THE ROLE OF STROBOSCOPIC MOTION IN TWO TRANSIENT U-SHAPED BACKWARD CONTOUR MASKING

A Senior Honors Thesis

Presented to

the Faculty of the Department of Psychology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

By

Frank J. Battaglia

May, 1976

ACKNOWLEDGEMENTS

I extend to each member of my committee, Dr. Bruno Breitmeyer, Dr. Jane Malin, and Dr. Steven Cool, my sincerest appreciation for their time and consideration and interest not only in my research but in me as a person.

I am forever grateful to my advisor, Bruno Breitmeyer. My association with Dr. Breitmeyer has been the most rewarding, productive, and inspiring experience of my entire twenty year education. I could never thank him enough for his friendship, patience, and invaluable assistance.

Last but unequivocally not least, I want to express my love and appreciation for my wife Dorothy. Without her love, support, and encouragement, none of my past nor future achievements could be possible. Her presence gives meaning to all my endeavors. I thank her for the long hours she spent typing the many drafts of this paper.

THE ROLE OF STROBOSCOPIC MOTION IN

TWO TRANSIENT U-SHAPED BACKWARD CONTOUR MASKING

An Abstract of a Senior Honors Thesis

Presented to

the Faculty of the Department of Psychology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

By

Frank J. Battaglia

May, 1976

ABSTRACT

The sequential presentation of two stationary and spatially separate transient stimuli is known to produce both stroboscopic motion effects and contour masking. Not only is the magnitude of stroboscopic motion a U-shaped function of the temporal interval separating the onsets of the stimuli, but recently, two transient contour masking has been shown to be a U-shaped function of the temporal separation similar to Type B metacontrast. Since diametrical spatial-temporal properties have been reported for stroboscopic motion and metacontrast, the present study addresses the problem of delineating the spatial-temporal relationships attending two transient contour masking in order to evaluate the different stroboscopic motion-contour masking relationships proposed in two recent visual masking models. For two subjects, stroboscopic motion ratings and contour masking data were obtained as the interstimulus distance was varied using both a horizontal and a unilateral vertical stimulus display. The overall findings differentiate the two phenomena by the clear temporal dissociations demonstrated. Although neither model alone is adequate to explain the current results, a possible synthesis of the two models is proposed to account for the two transient apparent motion-contour masking data obtained.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Within certain spatio-temporal limits, the sequential presentation of two spatially separate transient stimuli can produce two salient observations. The first and most obvious consequence of such a paradigm is the occurrence of a phenomenon referred to as apparent motion, i.e. the illusory movement of a single object from the locus of the first stimulus to the position of the second stimulus presentation. A not so dramatic, but nevertheless important observation to be made from this type of stimulus display is the effect the second stimulus has on the perceived brightness of the first stimulus. Typically, this effect is a noticeable reduction in its apparent brightness. Though the latter effect was reported by Max Wertheimer (1912) in his initial systematic investigation of apparent motion, the dimming of a stimulus by the subsequent presentation of an adjacent non-overlapping second stimulus had been studied independently of apparent motion by investigators of visual masking until fifteen years ago (Kahneman, 1967; Fehrer and Raab, 1962).

While research in apparent motion was primarily concerned with the delineation of the spatial, temporal, and luminance stimulus parameters defining the occurrence of apparent motion and its relationship to real movement, investigators of visual masking were using a similar paradigm to produce a phenomenon known as metacontrast. To illustrate the similarity, compare the above stimulus sequence used for apparent motion studies with the following typical masking paradigm: The brief presentation of a target stimulus is followed at varying intervals by the brief, simultaneous presentation of two masking stimuli at adjacent areas flanking the first object. With the appropriate luminance and spatial relationships, variation of the temporal interval separating the onset of the target from the onset of the masking stimulus (stimulus onset asynchrony ≡ SOA) results in brightness suppression of the target ranging from a slight dimming to complete suppression. Using similar designs, investigators of metacontrast began noting similarities between apparent motion and metacontrast, such as the reports of the apparent motion of the flanking stimuli when optimal metacontrast suppression occurs (Schiller and Smith, 1966; Fehrer and Raab, 1962), and particularly striking similarity in the data. Under certain conditions, the indexing of both stroboscopic motion and metacontrast yields an inverted U-shaped function of the SOA (Kahneman, 1967). That is, optimal stroboscopic motion and optimal metacontrast both occur at intervals separating the onset of the target and the onset of the mask that are greater than zero, and the effect gradually diminishes at progressively larger and smaller SOA's about the optimal interval. Accounts such as these lead to a new interest in apparent motion and, more specifically, its relationship to metacontrast. It has even been proposed that metacontrast is a special case of apparent motion (Kahneman, 1967). Although subsequent investigations indicate that the relationship between metacontrast and apparent motion need not be a causal one (Weisstein and Growney, 1969; Breitmeyer, Love, and Wepman, 1974), the high correlation between the two phenomena does exist and it has been hypothesized that they may share the same mechanism (Matin, 1975; Breitmeyer, Love, and Wepman, 1974; Weisstein and Growney, 1969).

The present study is an attempt to further specify the relationship between metacontrast and apparent motion and the possible mechanism they share with respect to two recent models for metacontrast; the two channel model of Breitmeyer and Ganz (1976) and Matin's (1975) three neural classes model.

Metacontrast

Before discussing the specific differences between the Breitmeyer-Ganz model and Matin's model for metacontrast, it is necessary to briefly review the visual masking literature. It should be noted that this review will be concerned specifically with those topics directly related to the apparent motion-metacontrast controversy. For comprehensive coverage, the reader should refer to the following: for visual masking (Breitmeyer and Ganz, 1976; Kahneman, 1968), for metacontrast (Alpern, 1953; Lefton, 1968; Weisstein, 1972) and for the models being discussed (Breitmeyer and Ganz, 1976; Matin, 1975).

Generally defined, visual masking is the reduction of visibility of a stimulus (target) as a result of the presentation of another stimulus (mask). As previously mentioned, the temporal interval between the onset of the target and mask is the stimulus onset asynchrony (SOA). Positive SOA's (target followed by the mask) indicate backward masking and negative SOA's (mask preceeding target) indicate forward masking. Visual masking is further classified on spatial, temporal, and luminance parameters, the types of stimuli used, and the data obtained. With these properties it is possible to operationally define the type of metacontrast that is the subject of this investigation as follows: The suppression of a target's visibility by the sequential presentation of a spatially adjacent, non-overlapping mask of equal luminance within a limited range of positive SOA's. Suppression is manifested in a reduction of brightness (Alpern, 1953) or form (Weisstein and Haber, 1965) or contour information (Breitmeyer, Battaglia, and Weber, 1976; Breitmeyer, Love, and Wepman, 1974).

If the degree of metacontrast is graphed as a function of the SOA, two types of functions are commonly obtained which are used to further classify metacontrast (Kolers, 1962). If optimal masking occurs at SOA's near zero and decreases monotonically as a function of both positive and negative SOA's it is termed a Type A function. The Type B function represents a masking paradigm in which the optimal masking has occurred at an SOA between 50-100 msec with the masking effect decreasing at progressively larger and smaller positive SOA's. It is the Type B function (also referred to as a U-shaped masking function) that is important to the metacontrast-apparent motion topic because, as it will be demonstrated, apparent motion is also an inverted U-shaped function of SOA. Whether or not one obtains a Type A or a Type B function in metacontrast experiments seems to be governed by the relationship between the target and mask energies (Weisstein, 1968; 1972). In general, when the target to mask energy (luminance x time) ratio is great (i.e. T/M = 10), Type A functions are typically obtained while smaller target/mask ratios (i.e. $T/M \leq 1$) will produce Type B functions.

Studies indicating that stimulus luminance is also a parameter affecting apparent motion (Korte, 1915) will be discussed later. At this time it is evident that if equal time integrated luminances of target and mask are used in order to produce a Type B masking function, then the energy of the stimuli used in an apparent motion task must be comparable to that of the masking stimuli in order to compare the data obtained on each phenomenon.

Theories of U-shaped backward masking

Theories of masking appear to be divided into two main categories (Breitmeyer and Ganz, 1976; Lefton, 1973). Of the three theories to be discussed with respect to apparent motion, the Kahneman (1967) approach can be classified as a cognitive model while both the Breitmeyer-Ganz (1976) and Matin (1975) models are neurosensory theories. For further discussion of the various metacontrast models, refer to the sources mentioned earlier.

The similarities between the designs used and the results obtained in metacontrast and apparent motion experiments and the possible relationship between the two phenomena were being discussed in the early sixties (Fehrer and Raab, 1962; Fehrer 1965; 1966; Schiller and Smith, 1966). It was Kahneman (1967) who extended these relationships to construct a model of metacontrast based on a causal relationship between it and apparent motion. Citing empirical findings from his study (Kahneman, 1967) and from earlier work by others in the field (Fehrer and Raab, 1962; Schiller and Smith, 1966) Kahneman contended that metacontrast was a special case of impossible apparent motion as a consequence of the following facts: 1) apparent motion is observed during optimal metacontrast suppression; 2) both metacontrast and apparent motion are U-shaped functions of SOA; 3) at SOA smaller than that needed for optimal metacontrast suppression, brightness and contrast suppression is observed similar to that observed in apparent motion studies. To Kahneman, metacontrast suppression was a consequence of the perceptual system's inability to analyze the simultaneous movement of the target in two opposite directions. Kahneman's formulation has been refuted on two important points.

Before discussing the discrepancies between Kahneman's model and other empirical findings, it is advantageous at this point to introduce the literature of apparent motion. As previously mentioned in the introduction, Wertheimer (1912) in his initial investigation of apparent motion systematically studied the effects of varying SOA's on observed stroboscopic motion. As a result of these manipulations, he categorized his observations as follows (Kaufman, 1974): 1) at SOA between 0 and 30 msec - clearly simultaneous; 2) at SOA greater than 200 msec - clearly sequential; 3) at SOA greater than 60 msec but less than 100 msec - optimal stroboscopic motion (beta movement); 4) at SOA between the SOA for beta movement and the sequential category - pure movement (phi), i.e. movement without form. This last category was of particular interest to the early Gestaltists and led to other parametric studies of apparent motion of which Korte's (1915) is of great significance for the discussion of the metacontrast apparent motion problem. By varying not only the interstimulus interval, but also the interstimulus distance and intensity, Korte generated a set of rules governing apparent motion which he loosely defined as "laws" (Kaufman, 1974; Kolers, 1964). Though many discrepancies exist concerning the results of the intensity manipulations (Kaufman, 1974; Kolers, 1972) the generalization of significance here is that if intensity is constant, the interstimulus interval is directly proportional to the interstimulus distance, i.e. as the spatial separation between the first and second stimulus is increased, the SOA at which optimal beta movement occurs also increases.

In the study that Kahneman introduced his apparent motion explanation for metacontrast, subjects rated both apparent motion for a two square display and metacontrast for a three square display. The results of this rating procedure indicated a striking similarity for both the apparent motion and metacontrast functions. Not only were they both U-shaped functions of SOA, but both had maximas occurring at SOA's of around 100 msec. Challenging Kahneman's statement of causality, Weisstein and Growney (1969) argued that if apparent motion and equal energy U-shaped backward masking were the same, then manipulation of the parameters attending stroboscopic motion should yield identical functions for metacontrast.

Varying luminance, duration, and spatial separation, Weisstein and Growney demonstrated that stroboscopic motion and metacontrast yield identical functions only under certain conditions. Of great importance to the present study was their finding that while the metacontrast functions changed shape and decreased in amplitude as the visual angle separating the stimuli was increased, the shape and amplitude of the apparent motion functions remained relatively constant. It should be noted that the visual angle manipulation failed to produce significant changes in the maximas for both the stroboscopic and the metacontrast functions. Neither the inverse relationship between the interstimulus distance and interstimulus interval observed for metacontrast (Alpern, 1953), nor the direct relationship between the spatial and temporal separation observed for apparent motion (Korte, 1915) was reported in their study.

Kahneman's explanation of metacontrast as paradoxical stroboscopic motion also receives refutation from a recent study investigating contour suppression and apparent motion (Breitmeyer, Love, and Wepman, 1974).

Using a rating technique similar to Kahneman (1967), it was shown that contour suppression for a two stimulus display and apparent motion were not only both U-shaped functions of SOA, but that optimal suppression and optimal stroboscopic motion occurred at SOA's between 95 and 100 msec. Since suppression was occurring under conditions of possible stroboscopic motion, anomalous or impossible apparent motion need not be a requirement. Moreover, in a replication of this study in effort to investigate the locus of the contour suppression, it was further demonstrated that it was the contour information of the first stimulus that was being masked, therefore implying that Type B backward masking was occurring (Breitmeyer, Battaglia, and Weber, 1976). Thus one is forced to conclude that though apparent motion and metacontrast need not be causally linked, there is nevertheless a high correlation between the two phenomena that seems to indicate that they share a common neurological mechanism (Matin, 1975; Breitmeyer, Love, and Wepman, 1974; Weisstein and Growney, 1969). The Breitmeyer-Ganz model and Matin's model offer two different proposed mechanistic relationships between the two phenomena.

Numerous neuro-sensory models for visual masking have been developed (Purcell, Stewart, and Dember, 1968; Weisstein, 1968; Bridgeman, 1971) in the last fifteen years. Only two of the most recent theories, the Breitmeyer-Ganz model and Matin's theory, will be considered. Because of the scope and comprehensive coverage given to the literature of psychophysical data by the Breitmeyer-Ganz model, only the mechanism proposed to account for Type B metacontrast will be discussed.

According to the Breitmeyer-Ganz model, U-shaped backward masking is a result of inhibitory interaction between two types of neural channels identified in the visual system on the basis of their spatio-temporal response properties. One channel, consisting of neurons classified as transient cells, is concerned with spatial and motion information processing while the other channel, composed of neurons termed sustained cells, functions in figural or contour analysis and the processing of structural information.

Identification and classification of the transient and sustained channels was achieved on the neurological level through the study of lower mammalian visual systems and later their presence in the human visual system verified through their psychophysical manifestations. To understand the logical basis for the Breitmeyer-Ganz mechansim, it is necessary to discuss the properties of the transient and sustained systems.

In general, the transient cells can be differentiated from the sustained cells by the former's relatively greater sensitivity to stimulation of transient character, i.e. rapid motion (Breitmeyer, 1973; Tolhurst, 1973), abrupt stimulus onset (Breitmeyer and Julez, 1975) and high frequency temporally modulated stimuli such as flicker stimulation (Kulikowski and Tolhurst, 1973). The sustained cells, while preferring stimuli that are stationary or of lower temporal frequencies, show relatively greater sensitivity to higher spatial frequencies compared to the transient cells which prefer low spatial frequency stimuli (Cleland et. al., 1973). Thus distinguishing the trade-off; transient cells prefer low spatial frequency-high temporal frequency stimuli while sustained cells are more sensitive to high spatial frequency-low temporal frequency stimuli. Crucial to the Breitmeyer-Ganz model for U-shaped backward masking is the evidence on the neurological level (Dow, 1974) and psychophysical level (Breitmeyer, 1975) that when response latencies between the two systems are compared, the transient cells exhibited latencies 50 msec or more shorter than those of the sustained cells (Cleland, et. al., 1973).

It was stated at the outset that this model postulated inhibitory interaction between the channels to be responsible for Type B metacontrast results. The neurological basis for this type of inter-channel inhibition is found in studies that have demonstrated transient cell inhibition of sustained cell activity at the LGN level (Singer and Bedworth, 1973) and quite possibly at the striate cortex (Stone and Dreher, 1973).

Thus it has been hypothesized that in an equal energy two transient masking paradigm, the transient and sustained cells function in the following manner. Due to differential response latencies and propagation velocities, at appropriate SOA's the transient cells activated by the second stimulus inhibit the sustained channels activated by the first stimulus. At SOA's progressively larger or smaller than the optimal interval, transient cell inhibition of the information for figural analysis carried by the high spatial frequency sustained channels is not as pronounced. To account for the fundamental difference between transient and sustained channels with regard to response discharge duration, i.e. sustained cell response persistence being greater than a transient channel (Cleland, et. al., 1971), the Breitmeyer-Ganz model postulates that prolonged inhibition of sustained channels is achieved through the inhibitory activity of internuncial neurons interposed between the transient and sustained neurons.

Accordingly then, this type of two channel model postulates that the mechanism that is common to both metacontrast and apparent motion phenomena is considered to be a product of transient channel properties.

Whereas metacontrast is a result of interaction between transient and sustained channels, apparent motion is attributable to transient neuron activity (Felder and Ganz, 1975). Thus it is the transient cells, sensitive to temporally modulated stimulation, that operate in motion processing and also are responsible for Type B metacontrast.

The other recent neuro-sensory theory for masking to be considered is Matin's model for two transient masking paradigms (Matin, 1975). In contrast to two channel models similar to the Breitmeyer-Ganz (1976) model, Matin contends that metacontrast can be explained by the responses of three classes of neurons. It is imperative at the outset to distinguish Matin's "classes" of neurons from the neural channels discussed with respect to the Breitmeyer-Ganz position. Neural classes refer to the assortment of neurons and neural channels that are defined on the basis of the stimulus that produces a response in that class. Thus, the target neurons and mask neurons are classes consisting of several types of visual channels (i.e. transient and sustained channels can co-exist in the same class) that respond to the target and the mask respectively in a two transient masking experiment.

It is the third class, the target-mask neurons, which forms the crux of Matin's argument against restricting metacontrast explanation to two channel models. Though the target-mask neurons (T-M) can respond to either the target or mask alone, it is the combined presentation of the target and mask at the appropriate SOA that causes an optimal response from this neural class. Using neurological evidence to argue for their existence, Matin suggests that the high order, large receptive field T-M neurons are sequence analyzers that are components of the movement detection system.

At this point it becomes increasingly difficult to distinguish Matin's model from other two channel masking models. The problem is created by Matin's use of the same neurophysiological and psychophysical evidence for separate spatial and motion detection channels that was discussed earlier with respect to the Breitmeyer-Ganz model. Essentially, Matin's target neurons and target-mask are analogous to the sustained and transient channels respectively in the Breitmeyer-Ganz model. It is the inhibitory interaction between the target and target-mask neurons at SOA corresponding to latency and conduction velocity difference between the neural classes that gives rise to the U-shaped backward masking functions under consideration.

As was previously mentioned, the two models under consideration differ in the mechanism that contributes to the observed similarity in results obtained in apparent motion and U-shaped backward masking studies. According to Matin's formulation, it is the high order succession detecting T-M neurons responding optimally to sequential presentation of the target and the mask at intervals appropriate for the temporal frequency properties of these 'transient' type cells that are responsible for Type B metacontrast. Matin emphasizes that although the sequence analyzers are involved in movement detection, firing of sequence analyzers does not necessarily elicit the sensation of motion. That is, transient cells have been identified which are sensitive to very high temporal frequency stimulation (Singer and Bedworth, 1973) well beyond those velocities producing a sensation of motion. However, when the sequential presentation of brief stimuli occurs at an SOA that elicits a sensation of motion (i.e. a typical apparent motion paradigm), it follows that sequence analyzing T-M neurons tuned to that temporal frequency have been activated.

This differs significantly from the Breitmeyer-Ganz model which, as described above, involves inhibition of sustained channels activated by the target by transient channel activity activated by the abrupt on-off mask stimulus presentation. The Breitmeyer-Ganz model only requires that the target preceeds the mask by a temporal interval that corresponds to the response latency difference between the two types of visual channels.

Thus, given conditions producing both apparent motion and contour masking, the question is whether or not maximal contour masking always occurs at the same SOA producing optimal stroboscopic motion. To further understand the role of stroboscopic motion in U-shaped backward masking experiments, the present study takes an approach similar to the Weisstein and Growney (1969) study discussed earlier. While Weisstein and Growney (1969) investigated the effects of visual angle variations on metacontrast using a three stimulus display and on apparent motion using a two stimulus display, comparison of spatial separation effects in the present study will be achieved using a two transient display for both masking and apparent motion. Masking will be accomplished via the suppression of the high spatial frequency information used for edge or contour analysis in a manner identical to the method used in two earlier studies illustrating the occurrence of this type of U-shaped backward masking (Breitmeyer, Love, and Wepman, 1974; Breitmeyer, Battaglia, and Weber, 1976).

The second important consideration of the present study is the comparison of metacontrast and apparent motion when stimulus presentations occur in a vertical direction, i.e. the second stimulus is presented below the locus of the first stimulus presentation. In the past, masking investigations of this type have employed spatial arrangements which have the target and mask presented on opposite sides of the vertical meridian passing through the fovea. Though traditionally it has been postulated that stimuli presented to the nasal and temporal hemifields are projected exclusively in contralateral and ipsilateral manners respectively (stimuli to the left of fixation processed by the right hemisphere and stimuli to the right of fixation processed by the left hemisphere), recent studies indicate that this need not be the case. It has been demonstrated that along the vertical meridian there exists an area 1-1.5° wide on each side of the meridian which is represented in the visual cortex of both hemispheres (Rocha-Miranda, Bender, Gross, and Mishkin, 1975). Evidence also indicates that this area of the central visual field is dually represented at the subcortical level (Stone, 1966; Stone, Leicester, and Sherman, 1973). This is particularly important with respect to the Breitmeyer-Ganz model. Though the classical view of the mapping of the visual pathway requires the inhibitory activity of the transient and sustained cells of the mask and target respectively to be solely interhemispheric, it now appears that when the stimuli are presented within 2-3° of the vertical meridian through the fovea, the inhibitory interactions need not be exclusively interhemispheric. By presenting both the target and mask to the same side of the fixation cross, interhemispheric interaction is minimized and intrahemispheric interaction is maximized.

As was previously mentioned, variation of the interstimulus distance affects both apparent motion and metacontrast results. It has been shown that the interstimulus distance and interstimulus interval are directly proportional for apparent motion (Korte, 1915). The two models under consideration predict different results for the contour masking functions generated when the spatial arrangement of the target and mask is varied. According to the Breitmeyer-Ganz model, if the interstimulus distance is increased, the SOA at which optimal masking occurs should be smaller. They postulate that since the striate cortex is retinotopically organized (Brooks and Jung, 1973), if the inhibitory effect of the transient channels activated by the masking stimulus is to be optimally superimposed upon the sustained channels activated by the target, then the transient channels responding to the mask must be stimulated earlier in order for their inhibitory activity to traverse the greater cortical distance. Support for their predictions is found in an earlier metacontrast study demonstrating an inverse relationship between the target and mask spatial and temporal separation (Alpern, 1953). As a result of their presumption that interchannel inhibition is greatest within a cortical column, the model also predicts a decrease in the magnitude of the contour masking as the interstimulus distance is increased. This is in agreement with the finding of Weisstein and Growney (1969). The interchannel inhibition model also indicates that the magnitude of the contour masking should be strongest when the target and mask are presented to the same hemisphere as compared to different hemispheres when the same interstimulus distance is maintained across conditions.

According to Matin's model, the perception of motion is sufficient but unnecessary for the observance of metacontrast. That is, though activation of the T-M neurons involved in succession (movement) detection and responsible for U-shaped backward masking does not always result in the sensation of motion, when the sequential presentation of two transient stimuli does result in the observance of stroboscopic motion, it must be assumed that the sequence analyzing T-M neurons have been activated and their inhibitory effect should be manifested at the SOA which produced the illusory movement. Therefore, if the interstimulus distance is increased in a two transient apparent motion-contour masking paradigm, since optimal stroboscopic motion occurs at a larger SOA (Korte, 1915), optimal contour masking should also occur at a larger SOA. Though Matin does not specify the effect that increasing the visual angle has on the magnitude of masking produced, it is reasonable to assume that an inverse relationship should be observed. That is, as the interstimulus distance increases, the number of high order T-M neurons that have receptive fields encompassing both stimuli should decrease and therefore the amount of inhibitory activity on the target neurons should be reduced. The present study will further specify the role of stroboscopic motion in contour suppression to provide information for a better evaluation of the above postulated mechanism.

CHAPTER II

METHOD

Subjects

The subjects, a 22 year old female and a 24 year old female, were psychology undergraduates at the University of Houston. Though both were experienced psychophysical observers, having previously participated in masking experiments, they were naive with regard to the purpose of this study. Both volunteers had uncorrected, normal vision.

Apparatus and Stimuli

Stimulus presentation was accomplished via a three channel Scientific Prototype Tachistoscope. The stimuli, disk figures obtained from Prestype lettering sheet number 5604, were placed on 5 x 7 inch white index cards. Luminance level for each field is 94 candles - m^{-2}. The black disks against the white background produced a contrast of approximately 0.9. All stimuli had sharp contours. Disks with sharp outside edge deletions were used only in the contour masking studies. The contour deletions always subtended a visual angle of 0.1°.

The stimuli were arranged with the following spatial relationships (see Fig. 1). Studies have shown that metacontrast effects are a function of retinal location. That is, while foveal masking is weak (Alpern, 1953; Kolers and Rosner, 1960), the effect becomes progressively more pronounced at progressively greater parafoveal positions (Kolers and Rosner, 1960; Stewart and Purcell, 1970). In order to minimize variation in retinal locus masking effects, the center of each disk was positioned on the circumference of an imaginary circle with a radius of 1.4°. The center of this circle served as the fixation point. Viewing distance was 125 cm.

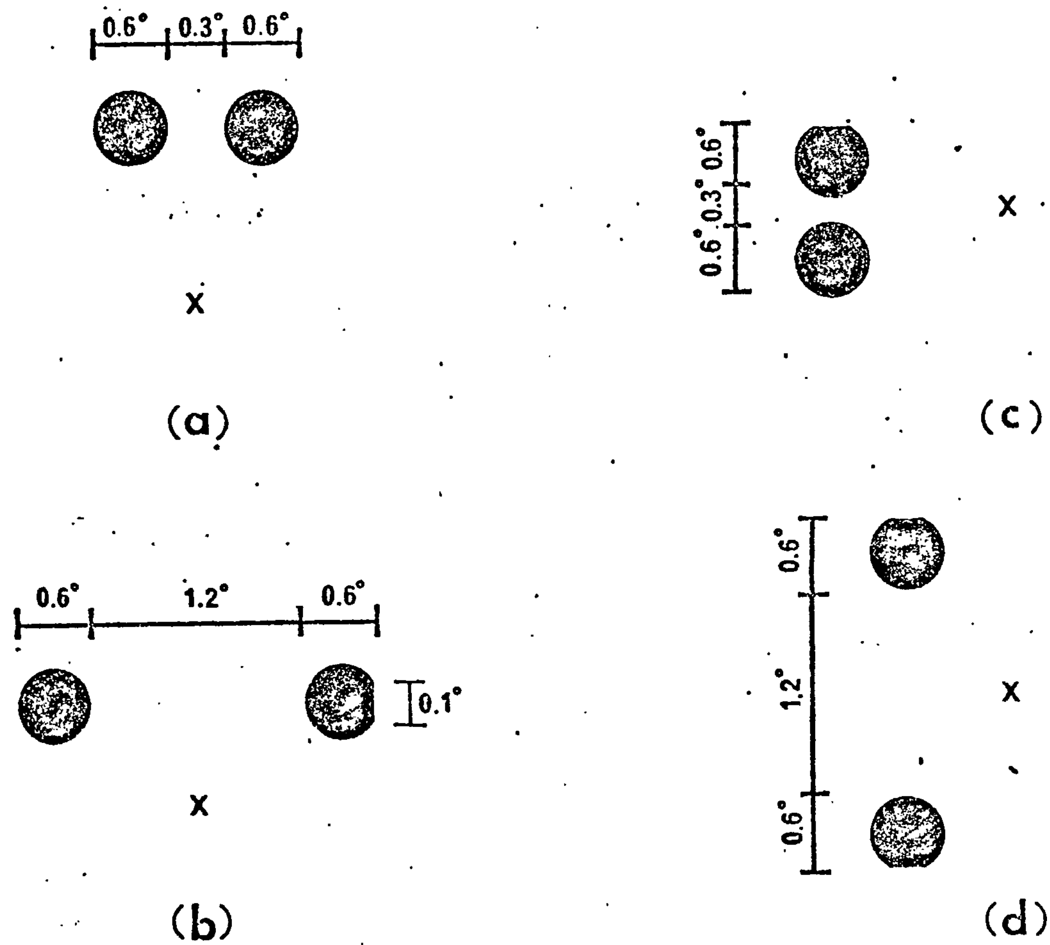

Fig. 1. Spatial arrangement of stimuli used in Experiments 1-4. All disks were placed on the circumference of an imaginary circle so that the distance from the fixation cross to the center of each disk subtended a visual angle of 1.40°. a) Stimulus arrangement in Experiment 1. Illustrates both the type of disks used for rating stroboscopic motion and the combination requiring a "same" response in the contour masking task. b) Stimulus arrangement in Experiment 2. Also illustrates stimuli requiring a "different" response for the contour masking sections. c) Stimulus arrangement for Experiment 3 indicating the second combination requiring a "different" reply in the masking section. d) Stimulus arrangement in Experiment 4 which in contour masking requires a "same" response. In each experiment the first stimulus was presented to the upper left visual field. That is, for Experiments 1 and 2, the stimulus sequence was left to right; for Experiments 3 and 4, top to bottom.

Procedure

The study was composed of four separate experiments designed to investigate the relationship between contour suppression and stroboscopic motion with respect to two spatial arrangements, both in a horizontal and in a vertical plane. The procedure used in each of the four experiments to measure the magnitude of observed stroboscopic motion and the contour suppression attending stroboscopic motion was similar to the method described in an earlier study (Breitmeyer, Love, and Wepman, 1974).

Stroboscopic Motion

The magnitude of observed stroboscopic motion measured as a function of stimulus onset asynchrony was achieved by the use of the five category rating technique employed in previous studies (Breitmeyer, Love, and Wepman, 1974; Kahneman, 1967). On this scale, optimal stroboscopic motion corresponds to a rating of five while a zero rating corresponds to a no observed stroboscopic motion situation. Intermediate ratings correspond to intermediate impressions of stroboscopic motion.

After instructing the subject to "fixate on the X", the experimenter initiated the following stimulus sequence: 1) 10 msec presentation of the first stimulus in field I; 2) immediately following the offset of field I, field II containing the fixation point was presented for a variable duration corresponding to one of the nine ISI's employed (0, 20, 40, 60, 80, 100, 120, 140, 160 msec); 3) field III containing the second stimulus presented for 10 msec followed by field II which remained on until the next trial.

On four consecutive days, two daily 36 trial sessions were completed with each session consisting of four trials per SOA presented in a random order. Thus 32 observations were obtained per subject per SOA. Each session was preceeded by a 18 trial warm-up session that allowed the subject to adapt to the luminance level used. All viewing was binocular.

Contour Suppression

Except for the difference in stimuli used and response criteria, the method used for the measurement of contour suppression was identical to that used in the apparent motion task. In this section of each experiment, the subjects were required to make a force choice judgement concerning the shape of both stimuli. For the four possible combinations of whole disks and disks with the outside edge deletions, the subjects were told to respond "same" when both stimuli were whole or both had contour deletions. A response of "different" was warranted when the first and second stimuli were of a different configuration, i.e. field I with a whole disk and field II with a deleted disk and vice versa. Each of the four combinations was presented once per SOA over a 36 trial session. Again, all viewing was binocular.

Experiment I

Using the above procedures, Experiment 1 investigated in separate blocks stroboscopic motion and U-shaped backward masking of contour information when the first and second stimuli were presented to the left and right visual hemifields respectively. (See Fig. 1a). Intercontour distance was 1.5°.

Experiment 2

Experiment 2 was identical to Experiment 1 except that the intercontour distance was increased in order to shift the SOA at which optimal beta movement occurred away from the origin. Intercontour distance was 2.4° (see Fig. 1b).

Experiment 3

With the same intercontour separation used in Experiment 1, Experiment 3 (Fig. 1c) was designed to minimize interhemispheric interactions by presenting both stimuli to the left hemifield. Though controversy exists concerning the locus of the effects observed in perceptual primacy studies (Ayres, 1966), the left visual field was used and the order of stimulus presentation was from top to bottom due to evidence indicating increased perceptual accuracy of the left and upper hemifields as compared to the right and lower hemifields respectively (Horcum, Hartman, and Smith, 1963).

Experiment 4

Employing the intercontour distance used in Experiment 2 and the left hemifield mode of stimulus presentation used in Experiment 3, Experiment 4 (Fig. 1d) rated stroboscopic motion and indexed contour suppression by the same procedures used in the preceeding three experiments.

CHAPTER III

RESULTS

The results of Experiments 1-4 are shown for both subjects in Figures 2-5. The average rating for the apparent motion task and the proportion of incorrect responses from the contour masking section are plotted separately as a function of the nine onset-onset intervals employed. Each point is based on 32 observations.

The stroboscopic motion curves generated for both subjects in all four experiments demonstrate the typical inverted U-shaped function relating the magnitude of observed stroboscopic motion to the temporal interval separating the onset of the first stimulus from the onset of the second stimulus. The largest rating defines the SOA at which optimal stroboscopic motion occurred for the spatial arrangement used in each experiment. The progressive decrease in the apparent motion rating as the onset-onset interval becomes progressively larger and smaller than the optimal apparent motion SOA indicates the transition from maximal apparent motion to clear successiveness and simultaneity respectively. The results are in agreement with findings reported elsewhere (Breitmeyer, Love, and Wepman, 1974; Weisstein and Growney, 1969; Kahneman, 1967).

Moreover, the results obtained from the spatial separation manipulation are in agreement with Korte's third law (1915). That is, the direct relationship between the visual angle separating the stimuli and the temporal interval separating the onset of each stimulus was clearly demonstrated. In Experiment 1 (see Fig. 2), the apparent motion function for subject 1 peaked at SOA's of 60 and 80 msec and for

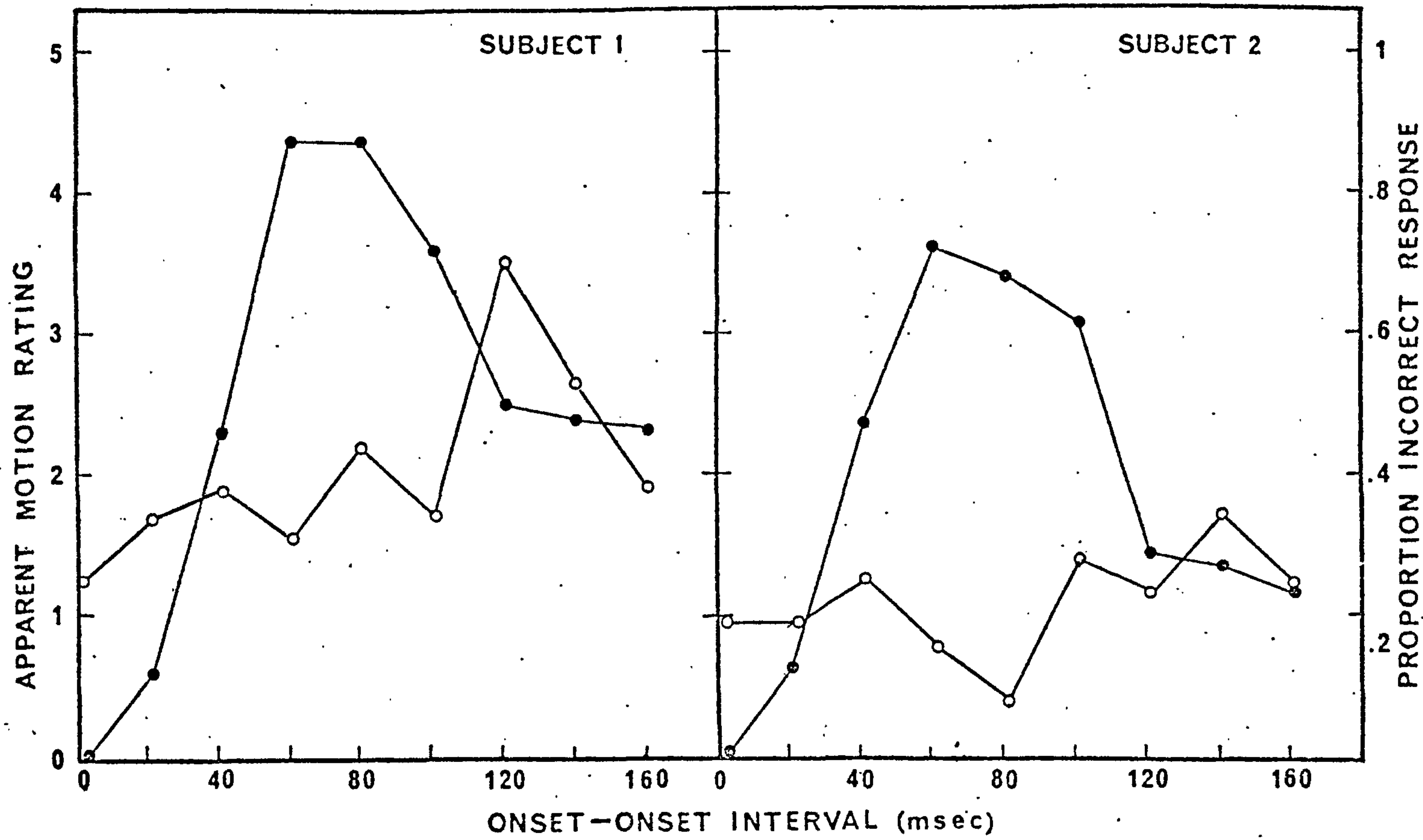

Fig. 2. Results of Experiment 1 plotted separately for each subject. Left ordinate indexes the stroboscopic motion ratings obtained; right ordinate, the proportion incorrect response. Data curves marked —●— indicate stroboscopic motion results; —o— indicate contour masking results.

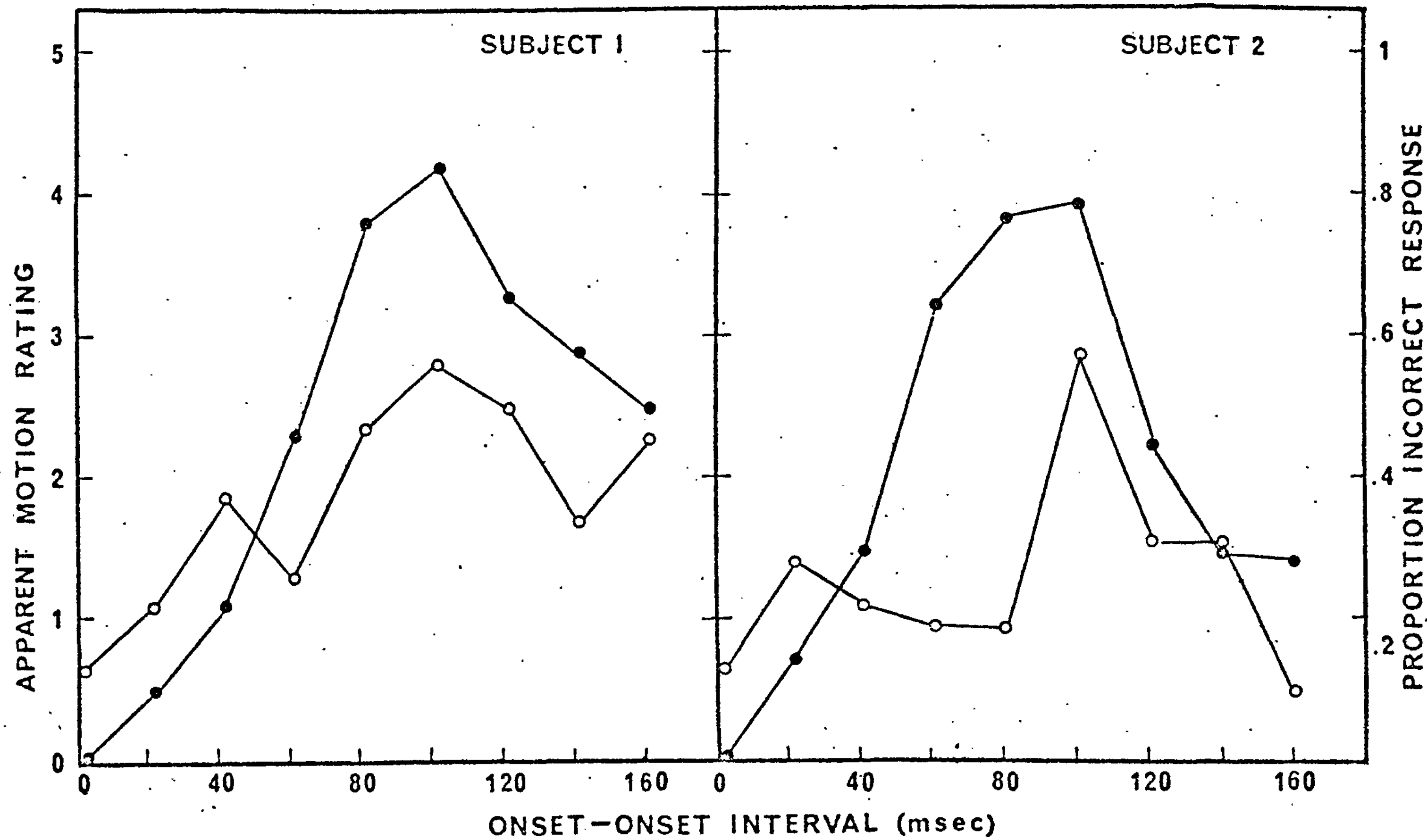

Fig. 3. Results of Experiment 2 plotted separately for each subject. Left ordinate indexes the stroboscopic motion ratings obtained; right ordinate, the proportion incorrect response. Data curves marked —●— indicate stroboscopic motion results; —o— indicate contour masking results.

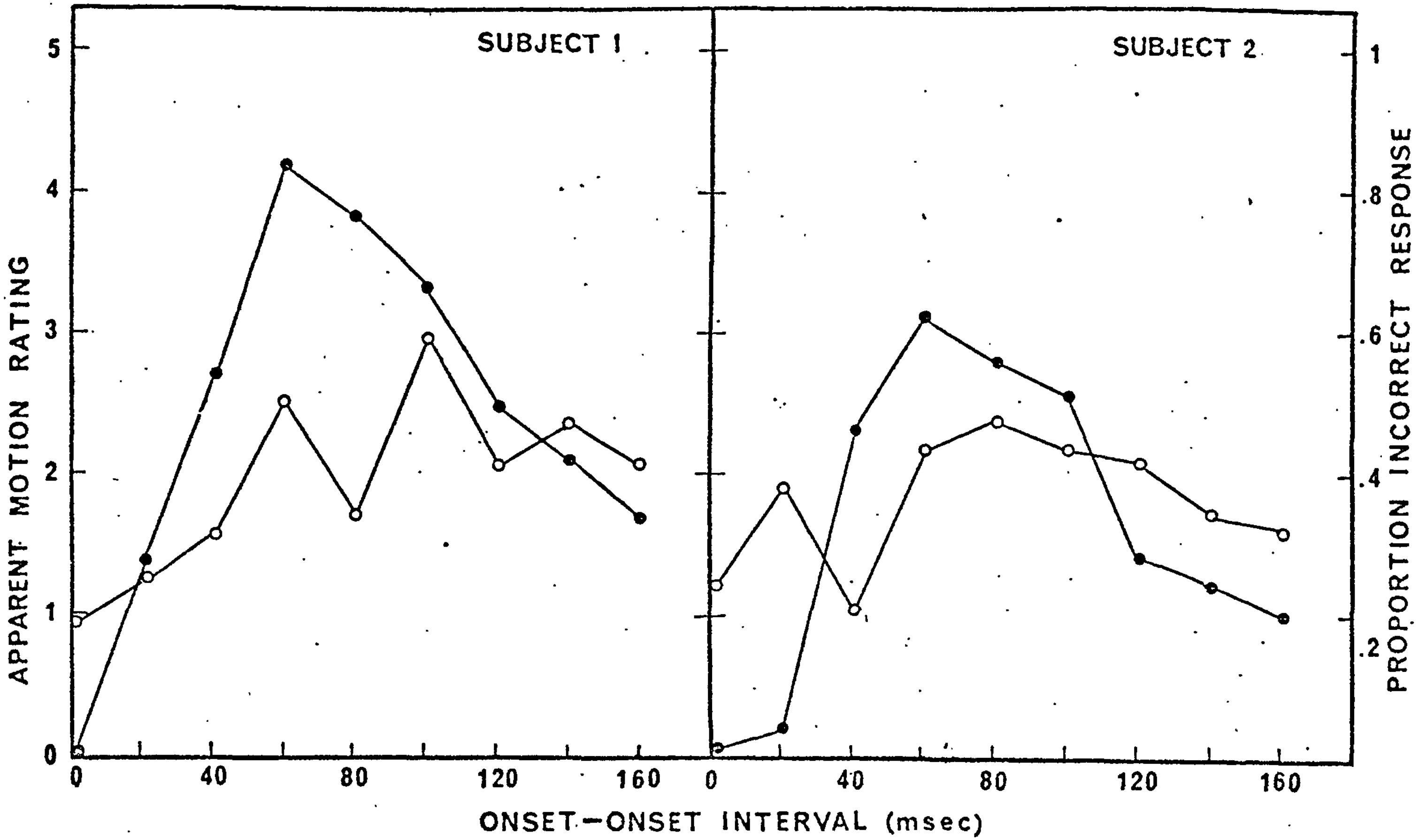

Fig. 4. Results of Experiment 3 plotted separately for each subject. Left ordinate indexes the stroboscopic motion ratings obtained; right ordinate, the proportion incorrect response. Data curves marked —●— indicate stroboscopic motion results; —○— indicate contour masking results.

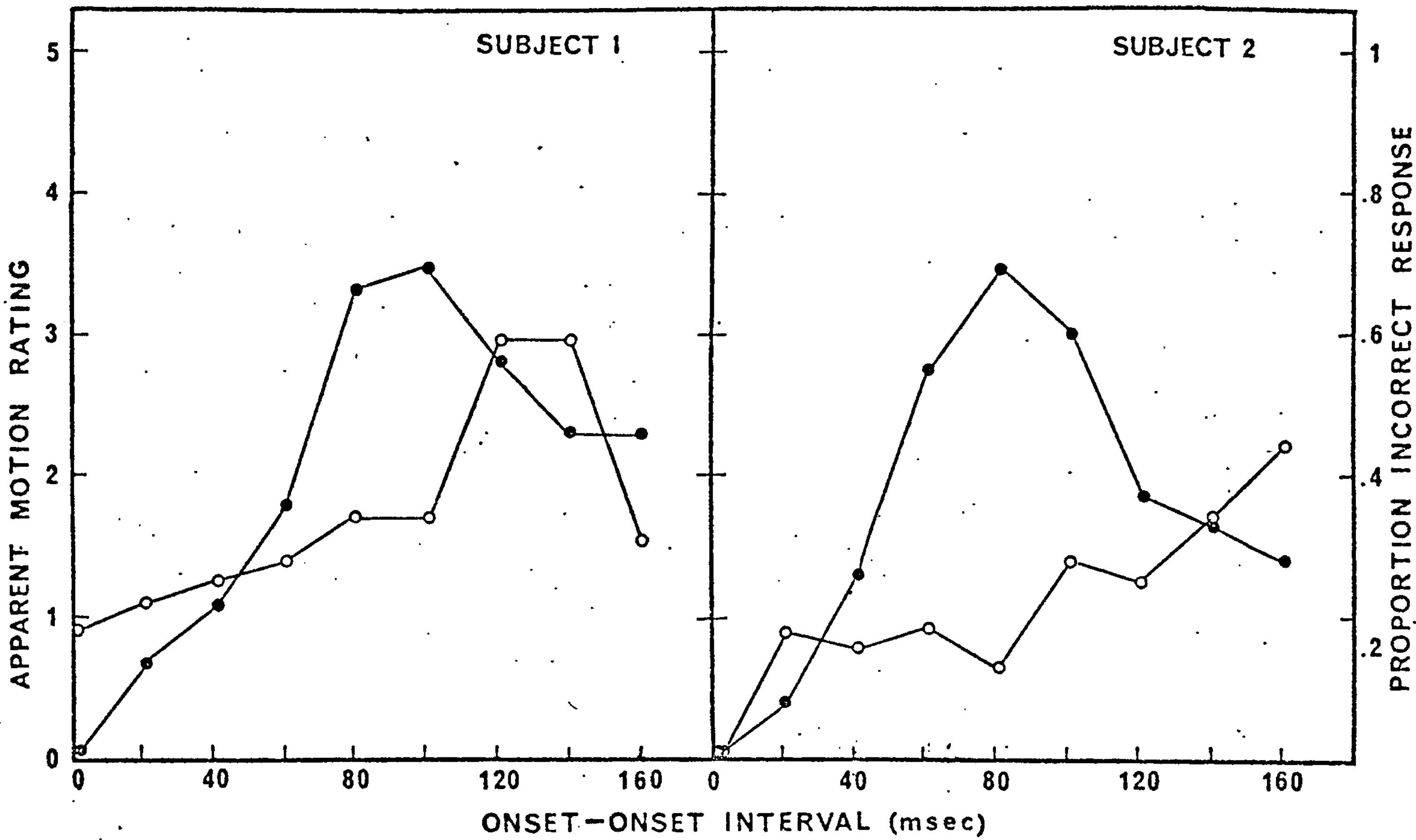

Fig. 5. Results of Experiment 4 plotted separately for each subject. Left ordinate indexes the stroboscopic motion ratings obtained; right ordinate, the proportion incorrect response. Data curves marked —●— indicate stroboscopic motion results; —○— indicate contour masking results.

subject 2 at a SOA of 60 msec. This corresponds to a velocity of approximately 15 deg/sec. In Experiment 3 (see Fig. 4), using the same interstimulus distance of 0.3° but altering the direction of stimulus presentation so that the second stimulus appeared below the locus of the first stimulus, the apparent motion functions for both subjects peaked at a 60 msec onset-onset interval. When the visual angle separating the stimuli was increased to 1.2°, the maxima for the apparent motion curve shifted to larger onset-onset intervals. In Experiment 2 (Fig. 3), both subjects had maximal rating occurring at an onset-onset interval of 100 msec corresponding to a velocity of 18 deg/sec. In Experiment 4 (Fig. 5), which used the vertical stimulus presentation mode, the same interstimulus distance produced an identical maxima for subject 1 while subject 2 had the optimal rating at an 80 msec SOA corresponding to a velocity of 23 deg/sec.

The results obtained from the contour masking section of each experiment will be reviewed in the following manner. The masking function generated by each subject in the four experiments will be examined to determine the onset-onset interval that produced maximal contour suppression as indicated by largest proportion of incorrect responses. The masking maxima will then be compared to the apparent motion maxima. Using a within-subject trend analysis of variance, the shape of each function will be examined to determine if significant characteristic U-shaped masking curves (quadratic trends) had been produced. The masking results will then be collectively analyzed with respect to the two manipulations employed and the proposed apparent motion-metacontrast relationships.

In Experiment 1, maximal contour masking occurred at SOA's of 120 msec and 140 msec for subjects 1 and 2 respectively. Optimal stroboscopic motion was observed at 60-80 msec SOA's for subject 1 and 60 msec SOA for subject 2. The results of the within-subject trend analysis of variance shown in Table 1 demonstrate that while the contour masking function for subject 1 yielded significant linear and quadratic trends at the .01 probability level and a cubic trend at the .05 probability level, the masking function for subject 2 yielded no significant trends. The latter results suggest that the data for subject 2 was not indexing the U-shaped contour masking as reported in earlier studies (Breitmeyer, Battaglia, and Weber, 1976; Breitmeyer, Love, and Wepman, 1974).

In Experiment 2 (Fig. 3) both subjects generated functions that had maximal contour masking occurring at an onset-onset interval of 100 msec. Optimal stroboscopic motion was also observed at a 100 msec onset-onset interval for both subjects. The within-subject trend analysis of variance as shown in Table 2 produced significant quadratic trends at the .01 probability level and cubic trends at the .05 probability level for the contour masking functions of both subject 1 and subject 2. Higher trends also reached significance at the .01 level for subject 2.

Experiment 3 (Fig. 4) produced masking functions which peaked at 100 msec and 80 msec onset-onset intervals for subjects 1 and 2 respectively. Beta movement occurred at the 60 msec SOA for both subjects. As shown in Table 3, a linear trend at the .01 probability level and higher trends at the .05 level were obtained for subject 1 while only a quadratic trend at the .05 level was recorded for subject 2.

In Experiment 4 (Fig. 5) maximal contour suppression occurred at SOA's of 120 and 140 msec for subject 1, while for subject 2, it occurred at the 160 msec SOA. Optimal apparent motion was recorded at 100 msec and 80 msec onset-onset intervals for subjects 1 and 2 respectively. The within-subject trend analysis of variance (see Table 4) produced significant linear trends at the .01 probability level for the contour masking functions obtained for both subjects. Higher trends were also significant at the .05 level for subject 1. It is important to note that the lack of quadratic trends may be due to nonsymmetry of the U-shape as a function of SOA, i.e. maximal contour masking was not occurring in the intermediate range of SOA's employed.

In order to test the hypothesized spatio-temporal relationships for metacontrast and apparent motion, the results obtained from Experiment 2 will be used as a reference standard. Under the conditions of this experiment only, contour masking and apparent motion functions had maximas at the same 100 msec SOA for both subjects. Upon comparison of the contour masking data from Experiment 2 with the results of Experiment 1 which employed an interstimulus distance that was one fourth of the spatial separation of stimuli in Experiment 2, it appears that an inverse relationship between spatial and temporal separation is indicated. Though the results of the trend analysis raise doubts concerning the occurrence of U-shaped backward contour masking for subject 2 in Experiment 1, the data obtained from subject 1 clearly demonstrates that as the interstimulus distance was reduced, maximal contour suppression occurred at larger onset-onset intervals as predicted by the Breitmeyer-Ganz model. On the other hand, comparison of the stroboscopic motion data generated in Experiments 1 and 2 reveals the direct relationship between the spatial and temporal separation of the stimuli that Korte (1915) had reported. That is, the smaller interstimulus distance used in Experiment 1 produced apparent motion functions that peaked at SOA's

TABLE 1

Within-subject trend analysis of variance for the nine onset-onset intervals of the contour masking functions from Experiment 1.

SUBJECT 1

Source	SS	df	MS	F	p
Between	5.06	8			
Linear	2.04	1	2.04	8.87	< 0.01
Quadratic	1.95	1	1.95	8.47	< 0.01
Cubic	1.03	1	1.03	4.47	< 0.05
Other Trends	0.04	5	0.01	0.04	n.s.
Error	65.41	279	0.23		
Total	70.47	287			

SUBJECT 2

Source	SS	df	MS	F	p
Between	1.38	8			
Linear	0.16	1	0.16	1.00	n.s.
Quadratic	0.06	1	0.06	0.40	n.s.
Cubic	0.04	1	0.04	0.25	n.s.
Other Trends	1.12	5	0.22	1.40	n.s.
Error	46.12	279	0.16		
Total	48.50	287			

TABLE 2

Within-subject trend analysis of variance for the nine onset-onset intervals of the contour masking functions from Experiment 2.

SUBJECT 1

Source	SS	df	MS	F	p
Between	4.63	8			
Linear	0.30	1	0.30	1.30	n.s.
Quadratic	3.24	1	3.24	14.09	<0.01
Cubic	1.05	1	1.05	4.57	<0.05
Other Trends	0.04	5	0.03	0.04	n.s.
Error	62.91	279	0.23		
Total	66.54	287			

SUBJECT 2

Source	SS	df	MS	F	p
Between	5.62	8			
Linear	0.16	1	0.16	0.89	n.s.
Quadratic	1.34	1	1.34	7.44	<0.01
Cubic	0.94	1	0.94	5.22	<0.05
Other Trends	3.18	5	0.64	3.53	<0.01
Error	49.37	279			
Total	54.99	287			

TABLE 3

Within-subject trend analysis of variance for the nine onset-onset intervals of the contour masking functions from Experiment 3.

SUBJECT 1

Source	SS	df	MS	F	p
Between	5.10	8			
Linear	1.80	1	1.80	7.83	<0.01
Quadratic	0.41	1	0.41	1.78	n.s.
Cubic	0.01	1	0.01	0.04	n.s.
Other Trends	2.88	5	0.58	2.50	<0.05
Error	63.12	279	0.23		
Total	68.22	287			

SUBJECT 2

Source	SS	df	MS	F	p
Between	2.50	8			
Linear	0.24	1	0.24	1.04	n.s.
Quadratic	0.92	1	0.92	4.0	<0.05
Cubic	0.06	1	0.06	0.26	n.s.
Other Trends	1.28	5	0.26	1.11	n.s.
Error	63.37	279	0.23		
Total	65.87	287			

TABLE 4

Within-subject trend analysis of variance for the nine onset-onset intervals of the contour masking functions from Experiment 4.

SUBJECT 1

Source	SS	df	MS	F	p
Between	5.72	8			
Linear	2.92	1	2.92	13.90	<0.01
Quadratic	0.22	1	0.22	1.06	n.s.
Cubic	1.11	1	1.11	5.29	<0.05
Other Trends	1.47	5	0.29	1.40	n.s.
Error	59.56	279	0.21		
Total	65.28	287			

SUBJECT 2

Source	SS	df	MS	F	p
Between	3.12	8			
Linear	2.42	1	2.42	14.24	<0.01
Quadratic	0.23	1	0.23	1.35	n.s.
Cubic	0.11	1	0.11	0.65	n.s.
Other Trends	0.36	5	0.07	0.42	n.s.
Error	47.75	279	0.17		
Total	50.87	287			

20-40 msec smaller than the apparent motion functions obtained in Experiment 2. The temporal dissociation between apparent motion and contour masking produced by the differential effect that spatial separation has on the two phenomena is clearly illustrated in the data for subject 1. Relative to Experiment 2, the plus 20 msec shift in the contour masking maxima and the minus 20-40 msec shift in the apparent motion maxima left a 40-60 msec difference between the optimal effects of the two phenomena in Experiment 1. Moreover, inspection of the data in Experiment 1 (Fig. 2) reveals that for both subjects, masking was minimal in the range of SOA's producing beta movement.

When the results from Experiment 2 are compared to the data from Experiment 4 which used the same interstimulus distance, it is evident though the apparent motion maximas remained at relatively the same SOA's (subject 2 shifted down to 80 msec SOA), the unilateral stimulus presentation mode caused the contour masking maximas to shift to larger onset-onset intervals. The masking results are consistent with the argument that by minimizing interhemispheric inhibitory activity and maximizing intrahemispheric inhibition, the cortical distance is effectively reduced. Contrary to the implications within Matin's model, optimal masking and apparent motion did not occur at the same onset-onset interval.

Comparing Experiments 3 and 4, it is observed that the use of the smaller spatial separation in Experiment 3 generated anomalous results with respect to both models under consideration. For both subjects, the reduced interstimulus distance in Experiment 3 produced contour masking function maximas at smaller onset-onset intervals relative to the contour masking maximas of Experiment 4. Since the smaller spatial separation caused the apparent motion maximas to shift toward the origin in Experiment 3 as compared to Experiment 4, the reduction in the visual angle separating the stimuli presented in a vertical display produced a shift in the contour masking function that paralleled the shift in the apparent motion function. As was mentioned previously, the Breitmeyer-Ganz model predicts that the maximal effects of the two phenomena diverge as the spatial separation is varied (i.e. the contour masking maxima shift to larger SOA's as the interstimulus distance is reduced). It is important to note that although the shift in the masking function is directionally the same as the shift in the apparent motion function, as expected according to Matin's model, there is still a 20-40 msec difference between the apparent motion and contour masking maximas.

In order to test the hypothesis that the magnitude of the contour masking increases when the spatial separation of the target and mask is decreased and when intrahemispheric activity is maximized as inter-hemispheric interaction is minimized, a within-subject three way analysis of variance was performed on the contour masking functions of Experiments 1-4. The results are summarized in Table 5. For subject 1, neither variable, spatial separation nor the direction of stimulus presentation significantly affected the overall magnitude of masking. For subject 2, the direction of stimulus presentation was significant at the .05 probability level while the two way interaction between the direction of stimulus presentation and interstimulus distance and the three way interaction between direction, interstimulus distance, and onset-onset intervals were significant at the .01 probability level. Of course, as expected, the variation of the temporal interval separating the onset of the target from the onset of the mask (SOA) was effective as indicated by the F values exceeding .01 probability levels obtained for both subjects.

TABLE 5

Within-subject three way analysis of variance for the contour masking functions from Experiments 1-4. Factor A refers to the direction of stimulus presentation, horizontal in Experiments 1 and 2 versus vertical in Experiments 3 and 4. Factor B refers to spatial separation, the small intercontour distance in Experiments 1 and 3 versus the large intercontour distance in Experiments 2 and 4. Factor C refers to the nine onset-onset intervals used in Experiments 1-4.

SUBJECT 1

Source	SS	df	MS	F	p
A (direction)	0.34	1	0.34	1.48	n.s.
B (distance)	0.58	1	0.58	2.52	n.s.
C (SOA)	13.57	8	1.76	7.39	<0.01
AB	0.03	1	0.03	0.13	n.s.
AC	1.78	8	0.22	0.96	n.s.
BC	0.60	8	0.08	0.35	n.s.
ABC	0.45	8	0.06	0.26	n.s.
Within	255.06	1116	0.23		
Total	272.41	1151			

SUBJECT 2

Source	SS	df	MS	F	p
A (direction)	1.01	1	1.01	5.61	<0.05
B (distance)	0.42	1	0.42	2.33	n.s.
C (SOA)	5.36	8	0.67	3.72	<0.01
AB	2.16	1	2.16	12.00	<0.01
AC	2.65	8	0.33	1.83	n.s.
BC	0.94	8	0.11	0.61	n.s.
ABC	4.74	8	0.60	3.33	<0.01
Within	205.50	1116	0.18		
Total	222.83	1151			

The important interaction effects between SOA and direction of stimulus presentation and between SOA and interstimulus distance did not appear to affect the overall masking obtained for either subject. It is important to note that the results of the three way analysis of variance for subject 2 are "questionable" when one considers that the trend analysis on the contour masking function from Experiment 1 suggested the absence of U-shaped backward contour masking. Thus, the present results fail to confirm that the magnitude of contour masking decreases as spatial separation increases. The inverse relationship between the magnitude of metacontrast Type B effects and the spatial separation of the stimuli has been reported elsewhere (Alpern, 1953; Weisstein and Growney, 1969).

CHAPTER IV

DISCUSSION

The overall results obtained from Experiments 1-4 are not consistent with the expectations of either masking model under investigation. Although the data does not provide the opportunity to make definitive comments concerning the two models, the data does provide the empirical basis to further specify the relationship between apparent motion and U-shaped backward contour masking.

For one experimental condition, the apparent motion and contour masking functions had maximas at 100 msec onset-onset interval for both subjects. Identical results have been reported elsewhere (Breitmeyer, Love, and Wepman, 1974). Kahneman (1967) reported optimal apparent motion and metacontrast occurring at 95-100 msec SOA's. A recent study investigating two transient contour masking effects also reported optimal contour suppression occurring at 100-120 msec SOA's (Breitmeyer, Battaglia, and Weber, 1976). Moreover, the visual angle manipulations used by Weisstein and Growney (1969), though successful in differentially affecting the shape of metacontrast and apparent motion functions, did not produce noticeable shifts in the maximas for apparent motion and metacontrast functions which were for the majority of conditions occurring at SOA's of 100 and 125 msec.

The two manipulations employed in the present study did produce shifts in the maximas for both apparent motion and contour masking functions. Consequently, it is possible to further distinguish the two phenomena based on the temporal dissociations demonstrated in three of the experiments. That is, given a paradigm possessing the ability to produce strong apparent motion effects and contour masking, the occurrence of maximal contour masking is not limited to the range of onset-onset intervals producing beta movement. Masking of contour information can, but does not always occur around the same onset-onset intervals producing optimal stroboscopic motion. Therefore, it is possible to conclude that the observance of optimal stroboscopic motion is not necessary for contour suppression to occur. It is important to note that the above statement is made specifically regarding optimal stroboscopic motion (beta motion) for reasons to be discussed later.

The spatio-temporal relationships governing U-shaped backward contour masking contained within the Breitmeyer-Ganz model were accurate in predicting the changes in contour masking function maximas for two out of three situations. For at least one subject, using the common stimulus arrangement having the target and mask presented to opposite sides of the vertical meridian passing through the fovea, the hypothesized inverse relationship between spatial and temporal separation was exhibited. This type of relationship has been demonstrated for metacontrast (Alpern, 1953). As was previously mentioned, implicit in the Breitmeyer-Ganz model is the assumption that presenting both target and mask to a single hemisphere effectively decreases the distance that the cortical inhibitory activity must traverse and also increases its effectiveness. As expected, given the same interstimulus distance, the maxima for the contour masking function when both target and mask were presented to the same hemisphere did occur at larger onset-onset intervals than the maximas for contour masking functions generated using the common horizontal stimulus display. The unilateral mode of stimulus presentation did not significantly affect the overall magnitude of contour masking.

However, the occurrence of optimal contour masking at smaller onset-

onset intervals as the visual angle separating the vertically arranged stimuli was decreased challenges the spatio-temporal relationships proposed in the Breitmeyer-Ganz model. Since the Breitmeyer-Ganz model predicts the occurrence of optimal contour suppression at larger SOA's as the interstimulus distance is decreased and/or as intrahemispheric activity is maximized while interhemispheric activity is minimized, under the conditions of Experiment 3 (small intercontour distance and unilateral stimulus display) maximal contour masking should have occurred at SOA's not only larger than the SOA's producing maximal contour masking in Experiment 4 which used a larger intercontour distance, but also SOA's larger than the SOA's producing optimal contour suppression in Experiments 1 and 2 which used identical and large intercontour distances respectively in a horizontal stimulus arrangement. In fact, optimal contour masking in Experiment 3 was observed at onset-onset intervals smaller than the SOA's producing maximal contour suppression in the other three experiments. Moreover, the spatial separation manipulation between Experiments 3 and 4 generated contour masking data not only diametrical to the expectation of the Breitmeyer-Ganz model, but also to the data obtained from the same visual angle variation used for the horizontally arranged stimuli of Experiments 1 and 2. As was demonstrated for stroboscopic motion in all four of the experimental conditions used, the data appears to indicate that a direct relationship also exists between the spatial and temporal separation of the target and mask in a contour masking paradigm using a unilateral stimulus display. The possibility that the results in Experiment 3 are an artifact of the experimental procedures used (i.e. limited range of SOA's) will be discussed later.

The direct relationship between the interstimulus distance and the onset-onset interval exhibited between Experiments 3 and 4 is predicted by Matin's model. Although the parallel apparent motion and contour masking function shifts are expected within Matin's model, the results of Experiment 3 do not strictly conform to the expectation of this model either. Contour masking was not observed at the same onset-onset intervals that received the maximal apparent motion ratings. In fact, the direction of the above masking function shift and the occurrence of optimal stroboscopic motion and maximal contour suppression at identical onset-onset intervals in Experiment 2 represent the only data agreeing with the relationships implied in Matin's formulation.

At first glance, it appears that the lawful behavior of the apparent motion functions and the inconsistencies observed for the contour masking functions favor a model that proposed a greater independence between the two phenomena than does the Matin model. Recalling that the perception of motion was a sufficient but unnecessary condition for Type B masking, Matin linked the two phenomena via a class of sequence analyzing neurons that, when stimulated by the appropriate temporal sequence, inhibited the information of the target signal. These T-M neurons also feed information into the system responsible for motion perception. In the Breitmeyer-Ganz model, the perception of motion is an unnecessary and insufficient condition for U-shaped backward masking. The only requirement for this model is that the target preceed the mask by the appropriate temporal interval for the spatial separation of the target and mask.

However, it is important to note that although for three out of four conditions, maximal contour masking occurred at SOA's different from the onset-onset intervals inducing optimal stroboscopic motion, optimal masking of contour information was always observed within a range of onset-onset intervals producing some illusory movement. Therefore, one cannot eliminate the possibility of succession detecting T-M neuron activity.

With the exception of Experiment 2 which had optimal apparent motion and contour masking occurring at identical SOA's, optimal contour masking always occurred at SOA's greater than the SOA that received the optimal stroboscopic motion rating. As was mentioned in the introduction, Wertheimer (1912) categorized a particularly interesting range of SOA's, extending outward from the optimal stroboscopic motion (beta motion) SOA to the SOA's giving rise to clear sequential impressions, that produced a category of partial motion perceptions that he termed phi motion. Kolers (1972) differentiates phi motion from beta motion as follows: "...phi motion correctly refers only to global 'figureless' or 'objectless' apparent motion, analogous to the very rapid passage of a real object across the field of view too quickly for its contours to be made out. Beta motion, on the other hand, refers to the perception of a well defined object moving smoothly and continuously from one location to another, analogous to the slow passage of a real object across the field of view." (pp. 10-11).

Koler's (1972) functional approach to motion versus figure perception bears significantly on the problem being discussed. For him, masking and apparent motion represent distinct and separate perceptual processes. Whereas apparent motion exemplifies the perceptual system's ability to create information, masking represents the system's ability to destroy and degrade information. According to Koler, in a typical apparent motion paradigm, two separate systems, one responsible for figural analysis and the other for motion detection, are functioning quasi-independently (i.e. Kolers assumes that although the interference of the figural signal by the motion signal is possible, the masking of motion without the loss of figural information has not been demonstrated). The category of apparent motion perceived is dependent on whether the threshold of one or both systems has been exceeded. For example, when the threshold for both systems has been exceeded, beta motion is observed. More important, whereas succession and simultaneity are observed when only the figural system is activated, phi motion is observed when the motion signal is strong enough but the figural signal is subthreshold.

Obviously, many analogies can be made between Koler's approach to apparent motion and both the Breitmeyer-Ganz and Matin models for U-shaped backward masking. However, the importance of the preceeding discussion is that it reveals several interesting implications concerning not only the two models under consideration, but also the methodological problems with investigations of this type as indicated by the present results. It is obvious that neither model under consideration is able to fully explain the current contour masking data. As indicated in the preceeding discussion, the spatio-temporal relationship for U-shaped backward masking proposed in the Breitmeyer-Ganz model did not hold when both the target and the mask were presented to the same hemisphere. The spatio-temporal relationships implied within Matin's model not only failed to predict the direction of the contour masking maxima shifts observed when the interstimulus distance of the horizontal stimuli was varied, but the temporal dissociations observed between beta movement and maximal contour suppression also contradicted the metacontrast-apparent motion relationship outlined in the model. Although neither model alone adequately explains the current contour motion masking results, it is possible that the contour masking data obtained from a two transient apparent motion-contour masking paradigm can be accounted for through the synthesis of the Breitmeyer-Ganz and Matin models. More specifically, the following discussion will speculate on the possibility that the contour masking curves in a two transient paradigm are a function of both U-shaped backward masking as explained by the Breitmeyer-Ganz model and the contour degradation associated with apparent motion. The latter factor will be explained through modification of Matin's model.

Before describing the mechanisms of such a model, it is important to review the empirical evidence suggesting the occurrence of two types of contour masking in apparent motion-contour masking studies. Metacontrast studies using the typical three display arrangements and/or the disk-annulus arrangement described earlier, have shown that the masking effect is only observed when the interstimulus distance is less than 2° (Alpern, 1953; Kolers and Rosner, 1960) and an inverse relationship exists between the interstimulus distance and the onset-onset interval (Alpern, 1953). On the other hand, good stroboscopic motion is obtained with spatial separation of over 4° (Neuhaus, 1930), and the spatial-temporal relationship is a direct one (Korte, 1915). If the categories of apparent motion are still evident as the interstimulus distance is increased to 4° or greater, then one would expect to observe beta and phi motion occurring at corresponding larger SOA's. Although neurophysiological evidence (Hess, Hegishi, and Creutzfeldt, 1975) suggests that inhibitory activity can occur between cortical columns that represent retinal location separated by about 4° visual angle, it would still be difficult to attribute the contour degradation associated with phi motion occurring at large SOA's due to the increased interstimulus distance to the masking model proposed by Breitmeyer and Ganz. According to their model, as the intercontour distance is increased, the temporal interval separating the initiation of the sustained channels responding to target from the initiation of the transient channels responding to the target should be smaller. That is, because of the divergence of the maximal effects of the two phenomena observed in the present study as separation of the horizontal stimuli was increased, optimal suppression of contour information should occur at smaller SOA's than both beta and phi motion. On the other hand, Matin's model cannot explain the spatio-temporal relationships reported for metacontrast (Alpern, 1953) nor the temporal dissociation exhibited between contour masking and apparent motion in the present study. Matin's model might possibly explain the loss of contour information reported during phi motion.

The crucial assumption for the hypothesized hybrid model for two transient apparent motion-contour masking paradigm is the possibility that inhibition of the contour information of the target can occur on at least two levels of visual processing and that at the higher level, the masking effect is much weaker. At the present time, there appears to be no neurophysiological nor strong psychophysical evidence available to accurately evaluate the relative effectiveness between two hypothesized levels of visual masking. Masking at the higher level is assumed to occur via a modified Matin model while the more potent masking at the primary level would function according to the Breitmeyer-Ganz model.

Much of Matin's model remains unaltered although it is proposed that the mechanism is not a major factor contributing to the masking in typical metacontrast studies. As described earlier, it is the high order, large receptive field sequence analyzing neurons responding optimally to the sequential presentation of the target and mask at the appropriate intervals that causes the inhibition of the high spatial frequency information. It is important to emphasize that the onset-onset interval producing an optimal response from the T-M neurons is not necessarily the same interval at which their inhibitory activity would be exhibited. In considering spatial factors (i.e. stimuli separation and locus of inhibitory activity in visual system) and the differences in response latency and propagation velocity between the transient channels and sustained channels responsible for motion and contour analysis respectively, it is suggested that the T-M neurons possessing a response sensitivity to a broad range of temporal frequencies would make the inhibition of contour information at intervals other than the interval inducing optimal stroboscopic motion possible. This is quite possibly the contour degradation observed during phi motion.

On the other hand, the more pronounced primary contour masking effects would be accounted for by the Breitmeyer-Ganz model. That is, transient channels activated by the abrupt onset-offset of the mask inhibit the high to intermediate spatial frequency information of the sustained channels activated by the target. Optimal inhibition would be achieved when the onset-onset interval is appropriate for the spatial separation of the stimuli and the response latency differences of the channels. Masking occurring via the mechanism outlined by the Breitmeyer-Ganz model will be referred to as primary masking. Masking occurring at higher levels of visual processing via sequence analyzing T-M neurons will be referred to as secondary masking.

The spatio-temporal relationship observed for the contour masking function in the two transient apparent motion-contour masking paradigm could be explained by the interactions of the two masking mechanisms. Because masking at the primary level is most effective, if conditions favor the occurrence of U-shaped backward masking as described in the Breitmeyer-Ganz model, then the temporal interval for optimal masking will be determined by the spatio-temporal properties of that model. The contour degradation associated with stroboscopic motion, suggested to be a function of high order sequence analyzer inhibition, would play an inferior role in the overall results obtained. It is important to note that although the combined effect of primary and secondary masking might be additive, since primary masking is assumed to be more effective than secondary masking, under conditions maximizing the occurrence of primary masking the contribution by masking at the secondary level to the optimal contour masking obtained may not be noticeable. The effects that masking at the secondary level could have on the shape of contour masking functions will be discussed later. Consequently, as demonstrated in this study, it is only under specific experimental conditions (i.e. spatial separation, luminance and/or contrast, retinal location) that optimal stroboscopic motion and maximal contour suppression both occur at the same onset-onset interval.

In general, contour masking results would be attributed to primary masking effects that function in accordance with the spatio-temporal properties as described in the Breitmeyer-Ganz model. With the exception of the direction of the contour masking shifts observed between Experiments 3 and 4, the results of the present study support the preceeding statement.

Upon careful consideration of the current results and of the hypothesized hybrid model, it appears that the results of this experiment might not represent data contradictory to the spatio-temporal relationships for Type B backward masking as proposed in the Breitmeyer-Ganz model. It is possible that since contour suppression in Experiment 3 was occurring at SOA's 20-40 msec greater than the SOA producing beta movement, the loss of contour information indexed in the data of Experiment 3 could be a function of the contour degradation associated with phi motion. If the loss of contour information during phi motion is assumed to be a product of the proposed secondary masking effects, then the contour masking observed in Experiment 3 would not be the Type B backward masking described by Breitmeyer and Ganz.

As previously mentioned, when the results of Experiment 2 and Experiment 4 were compared, even though the same interstimulus distance was used that produced beta movement and maximal contour masking at identical SOA's in Experiment 2, the contour masking maximas in Experiment 4 occurred at SOA's larger than the optimal contour masking SOA's of Experiment 2 and the beta movement SOA's of Experiment 4. This was explained by the implication contained within the Breitmeyer-Ganz model that unilateral presentation of the target and mask effectively decreases the cortical distance the inhibitory activity must traverse. An inverse temporal relationship was demonstrated. However, Experiment 3 used a smaller interstimulus distance and the contour masking function maximas shifted to smaller SOA's as did the stroboscopic motion maximas. Although the experimental conditions strongly favored the occurrence of Type B backward masking via a Breitmeyer-Ganz model, smaller spatial separation requires that the onset-onset interval be larger than the onset-onset intervals producing maximal contour suppression in Experiment 4. The limited range of SOA's employed could have prevented the observance of contour suppression due to primary masking. If one assumes that masking can occur at two levels of visual processing, then if the range of onset-onset intervals had been extended well beyond the 160 msec limit employed, one would expect to observe an inverted W-shaped contour masking function. Assuming that primary masking is much more effective than secondary masking, the height of the first peak in the contour masking function would be smaller than the height of the second contour masking function peak supposedly produced by masking at the primary level. A possible objection to the above proposal is that if masking at the secondary level is assumed to be rather weak, then the maximal error proportions of 0.59 and 0.47 are very large to be attributed to this type of contour masking. Explanation of this anomally can be found in a study (Gengerelli, 1948) that demonstrated that stronger stroboscopic effects can be obtained when both stimuli are presented to the same hemisphere. The stronger apparent motion effects imply increased succession detecting T-M neuron activity and as the results here suggest, increased secondary masking effects. On the other hand, the highly significant linear trends obtained for contour masking functions of Experiment 3 could suggest the absence of U-shaped backward masking or that the data over this limited range of SOA's represents the positive slope of a broad U-shaped masking function.

Because of the difficulty in specifying the relative effectiveness of the proposed primary and secondary masking effects and of the proposed interactions between the two levels of visual masking (i.e. in the range of SOA's that secondary masking effects are diminishing and primary masking effects are increasing) the data of Experiment 3 suggests the occurrence of secondary masking. However, the significant cubic trend for subject 1 in Experiment 3 does imply that a W-shaped function might have been observed if larger SOA's had been employed.

As the above discussion suggests, the possible existence of multi-level contour masking could manifest its effects in the shape of the masking function. For example, if larger spatial separations had been used, one should observe a shift in the stroboscopic maxima to larger SOA's as the contour masking maxima shifted to smaller SOA's. Under these conditions, maximal contour suppression should occur at onset-onset intervals smaller than those inducing beta and phi motion. The interaction effects between the primary and secondary levels of contour masking could be observed in a change in the overall shape of the masking function. Since secondary masking occurs primarily at SOA's beyond the SOA producing beta movement and the reduced primary masking due to the increased spatial separation occurs at smaller SOA's, the contour masking function should be flattened. Weisstein and Growney (1969) reported a flattening in the masking functions as the visual angle increased.

The study of U-shaped backward contour masking in a two transient apparent motion paradigm could be confounded by the proposed secondary contour masking effects associated with apparent motion. Investigations of Type B contour masking in a typical metacontrast design using either a three stimulus or disk-annulus display do not realize the effects of this problem as much since the experimental conditions favor the occurrence of U-shaped backward masking at the primary level. For example, since two mask stimuli are presented in positions flanking the target in a typical three stimulus display, the ratio of sustained channel activity of the target to transient channel activity of the masking stimuli is twice as great as the sustained/transient ratio in a two transient apparent motion-contour masking design as used in the present study. Thus, a typical metacontrast paradigm maximized the probability and/or effectiveness of contour masking at the proposed primary level via a Breitmeyer-Ganz mechanism as compared to a two transient paradigm. As a result, the shape of a contour masking function generated in a two transient apparent motion-contour masking paradigm could be affected by both proposed levels of visual masking. Thus, a contour masking function resembling the typical U-shaped backward metacontrast function could only be obtained under very specific experimental conditions.

Another problem with experiments of this type is the control of eye movement. It was pointed out earlier that metacontrast effects are a function of retinal location. Masking is very weak when the target is projected to the fovea (Alpern, 1953; Kolers and Rosner, 1960). To control this effect, all disks were positioned at equal distances from the fixation cross. Although the subjects were trained and frequently reminded to maintain the center of visual attention upon the fixation cross during each trial, there was no means of controlling or detecting eye movements in this study. This could explain the apparent absence of contour masking indicated by the flat contour masking function obtained for subject 2 in Experiment 1. Conditions for that experiment favored strong contour masking as indicated by the large error proportion (0.72) for subject 1 and it is possible that subject 2 quickly shifted her center of fixation during some of the trials in order to overcome the difficulty of the task.

In a study indicating that eye movements might contribute to the differences in visual acuity for selective visual hemifields, Ayres (1966) introduced an effective procedure for restricting eye movements which could and should be employed in studies investigating contour masking by the method used here. A very dim light, so dim that its onset could only be detected when the subject looked directly at it, was placed at the center of the fixation cross. The light was wired into the tachistoscope circuit in a manner that only allowed the subject to initiate the stimulus sequence during the very brief time (0.25-0.50 msec) that the fixation light was visible. Since the subjects were not aware of the exact time the light was to be turned on, they were forced to concentrate on the fixation point. Ayres (1960) assumed that since the subjects were forced to fixate on the light, the quick reaction required kept eye movements to a minimum. Measures to control confounding variables and to standardize experimental conditions would make the indexing of masking effects much easier to evaluate.

REFERENCES

Alpern, M. Metacontrast. Journal of the Optical Society of America, 1953, 43, 648-657.

Ayres, J. Some artifactual causes of perceptual primacy. Journal of Experimental Psychology, 1966, 71, 896-901.

Breitmeyer, B. A relationship between the detection of size, rate, orientation and direction in the human visual system. Vision Research, 1973, 13, 41-58. (a)

Breitmeyer, B. Simple reaction time as a measure of the temporal response of transient and sustained channels. Vision Research, 1975, (in press). (b)

Breitmeyer, B., Battaglia, F., and Weber, C. U-shaped backward contour masking during stroboscopic motion. Journal of Experimental Psychology: Human Perception and Performance, 1976 (in press).

Breitmeyer, B. and Ganz, L. Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression and information processing. Psychological Review, 1976, 83, 1-36.

Breitmeyer, B. and Julez, B. The role of on and off transients in determining the psychophysical spatial frequency response. Vision Research, 1975, 15, 411-415.

Breitmeyer, B., Love, R., and Wepman, B. Contour suppression during stroboscopic motion and metacontrast. Vision Research, 1974, 14, 1451-1456.

Bridgeman, B. Metacontrast and lateral inhibition. Psychological Review, 1971, 78, 528-539.

Brooks, B. and Jung, R. Neuronal physiology of the visual cortex. In R. Jung (Ed.), Handbook of Sensory Physiology (Vol. 7/3). New York: Springer, 1973.

Cleland, B., Dubin, M., and Levick, W. Sustained and transient neurones in the cat's retina and lateral geniculate nucleus. Journal of Physiology, London, 1971, 217, 473-496.

Dow, B. Functional classes of cells and their laminar distribution in monkey visual cortex. Journal of Neurophysiology, 1974, 37, 927-946.

Fehrer, E. Contribution of perceptual segregation to the relationship between stimulus similarity and backward masking. Journal of Perceptual and Motor Skills, 1965, 21, 27-33.

Fehrer, E. Effects of stimulus similarity on retroactive masking. Journal of Experimental Psychology, 1966, 71, 612-615.

Fehrer, E. and Raab, D. Reaction time to stimuli masked by metacontrast. Journal of Experimental Psychology, 1962, 63, 143-147.

Felder, R. and Ganz, L. Quantitative analysis of motion selectivity in complex neurons of cat visual cortex: II. Temporal Analysis. (unpublished).

Gengerelli, J. A. Apparent movement in relation to homonymous and heteronymus stimulation of the cerebral hemispheres. Journal of Experimental Psychology, 1948, 38, 592-599.

Harcum, E., Hartman, R., and Smith, N. Pre versus post knowledge of required reproduction sequences for tachistoscopic patterns. Canadian Journal of Psychology, 1963, 17, 264-273.

Hess, R., Negishi, K., and Creutzfeldt, O. The horizontal spread of intracortical inhibition in the visual cortex. Experimental Brain

Research, 1975, 22, 415-419.

Ikeda, H. and Wright, M. J. Evidence for "sustained" and "transients" neurones in the cat's visual cortex. Vision Research, 1974, 14, 133-136.

Kahneman, D. An onset-onset law for one case of apparent motion and metacontrast. Perception and Psychophysics, 1967, 2, 577-584.

Kahneman, D. Method, findings, and theory in studies of visual masking. Psychological Bulletin, 1968, 70, 404-425.

Kaufman, L. Sight and Mind. New York: Oxford University Press, 1974.

Kolers, P. A. Intensity and contour effects in visual masking. Vision Research, 1962, 2, 277-294.

Kolers, P. The illusion of movement. Perception: Mechanisms and Models. San Francisco: W. H. Freeman and Company, 1972.

Kolers, P. Aspects of Motion Perception. Oxford: Pergamon Press, Ltd., 1972.

Kolers, P. and Rosner, B. On visual masking (metacontrast): dicoptic observations. American Journal of Psychology, 1960, 73, 2-21.

Korte, A. Kinematoskopische Untersuchungen. Zeitschrift für Psychologie, 1915, 72, 193-296.

Kulikowski, J. and Tolhurst, D. J. Psychophysical evidence for sustained and transient detectors human vision. Journal of Physiology, London, 1973, 232, 149-162.

Lefton, L. Metacontrast: a review. Perception and Psychophysics, 1973, 13, 161-171.

Matin, E. The two transient masking paradigm. Psychological Review, 1975, 82, 451-461.

Neuhaus, V. Experimentalle Untersuchung der Scheinbewegung. Archiv für die gesamte Psychologie, 1930, 75, 315-458.

Purcell, D., Stewart, A., and Dember, W. Spatial effectiveness of the mask: lateral inhibition in visual backward masking. Perception and Psychophysics, 1968, 4, 344-346.

Rocha-Miranda, C., Bender, D., Gross, C., and Mishkin, M. Visual activation of neurones in the inferotemporal cortex depends on striate cortex and forebrain commissures. Journal of Neurophysiology, 1975, 38, 475-491.

Schiller, P. and Smith, M. Detection in metacontrast. Journal of Experimental Psychology, 1966, 71, 32-39.

Singer, W. and Bedworth, N. Inhibitory interaction between x and y units in the cat lateral geniculate nucleus. Brain Research, 1973, 49, 291-307.

Stone, J. The naso-temporal division in the cat's retina. Journal of Comparative Neurology, 1966, 126, 585-600.

Stone, J., Leicester, J., and Sherman, S. M. The nasotemporal division in the monkey's retina. Journal of Comparative Neurology, 1973, 150, 333-348.

Stone, J. and Dreher, B. Projection of x- and y- cells of the cat's lateral geniculate nucleus to area 17 and 18 of visual cortex. Journal of Neurophysiology, 1973, 36, 551-567.

Tolhurst, D. Separate channels for the analysis of the shape and the movement of a moving visual stimulus. Journal of Physiology, London, 1973, 231, 385-402.

Weisstein, N. A Rashevsky-Landahl neural net: simulation of metacontrast. Psychological Review, 1968, 75, 494-521.

Weisstein, N. Metacontrast. In D. Jameson and L. M. Hurvich (Eds.), *Handbook of Sensory Physiology*, Vol. 7, part 4 (*Visual Psychophysics*). New York: Springer, 1972.

Weisstein, N. and Growney, R. Apparent movement and metacontrast: a note of Kahneman's formulation. *Perception and Psychophysics*, 1969, *5*, 321-328.

Weisstein, N., and Haber, R. N. A u-shaped backward masking function in vision. *Psychonomic Science*, 1965, *2*, 75-76.

Wertheimer, M. Experimentalle Studien uber das Sehen von Bewegung. *Zeitschrift für Psychologie*, 1912, *61*, 161-265.