray illumination hypothesis by replacing the original mask with a stimulus (a) which would provide an equal amount of stray illumination, (b) whose properties are known to produce a <u>peripheral</u> masking effect, and (c) which is purported to have little or no effect on the contour detectors which comprise the neuronal make-up of the visual cortex - that is, diffuse light. In addition, the results of such a test should help confirm or reject the idea that it is the feature detecting system in areas 17, 18, and 19 that is responsible for the differential masking effect predicted by the model.[1]

That the neuronal information processors of the visual cortex are relatively insensitive to stimulation by diffuse light derives support from several sources. As mentioned in the general introduction to this report, Hubel and Wiesel (1965) find that simple, complex, and hypercomplex cells which constitute the neuronal make-up of areas 17, 18, and 19 respond either very weakly or not at all when stimulated by a field of diffuse light. One of the reasons for this, as the theory goes, is that a field of diffuse light simultaneously activates both the excitatory and inhibitory areas of the receptive fields of "dark" and "light" spot detectors which presumably converge their information onto the more complex edge and line detectors. The end result apparently is cancellation of any appreciable neural response.

Behavioral evidence, as also mentioned earlier, is provided by the visual masking experiments of Schiller (1965). Diffuse light was found to produce a considerable peripheral masking effect, as when target and a light flash are exposed to overlapping areas of the same eye (s). However, and

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[1] While it is, of course, not known how this system works to effect the "experience" of pattern recognition, it is indisputable that these single cells detect fragments of visual pattern stimuli. Also, it should be noted that "a few" such cells have been recorded in the visual cortex of man, and they were found to have the simple, complex, and hypercomplex properties originally described by Hubel and Wiesel (Marg et al., 1968).

in sharp contrast to the effect of a pattern, it was found to produce no effect dichoptically; that is, when target and mask information first meet in the "primary" cortical projection area (17). Others (Battersby & Wagman, 1962, and Boynton, 1961) find a "slight" dichoptic effect when target stimuli are near threshold and target and mask borders are in "relatively close" proximity.

Finally, Spehlman (1965) has demonstrated differences in visual cortex responses to diffuse light versus pattern stimuli by the gross evoked potential techniques (EEG-type recordings from surface electrodes on the scalp). Cortical responses (occipital lobe of humans) differed not only in waveform but in magnitude to the two kinds of stimuli. When amount of contour information was varied, he found that magnitude of the evoked responses was directly proportional to the "<u>density</u> of contrast borders" - diffuse light being the low point on the scale.

The above paragraphs should not be taken to imply that the response of the visual cortex to diffuse light stimulation is zero; far from it. A case in point is the "photic driving response" (obtained from scalp electrodes over the occipital region) to strobe-light flashes used in traditional diagnostic electroencephalography. Unfortunately, it is not known what electrical events contribute to such changes in scalp potential. Rather, the point is that this area of the brain appears, in humans, to be restricted to the initial processing and <u>perception</u> of pattern stimuli (see for example Stone & Freeman, 1973). In fact, the "experience" of diffuse light apparently does not <u>depend</u> on the visual cortex at all (cortical ablation and brain damage studies, ibid., 1973).

In a manner similar to Experiment II one of the previous groups was selected for purposes of comparison with the results of the present experiment. In this instance, Group V was chosen because the conditions for that group produced the largest differential masking effect when the noise pattern was used as masking stimulus. Consequently, the procedures and stimulus parameters employed for Experiment IV were identical in every aspect to those of Group V (Experiment II) with the single exception that the noise pattern was replaced with an equally bright diffuse light flash on masking trials. The predictions were that *some* "masking effect" would be produced - hypothetically resulting from stray illumination and possibly cortical mechanisms other than areas 17, 18, and 19; the overall masking effect would be smaller than that produced by the pattern; and the crucial *differential* masking effect would disappear.

## METHOD

### Subjects

The subjects were four paid graduate students in various non-perception areas of psychology at Michigan State University. All were right-handed males with 20-20 or better corrected vision in each eye and naive to the purpose of the experiment.

### Apparatus

Same as for all preceding experiments.

### Stimulus materials

A new set of "masking" slides were prepared which were "black" on one half and transparent on the side which previously contained the noise pattern. Each of the pattern mask slides that were used for Group V (and also Groups I-IV) were replaced on a one for one basis with one of the new slides. Consequently, on a "masking" trial for the present experiment, the subject saw a contourless flash of light (except for the outside rectangular boundaries) in the same location where he had previously seen the pattern mask. The spatial dimensions defining the boundaries of the masking field were, of course, the same. All other stimulus materials and their order of arrangement etc. remained unchanged from what was described for Experiments I and II.

## Procedure

The physical features of the previous pattern mask were such that 50% of the total mask area was "black" and 50% was "white." In order to produce a patternless light flash of equivalent overall brightness, it was necessary to halve the luminance of the masking field.[1,2] This was most easily accomplished by using the same intensity setting for the masking channel that was employed for Group V (i.e. maximum) and inserting a Kodak 0.30 neutral density filter in the masking field. This filter has 50% light transmission characteristics.

Except for the modification just described all other experimental procedures and stimulus parameters, including the use of the constant SOA value of 10.38 ms for all subjects, remained the same as for Group V.

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[1] While it is recognized that the experience of "brightness" is not an absolutely linear function of stimulus intensity, it was felt that the above procedure was a close enough approximation for present purposes.

[2] Halving the luminance or light intensity halves the "flux density" which is equivalent to the average effect (over the entire field) of the 50% black pattern stimulus.

## RESULTS AND DISCUSSION

The results of this experiment (Group VII) and those of Group V, Experiment II, are presented in Table 14. A comparison "one between - two within subjects" analysis of variance[1] is reported in Table 15.

Table 14. Percentage of correct responses for left-right hemisphere and no-mask - mask conditions for pattern versus light flash masking stimuli, percentage decrement produced by masking, average across hemisphere conditions, difference in percentage decrement, and mean target exposure time at threshold

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| Group V | no-mask | 53.3 | 57.3 | 55.3 | | |
| pattern mask | mask | 48.8 | 41.8 | 45.3 | 18.6 | 5.0 |
| | % decr. | 8.5 | 27.1 | 17.8 | | |
| Group VII | no-mask | 50.0 | 57.2 | 53.6 | | |
| light flash | mask | 33.8 | 44.8 | 39.3 | -10.7 | 3.7* |
| | % decr. | 32.4 | 21.7 | 27.1 | | |

*26.0% decrease from 5.0 ms

Note. Brightness and SOA conditions identical for Groups V and VII. T=target; H=hemisphere; R=right; L=left; % decr.=percentage decrement produced by masking

The difference in percent decrement (right minus left hemisphere) changed from 18.6% for the pattern mask condition to -10.7% for the bright flash condition! This effect was significant ($p < 0.05$, two-tailed) as expressed by the triple interaction term. Not only did the hemispheres X mask conditions interaction change in a direction toward equality (i.e. no interaction), as predicted, but the diffuse light condition produced what must

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[1] As was the case for Experiment II, subjects were not randomly assigned to the two groups. Additionally, the composition of Group VII differed slightly in both age and academic status in comparison to Group V. However, the psychology graduate students that were run in the pilot studies showed the same phenomenon with the pattern mask as did the undergraduates in Groups I through V.

Table 15. Analysis of variance summary based on percentage correct scores for Groups V and VII of Experiment IV

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 31 | 2787.219 | | |
| Between subjects (S) | 7 | 314.969 | | |
| Groups (A) | 1 | 116.281 | 116.281 | 3.512 (ns) |
| S/A | 6 | 198.688 | 33.115 | |
| Within subjects | 24 | 2472.250 | | |
| Hemispheres (B) | 1 | 116.281 | 116.281 | 1.548 (ns) |
| AB | 1 | 225.781 | 225.781 | 3.006 (ns) |
| SB/A | 6 | 450.688 | 75.115 | |
| Mask conditions (C) | 1 | 1188.281 | 1188.281 | 29.561 ($p < 0.005$) |
| AC | 1 | 38.281 | 38.281 | 0.952 (ns) |
| SC/A | 6 | 241.188 | 40.198 | |
| BC | 1 | 26.281 | 26.281 | 2.056 (ns) |
| ABC | 1 | 108.781 | 108.781 | 8.511 ($p < 0.05$) |
| SBC/A | 6 | 76.688 | 12.781 | |

be considered a sizeable interaction in the opposite or negative direction. (When the results of Group VII were analyzed separately, this interaction in the opposite direction was not statistically significant.) Three of the four subjects in this group produced the above effect quite markedly, while the fourth showed a small interaction trend in the direction produced by the pattern mask.

This "negative" interaction trend was first observed when the results of the first daily session of 200 trials were scored and recorded for each of the first two subjects. This striking trend immediately aroused suspicion that some sporadic alteration of the equipment may have occurred which could affect the left-right luminance conditions in one of the stimulus channels - especially the masking channel. This was always a possibility since the left or right member of each vertically mounted pair of bulbs (though carefully matched at the onset) could deteriorate at a different rate. This possibility was controlled for by reversing, left for right and right for left, the fluorescent bulbs and the vacuum tubes which independently drive each bulb for all stimulus channels. Consequently, any idiosyncrasy that could have affected left-right field conditions was now <u>reversed</u>. The <u>last</u> 200 trials were then administered to the first two subjects with the altered apparatus. Their performance did not change.

The other prediction made regarding the relative effects of the pattern versus diffuse light stimuli was that the flash would produce a smaller overall masking effect than the pattern. As previously, there are two indices which reflect this change: the overall percentage decrement (averaged across hemisphere conditions) obtained <u>at threshold</u>, and the mean target exposure time required to <u>maintain</u> threshold across all conditions. The first index (column 3, Table 14) showed an increase in average percent decrement from 17.8% for the pattern mask to 27.1% for the light flash. This change was not statistically significant (between groups factor, Table 15), and it is seen (column 1, Table 14) to result from the increase in percent decrement from 8.5% to 32.4% for the left hemisphere condition (which also accounts for the shift in direction of the interaction). On the other hand, the average target exposure time to maintain threshold decreased from 5.0 ms for the pattern condition to 3.7 ms for diffuse light - a 26.0% decrease. (The latter mean includes a value of 5.1 ms obtained for the subject producing a position interaction.) This is a substantial decrease because experience proved that a change by as few as two 5% increments in target exposure time in either direction usually took the subject completely out of threshold responding level - to either 100%

or 0% correct. Stated in different terms, if Group VII had been run at a fixed target exposure time of 5.0 ms, no masking effect would have been observed, and average percent correct would have been close to the 100% level. The weight of the above considerations favors the interpretation that the targets were easier to detect for the diffuse light as compared to the pattern mask conditions - given the qualifications as stated.

By whatever means one wishes to interpret the above data, the results must be considered somewhat striking. For simply by removing the contour information from the pattern mask stimulus, there occurred what may be a totally different phenomenon (although the negative interaction was not statistically significant). That is, the percentage decrement produced by the flash for the left hemisphere condition was greater than the right by 10.7%.

Most important for immediate purposes, however, are the answers to the issues posed above. All predictions made for Experiment IV were confirmed. A "masking" effect was produced by the diffuse light stimulus; the effect was (by the writer's reckoning) smaller than that produced by the pattern; and the differential hemispheres X mask conditions interaction effect predicted by the model for the pattern mask was not reproduced by the diffuse light stimulus. (The interaction for Group V was significant in the direction predicted at the 0.01 level, while that for Group VII was not significant and showed a "trend" in the opposite direction. Or equivocally, the interactions were significantly different - $p < 0.05$). Consequently, the hypothesis that the differential cross-field visual masking phenomenon was produced by stray illumination is rejected. Similarly, any "distraction of attention" type hypothesis is also rejected since diffuse light flashing to either side of fixation must be considered equally distracting. The effect that was produced by the diffuse light stimulus was likely due, at least partly, to stray illumination; but, since a new interaction "trend" was observed, the possibility of involvement of other cortical (hemispheric) mechanisms cannot be ruled out. Obviously, statistical confirmation of this new "trend" must be established before it is taken as a serious issue.

The obtained hemispheres X light flash interaction "trend" (if confirmed) is indeed most difficult to account for in terms of a model like the one presented here. To reiterate, the effect observed was that when the stimulus to be verbally coded was flashed directly to the left hemisphere and the diffuse light to the right, the masking effect was greater than when the situation was reversed. A model which stresses hemispheric differences in signal-to-noise ratios and relative stimulus arrival times simply cannot explain that effect, at least not without the superimposition of additional concepts.

At the moment, it seems that a model which could account for the above effect must include the following concept: the right hemisphere (not necessarily the visual cortex) is somehow so specialized for the processing of diffuse light that it produces a greater effect on both hemispheres, when it is the recipient of the initial flash, than does the left hemisphere when it is the initial recipient. In other words, on either the input or the output side of the information processing equation, the right hemisphere may handle diffuse light in a different manner than does the left. In the overall scheme of things, this is not so outlandish as the now accepted notion that the left hemisphere "speaks" and the right does not. One kind of evidence which supports the above possibility is the finding by Jeeves and Dixon (1970) that the right hemisphere is at least a "more efficient" processor of "unstructured" light stimuli than the left. They measured motor (manual) reaction time to "unstructured" light flashed alternately to the left and right hemispheres. After counterbalancing for all possible combinations: nasal versus temporal hemiretinae, right versus left hand, and left versus right hemispheres; they concluded that motor reaction time was 5 to 8.5 ms faster to diffuse light flashed to the <u>right</u> as opposed to the left hemisphere.

Another, so far unmentioned, visual pathway is a possible mechanism for interaction with diffuse light. This is the projection from the lateral geniculate through the superior colliculus and pulvinar structures to "higher" visual centers in the temporal lobe (see Stone & Freeman, 1973). This sub-cortical pathway is bilaterally represented and completely bypasses the visual cortex. Although its real significance is so far unknown, present evidence suggests that: it is phylogenetically an older pathway (excluding the temporal lobe); it seems, in higher vertebrates, to be relatively unrelated to form discrimination per se; it appears to have something to do with the detection of moving objects; it may mediate the pupillary response; and it responds easily to "light" versus "dark" as do some single cells in the temporal lobe (Stone & Freeman, 1973).[1] The fact that both this pathway and the geniculo-striate path through the visual cortex appear to terminate in the visual centers of the temporal lobe lends credence to the possibility of a diffuse light masking effect in the temporal cortex.

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[1] My appreciation to Dr. J. I. Johnson, Michigan State University, for the use of this reference chapter from a book still in press.

# Chapter 6: GENERAL SUMMARY AND CONCLUSION

The purpose of this study was to develop and test a new visual masking paradigm which, if successful, could be employed as a procedure for increasing observed laterality differences in visual perception. The technique devised was to tachistoscopically flash target information to the "preferred" hemisphere while flashing a visual noise or masking pattern to the hemisphere opposite. When the target information transfers from the "preferred" to the opposite hemisphere via the corpus callosum, it was predicted that processing of that information would be partially disrupted in the "masked" hemisphere. In order to demonstrate that a gain in laterality difference was actually obtained, it was necessary to show that disruption of processing was greater in the "masked" hemisphere than it was in the "preferred" hemisphere - which would also be influenced by mask information crossing the callosum. In other words, when compared to no-mask conditions, a difference in "percentage decrement" produced by the mask should obtain between the "preferred" and "masked" hemispheres. A theoretical model was developed which predicted that such a difference would be observed on the basis of a higher "signal-to-noise" ratio that would obtain in the "preferred" as compared to the "masked" hemisphere.

The specific goals of the study were to determine whether or not such a phenomenon would occur and, if so, to study various stimulus parameters which would or would not influence the effect. The general findings are summarized below.

1. Employing single alphabetic letters and the left hemisphere as main processor, the predicted differential masking phenomenon was statistically confirmed.

2. Difference in energy levels between target and mask stimuli did not substantially influence the masking effect.

3. Altering the stimulus onset asynchrony between target and mask and therefore their arrival-arrival time relationships in the respective hemispheres had a marked influence on the magnitude of the effect.

4. Size of the visual noise pattern was a crucial determinant of the effect since masking nearly disappeared when the noise pattern was reduced to 1/10th of its original area.

5. A difference in effect resulting from projection of the "small" noise patterns to corresponding versus non-corresponding retinal areas relative to the target could not be demonstrated.

6. Diffuse light, equal in brightness to that of the pattern mask, did not produce the phenomenon predicted by the model and resulted in a non-significant differential masking trend in a direction opposite to that obtained for the pattern.

Results 1, 2, 3, 4, and 6 above supported in various ways the hypothesis that the cross-field masking phenomenon was due to the interaction of central (i.e. cortical) rather than peripheral mechanisms. Initial observation of the phenomenon itself (1 above) is argument for the rejection of peripheral mechanisms since peripheral models cannot account for the obtained laterality differences in masking effect. The findings (2 and 3 above) that differing mask - target energy levels <u>did not</u> influence the phenomenon, whereas variation of the SOA parameter <u>did</u>, agree with Turvey's (1973) conclusions regarding the parameters which <u>do</u> and <u>do not</u> influence noise pattern masking by central mechanisms (via the dichoptic procedure). Item 4 above indirectly supports the possibility that "complex" cells in visual area 18 may have played a role in the masking effect because the mask size which proved an effective stimulus (compared to the size which did not) corresponds to the receptive field dimensions of complex cells in higher primates. Finally, the finding that diffuse light did not produce the masking effect obtained for the pattern permits rejection of the hypothesis that stray illumination within the eye (the peripheral mechanism most likely to provide an interaction effect) accounted for the phenomenon. In addition, it increases the tenability of the notion that the effect obtained for the pattern mask involved an interaction via the contour detectors in the visual cortex.

The combination of stimulus parameters which produced the largest differential masking effect (Group V, Experiment II) was one which attempted to combine the hypothetical effects of differing signal-to-noise conditions with a particular set of arrival-arrival time relationships between target and mask in the respective hemispheres. Specifically, stimulus onset asynchrony was adjusted so that simultaneity of mask and target arrival would occur in the low signal-to-noise hemisphere (the "masked" hemisphere) and target would precede arrival of the mask in the high signal-to-noise hemisphere (the "preferred" hemisphere). Actually, since only verbal stimulus material was used, the left hemisphere was alternately made to play the role of both the "masked" and the "preferred" hemispheres by reversing target and mask stimulus fields. When the left hemisphere was defined as "preferred" (target to left h. - mask to right h.), percentage decrement produced by the mask was only 8.5%. But when the left hemisphere acted as the "masked" hemisphere (target to right h. - mask to left h.), percentage decrement was 27.1% - a difference of 18.6%. This effect was significant at the 0.01 level (n=4).

In terms of the original goal to increase laterality differences in perception of tachistoscopically presented visual stimuli, the gain produced by cross-field visual masking is somewhat small. For the best set of stimulus conditions (just described) the ratio of the performance of one hemisphere to that of the other increases by 25% under masking. For example, if the ratio in, say, "recognition accuracy" for one hemisphere to the other is 2 to 1, then under cross-field masking it should become 2.5 to 1. Similarly, a ratio of 4 to 1 improves to 5 to 1 under masking - and so on. Obviously, if the ratio without masking is already large (say, 3 to 1 or more), then employment of this paradigm seems hardly worth the effort. On the other hand, for borderline instances, i.e. ratios close to 1 to 1, employment of this paradigm could make a difference between detection and non-detection of hemispheric differences (assuming "true" differences do exist). As stated in the general introduction to this paper, most left-right differences found for visually presented stimuli are close to borderline. Kimura (1973) summarizes in ratio form some of the findings for visual stimuli. A left to right hemisphere superiority is observed for letters (1.23 : 1) and words (1.47 : 1); and a right to left superiority for two-dimensional point location (1.18 : 1), dot and form enumeration (1.20 : 1), matching of slanted lines (1.05 : 1), and stereoscopic depth perception (1.28 : 1). The average of these ratios of 1.24 to 1 should become 1.55 to 1 if cross-field visual masking is used.

Whether the above gain produced by this masking paradigm is large enough to aid the unilateral (left-right) study of more complex information processing models is a question that remains open for the present. There is, however, reason for optimism. Chances are that the magnitude of the above gain is a conservative estimate of what could be obtained for more complex stimuli or tasks. The use of single alphabetic letters in this experiment required a large number of observations (400 per subject) to obtain reliability of measurement. (Even at that, many subjects did not demonstrate a left hemisphere superiority at all under the no-mask conditions.) This requirement enhanced the probability of extended practice effects, and it has been shown (Schiller, 1965) that central masking with a pattern stimulus considerably decreases with practice. Consequently, the use of stimulus material requiring a small number of trials would seem to favor observation of a larger overall masking effect, and possibly a larger differential effect as well.

While it has been demonstrated that the cross-field masking technique is of value for increasing observed laterality differences in perception, the model, or the set of interrelated explanatory constructs employed in the conceptual development of the technique, has itself been supported by the results of this study. The string of neurological assumptions, though lengthy, has been shown to have the utility of generating behavioral predictions in advance of the empirical observations - an essential criterion for theory validation. Consequently, the potential of this technique as a method for studying central neurophysiological processes in man should not be overlooked.

It is well understood that direct study of the characteristics of single neurons in the human cortex can be conducted only under the most extreme of circumstances and even then involves difficult questions of ethics. While the microelectrode studies on animals provide crucial leads, less direct, behavioral, procedures are required for human subjects. The "cross-field" as well as the dichoptic masking paradigms offer such possibilities. By finding the size of a pattern which produces the optimum cross-field masking effect (as suggested in Chapter 4), it is possible to infer the receptive field dimensions of single cells in areas 18 and 19 of the human visual cortex. Similarly, by systematically varying the physical features of the masking pattern to produce an optimum interference effect it is possible to infer the stimulus parameters to which the cells are specialized. This same procedure might even be extended to the study of "engram" coding by neurons in the visual area of the temporal lobe.

Finally, brief mention will now be made of the need for some further studies that bear on the theoretical issues of the masking technique itself. As mentioned above, this procedure should be tried with more complex stimuli, and 4-letter common nouns presented vertically would be a good starting point. Secondly, if the proposed mechanisms are operating, it ought to be possible to show that the effect works in the opposite direction. That is, stimuli should be chosen for which the right hemisphere has been shown to be the preferred processor. A differential masking effect should then be obtained which is opposite in direction to the one observed for this study. Thirdly, "target distance from fixation" should be an interesting variable to investigate. The hypothetical mechanisms proposed to be operative for this paradigm are the ones which supposedly relate to continuity of vision between the two half-fields and binocular stereopsis along the vertical meridian. If that is the case, then stimuli which project more than $3^{\circ}$ lateral to the fixation point should avoid this system entirely and would probably involve different commissural pathways. Finally, it should be shown that an effect is obtainable by totally eliminating any possibility for the occurrence of peripheral interactions. This would be made possible by combining the dichoptic with the cross-field visual masking paradigms. By employment of a 5-channel tachistoscope (or a 3-channel scope with polarizers) it is possible to control both field of presentation and the eye to which it is presented. For example, left-field presentations could be projected to the temporal hemiretina of the *right eye* (and therefore to the right hemisphere) and right-field presentations to the temporal hemiretina of the *left eye* (left hemisphere); in other words, projection to *separate hemispheres* via corresponding retinae of the *separate eyes*. Obviously, in this instance, *only* cortical mechanisms could interact. The effects of eye dominance could be counterbalanced by making an equal number of cross-field presentations to the nasal hemiretinae of the two eyes which then project to the contralateral hemispheres.

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# APPENDICES

# APPENDIX A

## Brief Review of Controversial Issues Concerning Left Versus Right Field Differences in Tachistoscopically Presented Visual Stimuli

Beginning with Mishkin and Forgays' (1952) and Heron's (1957) lateral presentation experiments, a large number of such studies have been conducted (see review by White, 1969), mostly with verbal stimuli. The general findings are that for unilateral tachistoscopic presentation of verbal stimuli, a right field (left hemisphere) superiority is demonstrated. However, with bilateral presentations, a left field superiority, under some stimulus conditions, seems to predominate. This has given rise to the "reading scan hypothesis" which provides a parsimonious explanation for both observations. Briefly, it states that for unilateral presentation the subject tends to scan (from the fixation point) the neural trace from a left to right direction according to his reading habits, and for bilateral presentation or presentation of material across the vertical meridian, the subject starts "reading" from the left-most point. McKeever and Huling (1971) who find a right field superiority under bilateral conditions, have countered the reading scan hypothesis by arguing that some of the early studies did not provide adequate control of fixation and by citing recent experiments by Barton et al. (1965) and Orbach (1967) who found right field superiority with native Israeli subjects (who read from right to left) and tachistoscopic presentation of Hebrew words. Perhaps the fairest assessment is provided in White's (1969) conclusion where he categorizes into two sets the experimental conditions of the conflicting studies: (a) those in which the exposure durations were well above threshold, 50 - 150 ms (which support the reading scan hypothesis) and (b) those in which displays were presented at threshold durations (which support the lateral specialization hypothesis). White states: "It is to be expected that as stimulus information and exposure durations tend towards the minimal, these factors (hemispheric, etc.) should dominate a "scanning" process which itself demands maximal information and time to process it." The present project was concerned only with the second (b above) type of stimulus condition.

# APPENDIX B

## Errors (Guesses) Classified as "Stimulus Dependent" for Each Target Letter Used in Experiment I (Error Analyses 1 and 2)

| Error Analysis 1 | | | Error Analysis 2 | | |
|---|---|---|---|---|---|
| Actual target | | Letters guessed (errors) | Actual target | | Letters guessed (errors) |
| A | - | V, H | A | - | |
| B | - | E, S, R, P | B | - | S |
| C | - | G, O | C | - | O |
| D | - | O | D | - | O |
| E | - | F, B, S | E | - | F |
| F | - | E, P, R | F | - | E, P |
| G | - | C, O | G | - | O |
| H | - | M, W, N, A, R | H | - | M, W |
| I | - | T, L, J | I | - | T, L |
| J | - | U, L, I | J | - | U |
| K | - | R, X | K | - | R, X |
| L | - | J, I | L | - | I |
| M | - | N, W, H | M | - | H |
| N | - | M, H, W | N | - | |
| O | - | D, C, G, U | O | - | C, G, D |
| P | - | F, R, B | P | - | R, F |
| R | - | K, P, B, H, F | R | - | P, K |
| S | - | B, Z, E | S | - | B |
| T | - | I | T | - | I |
| U | - | V, J, W, O | U | - | J |
| V | - | U, W, Y, X | V | - | |
| W | - | H, M, N, U | W | - | H |
| X | - | Y, V, K | X | - | K |
| Y | - | X, V | Y | - | |
| Z | - | S | Z | - | |

## APPENDIX C

## Summary Table and Analysis of Variance for Error Analysis 1 Based on Percentage of Stimulus-Dependent Errors as the Dependent Variable

Table 16. Summary table for error analysis 1

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| Group I | no-mask | 57.9 | 38.3 | 48.1 | | |
| M=2.50 ft.l. | mask | 42.6 | 38.6 | 40.6 | -27.2 | 4.9 |
| T=0.40 ft.l. | % decr. | 26.4 | -0.8 | 12.8 | | |
| Group II | no-mask | 39.2 | 48.4 | 43.8 | | |
| M=1.05 ft.l. | mask | 40.3 | 34.3 | 37.3 | 31.9 | 4.4 |
| T=0.40 ft.l. | % decr. | -2.8 | 29.1 | 13.2 | | |
| Group III | no-mask | 56.9 | 44.3 | 50.6 | | |
| M=2.50 ft.l. | mask | 40.8 | 30.2 | 35.5 | 3.5 | 8.3 |
| T=0.20 ft.l. | % decr. | 28.3 | 31.8 | 30.1 | | |
| Group IV | no-mask | 46.1 | 39.2 | 42.7 | | |
| M=2.50 ft.l. | mask | 34.0 | 30.4 | 32.2 | -3.8 | 10.6 |
| T=0.10 ft.l. | % decr. | 26.2 | 22.4 | 24.3 | | |

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Note. M=mask; T=target; H=hemisphere; R=right; L=left; % decr.=percentage decrement produced by mask

Table 17. Analysis of variance for error analysis 1

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 63 | 7068.314 | | |
| Between subjects (S) | 15 | 1721.671 | | |
| Groups (A) | 3 | 448.904 | 149.635 | 1.411 (ns) |
| S/A | 12 | 1272.767 | 106.064 | |
| Within subjects | 48 | 5346.643 | | |
| Hemispheres (B) | 1 | 731.026 | 731.026 | 9.950 ($p < 0.005$) |
| AB | 3 | 483.502 | 161.167 | 2.194 (ns) |
| SB/A | 12 | 881.612 | 73.467 | |
| Mask conditions (C) | 1 | 1555.316 | 1555.316 | 23.413 ($p < 0.001$) |
| AC | 3 | 181.309 | 60.436 | 0.910 (ns) |
| SC/A | 12 | 797.162 | 66.430 | |
| BC | 1 | 8.629 | 8.629 | 0.458 (ns) |
| ABC | 3 | 481.999 | 160.666 | 8.528 ($p < 0.005$) |
| SBC/A | 12 | 226.087 | 18.841 | |

# APPENDIX D

## Summary Table and Analysis of Variance for Error Analysis 2 Based on Percentage of Stimulus-Dependent Errors as the Dependent Variable

Table 18. Summary table for error analysis 2

| | | T to left H | T to right H | average across H | diff. in % decr. (RH-LH) | mean T exp. time (ms) @ threshold |
|---|---|---|---|---|---|---|
| Group I | no-mask | 31.9 | 28.0 | 30.0 | | |
| M=2.50 ft.l. | mask | 25.2 | 21.7 | 23.5 | 1.5 | 4.9 |
| T=0.40 ft.l. | % decr. | 21.0 | 22.5 | 21.8 | | |
| Group II | no-mask | 23.5 | 30.2 | 26.9 | | |
| M=1.05 ft.l. | mask | 26.9 | 17.6 | 22.3 | 56.2 | 4.4 |
| T=0.40 ft.l. | % decr. | -14.5 | 41.7 | 13.6 | | |
| Group III | no-mask | 30.6 | 25.4 | 28.0 | | |
| M=2.50 ft.l. | mask | 25.4 | 18.0 | 21.7 | 12.1 | 8.3 |
| T=0.20 ft.l. | % decr. | 17.0 | 29.1 | 23.1 | | |
| Group IV | no-mask | 33.0 | 21.3 | 27.2 | | |
| M=2.50 ft.l. | mask | 17.4 | 16.0 | 16.7 | -22.4 | 10.6 |
| T=0.10 ft.l. | % decr. | 47.3 | 24.9 | 36.1 | | |

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Note. M=mask; T=target; H=hemisphere; R=right; L=left; % decr.=percentage decrement produced by mask

Table 19. Analysis of variance for error analysis 2

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Total | 63 | 3529.04 | | |
| Between subjects (S) | 15 | 901.44 | | |
| Groups (A) | 3 | 171.21 | 57.07 | 0.93 (ns) |
| S/A | 12 | 730.23 | 60.85 | |
| Within subjects | 48 | 2627.60 | | |
| Hemispheres (B) | 1 | 331.70 | 331.70 | 26.56 ($p < 0.001$) |
| AB | 3 | 78.40 | 26.13 | 2.09 (ns) |
| SB/A | 12 | 305.92 | 12.49 | |
| Mask conditions (C) | 1 | 754.19 | 754.19 | 22.88 ($p < 0.001$) |
| AC | 3 | 62.34 | 20.78 | 0.63 (ns) |
| SC/A | 12 | 395.58 | 32.97 | |
| BC | 1 | 16.50 | 16.50 | 0.57 (ns) |
| ABC | 3 | 336.79 | 112.26 | 3.89 ($p < 0.05$) |
| SBC/A | 12 | 346.18 | 28.84 | |