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I Terminology

Masking

Masking is a term which has been used to describe a phenomenon that can occur in the auditory, cutaneous and visual systems. One definition of masking can be extracted from the audition literature:

> "Masking is the process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound." (The American Standards Association 1960, pp. 46)

In a typical auditory masking experiment, the detection threshold for a stimulus (target) is measured alone and in the presence of another stimulus (mask). The difference between the two thresholds reflects the influence of the mask, or the amount of masking.

Visual masking was first investigated in 1871 by Baxt, who worked in Helmholtz's laboratory. He found that if briefly presented letters were followed within a short period of time by a flash of light, the clarity of the letters was impaired. Piéron (1925), investigating the role of neural latencies with this paradigm, coined the term "visual masking" to describe the phenomenon. In 1947, Crawford investigated the perceptual effect of presenting a large flash of light (conditioning stimulus) before, during and after the presentation of a smaller test flash. He found that when the conditioning stimulus followed the test flash, the latter's threshold increased. This specific paradigm of masking came to be known as the "Crawford effect".

Boynton & Kandel revived and generalized the use of the term "visual masking" in 1957 and since then, differences in terminology have generally reflected differences in theoretical orientations. For instance, Averbach & Coriell (1961) used the term "erasure" to describe this phenomenon because they believed that a neural representation to the target can be erased by the representation of a mask. Throughout this thesis, the term "masking" will be used to refer to the general phenomenon that describes the perceptual attenuation of a target due to the presence of a mask.

In a typical visual masking experiment, a measure of the effective visual impact of a target stimulus, such as detection, brightness or clarity is assessed as a function of different levels of the spatial, temporal or energy relationships between the target and mask. Changes in the dependent measure reflect changes in the perceptual impact of the target and hence, can be used as an index of the amount of masking. Since many dependent measures of the visual masking phenomenon can be employed, a generalized, rather than operational, definition of visual masking is warranted and offered by Kahneman (1968):

> "It (visual masking) covers the class of situations in which some measure of the effectiveness of a visual stimulus is reduced by the presentation of another visual stimulus in close temporal contiguity to it" (pp. 404).

Temporal Order & Metacontrast

Within the masking paradigm, targets have usually consisted of letters (Schiller & Smith, 1965), geometric forms (Brussell & Favreau, 1977), or flashes of light (Alpern, 1965), while masks have generally been large flashes of light (Alpern, 1965), fields of visual noise (Turvey, 1973), geometric forms (Alpern, 1952) or patterned fields (Turvey, 1973).

Targets and masks may be presented such that their images fall on spatially overlapping or adjacent areas of the retina. They may also be presented in one of two temporal orders. When a target temporally precedes a spatially overlapping mask, the paradigm is referred to as backward masking. when a target follows the mask, it is referred to as forward masking. With a spatially adjacent stimulus configuration, such as a target disc and a concentric masking ring, the temporal relationship described as forward masking with overlapping stimuli is called paracontrast, and what is known as backward masking is termed metacontrast.

Stigler (1910) was first to conclusively demonstrate and label the masking phenomenon with spatially adjacent stimuli, as "Metakontrast" (now known as Metacontrast).

Because this thesis focuses on the paradigm of metacontrast, the term "metacontrast" will be used to describe the phenomenon associated with non-overlapping stimuli, while "masking" with overlapping stimuli will be referred to as non-metacontrast masking. The general term "masking" will be used to refer to the masking phenomenon without respect to the spatial or temporal characteristics of the stimuli.

ISI & SOA

Targets and masks are usually presented separately in time. The temporal interval between the offset of the first stimulus and the onset of the second, is defined as the inter-stimulus-interval (ISI) while the interval separating the onsets of the two stimuli is referred to as the stimulus-onset-asynchrony (SOA). These two intervals, which are generally specified in milliseconds (msec), are commonly employed as two of the many possible independent variables used in masking studies. (The cases in which they can be employed as dependent measures are discussed in a following section.) The use of either ISI or SOA varies for different experimental situations. The rationale is now discussed.

Suppose a target consists of a letter which reflects 1 foot lambert (fL) against a background of 5 fL. The clarity of this target could be specified by computing its contrast ratio using the following formula:

$$\text{Contrast Ratio} = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

where L_{max} = the highest luminance of a stimulus and L_{min} =

its lowest luminance. This measure, which reflects the edge definition of a stimulus with respect to its background, is related to how well an observer perceives that stimulus. A perceptually well defined stimulus would probably have a contrast ratio approaching 1.0, while a less well defined stimulus would be reflected by a contrast ratio approaching 0.

The contrast ratio of this hypothetical target can be calculated to equal .67. If a mask of a higher uniform luminance, for instance of 10 fL, is concurrently presented such that it spatially and temporally overlapped the target, the perceptual effect would be an image formed by the addition of the luminances of both stimuli. That is, the luminance of the mask would be added to each part of the target. Therefore the luminance reflected to the retinal area representing the target letter would increase to 11 fL, while that of the background of the target would increase to 15 fL. Hence, if a new contrast ratio were computed with these new luminance values, it would be attenuated to .16. Phenomenally, the observer would report a target letter which is not as clear as the unobstructed target. It can therefore be said that this reduction in clarity, within the target, is due solely to the physical superimposition of the two stimuli.

Masking would not be an interesting phenomenon if it was merely described by this physical reduction in contrast.

In fact, masking studies are invariably interested in target suppression in the absence of concurrently presented overlapping stimuli. One tradition has been to de-emphasize those cases which produce any physical superimposition of the stimuli. That is, when spatially overlapping stimuli are used, as in forward and backward non-metacontrast masking paradigms, it is common to use the ISI as an independent measure because it excludes those conditions in which the stimuli overlap temporally. Since in metacontrast and paracontrast paradigms, spatial overlapping does not exist, physical superimposition may not be a problem and hence, the SOA variable is often used.

Various metacontrast studies have assigned positive and negative values of SOA to distinguish metacontrast from paracontrast. For instance, Raab (1963) used negative values of SOA to represent metacontrast, while Weisstein (1970) implemented positive SOA's to describe this condition. In being consistent with Weisstein, throughout this thesis positive and negative SOA's will represent the metacontrast and paracontrast conditions respectively.

The Metacontrast Function

Metacontrast is a phenomenon which involves a multitude of possible experimental manipulations. Historically, in a quest to refine the methods for investigating the phenomenon, researchers have modified previous designs and used varying measuring techniques. It has therefore been quite difficult to ascertain whether differences in the results of various studies are a function of the design of the experiment or reflects differences occurring in the metacontrast phenomenon itself. Although the literature is plagued with conflicting results, some common trends have been reported in the data of many studies.

Two general types of metacontrast functions have been documented in the literature. Kolers (1962) has referred to these as type A and type B functions. Type A functions usually describe relationships where maximum masking occurs at an SOA of zero (msec). Paracontrast as well as metacontrast is evident and the masking effect tapers off with an increase in SOA (fig. 1a). Type B functions are usually described by little or no paracontrast, and peak masking occurs at some SOA greater than zero, usually between 30 - 100 msec (fig. 1b). Type A functions are usually referred to as monotonic functions, while type B functions have been called non-monotonic, or U shaped functions.

Type B functions were generally believed to be obtainable only in experiments using brightness measures (Alpern, 1953; Matteson, 1969), while type A functions were reported in detection and identification tasks, especially when the paradigm involved the use of masks which had high luminances or durations relative to the targets (Fehrer & Smith, 1962; Kolers, 1962). Ericksen et. al. (1970) explained that this might indicate that brightness reflects "an independent or

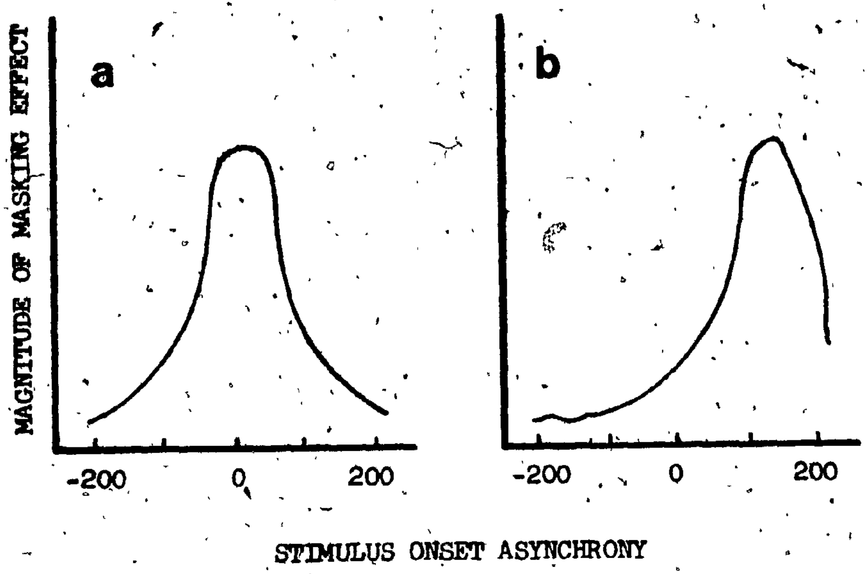

Fig. 1: Two common types of masking functions found in metacontrast.

parallel effect to the identification (detection) process" (pp. 258). However, Kolers & Rossner (1960), using discs as targets and rings as masks, as well as Weisstein & Haber (1965) and Mayzner et. al. (1965) using letters as targets and rings as masks, reported that correct detection and identification could vary as a non-monotonic function of SOA with maximum masking occurring between SOA values of 30 - 50 msec. Ericksen (1970), failing to replicate the Weisstein & Haber study, claimed that their results were probably the result of artifactual "flaws" in their apparatus. For instance he discussed the possibility that target-mask misalignment problems, luminance relationships and intersubject differences might have somehow produced the U shaped metacontrast function.

In Ericksen's criticism of the Weisstein & Haber experiment, he substantiated his claim that detection and identification procedures produce only monotonic metacontrast functions. However, it seems unlikely that Kolers & Rossner as well as Mayzner et. al.'s data were the result of artifactual "flaws". Repeated reports of U shaped metacontrast findings in conjunction with Weisstein et. al.'s (1970) finding, which showed that U shaped metacontrast functions obtained from magnitude estimation and detection tasks do not significantly differ, clearly point to the reality of non-monotonic metacontrast functions.

II Theories of Metacontrast

This section will review and evaluate some of the major theories that have attempted to explain the phenomenon of metacontrast. These theories fall under four general categories: apparent motion, integration, interruption, and theories that are based on lateral inhibition. Each theory will be considered sepafately.

Apparent Motion & Metacontrast

Kahneman (1967) developed a theory of metacontrast based on the visual phenomenon known as apparent motion. Apparent motion is described in the following manner: Suppose an illuminated square, which is temporally followed by another spatially adjacent illuminated square, is presented to an observer. At an optimal SOA, the observer would report "seeing" a square moving from the location of the first stimulus to that of the second. This phenomenon,which was first described by Wertheimer (1912), can be seen when looking at the "moving lights" which are often on the marquis of movie theatres.

In metacontrast, a patch of light which is called a target is flanked by two other patches of light, which are masks. The target and masks are presented in some temporal order such that if one of the masks is removed, the target will have appeared to move in the direction of the visible mask. However, when both masks are presented, apparent motion should predict that the target would appear to move in the direction of both masks. Since a stimulus cannot be perceived to move in two opposite directions at the same time, the visual system is confronted with an impossible situation. It therefore suppresses the visual information about the target in order to resolve this conflict. This results in the perceptual degradation of the target in the metacontrast paradigm.

In explaining the data of many of his apparent motion experiments, Kahneman postulated that a response to a brief stimulus lasts longer than that of the stimulus itself, and the neural responses to two stimuli which follow one another must overlap in time. Apparent motion is seen "when a period of response to the first stimulus alone is followed by a period of overlap - provided that the overlap is of intermediate duration - and the overlap is itself followed by a period of response to the second stimulus alone" (Kahneman, 1967; pp. 582). Kahneman claimed that the response to a brief stimulus does not appreciably change as a function of exposure duration. He suggested that, the amount of overlap between the two neural responses is dependent mainly on SOA, and not on the durations of the stimulus. Thus, apparent motion varies as a function of SOA. This is known as "the onset-onset law" of apparent motion. According to Kahneman, when stimuli are presented for longer durations, their neural responses become sensitive to the duration variable and the "onset-onset law" breaks down.

Extrapolating the "onset-onset law" to metacontrast, Kahneman suggested that with brief stimuli, metacontrast varies as a function of SOA. He showed (Kahneman, 1967) that the manipulation of target and mask durations (between 25 and 125 msec) does not affect the metacontrast function in that it only varied as a function of SOA.

Using the above description of the visual system, Kahneman explained how metacontrast varies as a non-monotonic function of SOA. At short SOA's, the response overlap of the target and masks is small and consequently, the two stimuli are perceived as occurring simultaneously; at moderately long SOA's, conditions are such that apparent motion is optimum, and hence masking of the target is maximum; and at longer SOA's, the response to the first stimulus is complete before the response to the second stimulus begins, resulting in the two stimuli being seen separately in time.

Since monotonic metacontrast functions have also been reported throughout the literature (Ericksen & Collins, 1964, 1965; Schiller, 1965; Schiller & Smith, 1966), Kahneman postulated that a mechanism other than apparent motion operated under certain stimulus conditions. When Fehrer & Smith (1962) varied the luminance ratio of their target and mask squares in a metacontrast experiment, they found that metacontrast functions were U shaped when the luminance ratio of the stimuli approached 1, and became monotonic when the ratio approached 0. Employing this finding in a theory of metacontrast, Kahneman appealed to the phenomenon of simultaneous brightness contrast to explain monotonic metacontrast functions.

Simultaneous brightness contrast describes a condition where the perceived brightness of a visual stimulus is attenuated when it is surrounded by a field of higher luminance.

In Fehrer & Smith's experiment, a luminance ratio approaching 0 was described by a higher luminance mask and lower luminance target, which satisfies the stimulus luminance conditions necessary for producing simultaneous brightness contrast. Thus, Kahneman explained that at an SOA of zero, the perceptual suppression of a target in a metacontrast paradigm is the result of simultaneous brightness contrast. As the SOA increases the target and mask(s) perceptually separate therefore reducing the simultaneous brightness contrast effect, and producing the monotonic function. Brightness contrast which relies on the luminance differences between two fields, falls off as the luminance of the two fields approaches equality. Therefore, as the stimulus luminance ratio between a target and mask approaches 1, metacontrast can no longer be explained by brightness contrast, and, thus, may be explained by apparent motion.

Weisstein & Growney (1969) conducted a parametric investigation comparing the phenomenon of apparent motion with that of metacontrast. Their results seemed to indicate that the two phenomena are mediated by separate mechanisms. They found for instance, that metacontrast functions decrease in amplitude and change shape with an increase in visual angle, while functions obtained from an apparent motion paradigm did not. Metacontrast was shown to be sensitive to energy changes in the stimuli, while apparent motion was not. Because of these differences, Weisstein & Growney concluded that apparent motion was not a tenable explanation of metacontrast. However, because of their similarities, they suggested that they might share some common visual mechanisms located in the striate cortex.

An Integration Theory of Non-metacontrast Masking & Metacontrast

Since the figure-ground contrast of a stimulus is critical in visual discrimination, Ericksen & Lappin (1964) believed that somehow masking was the result of an attenuation of this contrast within the target. They suggested that in the cases where a target and mask are separated by very short periods of time, the visual system might integrate the two stimuli over time, creating a stimulus image not unlike that of a double exposed photograph. In non-metacontrast masking, they explained that during this integration, the luminance from the mask is added to the light and dark sections of the target, thereby reducing the figure-ground contrast within the target. As this contrast decreases, the perceptibility of the target attenuates, resulting in its perceptual degradation, or masking. They explained that this theory predicts monotonic masking functions because as the SOA (or ISI) is lengthened, the probability of the two stimuli integrating decreases.

For metacontrast paradigms, they also suggested that the stimuli temporally integrate. The following example is a description of this explanation.

Suppose a dark target letter on a lit background is presented within a dark masking ring. If the two stimuli integrate, the high luminance of the mask background will add to the dark portion (letter) of the target. Thus, the figure-ground contrast within the target will decrease, resulting in masking. According to this explanation, the background of the mask is responsible for the perceptual attenuation of the target. Thus, the mask itself is not important in metacontrast, suggesting that this phenomenon is merely an artifact of luminance summation. Although this theory is suitable for describing how masking is produced using dark stimuli, it seems to break down when describing the phenomenon when illuminated (lit) stimuli are employed.

A lit letter on a dark background can be presented within a lit concentric ring. If the effective luminance of the two stimuli integrate over time, the low luminance background of the mask will add with the high luminance of the target letter. This should have no effect on the figure-ground contrast, since the overall luminance of the target would not be changed by much. In this case, according to the luminance summation theory, one should not expect masking. However, the results of many studies (Purcell & Stewart, 1974; Heckenmeuller & Dember, 1965; Matteson, 1969) have shown that masking does exist with lit stimuli.

Another major criticism of this theory is its inability to explain non-monotonic metacontrast functions. However, Ericksen et. al. (1970) offers an explanation for these U shaped functions. As was explained earlier, he suggested that U shaped functions were an artifact of dependent measures which are based on judgements of the apparent brightness of targets. He cites data which suggests that a target becomes progressively less bright as ISI increases up to some value, and then becomes progressively brighter, as the ISI is further increased. Although he does not describe the underlying mechanisms that are operating, he suggested that the phenomenal dimming of the target is an independent or parallel effect to the identification process and that the information necessary for detection or identification does not seem to be affected by the phenomenal dimming. However, the results of the Weisstein & Haber (1965) study (not withstanding Ericksen's criticisms) and the Purcell, Stewart & Brunner (1974) study show that U shaped functions do occur in paradigms in which identification or detection procedures are used. In order to explain the results of these latter experiments, one would have to speculate that either detection and identification tasks are not independent of the phenomenal dimming effect, or that all the dependent measures are reflecting a characteristic function occurring in metacontrast.

Because the theory of luminance summation cannot in and of itself adequately account for much of the metacontrast data, this theory has all but been abandoned as a complete explanation of the results obtained from this paradigm.

Interruption Theories of Masking

Averbach & Coriell (1961) suggested that the presence of a mask erases any image of a target that has already been formed and placed in a sensory store. Lindsley (1961) argued that the mask interferes with any processing of the target so that its perceptual representation is never reached, while Sperling (1960) hypothesized that the mask interferes with reading out the already formed image of the target from the sensory store.

In the explanations of masking, integration and interruption theories differ in that the former set of theories specifies that two already formed images of the stimuli temporally combine, while the latter set explains that the mask interferes with the processing of the target so that the target's perceptual representation (in sensory storage for instance) is never reached.

Because the processing time of a visual stimulus is inversely related to its energy level (energy being defined as the product of luminance and duration), interruption hypotheses would explain that backward masking occurs because a late-coming mask of high energy quickly catches up to a slowly processed target of low energy, and interrupts this processing.

Specifically, interruption theories would explain U shaped functions in the following manner. They suggest that at short SOA's, a target and mask can be processed sensitivity to an aftercoming low energy target.

Integration and interruption models of masking have traditionally been regarded as opposing explanations of masking. Recently however, Turvey (1973) proposed a masking model which incorporates "integration" and "interruption" principles.

The Concurrent-Contingent Model of Masking

Turvey (1973) hypothesized that masking is mediated by peripheral and central mechanisms. He refers to peripheral processing as that which occurs in the retina, lateral geniculate nucleus, parts of the striate cortex and the transmission lines among these. Central mechanisms basically refer to a "relatively late stage in the cortical processing of visual data". These two types of mechanisms are related in that the two processes occur concurrently with the operation of the central processes being contingent on the output from the peripheral mechanisms.

A visual image stimulates receptors located in many peripheral nets. Each net processes specific information about the stimulus. For instance, one net may process intensity information, while another, size or temporal information. Each of these nets are connected to central storage units which combine their information serially. That is, the input to a central store consists of two bits of information. The first, being the output from the preceding central store, and the second, the output from the peritogether in sensory storage without interfering with each other. However, at longer SOA's when a target is processed alone in sensory storage, its processing is sensitive to "intruders" coming into this storage level. Thus, an aftercoming mask may interfere with the processing of the target if it enters into sensory storage before the target has a chance to be processed through it. At greater SOA's, the target is processed through sensory storage before the aftercoming mask can interrupt its processing.

The results of some experiments (Ericksen & Collins, 1964; Ericksen & Lappin, 1964), which have shown that the magnitude of visual masking varies as a monotonic function of ISI or SOA with maximum masking at an SOA of 0, have been the basis for the rejection of the interruption hypothesis. According to the interruption explanations, there should be no erasure with concurrent presentation nor with forward masking.

In summary, there are two shortcomings of the interruption model. First it has difficulty in explaining the occurrence of monotonic masking functions which have been reported in the literature; and second, a problem related to the first, is that it generally can not account for forward masking. As Kahneman (1968) pointed out, the second problem may not be fatal. The following description may account for forward masking. If a high energy mask light adapted the eye, then this would serve to reduce its pheral net associated with that specific storage unit. The information from a peripheral net must, therefore, be processed and stored in [illegible] central store before output from the central store is released to the next central unit. Therefore, processing of information at the central level can be delayed by peripheral mechanisms.

Masking may be peripheral or central in nature, depending upon where the information from the two stimuli interact. If a target and mask fuse or integrate at the peripheral nets, or in the transmission line between these nets and the central stores, then the central stores receive and process the *integrated* image of the two stimuli, which results in the attenuation of the perceptability of the target, which describes peripheral masking. If the two stimuli do not interact before the central stores, then the central processor receives the two stimuli in succession and must process the target before the aftercoming mask has a chance to catch up and *interrupt* the ongoing processing of the target. If the mask catches up and interferes with the processing of the target, then the resulting perceptual suppression of the target is termed, central masking.

Turvey suggested that nonmonotonic masking functions are only produced when stimuli which have specific energy characteristics are employed. He claimed that in non-metacontrast masking, a non-monotonic function is formed when a high energy target and lower energy mask are used.

He explained that at brief SOA's, the target and mask will share some common peripheral nets, and because the energy of a stimulus is crucial at these peripheral stages of processing, the high energy target will fail to be masked by the lower energy mask when integrated with it. He proposed that at the central levels of processing, the energy characteristics of the stimuli lose their importance and thus, as the SOA is increased, the "late-coming" mask can interrupt the processing of the target by merely entering into the central stages before the central processing of the target is complete. As the SOA is further increased, the processing of the target is finished before the mask can centrally interfere with it.

In summary, a high energy target and low energy mask would produce the following non-monotonic masking function: At short SOA's, the target would evade peripheral masking; at moderate SOA's, it would be centrally masked and at longer SOA's, it would evade masking.

Turvey (1973) suggested that this explanation of U shaped non-metacontrast masking functions can be extrapolated to explain similar functions found in metacontrast. He explained that although U shaped metacontrast functions are probably produced by similar mechanisms (as those described above), these metacontrast paradigms probably involve "decisions beyond the central storage mechanisms which were described in the model". (pp. 41)

The concurrent-contingent model successfully unifies integration and interruption explanations of non-metacontrast masking into one comprehensible model. However, because it is a model which is based on the data from non-metacontrast masking, it fails to fully explain the data found in the metacontrast paradigm. For instance, Turvey would predict from his model that in order to produce a U shaped masking function, one would need a high energy target and low energy mask. He would have therefore had ~~have~~ difficulty explaining the production of U shaped masking functions when equal energy stimuli are employed, a common finding in the metacontrast literature.

Because this model does not fully explain the findings found in the metacontrast literature, it has not been considered a viable explanation of metacontrast.

Two theories which are based on the neural mechanism known as lateral inhibition have been proposed to explain masking. Before these theories are reviewed, Lateral Inhibition will be defined.

Lateral Inhibition

In 1942, Hartline, investigating the compound eye of the horseshoe crab (Limulus), first demonstrated the phenomenon of lateral inhibition. The compound eye of the Limulus is composed of many facets called ommatidia. Light hitting the eye creates an image to the crab that is probably not unlike a mosaic picture. Hartline's experiments consisted of stimulating ommatidiam with light, and by placing an electrode at an optic nerve fibre, he monitored changes in the response rate of these cells. For instance he found that the stimulation of a particular ommatidiam (receptor) resulted in the increased firing rate (above the baseline spontaneous firing rate) of a nerve fibre. That is, if a light stimulated receptor A, an increased firing rate occurred in nerve fibre X. Similarly, if he stimulated another receptor B, an increase in the spontaneous firing rate occurred in another nerve fibre Y. However, if he stimulated both receptors A and B, and monitored the firing rates of nerve fibres X and Y, he noticed that the firing rates in these nerve cells were lower than when either of these cells were being stimulated alone. Thus, the attenuation in the firing rate of nerve cells due to the activity of a neighboring nerve cell was called Lateral Inhibition.

Purcell, Stewart & Dember's (1968) Lateral Theory of Masking

From the data of the limulus studies, Purcell et. al. proposed the following theory of visual masking based on lateral inhibition. Their model assumes that:

1. The firing of an aggregate of neural cells in the visual system has the effect of inhibiting or lowering the firing rate of those and adjacent cells to present and subsequent stimulation.
2. The amount of inhibition generated by a given flash of light is an increasing function of the intensity of that flash.

3. Inhibition decays as a monotonic function of time since termination of stimulation.

4. The relative amount of inhibition on a given neuron, firing or nonfiring, is a positive function of the number and proximity of firing neurons surrounding it.

5. The phenomenal brightness of a given visual stimulus or a train of intermittent stimuli results from the integration of firing to that stimulus presentation within some critical time period. (pp. 344)

Suppose an aggregate of neurons (group 1) responded to a low luminance target (disc) while another aggregate (group 2) responded to the target's higher luminance background. The presentation of the target stimulus would result in little activity of group 1 (due to the low luminance of the target) thereby producing no, or little, inhibition to subsequent stimulation in the same retinal area. Because of the high luminance of the background, group 2 would generate much activity and consequently much inhibition. If a lit homogeneous flash mask was presented after the target, such that it spatially covered the retinal areas of the target and its background, group 1 which had little inhibition would fire at a high rate, while group 2 would change from an area of high firing rate to one of a low rate (due to inhibition already present in this area). Since the perceived brightness of an area is a function of the temporal integration of their respective firing rates to the target and masking flashes, three phenomenal outcomes are possible.

1. If the differential between the inhibition of group 1 and 2 was sufficient, then group 1's firing rate to the masking field would be much greater than that of group 2. This would result in the central target area to be perceived as being brighter than its immediate background, a phenomenon which Purcell et. al. have called brightness reversal of the target.

2. With less differential, the integration of the two stimuli would result in the perception of a target which is phenomenally the same brightness as the background (mask) and the dark target could be said to be masked.

3. With even less of a differential, integration would result in the target appearing from grey to black.

For the third outcome, one way to increase the differential of inhibition between group 1 and 2 would be to increase the luminance of the background. There is also another method for increasing this inhibition. If a black figure such as a ring concentric to the target was added to the masking stimulus, the following might result. Taking into account assumption 4, the black masking figure would "serve to protect neurons adjacent to and surrounding it from receiving as much lateral inhibition as they would if the masking field was homogeneous." Consequently, neurons adjacent to this figure (ring) could fire at a higher rate than if they were stimulated by a uniform flash. The result would be more increased firing in group 1 than in group 2 because the latter group is inhibited to a greater extent - from the first presentation of the target.

In order to explain disinhibition or re-reversals of the target, Purcell et. al. assumed that the dependent criteria of an observer was critical in producing this phenomena. Suppose for instance that in a given paradigm observers were required to identify or detect a <u>dark</u> target. In the case of a brightness reversal, an observer might fail to locate the target for his criterion is based on the perception of a dark stimulus. Therefore, this stimulus would be operationally described as being masked. In this case the "masked" target is still represented in the visual system. Since one masking stimulus can reverse a target, a second mask might in the same way as the first, act upon the reversed target to restore it to its original appearance (Purcell & Dember, 1968). Thus an observer might report a stimulus which is masked in one condition and to be "recovered" in the second.

Purcell et. al. explained that the magnitude of inhibition generated by any region of the target stimulus would be greatest immediately after its presentation and would gradually "decay as a monotonic function of time". They would therefore predict that metacontrast is maximum at short SOA's. To illustrate, the amount of inhibition generated by the background of the target described earlier (group 2) would decay with time. Since there would be little or no inhibition to the second group of neurons responding to the target, at longer SOA's, the inhibition differential between these two aggregates of neurons would decrease, resulting in an attenuation of masking. This type of explanation suggests that metacontrast varies as a monotonic function of SOA.

Due to the occurrence of U shaped functions in metacontrast, Stewart & Purcell (1974) described a visual model which explains how non-monotonic metacontrast functions are produced.

Stewart & Purcell's (1974)
Persistence Theory of Masking

Stewart & Purcell proposed that the detection or recognition of any visual stimulus, which consists of a target figure and background, requires some finite amount of time and recognition continues after the offset of the target. This persistence of the visual image has the same figure-ground relationship as the target that generated it and appears to dim from the offset of the stimulus presentation. An index of legibility of the persisting image, analogous to the contrast ratio used by Ericksen (1966), is the ratio of the persistence of the surround to the persistence of the target.

Thus the index of legibility for this target stimulus may be expressed in the following form:

$$r(t) = \frac{s(t)}{f(t)}$$

where r(t) is the index of legibility for the target stimulus at time t; s(t) = the persistence of the surround at time t; and f(t) is the persistence of the target figure at time t.

In a backward masking situation, if a white homogeneous overlapping mask is presented together with the target, the visual persistence of the target may be represented by:

$$r(t) = \frac{s(t) + K}{f(t) + K}$$

where K = the persistence of the mask. The effect of simultaneous exposure of the target and mask fields would be to reduce the physical contrast of the target stimulus. One would expect poorer performance in identification or recognition tasks, however, in some cases, where the contrast of the target is high, a white uniform mask presented at an SOA of 0 would not affect performance. With this high contrast target, as the SOA is increased and the target presented, the persistence of the image decreases before the onset of the mask. When the mask comes on, its persistence instantly summates with the weaker persistence of the target and its background. Since a constant mask value sums with s(t) and f(t) (because the mask stimulates the same retinal tissues as the target and its background), as they decrease, the value of r(t) approaches 1, indicating that the legibility of the target is decreasing, which would result in masking. As the SOA is further increased, the target is perceived before the persistence of the mask can integrate with the persistence of the target. Thus, masking in this case has been described as varying non-monotonically with SOA. Stewart & Purcell claim that U shaped functions tend to be generated when the mask luminance is low relative to the target luminance (Turvey's (1973) results confirm this) and monotonic functions occur when the mask luminance is high relative to the target luminance.

Stewart & Purcell (1974) claimed that it "would be naive to assume that all U shaped masking functions can be explained by recourse to the simplified model we have presented" (pp. 565). Indeed, since the masks in metacontrast studies do not spatially overlap with the targets, this model would fail to explain the paradigm of metacontrast. However, like Turvey's (1973) model, it is able to explain all types of non-metacontrast masking.

Other inhibitory models which differ from Purcell & Stewart's "point-to-point" inhibitory model are Weisstein's et. al.'s (1975) and Breitmeyer's & Ganz (1976) receptive field models. These models propose that metacontrast is the result of interactions between neural events that begin on the retina. They view the visual system as having many channels which process different kinds of information about a visual stimulus. Breitmeyer & Ganz for instance, suggest that forward masking and backward masking differ in that they are mediated by different underlying mechanisms. They suggest that forward masking is mediated by integration occurring in the receptive fields of one channel, while in backward masking, lateral inhibition is mediated by inter channel inhibition.

Weisstein et. al. (1975) however, do not make this distinction, and suggest that all forms of metacontrast can be explained by appealing to an inter channel inhibitory model of metacontrast. Weisstein et. al.'s (1975) model was derived from one that she proposed in 1968. The following is a discussion of both models.

Weisstein's Metacontrast Model

Metacontrast is a perceptual phenomenon which is the result of one visual stimulus affecting a neighboring visual stimulus. Noting the similarity between this phenomenon and that of lateral inhibition, Weisstein (1968) proposed a model of metacontrast which bases itself on the principles of lateral inhibition.

Her model makes use of the Rashevsky (1948) 2-factor neuron which is "a responding element that combines both excitatory and inhibitory processes". Some characteristics of this neuron are; (1) if the sum of the inhibitory and excitatory influences is above zero, the neuron will fire in proportion to its excitation and, (2) a target or mask presented alone, results in more excitation than inhibition, while a target and mask presented together, results in more inhibition than excitation to the target stimulus. Weisstein's net describes 5 neurons (see fig. 2). Two are identical peripheral neurons which transmit information about the stimuli; one, (a) conveys messages about the target, while the other, (b) conveys messages about the mask. The three other neurons are centrally located. One, (c) is a second order neuron which continues conveying excitatory messages about the target, while the other, (d) is an inhibitory collateral coming from the peripheral neuron excited by the mask. The third central neuron is called a decision neuron (e) and it sums the excitation from the target with the inhibition from

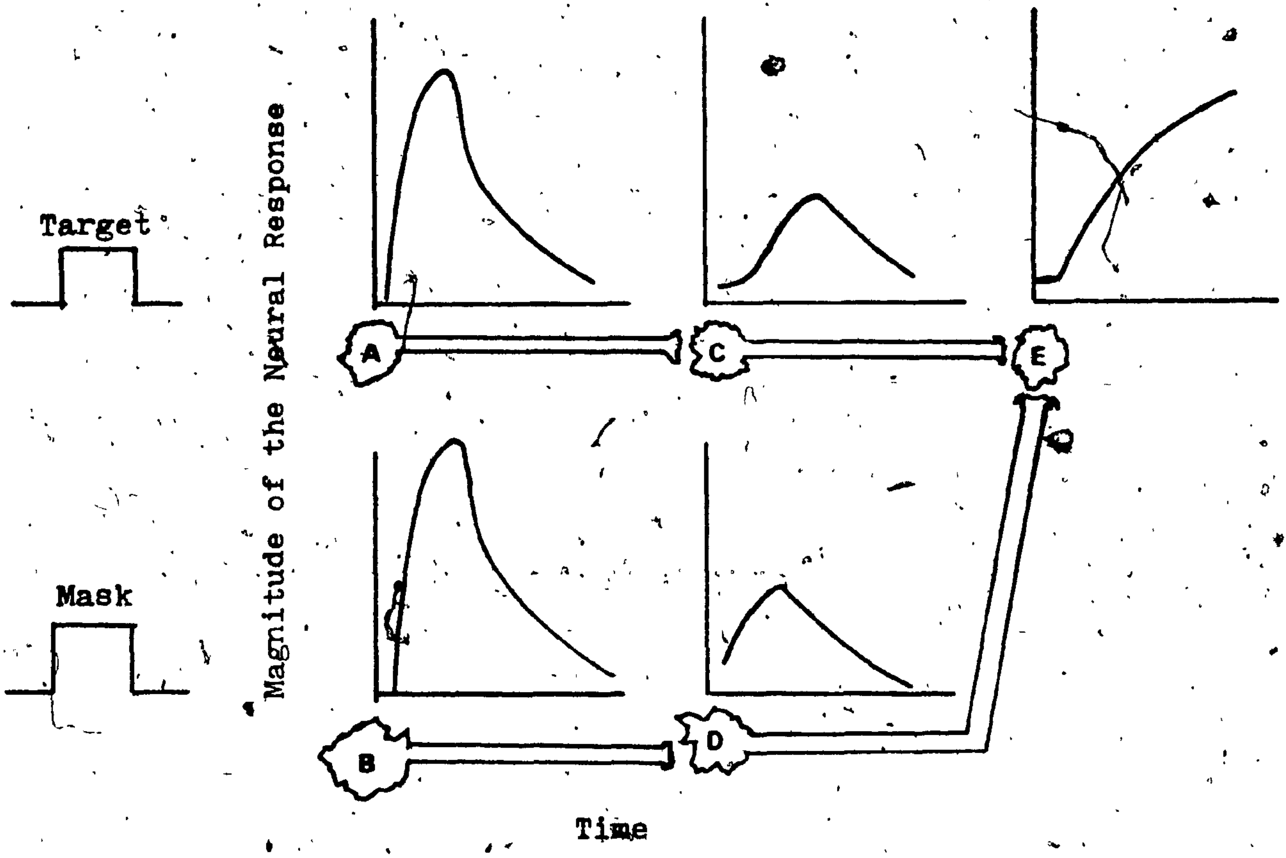

Fig. 2: Weisstein's (1968) neural net model of metacontrast.

the mask. If the result of this sum is above threshold, then the decision neuron fires and this is indicated by some psychophysical measure. The existence of one decision neuron implies that the locus of metacontrast occurs at some place in the brain where one unit is receiving all the information of a stimulus configuration.

One assumption made by this model is that with equal energy stimuli, excitation and inhibition develop at different rates, while a second assumption is that maximum masking occurs when there is a large overlap in time between the inhibitory response of a mask and the excitatory response of a target. With these assumptions a U shaped metacontrast function can be easily explained.

Using equal energy stimuli, the model assumes that the rate constant for the buildup of excitation for the target is slower than the rate constant for the buildup of inhibition from the mask. Therefore, at an SOA of zero, there would be a quick buildup of inhibition coming from the mask, and some time after that onset, the excitation from the target would begin to grow. Figure 3a illustrates this temporal relationship. It shows that there is minimal overlap of these two neural response functions, indicating an absence of masking. However, if the mask was delayed in time by introducing a longer SOA (fig. 3b), then it is possible to obtain maximum overlapping of inhibition and excitation, resulting in maximum masking. As the SOA is further in-

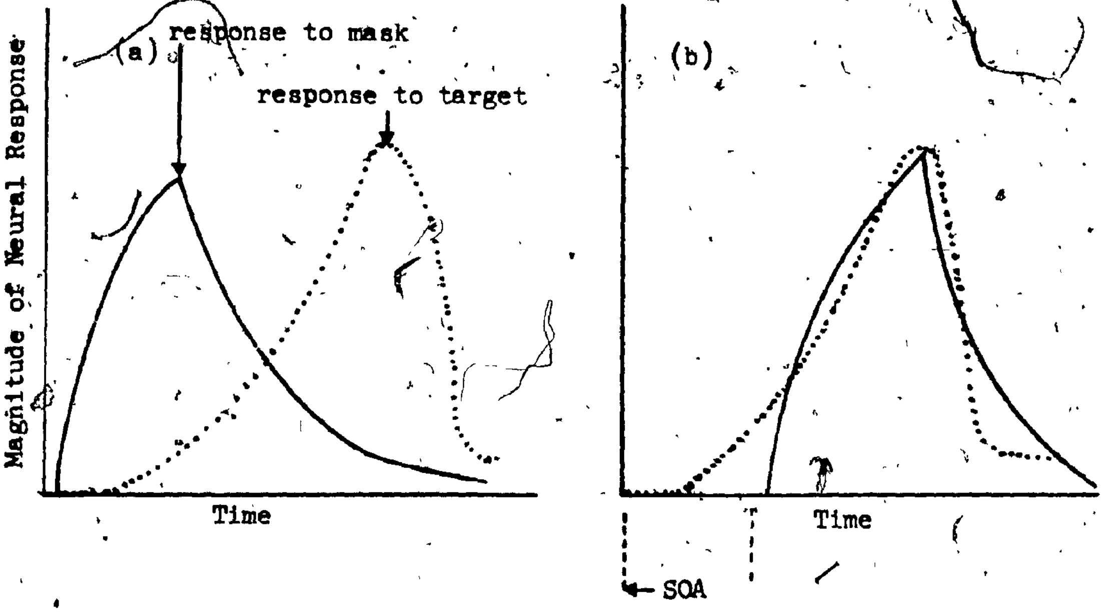

Fig. 3: At an SOA of 0 (a), the neural response of the mask is faster than that of the target. Therefore, there is little overlap between the two responses. With an introduction of SOA, however, the amount of overlap increases (b), as the mask onset is delayed in time.

creased, the excitation response to the target might build up and terminate before the onset of the mask, resulting in no masking at all. This description might explain the occurrence of non-monotonic metacontrast functions.

Bridgeman (1971) criticized this model because the concept of a fast inhibiting collateral coming only from the mask makes no provision for masking to take place if the temporal order of the target and mask were interchanged (as in the paracontrast paradigm). Weisstein, Ozog & Szoc (1975) made changes in the original model to account for masking in these situations. They proposed that if two peripheral neurons receive equal stimulations, the response of one of these neurons might be faster than the other, due to differences in the processing rimes of these stimuli (specifically differences in the processing times of the different channels). The neuron that is responding faster will inhibit its neighbor, and since this response is fast, inhibition will only be effective if the stimulus is delayed. All that is required for one stimulus to suppress another, then, is that its neural response follows the other. Therefore, in Weisstein et. al.'s new model, they added an inhibitory collateral coming from the target (see fig. 4) which can be an inhibiting influence to the decision neuron. This addition makes the scheme symmetrical in that masks and targets can mutually inhibit each other.

A variable which has been described (in Weisstein's

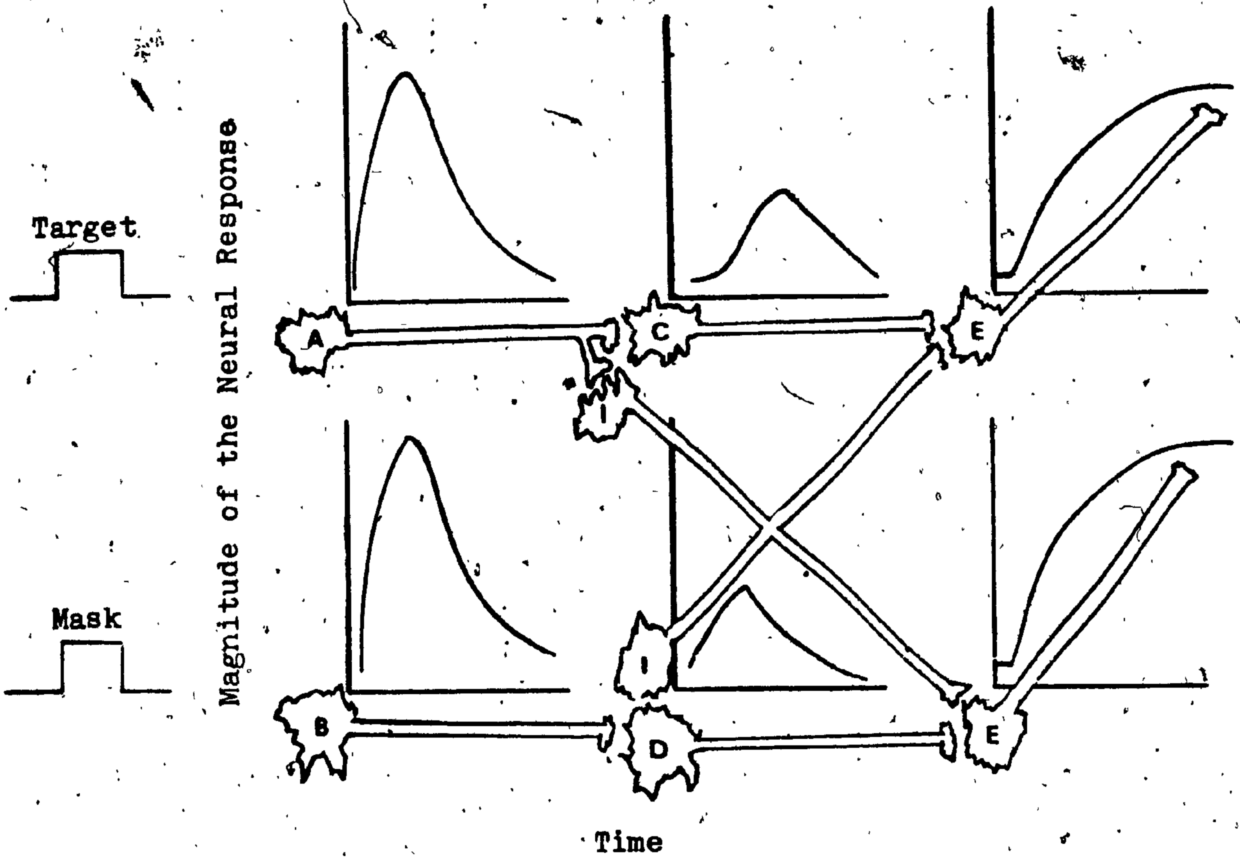

Fig. 4. In Weisstein Ozog & Szoc's updated version of the model, an inhibitory collateral (I) coming from the target, can be an inhibitory influence to the decision neuron.

1968, 1972 & 1975 models) to critically affect the metacontrast function is the energy ratio between a target and mask. The following is a discussion of this variable, and how it affects the metacontrast function in Weisstein's model.

Weisstein's Explanation of the Energy Variable

Weisstein, Ozog & Szoc (1975) explained that as the energy of a stimulus is increased, its neural response "smears out in time". Thus, if the energy of a mask was increased relative to that of a target, it would not have to be delayed in time for its neural response to overlap with the response to the target. If the energy of the mask was high enough, its neural response would overlap a slowly processing target such that maximum masking could occur at an SOA of 0. As SOA is increased, the amount of neural overlap would decrease, producing a monotonic metacontrast function.

Weisstein (1968) studied the stimulus energy relations of 25 studies reported in the literature. For each study, she entered the stimulus energy values into the computations of her model and simulated the metacontrast function that she would expect to find. For 24 out of the 25 studies, the masking function was similar to the originally reported function. A summary of these findings suggested that equal energy targets and masks (energy ratios of 1) produced nonmonotonic metacontrast functions, while unequal energy stimuli (with higher energy masks) produced monotonic metacontrast functions. Weisstein (1972) claimed that because it was shown that metacontrast varied as a function of the stimulus energy variables (Weisstein, 1968, 1971; Weisstein & Growney 1969; Kahneman, 1967), the energy ratio between a target and mask should be considered to be critical in the production of metacontrast functions.

In summary, it seems as if all the theories discussed, claim that energy is an important determinant of masking. For instance, Kahneman (1967) showed and explained why stimuli which had a luminance ratio of 1 produced a U shaped metacontrast function, while those which had a luminance ratio approaching 0 produced monotonic metacontrast functions. Turvey (1973) and Purcell & Stewart (1974) specified that U shaped non-metacontrast functions were produced only when stimuli in which the target was of a higher energy than the mask, was used. Finally, Weisstein (1968, 1972) proposed that it was the energy ratio variable that is responsible for the shape of the metacontrast function.

In the following section, the energy variable will be discussed in terms of how investigators have looked at its components, and it will be shown why energy ratios may be an inappropriate way of specifying the energy relationship between a target and mask.

III The Energy Variable

A number of the above mentioned investigators have found that there are two crucial parameters which influence the magnitude of masking; the exposure duration and luminance of targets and masks.

Duration

Alpern (1953) found that increases in the duration of a target led to decreases in the masking effect, while increases in the duration of the masks led to increases in masking. The results of a number of more recent experiments (Kinsbourne & Warrington, 1962; Kahneman, 1966; Donchin, 1967; and Turvey, 1973) have confirmed Alpern's initial findings. The effect of target duration on masking has also been explored by Turvey (1973). As a dependent variable, he used the minimum duration of the interval between the target offset and mask onset that resulted in accurate identification of a target letter. This dependent variable is termed the critical inter-stimulus-interval (ISI_c). Turvey found that increases in target duration resulted in lower ISI_c's or less masking. Increases in the mask duration resulted with large initial increases in masking until it reached an asymptotic level (at about a mask duration of 10 msec) beyond which increases in the duration of the mask did not affect the amount of masking.

Luminance

Many studies (Alpern, 1965; Kahneman, 1966; Fehrer & Smith, 1962; Weisstein, 1971; Matteson, 1969; & Faswan & Young, 1963) have investigated the role that luminance plays in masking. The results of these experiments have been complex.

Fehrer & Smith, for instance, varied test flash luminance while holding the mask luminance constant. For each condition, they expressed the target and mask luminance in the ratio form of target/mask luminance. When looking at the detection rates of their observers across SOA's, they found that a complex relationship between luminance ratio and metacontrast occurred. When the luminance ratio was 1, there was no masking at an SOA of zero msec. As the SOA increased, the test flash began to darken, with the magnitude of metacontrast reaching at around an SOA of 75 msec. When the SOA was increased above 75 msec. the metacontrast effect weakened. With stimuli which had a low luminance ratio, they found that at an SOA of zero, the target was maximally masked and as SOA was increased, the effect attenuated.

Alpern (1953) however, found that stimuli which had an equal energy ratio produced no metacontrast. As he decreased the luminance ratio, by increasing the luminance of the mask, he found that metacontrast increased, with maximum masking occurring at an SOA of approximately 100 msec.

Kaswan & Young (1963) varied target luminance and found that their observers' performance on a forced choice task did not significantly vary as a function of luminance.

There may be many explanations for these "conflicting" data. For instance, the dependent measures of the above studies were not the same, which may imply that masking varies as a function of the type of measurement used (this argument as proposed by Ericksen was reviewed earlier).

The duration and luminance levels of the stimuli also varied in these studies. For instance, Alpern changed the luminance ratio of his stimuli by varying the mask luminance from 10 fL to 400 fL, while holding the target luminance constant at 36.4 fL. Fehrer & Smith, however, varied the luminance of the target stimulus from .01 fL to 10 fL, while holding the mask luminance constant at 20 fL.

In all these studies, variations in the luminance and duration of the stimuli seemed to strongly affect masking. These two variables have been described as being intimately related in another way.

The results of a number of psychophysical studies have revealed that for threshold measurements below a critical duration[1], the visual system is able to temporally integrate luminance. For example, at threshold, a stimulus of 20 fL presented to an observer at 5 msec. will produce the same perceptual effect as a stimulus reflecting 10 fL presented at 10 msec. In both cases the energy is 100 units and the visual system processes the information similarly. This relationship, which is known as Bloch's law implies that

[1] Barlow (1958) and Herrick (1956), for example, have shown that the temporal integration of luminance usually occurs for stimuli presented for durations below 100 msec.

the effects of luminance and duration of the visual system are reciprocally related. That is, if one inversely varies luminance and duration by the same amount, then the perceptual impact of the stimuli should be the same. To the extent that energy is a relevant variable, we would expect Bloch's law to hold in a metacontrast paradigm. However, the results of two metacontrast experiments (Kahneman, 1966; Kaswan & Young, 1963) have provided evidence that changes in the duration variable are more effective in altering the perception of a target, than similar changes in its luminance. More investigation in this area is needed before conclusions can be postulated.

Energy Ratios & Differences

Fehrer & Smith (1962) used luminance ratios to express the luminance relationship between a target and mask. In a similar manner, the energy relationship between a target and mask can be expressed in a ratio form. One tradition has been to express this ratio as the energy of the target divided by the energy of the mask. Because the durations of the stimuli in Fehrer & Smith's experiment were held constant, their luminance ratios could be expressed as energy ratios. Their data could be summarized in the following: the metacontrast function was U shaped when the energy ratio approached 1, and became monotonic when the ratio approached 0. Kahneman (1967), Weisstein (1968) and Schiller (1965) all reported a similar relationship between energy ratios and the shapes of their masking functions.

However, there is another way of specifying the energy relationship between targets and masks. That is, the energy difference between a target and mask could be calculated. To illustrate, Weisstein (1972) and Kahneman (1967) investigated the effect of varying energy ratios on metacontrast by holding the energy ratio constant but changing the absolute durations of the targets and masks. The durations of the targets and masks were always equal, and produced an energy ratio of 1. Since identical metacontrast functions were obtained across all their stimulus durations, they each concluded that the variable which remained fixed, the energy ratio, was responsible for the identical functions. However, another variable, the energy difference, also remained fixed at 0.

Evidence suggesting that energy differences are critical in metacontrast has been provided by Brussell & Favreau (1977). They investigated backward masking using as their target, a grey isoceles triangle which was surrounded by a lighter circular field, and a random-line pattern as the mask. They assessed critical ISI's for different target durations and found that the critical ISI varied non-monotonically with target duration. By conducting a series of experiments, they ruled out the possibility that the mask, and/or the contour of the circular surround, was the source of this non-monotonic function. Rather, they explained that the target stimulus configuration used in their experiment could be conceptualized in the language of metacontrast as a triangular target and a circular surrounding mask which occurred at an SOA = 0.

In order to substantiate their argument, Brussell & Favreau (1977) conducted an experiment in which they presented only the triangular target and circular surround to their observers. The observers' task was to estimate the magnitude of target contrast by reporting how much lighter or darker the triangle was than its immediate surround. The brightness of the surround served as the referent and was assigned a value of 100. Numbers less than 100 meant that the triangle was seen as darker than its surround. The results of their experiment showed that target contrast varied as a non-monotonic function of target duration. Thus, they were able to conclude that the non-monotonic masking function found in their first paradigm was the result of metacontrast occurring between the triangular target and circular surround.

Brussell & Favreau stated that when target duration was manipulated in their first experiments, they were in effect simultaneously varying the durations of the triangular target and circular mask by the same proportion. Therefore, as the durations of these metacontrast stimuli changed, the energy ratio remained the same but the energy differences did not. They therefore concluded that the non-monotonic functions found when target duration was varied was the result of changes in the energy difference between the metacontrast stimuli. This would suggest that the energy difference between metacontrast stimuli is the more appropriate way of specifying the energy relationship with respect to the metacontrast function. Brussell & Favreau pointed out that energy ratios and energy differences between a target and mask correlate perfectly for all but two cases. That is, energy differences and ratios do not correlate when unequal energy stimuli are changed by the same amount, or by the same proportion. For instance, if a 5 fL target and a 10 fL mask were presented at 10 msec. each, the energy ratio would be .5; and the energy difference would equal 50 units. If the 5 fL target and 10 fL mask were again presented at 20 msec. each, then the energy ratio would remain the same at .5, but the energy difference would increase by 50 units. This separation of the energy ratio and difference variable can also be demonstrated if the unequal target and mask energies are varied by the same amount.

In the preceding sections, two areas of interest have emerged. First, it must be determined which of the two, energy ratios or energy differences, is critical in metacontrast and second, whether Bloch's law "holds" in metacontrast is a question that has not been conclusively answered. The aim of this thesis is to investigate both these problems. However, before the methodology is reviewed, a discussion of other dependent variables used in metacontrast would be appropriate.

IV Some More Dependent Measures

Duration Thresholds

One method for investigating metacontrast is to use target duration as a dependent measure of masking. Since in many paradigms the presence of the mask causes full occlusion of the target, the duration of the target can be manipulated until recognition (identification of the target) or detection (acknowledging the presence of the target) is reached for a given ISI. Fehrer (1966) and Schiller & Smith (1965) used this type of method in their investigations of metacontrast and non-metacontrast maskings, respectively. They found that as they increased the magnitude of an independent variable such as ISI, their observers needed higher target durations for recognition (detection) of the target.

Kahneman (1968) criticized the use of this method, which he calls duration thresholds because as the duration of a target is varied for individual values of ISI, so does the SOA. Since SOA has been shown to critically affect the amount of masking (Kahneman, 1967), when using this method, there is a confounding of the target duration and SOA variables. Thus, it is not clear from a critical duration measurement, which is affecting the phenomenon, the duration or SOA. Consequently, duration thresholds have not been used often in studies of masking subsequent to Kahneman's criticism.

Forced Choice Procedures

A target disc can be presented such that it appears concentrically centered in one of two simultaneously presented masking rings. For each trial, the observer is required to detect in which of the two rings the target appeared. Many studies (Dember, 1960; Heckenmeuller & Dember, 1965; Purcell, 1969; Purcell, Stewart & Brunner, 1974) have used this type of two alternative spatial forced choice paradigm in assessing the metacontrast phenomenon. In these investigations, the observers were always forced to respond to the mask in which the target appeared whether or not they saw the target. The index of metacontrast was the probability of correct detection of the target as a function of an independent variable (usually SOA). Under conditions of maximum masking, correct detection must always approach chance level (50%) and as the target comes into view, the detection rate approaches 100%.

A number of investigators have modified this technique in order to use it in recognition tasks. For instance, Weisstein & Haber (1965), Mayzner et. al. (1965) and Lefton (1970) used the letters O and D as target stimuli and a concentric ring as the mask. For each trial, one of the letters was presented in the presence of the masks, and the observers were required to identify the letter (this paradigm is referred to as acuity measures by Kahneman, 1968). The magnitude of metacontrast was usually evaluated by plotting % correct identification of the letter as a function of an independent variable.

There are several difficulties associated with two-alternative forced choice procedures. In some paradigms the detection of a target varies from chance to certainty within a very narrow range of SOA's, and consequently provides little information about the temporal properties of the masking function. One way for increasing the sensitivity of monitoring masking in these cases, would be to use small intervals of the independent variable. For instance, if pilot work, using a two-alternative spatial forced choice paradigm, indicated that chance guessing changed to accurate detection within an SOA interval of 20 msec., then small intervals of the SOA (such as 2 msec.) should be employed in order to reflect all the changes of the phenomenon.

A second drawback of this method is that it does not necessarily measure the full effect of masking. Suppose, for instance, that a target can be detected 100% of the time in a forced choice paradigm. This does not necessarily imply that the target is not somehow being affected by the mask. It is possible, and most likely, that when a target is above threshold its clarity, brightness, texture or completeness might be greatly attenuated, even though by detection standards, the target has evaded masking.

One type of measurement that is sensitive to suprathreshold changes in perception is the subjective rating or categorizing method.

Subjective Rating Methods

In one of the early studies of metacontrast, Werner (1935) presented a black disc on a white background to his observers. A concentric black ring was presented at various temporal contiguous intervals with the disc. The observers were asked to categorize the brightness of the black disc in terms of its "blackness or whiteness". An estimate reflecting "whiteness" indicated masking while that approaching blackness suggested an absence of masking.

Kahneman (1967) demonstrated the versatility of the subjective rating method in his study of the comparison between metacontrast and apparent motion. The phenomena of apparent motion and metacontrast were described in detail to the observers. They were then shown many stimulus displays and told to categorize them according to their similarity to the phenomena described to them. One hazard that is quite evident with this method is its susceptibility to experimental bias. That is, the observer rates the phenomenon according to the criteria set by the experimenter, and consequently might alter his report of the phenomenon to conform to these standards. As an example, Kahneman described the apparent motion effect to his observers, but did not show them a stimulus display that elicited the perception. Consequently, their categorizing were relative to his specification of apparent motion, and thus, making the comparison difficult to generalize. However, when trying to standardize a measure, an experimenter might carefully choose dependent measures which clearly reflect the perceptual characteristics of the observers. In conforming to the standards of the experiment, an observer must do so reliably, and therefore it is necessary to train him thoroughly before "running" him through the conditions of an experiment.

Weisstein (1970) suggested that because magnitude estimates are so versatile, they could be used to measure many perceptual dimensions of metacontrast. For instance, since she believes that metacontrast is an "edge phenomenon", Weisstein (1971) was able to use estimates of the clarity of the edges of a target (contour definition, edge fragmentation) to measure the magnitude of metacontrast.

Ericksen & Marshall (1969) objected to the use of subjective rating methods on the grounds that observers may change their criteria as the conditions change. Weisstein et. al. (1970) responded to these criticisms by comparing two measures of metacontrast: subjective ratings and forced choice. The results of their experiment demonstrated that the small differences (non-significant) found in the metacontrast functions were not attributable to differences between the two types of measurements.

A Summary of the Dependent Measures Used in Masking

In this thesis some of the dependent variables which have been used in assessing the phenomenon of masking were reviewed and criticized. It was found that many of these measures contains confounding variables, as well as being limited in their application to different paradigms. For instance, critical durations were shown to be invalid measures of masking, as this measure confounds two variables, SOA and target duration.

Recently, magnitude estimations of perceptual edge clarity have been employed by Weisstein (1970, 1971) and Growney (1976) to assess changes in the phenomenon of metacontrast. However, this type of measure, in which observers judge the clarity of the edges of a target may be too specific. That is, metacontrast probably affects other perceptual dimensions of the target, for example, its brightness, which an edge clarity measure might not be sensitive to. Therefore, it does not seem unreasonable to suggest that an experimental paradigm of masking should include more than one dependent measure, so that the study is sensitive to more than one perceptual dimension.

For instance, a magnitude estimation task of contour clarity could be used in conjunction with a spatial forced choice detection task. In this way, the design is sensitive to changes in the perceptual threshold of the target as well as changes in edge clarity at the suprathreshold level. Thus, a more comprehensive account of the phenomenon is available for theoretical considerations.

Introduction to the Experiment

In the preceding sections, two problem areas have emerged. This section reviews the methods that were employed to investigate these problems.

Differences or Ratios?

The energy ratio between a target and mask has commonly been associated with the shape of the metacontrast function. However, because it has been shown that the energy differences and energy ratios between metacontrast stimuli correlate perfectly (except in 2 special cases), it is possible that associating the shape of the metacontrast function with energy ratio level has been misleading. Since there are special conditions where a change in the energy ratio is not accompanied with changes in the energy difference or vice versa, it was necessary to employ these conditions to determine which of the two variables is critical in predicting the metacontrast function.

The conditions that were used for investigating this matter are represented in Table I. In Table Ia (the top half of the table) the two fractions displayed at the top of the columns represent the durations (in msec) at which the target (numerator) and mask (denominator) were presented to the observers. Similarly, the fractions on the left

TABLE I

The Parameters of the Stimulus Energy Conditions

(a)

Duration (msecs)

$\frac{\text{target}}{\text{mask}}$

Luminance (fL)	$\frac{10}{10}$	$\frac{40}{40}$	
$\frac{1}{4}$	(.25) /30/	(.25) /120/	
$\frac{4}{7}$	(.57) /30/	(.57) /120/	'Duration' Conditions
$\frac{7}{10}$	(.70) /30/	(.70) /120/	

(b)

Luminance (fL)

$\frac{\text{target}}{\text{mask}}$

Duration (msecs)	$\frac{2.5}{2.5}$	$\frac{10}{10}$	
$\frac{4}{16}$	(.25) /30/	(.25) /120/	
$\frac{16}{28}$	(.57) /30/	(.57) /120/	'Luminance' Conditions
$\frac{28}{40}$	(.70) /30/	(.70) /120/	

hand side of the table specify for each row, the luminance level (in fL) at which the target (numerator) and mask (denominator) were presented. Within this 3 X 2 matrix, each condition is specified in terms of the luminance and duration at which the stimuli were presented.

With respect to the first row of this matrix, reading across the 2 columns, conditions were constructed such that the energy ratio - expressed inside brackets () - of the two conditions remained unchanged at .25, while the energy difference between the two conditions - expressed inside slashes // - varied (30 units versus 120 units). Similarly, in row 2 or 3, comparing the conditions expressed by both columns, changes in energy differences were not accompanied by changes in energy ratios.

Conversely, for each column, if we compare the conditions expressed in the rows, changes in the energy ratios were not accompanied by changes in the differences.

If Weisstein's contention is correct, that is, that energy ratios are critical in metacontrast, then, a) we would expect no differences in the shape of the metacontrast function for equal energy ratio conditions (comparing the conditions across rows in the matrix) and, b) we would expect to find different shapes in the metacontrast functions when comparing stimuli of unequal ratios (comparing the conditions across the columns in the matrix).

Bloch's Law?

An investigation of reciprocity in Bloch's law centers around the following question: Do differential manipulations of either duration or luminance of equal energy stimuli, produce differences in the metacontrast function? In order to explore this question, the conditions represented in Table I were set up in the following manner. For each condition shown in Table Ia, there was a condition depicted in Table Ib in which the energy differences and ratios between the target and mask were identical. The only difference between these "equivalent energy conditions" was the manner in which the values of luminance and duration were assigned to produce a specific energy level. For instance, for the conditions in Table Ia, in order to produce a stimulus configuration with a stimulus energy ratio = .25 and energy difference = 30 units, a target reflecting 1 fL and mask reflecting 4 fL were each presented at 10 msec. to the observers. For conditions shown in Table Ib however, in order to produce these identical energy relations, a target and mask of 2.5 fL were presented at 4 and 16 msec. respectively. If reciprocity exists in metacontrast, then we would expect no differences between the metacontrast functions produced by these "equivalent energy" conditions.

It may also be noted that the conditions represented in Table Ia differ in another manner from those shown in Table Ib. For the conditions shown in Table Ia, unequal luminous stimuli were varied by the same duration (10 msec. versus 40 msec.) while for those represented in Table Ib, the unequal temporal stimuli were varied by the same luminance (2.5 fL versus 10 fL). These conditions will be referred to as the "duration" and "luminance" conditions respectively. If the results of the Kahneman and Kaswan & Young study are correct, then we would expect that reciprocity does not hold for the masking paradigm and duration manipulations of the stimuli are more effective in altering the metacontrast function than similar luminance manipulations. Specifically, we might expect that the metacontrast function will be more sensitive to changes in the duration variable (represented by the "duration" conditions) than similar changes in the luminance variable (represented by the "luminance" condition).

The data collected by Brussell & Favreau (1977) suggested that the magnitude of masking varies inversely with the state of adaptation of the eye. Purcell & Stewart (1974) also reported data which showed that the magnitude of metacontrast decreased with increases in the state of adaptation of the eye.

In order to determine how a change in the state of adaptation of the eye affects metacontrast for the condition in this experiment, all the conditions in Table I were presented to light and dark adapted observers.

The Stimuli & Dependent Measures

Purcell & Stewart (1974) obtained U shaped metacontrast functions using a forced choice detection measure. For each trial, they presented their observers with a dark disc (target) which could appear in the middle of one of two dark concentric rings (masks). Their observers were required to report in which ring the target appeared. Because their stimuli consisted of dark targets and masks, presented on lit backgrounds, a methodological criticism similar to the example given in criticism of Ericksen's luminance summation model may be made. To recapitulate, for the SOA's in which the stimuli temporally overlapped, the dark target was superimposed (overlapping spatially and temporally) upon the illuminated background of the mask, and therefore, the detection of the dark target might have, in part, been affected by the physical superimposition of the stimuli. If illuminated stimuli presented on dark backgrounds were used, this problem would not arise, because the addition of the low luminance of the mask background should in no way interfere with the detection of the illuminated target. Therefore in this experiment, illuminated stimuli with black backgrounds were used. The discs and rings were of the same dimensions as those used by Purcell & Stewart (1974) as well as Heckenmeuller & Dember (1965a). The 2 alternative spatial forced choice paradigm, similar to the one used by Purcell & Stewart (1974), required the use of 2 masks (rings) and 1 target (disc) which could appear within the middle of either ring.

Since it was suggested (in the summary section of the dependent measures) that whenever possible, more than one dependent measure should be employed in masking studies (in order to monitor more than one perceptual dimension), a magnitude estimation task was also used. This magnitude estimation procedure was the same as that used by Weisstein (1971) and Growney (1976) in which they used a measure of contour clarity.

Method

Subjects. Ten paid observers, all with corrected or uncorrected Snellen acuity of 20/20, participated in the experiment.

Apparatus. A three channel, Scientific Prototype tachistoscope (t-scope) - model GB was used for the stimulus presentations.

The masks consisted of two rings, which flanked a fixation point. For each trial, a target disc could appear concentrically in the middle of either the left or right ring. The stimuli were viewed from a distance of 124.5 cm producing the following visual angles: disc diameter = 24', ring inside diameter = 24', ring outside diameter = 44', separation between the borders of the two rings = 16'.

The target image was made by covering a transparent piece of plexiglass with black opaque carbon paper. Two 24' holes were cut out of the paper such that the centres of the two holes were separated by 60' of visual arc. When the plexiglass was placed into one channel of the t-scope, back illumination resulted in the perception of two illuminated discs.

Two A.C. pull-type solenoids were placed between the plexiglass and the observer, such that they were each located below and in front of one of the target holes. Attached to each of the cores of the solenoids was a piece of black cardboard (baffle). The cores were held up vertically from the solenoids by a spring, such that the baffles blocked any rear illuminating light from entering into the t-scope. Upon completion of one of the solenoid circuits, the corresponding core withdrew into the solenoid, pulling down the baffle, and allowing the light emitted from the rear illuminator to reach the eye of the observer. In this way, for any trial the experimenter was able to present either the left or right disc to an observer. A 24 volt D.C. power pack supplied the voltage to the solenoids, because it was found that "shutterong" accompanied an A.C. power source.

The "standard" stimulus which was used for comparisons in the magnitude estimation task consisted of a target which was presented in the absence of the mask.

The masking stimuli were constructed in the same fashion as the targets. Two pieces of plexiglass (masking sheets) were mounted (via volts and wing nuts) on a larger plexiglass holder such that they could be independently moved and secured in any position on the holder. Black opaque carbon paper covered the two masking sheets, except for two rings which were cut out of the paper to the above specified dimensions. When the holder was placed into another channel of the t-scope, back illumination of this channel resulted in a display of two illuminated rings. These rings could be adjusted (by the bolts and wing nuts), such that upon simultaneous presentation with the unbaffled targets, the rings appeared to concentrically surround the two discs. A schematic diagram of the stimuli and apparatus are depicted in fig. 5a and 5b respectively.

The luminance of the stimuli was adjustable by varying the intensity dials corresponding to the bulbs in each channel. Because low luminance levels were not often obtainable by dial adjustments alone, wratten neutral density filters placed between the rear illuminators and stimuli were used when necessary. All luminance levels were measured with a Spectra Spotmeter (Photo Research, Hollywood). In each trial, the presentation of the stimuli, that is, the time the bulbs were on, never exceeded 40 msec. Therefore, the bulbs could be specified as always being in a "cold state". Since the illuminance emitted from a bulb increases with the amount of time it is on (as the bulb gets warmer), in order to properly adjust the luminance levels of the stimuli, photometric measurements were made with "cold bulbs".

For the dark adaptation condition, in the third channel of the t-scope, a rear illuminated piece of black paper containing a dim red fixation point (fixation field) was exposed between trials. The luminance of this field was approximately .1 fL. The fixation point was placed such that upon concurrent presentation with the masks, it appeared midway between the two rings. Between the trials, for the light adaptation condition, the fixation field was withdrawn from the channel, exposing a 10 fL adaptation field which was of uniform luminance.

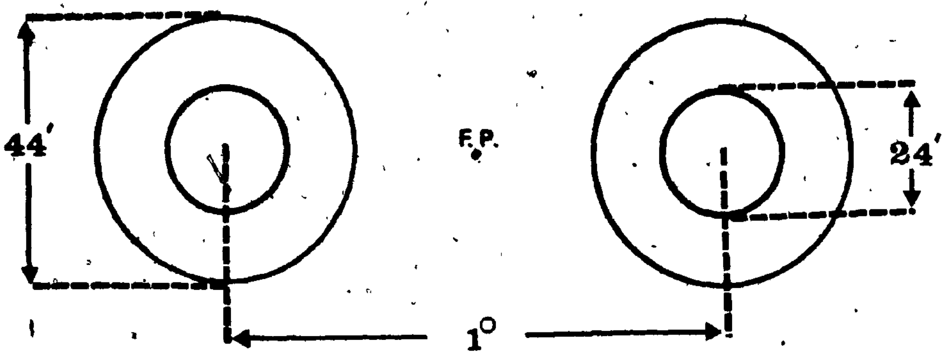

Fig. 5a: The stimulus dimensions (in visual angle). The target disc can appear in either of the annuli which are shown, and has the same diameter as the inside portion of an annulus.

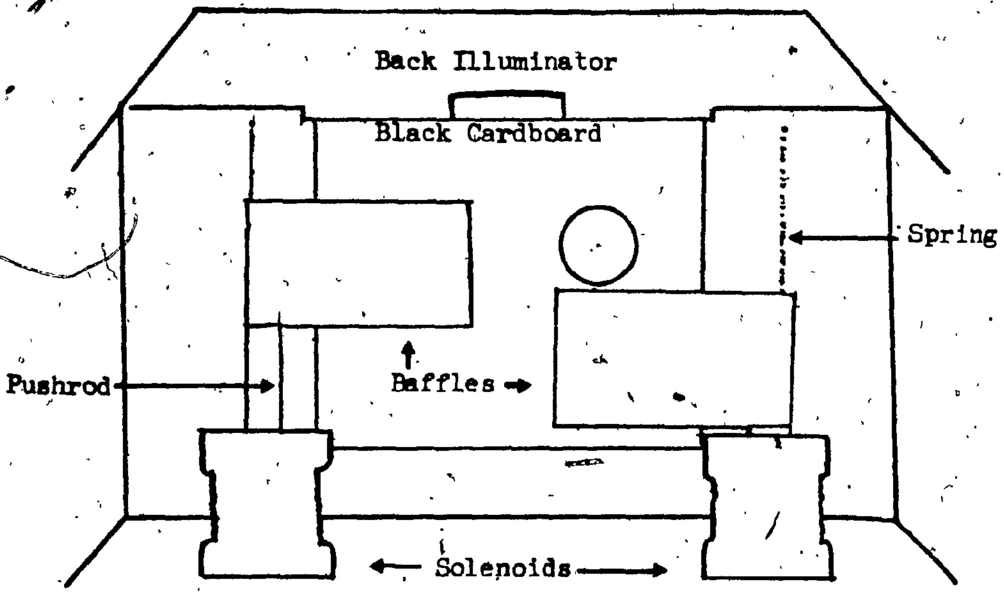

Fig. 5b: A schematic diagram of the 'target' channel of the t-scope. (front view)

The t-scope and solenoids were connected to a multiple bank timer such that the following sequence of events occurred for each trial: The closure of either the left or right pole of a two pole center off switch, activated the corresponding solenoid bringing its baffle down. One and a half seconds following the onset of the switch, one bank of the timer fired the t-scope which presented the stimuli to an observer. Approximately one second after the offset of the t-scope, the solenoid circuit opened, releasing the baffle into place (via the spring) covering the target hole. In this manner, the operation of the solenoids never interfered with the operation of the t-scope, and the events during a trial were completely automated.

The solenoids could not be differentiated by sound, however, the activation of either one of the solenoids resulted in a noise which signalled the observer to fixate.

In order to eliminate any possible depth cues between the target and mask due to binocular parallax, the observers in this experiment viewed the stimuli monocularly.

Procedure. The 10 observers were randomly assigned to one of the two adaptation levels such that 5 observers participated in each condition. Each observer was exposed to 12 blocks of trials, each of which are described in Table Ia and Ib. Within each block, the stimuli were separated by 15 SOA's of varying durations. They were (in msecs.) -100, -75, -50, -25, -15, 0, 15, 30, 45, 60, 75, 90, 105, 200.

The sequence of presentation of the SOA's was randomly determined (sampling without replacement). The ISI's were always dark.

The two alternative forced choice task required that the observers report the position of the disc by pressing a left or right button. For each SOA the sequence of presenting the 18 trials (the target was presented such that it appeared in the left and right orientation 9 times each) were randomly determined (sampling without replacement). For the estimation task, the observers were told to rate the target in terms of its clarity and completeness with respect to the standard stimulus. The instructions that were read to the observers are found in Appendix A. All the observers were well practised (they each had at least 4 hours of experience) before they participated in the experiment. Before each session the experimenter adjusted the luminance and duration of the target (which was also the standard stimulus) and mask to the specified levels in that condition.

Dark Adaptation Condition

Before the beginning of an experimental session the observer (with the aid of the experimenter) aligned the stimuli, such that the targets were superimposed upon the dark centers of the masks. The observers were then dark adapted for 10 minutes. At the end of this period, they freely viewed the fixation field for an additional 3 minutes. The observers were then told that prior to the presentation of the target and mask, they would hear a sound (created by the activation of one of the solenoids) which would indicate that they should look at the fixation point and "get ready". The subjects were then shown the standard three times prior to testing. It was randomly presented in either the left or right orientation. Between trials, which were 10 seconds long, the fixation field remained on.

Light Adaptation Condition

The same procedure was conducted for this condition, except the observers were dark adapted for 5 minutes and then light adapted to the adaptation field for another 5 minutes. Each trial was presented in the following sequence: the observers freely viewed the adaptation field until the fixation field was presented; they then fixated until the termination of the target and mask. The fixation field was then removed and the observers again viewed the adaptation field, for 10 seconds and the procedure was repeated.

Results & Discussion

For all conditions, it was found that the observers were able to correctly detect the ring within which the target was presented, at a rate of 96.4%. Hence, an analysis of the detection data was not warranted.

During the pilot work for this study, the absence of metacontrast in the forced choice data was apparent. However, since the forced choice task was helpful in monitoring whether or not the observers were attending to the stimuli, this procedure was maintained throughout the experiment. The fact that metacontrast was not found in these data was attributed to the low luminance levels that were employed in this study (the maximum luminance reflected by a stimulus was 10 fL). Other detection studies which reported the occurrence of metacontrast have generally used higher stimulus luminance levels (for example, Purcell & Stewart, 1974 used stimulus luminance levels of 20 - 40 fL).

When magnitude estimation tasks are used, it has been customary to compute the geometric mean of the estimates across trials and subjects (Weisstein, 1970; 1971; and Growney, 1976 used the geometric mean as a measure of central tendency). In this study, every observer was exposed to 18 presentations of the target and mask configuration, for each SOA. Because of the occurrence of 0 estimates which were reported by the observers in some conditions, the geometric mean was not used in measuring central tendency across the 18 replications since only one 0 estimate would result in a geometric mean estimate of 0. Instead, for each observer, a median magnitude estimate was calculated across 18 replications for each SOA. Using these medians, the geometric mean was computed across the 5 observers in each adaptation condition. These geometric means are plotted in figures 6 and 7 located in Appendix B.

The following 6-way analysis of variance was run on the log median magnitude estimates: Adaptation level (light versus dark) X energy manipulation ("luminance" versus "duration") X energy difference (30 versus 120) X energy ratios (.25 x .57 x .70) X SOA (15 values) X subjects (5; nested in Adaptation).

The results of the analysis are summarized in Table II (located in Appendix C).

Not surprisingly, the main effect of SOA was found to be significant; F (14, 112) = 11.04; $p < .01$. However, a more important finding was that SOA interacted with energy manipulation; F (14, 112) = 5.07; $p < .01$. This interaction can be seen in figure 8 which displays the means of the log magnitude estimations for the luminance and duration condition collapsed across all other conditions. In order to attempt to explain how changes in the luminance or duration of the metacontrast stimuli may have affected the metacontrast function, a more critical investigation of the use of clarity estimates is needed.

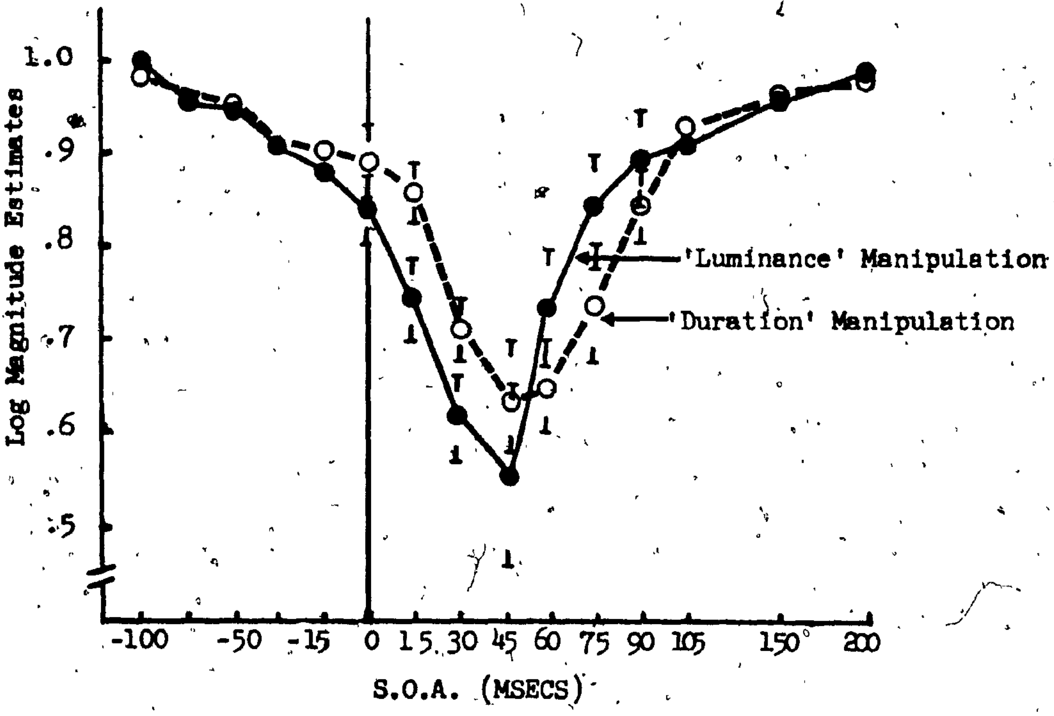

Fig. 8: The mean of the log magnitude estimates for the 'luminance' and 'duration' conditions collapsed across all other conditions.

Consider the Weisstein (1971) study in which she employed a similar edge clarity dependent measure. She reported that metacontrast was not present at an SOA = 0 msec. when nearly equal energy stimuli were used (the target/mask energy ratio equalled .875). That is, an adjacent disc and annulus (having an intercontour separation of only 1' of visual angle) presented at the same time, resulted in no masking of the contours of the disc. This is surprising, since a target and mask of nearly equal energy with such a small intercontour distance might be expected to elicit the perception of one large disc with a diameter equal to that of the mask. This should have been reflected by magnitude estimates near 0. However, because Weisstein's observers gave edge clarity estimates of 10 at an SOA = 0, it might be inferred that they were relying on other perceptual dimensions along which the target varied, such as brightness, for the basis of their judgements. In the following discussion, it will be argued that this possible artifact of edge clarity measures can account for many of the trends shown in figure 8.

In this experiment, although there was no equal energy condition, there were conditions in which the energy ratio approached equality, that is, of .70. Looking at figure 6c (located in Appendix B) at an SOA of 0, the dark adapted subjects gave clarity estimates near a value of 10 for a .70 duration condition. In that condition, a 7 fL target was presented simultaneously (SOA = 0) with a 10 fL mask, and for the same duration. The target should have been seen to have been surrounded by a white mask, and consequently its borders should not have been as strong as the standard stimulus, which was the lit target presented on a black background. We would have expected then, that the magnitude estimations of the clarity of the target's edges should have been somewhat lower than 10. Since the estimates of this duration condition shown in fig. 6c were all near a value of 10, it is likely that at an SOA of 0, for this condition (and probably others), the observers may have relied on the compelling brightness of the target instead of judging the clarity of its contours.

If it is assumed that around an SOA of 0 the observers were basing their judgements on brightness, then masking would not be expected since the data from many experiments using brightness measures (Alpern, 1953; Fehrer & Smith, 1962 for example) have reported that the metacontrast function is U shaped with little or no masking occurring at an SOA of 0, when the target and mask energies are similar.

As the SOA was increased above 0, the probability that the target was seen as being partly separated from the mask increased. That is, as SOA became greater, the probability that the target and mask were being centrally integrated decreased. Therefore, at longer SOA's, the observers were more likely to see the lit target on a black background and were therefore probably able to base their judgements on contour clarity.

The descending function for both conditions shown in fig. 8 could be explained by appealing to the possibility that the observers were basing their estimates on either brightness or clarity. That is, the descending portion of the U shaped function could be the result of brightness or contour metacontrast. However, in order to explain the interaction that occurred between energy manipulation and SOA, it must be assumed that the observers were basing their estimates on the brightness of the target at low SOA's and on the clarity of the edge of the target at higher SOA's. The following discussion shows why this assumption is necessary.

In order to explain why differences occurred between the "duration" and "luminance" conditions for SOA's of 15 and 30 msecs. (the confidence intervals in fig. 8 revealed that the magnitude estimations for the "luminance" condition did not overlap with those from the "duration" condition for these SOA's), one more assumption must be postulated. It will be assumed that at low SOA's (up to about an SOA of 30 msecs.) when the target and mask were probably seen as occurring simultaneously, luminance is a more critical determinant of contour clarity than duration.

At an SOA of 0, the magnitude estimations were probably based on the brightness of the target. However, as was mentioned earlier, as the SOA was increased to about 30 or 45 msecs., the probability that the magnitude estimations began to rely on the contour information, increased. To the extent that the estimations were affected by the contour information, the following might have occurred.

In the "luminance" condition, the contour of the target would not have been seen, because the luminance of the target and mask were always equal.

In the "duration" condition, however, the unequal luminances of the target and mask would have resulted in the perception of the edge of the target. If at SOA's of 15 and 30 msecs., contour information at least minimally affected the magnitude estimations, then we would expect that these values would have been lower in the "luminance" condition due to the absence of the physical border between the target and mask.

Although there was a tendency for the magnitude estimations to be higher in the luminance condition represented in fig. 8 for SOA's between 60 - 105 msecs., the confidence intervals revealed that there may not have been a significant difference between the two conditions for these SOA's. However, the following may explain this trend.

Above an SOA of 45 msecs. it may be inferred that the probability of the target being seen as occurring separately from the mask is increased. It is hypothesized that at these longer SOA's, the temporal separation between the stimuli becomes critical in the perception of the target.

For any given SOA, the ISI in the "luminance" condition was greater than that in the "duration" conditions for all the stimulus parameters. For instance, a target and mask which were presented for 40 msecs each in the "duration" condition had an ISI of 35 msecs when presented at an SOA of 75 msecs. In the comparable "luminance" condition, the target and mask were presented at 4 and 16 msecs respectively. At an SOA of 75 msecs there was an ISI of 71 msecs. Thus, the observers always had more time in the "luminance" condition between the offset of the target and onset of the mask to process information about the edge of the target. This may account for why metacontrast decreased more rapidly in that condition. At an SOA of 45 msecs, magnitude estimates based on brightness or clarity may have been reflecting maximum masking. If peak masking was equal for both types of measures, then we would expect that the amount of metacontrast would have been equal in both the "luminance" and "duration" conditions. For SOA's above 75 msecs the magnitude of metacontrast was attenuated in both conditions producing no significant differences.

In summary, in order to explain the interaction between energy manipulation and SOA, a closer look at the dependent measure was necessary. It was hypothesized that at very short SOA's the observers based their judgements on the compelling brightness of the target, while at other SOA's, judgements were probably based on the perception of both the brightness and contour clarity of the target. The remaining results of the analysis are discussed in light of this interpretation.

It was found that SOA interacted with adaptation; F (14, 112) = 1.91; $p < .05$, and this relationship can be seen in fig. 9. These results showed that an increase in the state of adaptation of the eye, resulted in increases in the metacontrast effect. The trend in these data contradicts the results reported by Purcell, Stewart & Brunner (1974) which showed that the magnitude of metacontrast was inversely affected by increases in the state of adaptation of the eye.

The differences between the results of Purcell et. al. and this study may be attributed to the different paradigms that were used. Purcell et. al. used a two-alternative spatial forced choice procedure, which involved detection threshold measurements. In this experiment, the observers were required to make suprathreshold judgements which were based on the brightness and contour clarity of the target. To the extent that changes in the state of adaptation of the eye differentially affected the visual mechanisms underlying each paradigm, then a comparison of the results of these two experiments may not be valid.

The results of the Analysis of Variance revealed that there was a significant interaction between Adaptation X

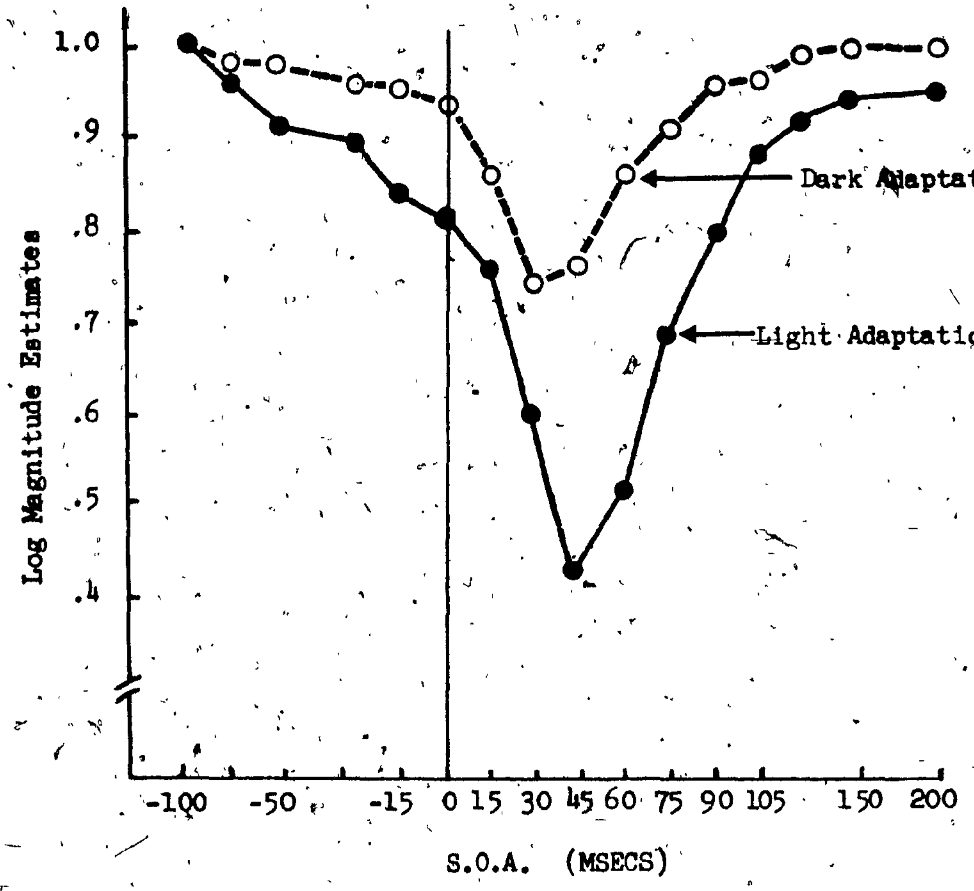

Fig. 9: The mean of the log magnitude estimates for the dark and light adaptation conditions collapsed across all other conditions.

Ratio X SOA; F (28, 224) = 1.53; $p < .05$. Since more information can be obtained from this interaction (as compared to Adaptation X SOA interaction), the following discussion explains how this might have occurred.

In order to determine the source of this interaction, two 5-way analyses of variance were run (Energy manipulations X Energy difference X Energy ratio X SOA X Subjects) for each adaptation condition. The results of these analyses (which can be seen in Table III located in the Appendix) showed that in the dark adaptation condition a significant interaction occurred between ratio and SOA; F (28, 112) = 1.99; $p < .01$. There was no significant interaction between ratio and SOA in the light adaptation condition; F (28, 112) = .81; $p < .05$.

An inspection of fig. 10 which shows the three levels of the ratio variable plotted against SOA for the dark adaptation condition, seems to suggest that even though ratio interacted with SOA, this was not a systematic effect. It seems that metacontrast was stronger (lower magnitude estimates) in the .25 ratio condition, than in the .57 or .70 conditions.

In fact, confidence intervals for the .57 and .70 ratio conditions overlapped for all SOA's while the intervals for these conditions at SOA's of 0, 15 and 30 msecs did not overlap with those in the .25 condition. A similar finding can be seen in the data reported by Weisstein (1971) where meta-

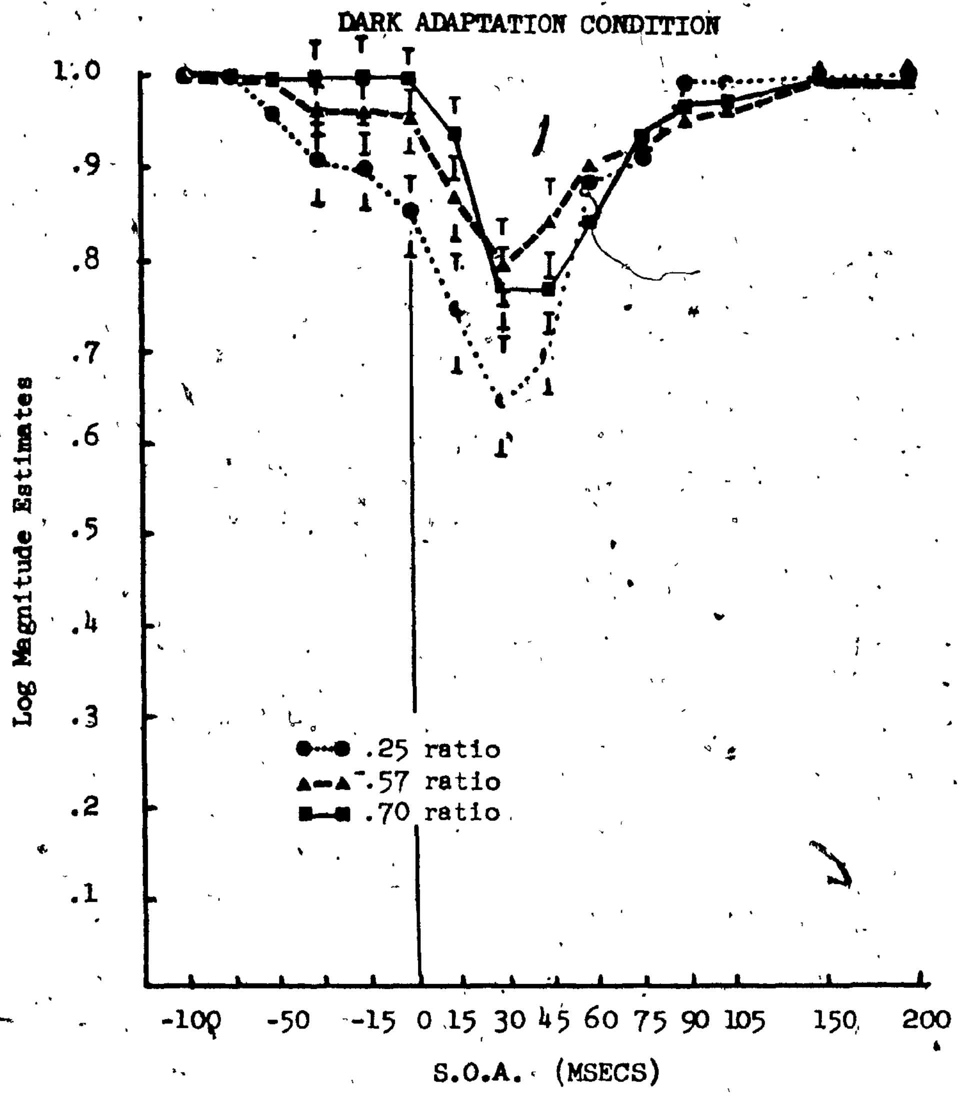

Fig. 10: The mean of the log magnitude estimates for the 3 ratio dark adapted conditions collapsed across all other conditions.

contrast functions did not differ between stimulus conditions which produced energy ratios of .875 and .50. The metacontrast function produced by a .20 energy ratio condition, however, showed markedly more masking than each of the other two conditions. In order to explain these data, we may investigate the manner in which luminance is processed by the visual system.

Fechner psychophysically demonstrated that perception is logarithmically related to stimulus intensity, such as luminance. Therefore, if a stimulus is presented to an observer at a fixed duration for different luminance levels, we would expect that the perceptual result would be logarithmically related to the luminance level of that stimulus. Since the energy level of the stimuli in this example is also varying as a function of luminance, we might reinterpret the stimulus parameters by suggesting that the perceptual impact of the stimulus is logarithmically related to its energy. If we assume then, that the visual system takes a log transformation of energy, then it may be specified how different stimulus energy conditions in this study affected the visual system.

If the difference between the log energies of a target and mask is related to the magnitude or shape of the metacontrast function, then the effect of each ratio condition may be calculated. In the .25 ratio condition, the difference between the log energies of the target and mask was

.60 units. The difference between the log energies of the target and mask for the .57 ratio condition was .24 units, and for the .70 condition was .15 units. By comparing these values the relative effect of the ratio conditions on metacontrast may be compared. For instance, in log units, the difference between the .57 and .70 conditions was .09 units (.24 - .15); while the difference between the .57 and .25 conditions was .36 units (.60 - .24); and the difference between the .70 and .25 conditions was .45 units (.60 - .15). In summary, due to the small difference between a .57 and .70 ratio condition, it seems that the metacontrast functions produced by these ratio conditions should be similar. To the extent that the differences between the log energies of a target and mask is related to the magnitude of metacontrast, then one should expect: a) differences in the metacontrast functions produced by .25 and either .57 or .70 energy ratio conditions, and b) the metacontrast functions produced by .57 and .70 energy ratio conditions should not differ by much.

A comparison of fig. 10 and 11 shows that for all ratio conditions the magnitude of metacontrast was higher (having lower estimates) in the light adaptation condition. In order to explain these data it is necessary to appeal to an assumption made earlier; that is that the observers were relying on brightness (to some extent at low SOA's) to make their judgements. This might have affected the general

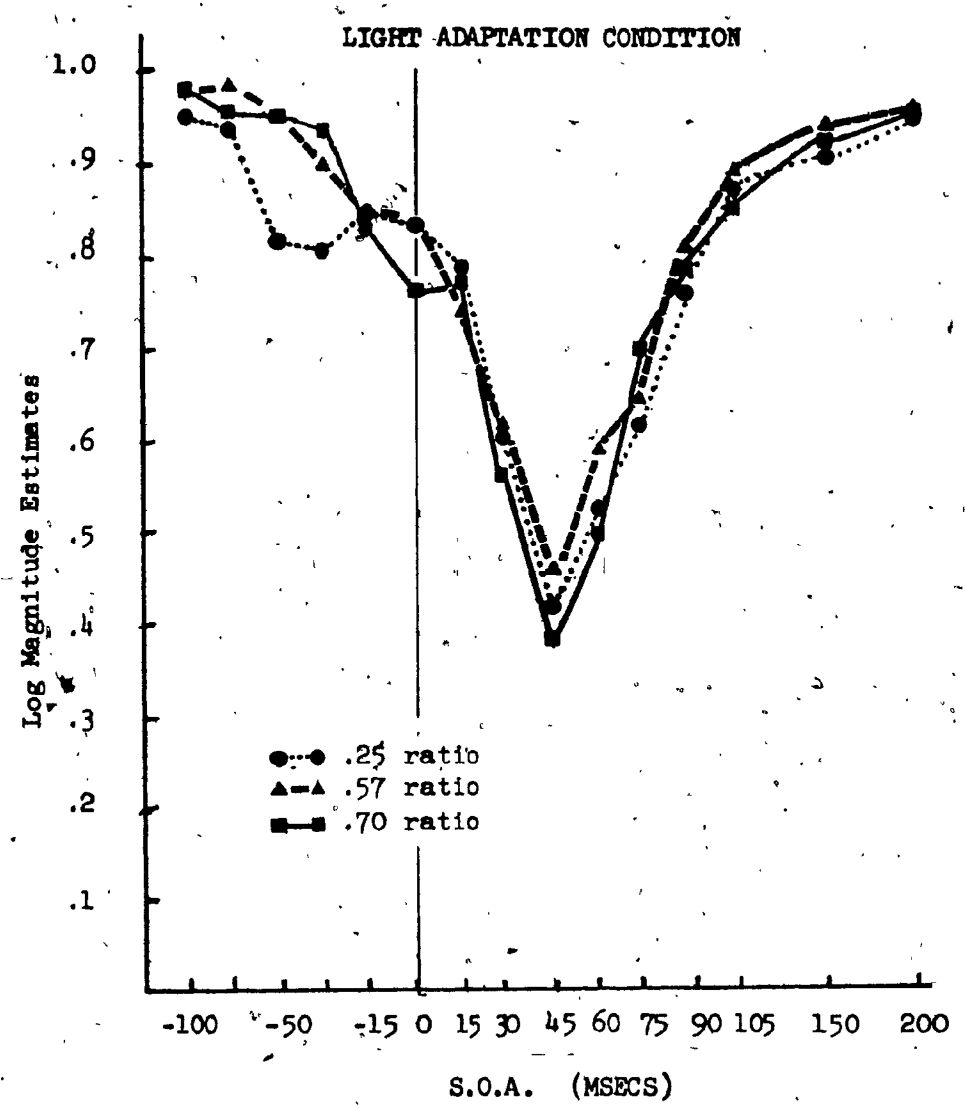

Fig. 11: The mean of the log magnitude estimates for the 3 ratio light adapted conditions collapsed across all other conditions.

amplitude of the metacontrast function. For instance, suppose that changes in the brightness of a target served to lower the magnitude estimates of the target at SOA's of 30 - 45 msecs (where there is maximum masking). We would expect that with increases in SOA (in either direction), the masking effect should taper off. However, if this attenuation in masking has similar rates across conditions, then we would expect the metacontrast function for this hypothetical stimulus to be consistently lower (across SOA's) than the other functions, if its point of maximum masking is lowest. Hence, if brightness played a role at low SOA's, this would have affected the entire metacontrast function. If brightness was involved in these magnitude estimates, then it is possible that the phenomenon of simultaneous brightness contrast played an important role in generating these metacontrast functions.

In the brightness contrast literature it has been shown that the brightness of a test field is greatly reduced when that field is presented on a background of higher luminance (Heinneman, 1955; Diamond, 1953; & Horeman, 1963). In this study, since there were 6 conditions where the mask was of a higher luminance than the target, then a condition necessary for producing simultaneous brightness contrast is satisfied. Although the stimuli were only presented together at an SOA = 0, the target and mask were probably seen as having been presented simultaneously for SOA's up to ± 45 this type of paradigm, then possibly two estimates should be employed. For instance, if observers were trained to report the brightness and clarity of a target, then they would not be susceptible to confusing the two perceptions.

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APPENDIX A

Instructions

"If you look in the t-scope, you will see a red spot of light. We'll call that spot the fixation point. If you look at the fixation point, you will see two rings located on each side of the fixation point. These rings will be called the masks. I will now show you a disc of light which we'll call the target. This target can either be presented alone (shown) or with the masks, and it can be presented such that it falls in the dark portion of the left or right hand side mask. When the target is presented alone, in the absence of the masks, it is referred to as the 'standard'. For each trial you will be required to do two things. First you are to tell me which mask the target was presented to by pressing the left or right button that is located in front of you.The second task is to judge the clearness of the edges of the target. This is the way you should do it.

Here is the standard (presented). If you look at the edge of this circle, it should appear to be clear and circular. I want you to assign the value of 10 to represent this clearness and completeness of the edge. On any given trial, you will be shown a target which will be presented sometime before, after or during the presentation of the masks. The clearness of the edges of the target may change from trial to trial. Your task is to rate the clearness of the edges of the target with respect to the standard. If the edge of the target is much clearer than the standard, then give it a value greater than 10. If it is less clear than the standard give it a value less than 10. Try to go by the following guidelines. If on one trial, you don't see a target, give it a value of 0. If you see a target which is just as clear as the standard, give it a value of 10. If it is half as clear as the standard, give it a value of 5, and if it is twice as clear as the standard, give it a value of 20. Use any number from 0 to infinity to represent the of the edge of the target. Keep in mind though, that you are always rating the clearness of the edge of the target with respect to the clarity of the standard's edge, which is a 10 rating.

The standard will be presented to you before each set of 18 trials, but if you ask, it can be presented at any other time. Before each trial you will hear this sound (one of the solenoids is activated). This means that you are to fixate on the fixation point, and the target will be presented to you in one and a half seconds. Remain fixated untill the target and mask are terminated. You will have 10 seconds between trials. Are there any questions?"

APPENDIX B

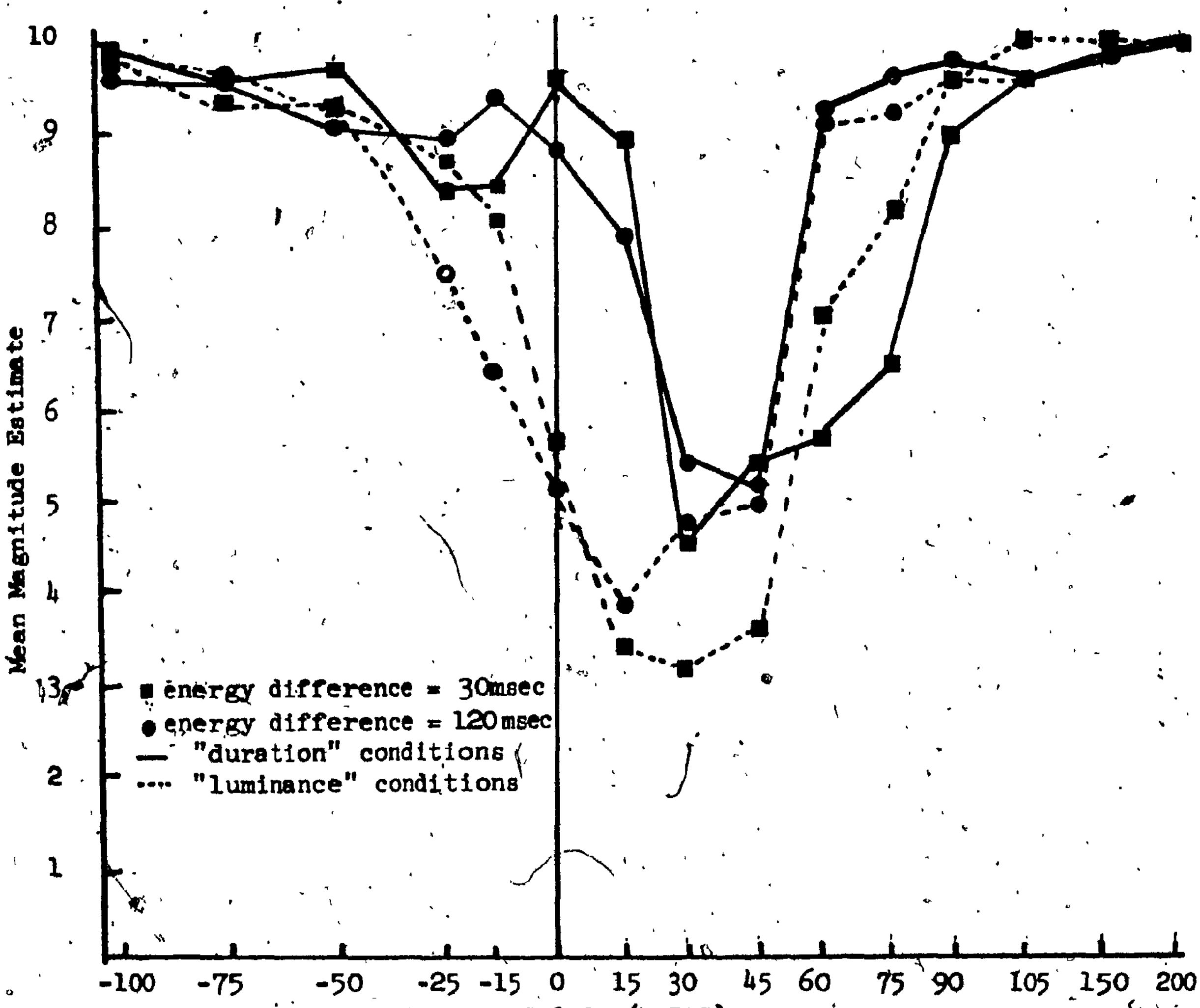

Fig. 6a: The geometric means plotted as a function of SOA for all the .25 ratio dark adaptation conditions.

APPENDIX B

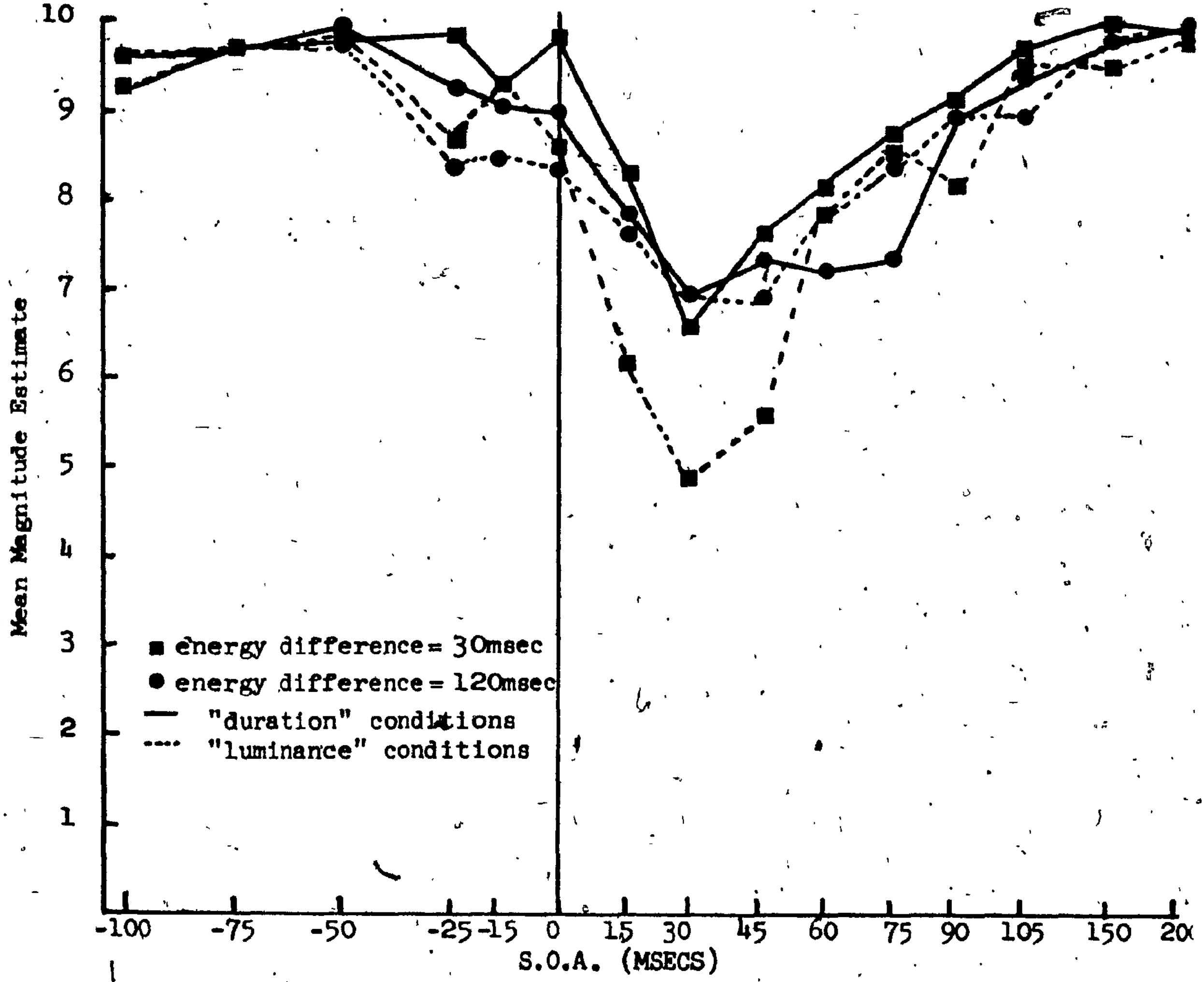

Fig. 6b: The geometric means plotted as a function of SOA for all the .57 ratio dark adaptation conditions.

APPENDIX B

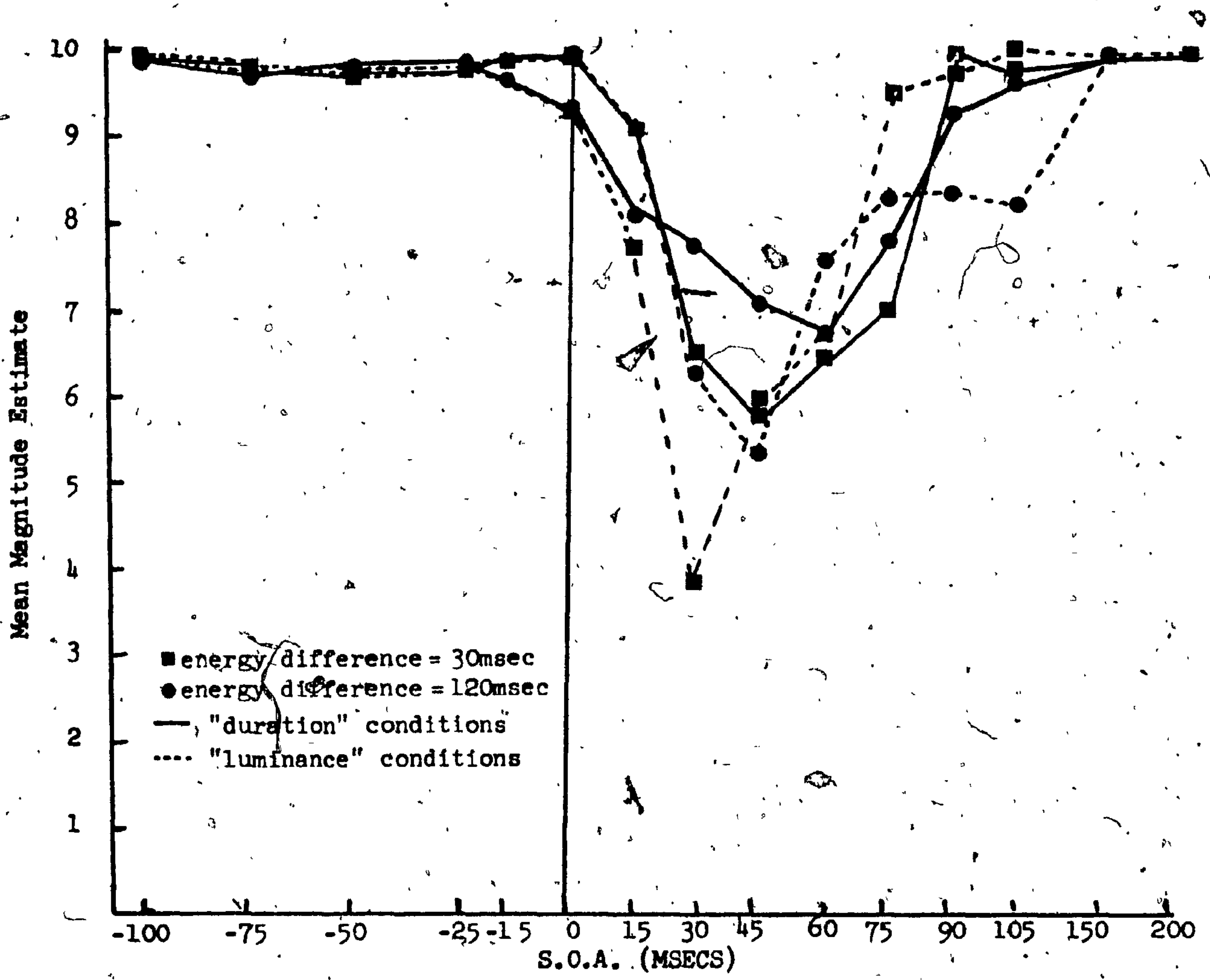

Fig. 6c: The geometric means plotted as a function of SOA for all the .70 ratio dark adaptation conditions.

APPENDIX B

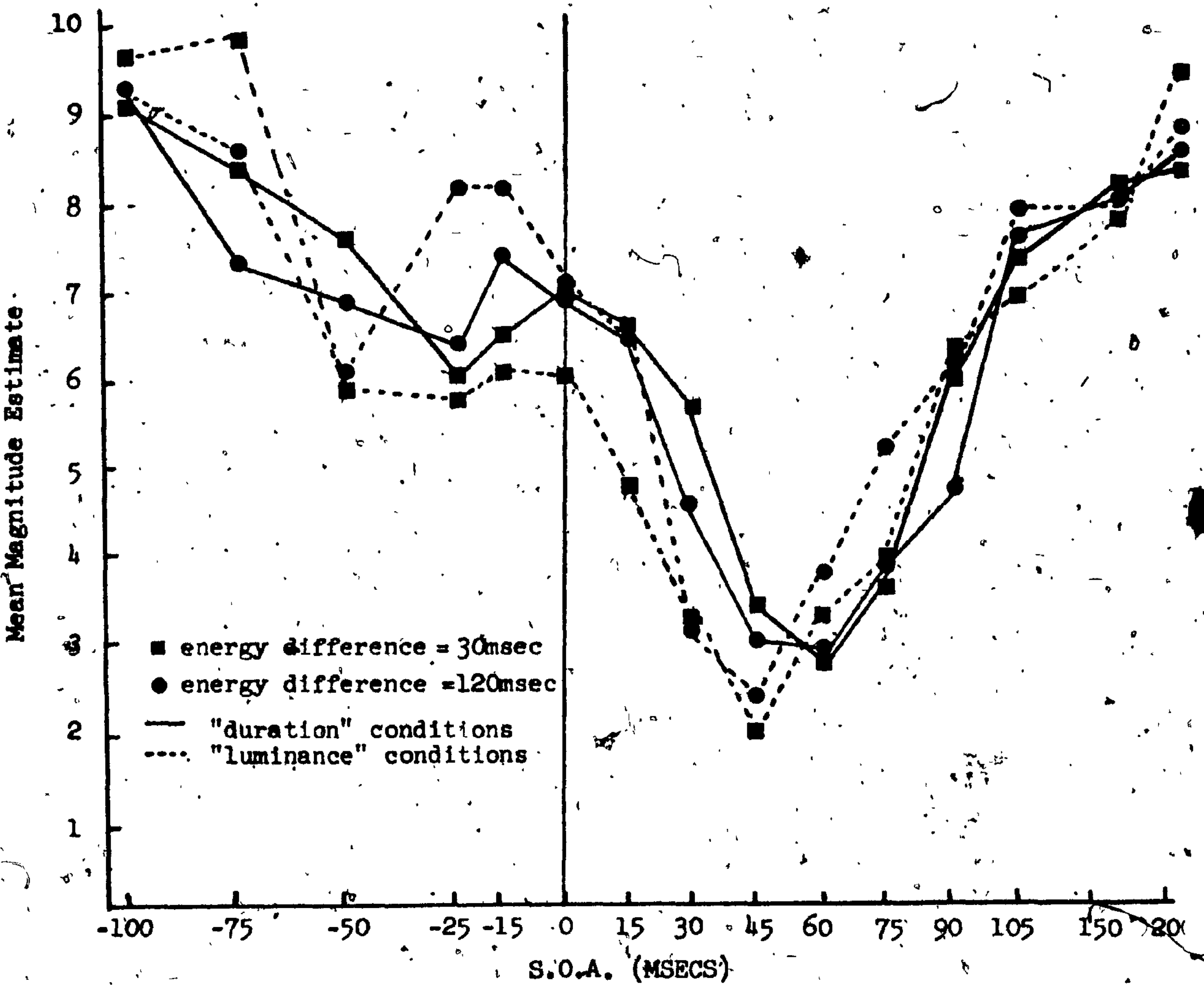

Fig. 7a: The geometric means plotted as a function of SOA for all the .25 ratio light adaptation conditions.

APPENDIX B

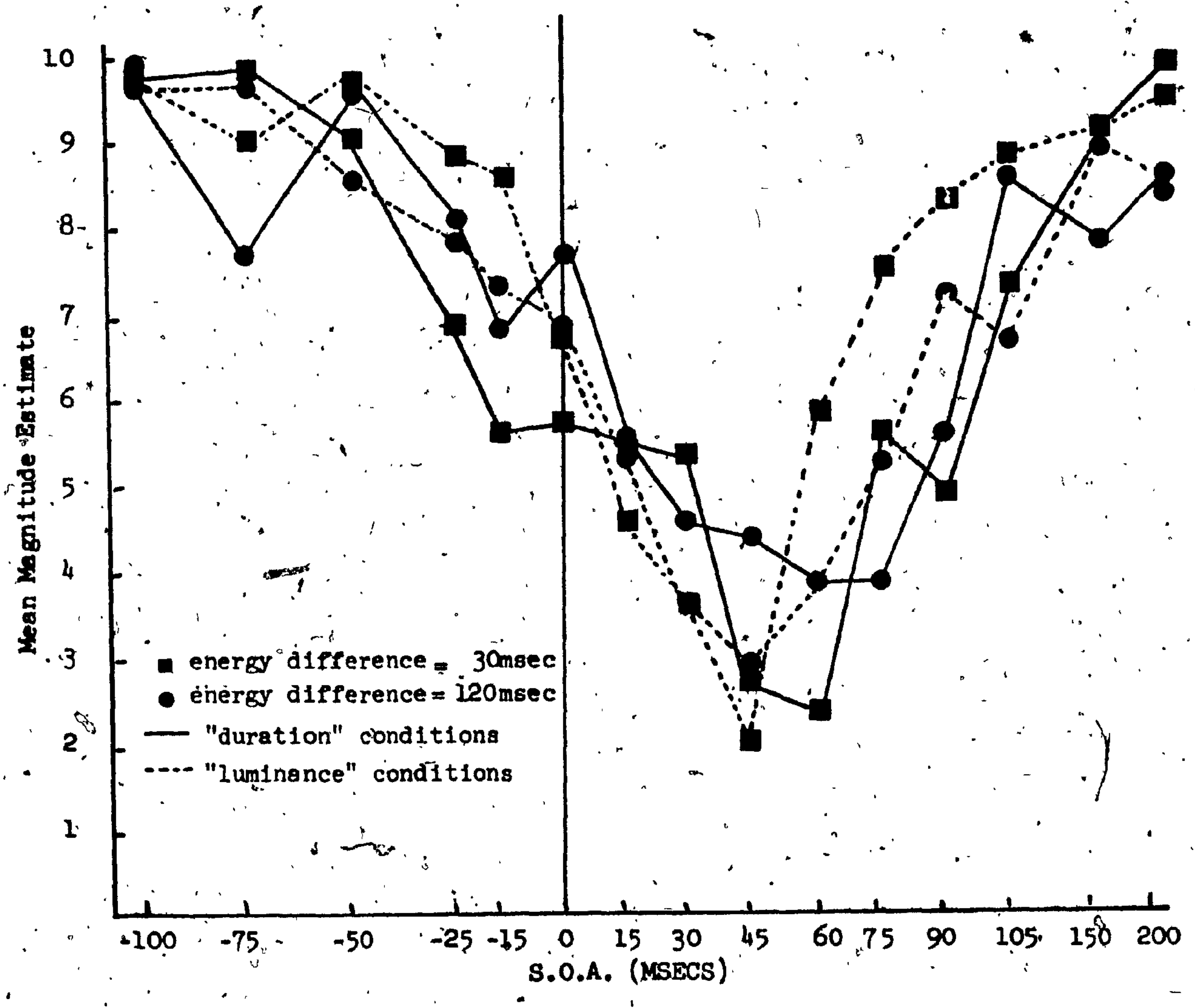

Fig. 7b: The geometric means plotted as a function of SOA for all the .57 ratio light adaptation conditions.

APPENDIX B

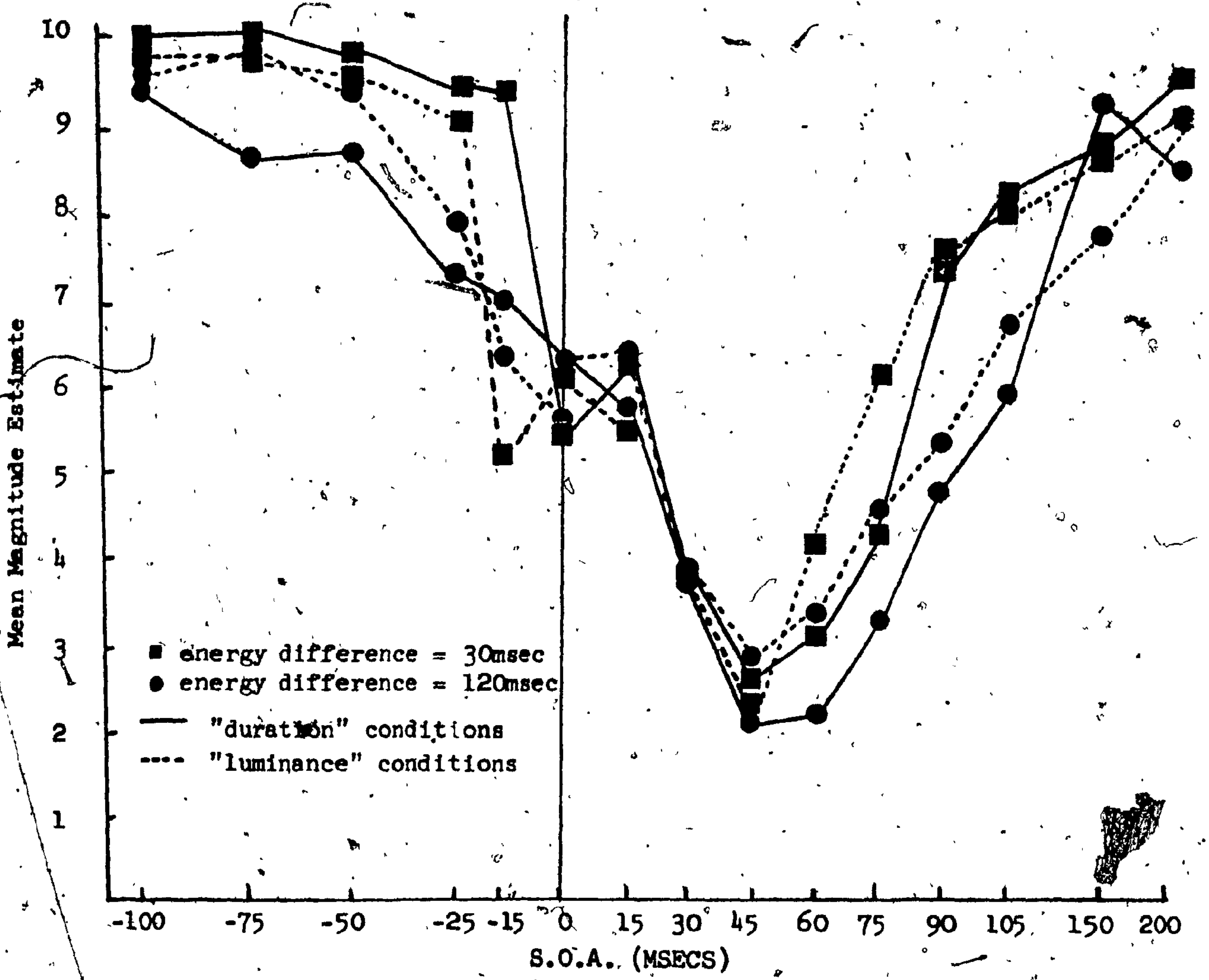

Fig. 7c: The geometric means plotted as a function of SOA for all the .70 ratio light adaptation conditions.

APPENDIX C

TABLE II

The Results of the Analysis of Variance I

Source	SS	df	MS	F
Adaptation (Y)	7.502	1	7.502	2.80
Subjects (S)$_{error}$	21.420	8	2.677	
Energy Manipulation (A)	.032	1	.032	.80
Y x A	.152	1	.152	3.85
A x S_{error}	.315	8	.039	
Difference (B)	.002	1	.002	.00
Y x B	.052	1	.052	.43
B x S_{error}	.955	8	.119	
Ratio (C)	.554	2	.277	3.32
Y x C	.079	2	.039	.47
C x S_{error}	1.333	16	.083	
SOA (D)	25.314	14	1.808	11.04 **
Y x D	4.387	14	.313	1.91 *
D x S_{error}	18.349	112	.164	
A x B	.029	1	.029	2.33
Y x A x B	.001	1	.001	.01
A x B x S_{error}	.099	8	.124	
A x C	.125	2	.063	1.24
Y x A x C	.013	2	.006	.13
A x C x S_{error}	.811	16	.050	
A x D	1.360	14	.097	5.07 **
Y x A x D	.405	14	.028	1.50
A x D x S_{error}	2.147	112	.019	
B x C	.111	2	.055	1.48
Y x B x C	.070	2	.035	.94
B x C x S_{error}	.597	16	.037	

APPENDIX C

TABLE II (cont'd)

Source	SS	df	MS	F
B x D	.282	14	.020	.91
Y x B x D	.326	14	.023	1.05
B x D x S_{error}	2.488	112	.022	
A x B x C	.063	2	.032	1.59
Y x A x B x C	.158	2	.079	3.96 *
A x B x C x S_{error}	.320	16	.020	
A x B x D	.282	14	.020	1.22
Y x A x B x D	.146	14	.010	.63
A x B x D x S_{error}	1.851	112	.016	
C x D	.616	28	.022	.97
Y x C x D	.976	28	.035	1.53 *
C x D x S_{error}	5.112	224	.022	
A x C x D	.597	28	.021	1.28
Y x A x C x D	.438	28	.016	.94
A x C x D x S_{error}	3.744	224	.017	
B x C x D	.455	28	.016	.98
Y x B x C x D	.237	28	.085	.51
B x C x D x S_{error}	3.722	224	.167	
A x B x C x D	.154	28	.005	.48
Y x A x B x C x D	.251	28	.009	.77
A x B x C x D x S_{error}	2.593	224	.012	

** $p < .01$

* $p < .05$

APPENDIX C

TABLE IIIa

The Results of the Analysis of Variance II for the Dark Adaptation Condition

Source	SS	df	MS	F
Energy Manipulation (A)	.161	1	.161	3.25
A x Subjects $(S)_{error}$	.198	4	.049	
Difference (B)	.037	1	.037	.27
B x S_{error}	.548	4	.137	
Ratio (C)	.388	2	.194	1.61
C x S_{error}	.962	8	.120	
SOA (D)	5.993	14	.428	6.57**
D x S_{error}	3.649	56	.065	
A x B	.012	1	.012	.82
A x B x S_{error}	.063	4	.016	
A x C	.099	2	.049	10.90**
A x C x S_{error}	.037	8	.004	
A x D	.583	14	.042	2.92**
A x D x S_{error}	.800	56	.014	
B x C	.019	2	.009	.19
B x C x S_{error}	.402	8	.050	
B x D	.291	14	.021	.74
B x D x S_{error}	1.568	56	.028	
C x D	.935	28	.033	1.99**
C x D x S_{error}	1.876	112	.017	
A x B x C	.017	2	.008	.57
A x B x C x S_{error}	.117	8	.015	
A x B x D	.235	14	.017	.93
A x B x D x S_{error}	1.014	56	.018	
A x C x D	.438	28	.016	1.22
A x C x D x S_{error}	1.431	112	.013	
B x C x D	.175	28	.006	.49
B x C x D x S_{error}	1.431	112	.013	
A x B x C x D	.116	78	.004	.47
A x B x C x D x S_{error}	.987	112	.009	
S	1.028	4	.256	

** $p < .01$

* $p < .05$