METACONTRAST: THE EFFECTS OBTAINED WITH CONSECUTIVELY PRESENTED CONCENTRIC DISKS & RINGS OF DIFFERENT WAVELENGTHS

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ABSTRACT

METACONTRAST: THE EFFECTS OBTAINED WITH CONSECUTIVELY PRESENTED CONCENTRIC DISKS & RINGS OF DIFFERENT WAVELENGTHS

by James William Walters

In order to determine what effect difference in wavelength would have on the phenomenon called metacontrast, two figures, a disk and concentric ring were successively presented to the left eye at interstimulus intervals of 0, 40, 70, 100, 130, 160, and 210 milliseconds. The left eye was presented with a disk which could be varied in intensity. The disk and ring were equated for area, duration and brightness. Four color combinations were used. They were red disk-red ring, blue disk-red ring, red disk-blue ring, and blue disk-blue ring. Two experienced observers served as subjects. Their task was to match the apparent brightness of the (metacontrast) disk in the left eye by adjusting the intensity of the disk being presented to the right eye. The results showed that when the disk and ring were the same color the disk being followed by the ring at intervals of 70 and 100 milliseconds appeared to be reduced to approximately 30% of its original brightness. For the red disk-blue ring condition, no significant reduction in brightness of the disk was found for

any of the interstimulus intervals employed. The red ring-blue disk condition did show a significant reduction in brightness for intervals of 70 and 100 milliseconds, where the disk appeared to be approximately 70% of its original brightness.

An additional experiment was done to insure that the differential effects obtained with the two multicolored conditions were not due to differences in brightness. The results of this experiment confirmed that color was the significant variable. In addition to the above findings, it was also noted that the presence of the blue comparison disk in the right eye enhanced the metacontrast effect in the blue disk-red ring condition being presented to the left eye. This phenomenon was not noticed when the red disks were being used. In spite of this complication, it was felt that the metacontrast found with the blue ring-red disk condition was not an artifact introduced by the measurement procedure.

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INTRODUCTION

Definitions

For the purposes of this thesis, metacontrast will be defined as that phenomenon wherein the perception of a tachistoscopically presented geometric figure is inhibited by the successive presentation of another figure or figures in an immediately adjacent region of the visual field. The phenomenon occurs regardless of whether the figures presented are black figures in a lighted surround or lighted figures in a black surround (Werner, 1935).

Visual masking (a phenomenon often called metacontrast and vice versa) for the purposes of this thesis will be defined as that phenomenon wherein the perception of a tachistoscopically presented geometric figure is inhibited by the successive presentation of a masking flash or pattern which covers that portion of the visual field previously occupied by the figure. The initial figure can be either a black figure in a lighted surround or a lighted figure in a black surround. The masking stimulus is frequently a uniformly illuminated field of higher intensity and longer duration than the stimulus being masked (Crawford, 1947 and Donchin, Wicke and Lindsley, 1963). Masking has been found with patterned fields, however (Schiller and Wiener, 1963), as well as with darker illuminated fields (Thompson, 1966).

These two definitions differ somewhat from those found in the available literature on the subject. The stimulus parameters about which these other definitions of masking and metacontrast differ are: (1) whether the second of the successively presented stimuli falls in an area adjacent to the initial stimulus or the same area; and (2) whether the stimuli are black figures in a lighted surround or lighted figures in a black surround.

Alpern (1954) defines metacontrast as "...the reduction of the brightness of a flash of light when it is succeeded by a second flash which is exposed in an adjacent region of the visual field". Kolers and Rosner (1960) essentially agree with Alpern when they define metacontrast as "...the apparent darkening of the first of two flashes of light". They also specify that the light must be in an adjacent portion of the retina. Kolers and Rosner define masking as the converse of metacontrast, or "...the apparent lightening of the first of two successively presented black figures". Again they specify that the second target fall in an adjacent portion of the visual field. It should be noted that metacontrast and masking, as defined by Kolers and Rosner, do not include the large body of data concerning the effects of following the first stimulus by a second which completely covers it.

Another approach to the relationship between masking and metacontrast has been set forth by Raab (1963).

Raab prefers to use the term backward masking in a generic sense, so as to include under this one rubric all situations where successive presentations of two visual stimuli result in the inhibition of the first by the second. Raab then defines various subsets of masking among which is found metacontrast as defined by Alpern above.

Finally, many investigators use the term masking in a manner consistent with the way it has been defined by this author, while at the same time making only a vague distinction between this type of phenomenon and that which is here defined as metacontrast (Thompson, 1966 and Heckenmueller and Dember, 1965).

It can readily be seen that there is a lack of definitional conformity in the literature on the subjects masking and metacontrast. Part of the difficulty appears to lie in the fact that as knowledge in these two areas is expanded by researchers working independently of each other, insufficient effort is given to the task of integrating the new knowledge with the old. The result is a series of overlapping subdefinitions which either strictly adhere to the historical root definitions without regard to the larger set of data which these definitions no longer adequately encompass, or they integrate only part of the existing data, while ignoring the rest.

It is the contention of this author that the two definitions set forth in the beginning of this thesis attend to the task of maintaining the historical root definitions while at the same time they integrate later findings in a manner which is both parsimonious and utilitarian.

Historically, the phenomenon called metacontrast was first labelled as such by Stigler (1910). In this experiment Stigler investigated the effects of successively presenting alternate halves of a white disk in a black field. He found that the presence of the first half disk diminished the perceived brightness of the second, while the second had an even larger effect on the first. The first of these phenomena he called parakontraste (paracontrast), the latter, metakontraste (metacontrast). These two terms were deemed necessary in order that the phenomena they represented might be separated from homophotische kontraste, which is the equivalent of simultaneous contrast. Of interest here is Stigler's choice of a word to describe the effect of the second stimulus on the first. The word metacontrast implies a kind of contrast after the fact, as denoted by the prefix "meta" from the Greek word meaning after, and contrast, meaning to place or set beside. Hence both the temporal and spacial aspects of the stimulus are specified by this term inasmuch as the contrasting stimulus comes after, and in an area adjacent to, the stimulus being evaluated.

Following Stigler's article came others (Baroncz, 1911 and Stigler, 1913, 1914, 1918, 1926), all dealing with various ramifications of metacontrast. The fact that they were all in German appears to have limited their audience, however, to the extent that the phenomenon was later rediscovered by two American investigators, Fry (1934) and Werner (1935). Fry's approach to the problem was very similar to Stigler's. He worked with a tachistoscopically presented patch of light followed by two adjacent patches, one on either side, and found the marked effect on the brightness of the first patch that Stigler had already labelled metacontrast. Fry used achromatic as well as monochromatic light to illuminate the three patches which were always identical in color for any single set of matches. He investigated a wide range of the spectrum (every 20nm from 440nm to 680nm), and found the magnitude of the effect to be the same regardless of the wavelength used. Fry did not attempt to label the phenomenon, however he did advance an hypothesis which he felt might explain the suppression of the first stimulus by the second. In Fry's words,

> What seems to happen is that the response of the retina to the first stimulus is considerably delayed and prolonged, and overlaps in time the response to the second stimulus and is inhibited by it by some kind of interaction between retino-cortical pathways at synapses either at the retina, or at the basal ganglia, or at the cortex.

Werner's approach to the problem of successive contrast of geometric figures was somewhat different than either that of Fry or Stigler. Though he did pilot work with successive tachistoscopically presented white figures in a black surround, he refers to it only by way of comparison to the effects he obtained using black figures in a white surround. The figures with which Werner got the best effects were a black ring and a concentric black disk, the two of which were arranged so that the inside edge of the ring coincided with the outside edge of the disk. Werner found that when the ring was presented first, followed by the disk, both were seen as clearly as they were when independently presented. When the sequence was reversed, however, and with optimum timing, the disk was made to completely disappear.

Werner chose to call this effect the "contour effect", as he felt the mechanism responsible for the disappearance of the disk was one by which the ring usurped the contour of the disk. In Werner's words,

> (1) Every visual object, even when it is presented simultaneously in all its parts, is built up by a psychophysical process which, as a process, has a certain temporal duration. (2) Normally such a construction comes into existence because of a psychophysical difference in relation to the surrounding field, that is the figure is conceived from the point of the strongest psychophysical difference, which is that of contour. Because of this, if some optical object is disturbed in such a way that, as a result of certain conditioning factors, the contour cannot be formed, then this optical stimulus becomes psychophysically ineffective. I mean this when I say that contour has a fundamental significance for the optical perception of objects. If this theoretical assumption is correct, the following must have occurred. In a certain succession of the two figures, of the disk and the ring, the process of forming the contour of the disk has been identified with the inception of the whole process of constructing the ring.

> This process of forming the contour of the disk will, therefore, be utilized in the building up of the ring. A specific separate perception of the contour of the disk, in consequence of this fact, is absent. Since this factor of greatest tension, the contour, is lacking, the whole picture of the black disk is also lacking. On the other hand, if the ring is presented first and the disk second, the ring, in this case, is already in the first stage of development, which permits the contour of the disk to be built up as a separate figuration. Therefore the whole disk can be seen.

The tendency to see the products of the investigations of Fry and of Werner as two separate phenomena (as the previously discussed definition of Kolers and Rosner, 1960, suggests) is perhaps explainable on the basis that Fry is dealing with the apparent <u>reduction in brightness</u> of the first of two successively presented light figures, while Werner is dealing primarily with the apparent <u>increase in brightness</u> of the first of two successively presented dark figures. This dichotomy does not bear up under close scrutiny, however, as there are many facts which indicate that they are the same phenomena.

There are perhaps two facets to the task of defining visual phenomena. The first of these deals with the stimulus configuration and its characteristics. Consequently, visual phenomena can be organized in part on the basis of spatial, temporal and energistic characteristics. The other facet attends to the effects that various stimuli have on an organism or group of organisms. Such effects are measured both in terms of overt motor responses of the organism and in terms of the activity of suborganismic components such as the central nervous system. A definition of visual phenomena must integrate both of these facets in a fashion which is internally consistent and at the same time make a meaningful distinction between different but closely related phenomena. Using this definitional approach, the dichotomy suggested by Kolers and Rosner (1960) is found lacking in several respects. From the standpoint of the stimulus configuration, Kolers and Rosner's term of masking as applied to a black disk-black ring sequence does not seem to be particularly appropriate. The second stimulus is not covering up the first as the term masking suggests, and because there are studies dealing with the effects of one stimulus covering the second, it would seem more appropriate to reserve the term masking for them. Of course it can be argued that the black disk and the black ring do not denote the stimulus inasmuch as the energistic input received by the organism is being emitted by the lighted surround. Such a distinction yields no further insight into the phenomenon, however. If such an assertion leads one into believing that it is the center of the ring (a white disk) which masks or covers the previously exposed black disk causing its disappearance, then by the same token the ring should disappear in a black disk-black ring sequence, as it is being covered by the white field surrounding the disk. This is not the case, however.

A case might still be made for Kolers and Rosner's distinction between Fry's and Werner's works if the disappearance of the first of two lighted figures in a dark field (which can be interpreted to mean the apparent reduction in brightness of the lighted figure) can be shown to be the result of a different mechanism than that which is responsible for the disappearance of the first of two black figures in a lighted surround (which can be interpreted to mean the apparent increase in brightness of the black figure). The evidence seems to indicate just the opposite, however, as there are many similarities between these two conditions which suggest that essentially the same mechanism is responsible for both.

Chief among these similarities are two which are most important. (1) Regardless of whether the stimulus pattern consists of white figures in a dark surround or the converse, the prerequisite that the border of the target being "inhibited" be contiguous with the border of the inhibiting target is of prime importance. Werner (1935) shows this by surrounding a black disk by only half a ring, consequently impairing the perception of only half the disk in a black disk-semi-ring stimulus sequence. Alpern (1953), using white targets in a black field, showed that no metacontrast occurred for targets separated by more than one degree of visual angle, regardless of their relative intensities. (2) The optimum time which must elapse between the presentation of light figures in a dark surround and between dark figures in a lighted surround is very similar. Alpern (1953) reports optimum "reduction in brightness" of the first target using a 5 millisecond white target in a dark field, when the first target was separated from the second by approximately 100 milliseconds. Werner (1940), using 12-25 millisecond black figures in a lighted surround, reported optimum "contour effect" to occur in the range of 150 to 200 milliseconds. The important point to be made from this last data is that there must be a delay of between 100 and 200 milliseconds for this phenomenon to optimally occur, regardless of whether black or white figures are being used.

The above two points also serve to show the difference between masking and metacontrast as defined at the beginning of this thesis. (1) As defined there the term denotes those conditions where the second stimulus covers the area formerly occupied by the first stimulus. It is certain then that contiguity of border is not a prerequisite for the occurrence of inhibitory effects under these conditions as has been shown to be the case with metacontrast. (2) In masking the optimum delay period exhibited by metacontrast is absent. Optimum masking comes when the first stimulus follows the second as soon after the cessation of the first as possible. The further the two stimuli are separated in time, the less becomes the masking effect. Donchin, Wicke and Lindsley (1963) show no masking after a 20 millisecond delay, a figure which falls far short of the 100 milliseconds needed for optimum metacontrast as reported by Alpern. In this study by Donchin, et al., the stimulus was a 10 millisecond flash with an intensity of .25 millilamberts, subtending a visual angle of 1°6'.

Thompson (1966) used black letters (A, T and U) in a lighted surround as the initial target which was masked by a uniformly illuminated field of various intensities. He found masking effects decreased as the time between the presentation of the letters and the masking stimulus increased. The times at which appreciable masking no longer occurred for Thompson varied with the ratio of illumination of the two successively presented fields. The best masking occurred with delay periods of less than 10 milliseconds after which masking effects rapidly diminished until after a delay of 50 milliseconds no masking of any significance was found.

Now that a definition of metacontrast as distinguished from masking has been set forth and supported, it is possible to turn to the task of taking a closer look at metacontrast with the intention of understanding the nature of the mechanism responsible for its occurrence.

Statement of Problem

The ideas of both Fry and Werner concerning a possible mechanism for metacontrast have already been reviewed.

It will be recalled that Fry thought the mechanism was one of neural inhibition, while Werner felt that the contour of the first figure was being taken over by the second figure, so-to-speak. The evidence for or against either one of these approaches is not conclusive. It is becoming increasingly certain, however, that a general inhibition of the first target does not occur. Fehrer and Raab (1962) have shown that metacontrast suppression of a light figure in a dark field does not affect the observer's reaction time to the first target, in spite of the fact that at optimum rates of presentation he may report seeing only the second target in the sequence. Schiller and Smith (1966) have confirmed this finding. They have also shown that in a forced choice situation where a subject is consistently presented with two rings and given the task of identifying the ring in which a disk has previously occurred, the accuracy of identification remains at a very high level (100% over a very wide range of disk brightness) regardless of the amount of metacontrast suppression reported. Schiller and Smith have also shown that the number of times a given subject reported the disk totally absent could be greatly reduced by interspersing the disk-ring sequence with presentations of the ring only. This fact suggests to them that subjects probably make relative estimates of the magnitude of suppression and hence report the stimulus absent where the first stimulus is least apparent. This latter point is a possible explanation of the apparent paradox of reacting to a stimulus which is reported as not being seen.

Schiller and Chorover (1966) have pursued the question of what kind of changes in neural activity occur during conditions of metacontrast, by the method of averaging stimulus evoked EEG potentials. This was accomplished by synchronizing a computer of average transients with the stimulus and then taking repeated measures from the scalp. In this fashion the non-stimulus bound portion of the EEG is assumed to average to zero over a number of trials because of its random, asynchronous nature. Schiller and Chorover, using a lighted disk-ring sequence in a dark field, found that the amplitude of the EEG was not attenuated under conditions in which the brightness of the first stimulus appeared markedly reduced. When the brightness of the disk was lowered by reducing the intensity, however, the EEG potentials did show a corresponding reduction in amplitude. It was also found that the latency of the EEG response to the disk was not affected under conditions of metacontrast, but that it was noticeably increased when the brightness of the disk was reduced by lowering the intensity.

As suggested earlier, the evidence against a general overall neural inhibition of the first stimulus by the second is fairly substantial. However, a selective neural inhibition at a relatively high level has not been ruled out. It is certain that the qualitative changes reported by the observer must somehow reflect neural differences. Where they are and what they are remains to be discovered.

Werner's (1935) suggestion that the formation of contour is the important feature may provide a clue as to what to look for. Werner's approach was strictly cognitive, but his ideas appear to have strong physiological correlates. The idea that the formation of contour can be identified as a fundamentally separate process is one of these (Hubel and Weisl, 1962, and Rodieck and Stone, 1965).

In terms of stimulus parameters, visual contour is perceived whenever a relatively sharp change in photic input to the organism occurs, provided that the magnitude of change is sufficient to provide a noticeable difference, the greater the difference the more pronounced is the contour. These changes in photic input can be of two types: (1) Changes in intensity; and (2) Changes in wavelength.

The studies of metacontrast to date, for the most part, have dealt with the effects generated by successively presenting geometric figures of the same wavelength composition. In terms of contour formation, these studies have dealt solely with the effects of switching the direction of the intensity gradient. For example, if a white disk is followed by a white ring which circumscribes it, the intensity gradient formed at the edge of the disk progresses from the lighted disk to the dark surround. This direction is reversed when the concentric ring comes on following the cessation of the disk, as the gradiation then progresses from the ring inward to its dark center. An analogous situation holds for the presentation of dark figures in a lighted field.

It is interesting to note that in the case of the lighted figures in a dark surround, if concentric figures of the same wavelength composition and intensity are presented simultaneously, only one figure is seen. If, however, figures of equal brightness but noticeably different wavelengths are simultaneously presented, two figures are seen, which is as much as saying that a contour is formed between them.

It has already been well demonstrated that metacontrast will occur if the wavelength composition of the two figures are the same (Fry, 1934), but insufficient work has been done where the figures have been of different wavelength compositions. Baroncz (1911) exposed a 1 centimeter square white patch of 7.2 milliseconds duration followed by a 7.2 milliseconds red surround 24 to 120 milliseconds later. The result was that the white target sometimes appeared to be a dark green. Werner (1935) reported in a footnote that a red disk followed by a black ring did not produce any experimental effect.

Baroncz's study suggests that perhaps only that portion of the white light which most closely corresponds to red is affected by the red surround which follows the white patch. Werner's contribution is inconclusive inasmuch as it amounts to flashing a red disk followed by a red or white disk (Werner did not specify), which is the center of the black ring. It should be noted that metacontrast can be generated with a black disk followed by a lighted ring, but that the converse does not hold. A discussion of this fact will be undertaken in the discussions section of this thesis.

The above two sources (Baroncz, 1911, and Werner, 1935) are the only published reports that this author can find on the use of figures of different chromaticity. Alpern (1952), in an historical review of metacontrast, makes reference to only Baroncz's findings in this area.

It will be the purpose of this thesis to investigate further the effects to be found when figures of different wavelength composition are presented in a sequence conducive to finding metacontrast.

METHOD

Subjects

Two male observers, each with several hundred hours of experience making brightness matches in other experiments, were utilized as observers in this study. In addition to this prior experience, one of the observers, J.W.W., had practiced for several months in pilot studies dealing with metacontrast. The other observer, R.J.B., had no prior experience with the metacontrast effect.

Stimulus

The stimulus consisted of a lighted disk and ring in a dark field presented to the left eye and a disk only presented to the right eye (see Figure 1). The disk and ring were of equal area and brightness, and were arranged so that the outside edge of the disk coincided exactly with the inside edge of the ring. The figures were an optical distance of 40cm from the observer. Both disks had a diameter of 3cm. The outside diameter of the ring was 4.24cm. The two disks were 6cm apart (center to center). As only one disk was seen by each eye, a small point source seen by both eyes was located between the two disks at an optical distance of 40cm, in order to keep binocular convergence constant. Two colors were

Fig. 1. Stimulus configurations shown full scale. The stimulus was located at an optical distance of 40 cm from the observer. The disk and concentric ring on the left were seen by the left eye only. The disk on the right was seen by the right eye.

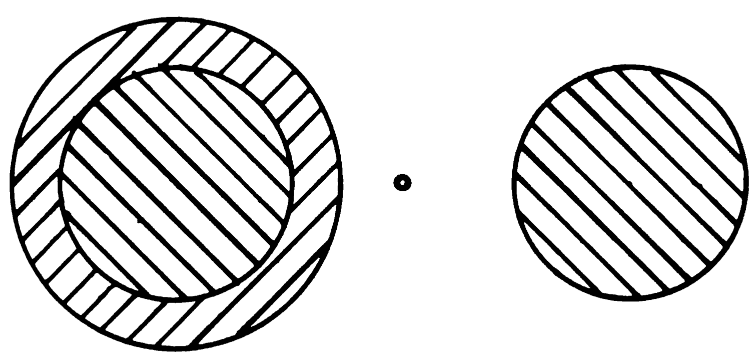


Figure 1

used, red and blue, which permitted 4 combinations. They were red disk-red ring, blue disk-blue ring, red disk-blue ring and blue disk-red ring. The brightness of the blue figures, as determined by a Pritchard photometer, was 1.90 foot lamberts. The red figures were metered at 2.90 foot lamberts. When figures of the same color were used together this brightness was left unaltered. When a blue and red figure were used together the red figure was reduced to 63% of its original brightness, or 1.92 foot lamberts, by the use of a .2 neutral density filter.

Apparatus

The apparatus is schematically depicted in Figures 2 and 3. A picture of the apparatus is provided in Figure 4. The stimulus configuration was presented in a Gerbrands Tachistoscope, illuminated with mercury vapor and neon gas discharge tubes. The tubes were interchangeable. The neon tubes were used when red figures were desired. The mercury vapor tubes provided illumination for the blue figures. The onset and cessation of the gas discharge tubes was controlled by two synchronized Grass S-4 stimulators (see Figure 2). The S-4's regulated the grid voltage on the gate tube and initiated the trigger pulse at the onset of each stimulus presentation. The trigger provided the extra voltage necessary to affect the initial ionization of the gas discharge tubes. As illustrated in

Fig. 2. Schematic block diagram of electrical apparatus used to control the gas discharge tubes in the tachistoscope.

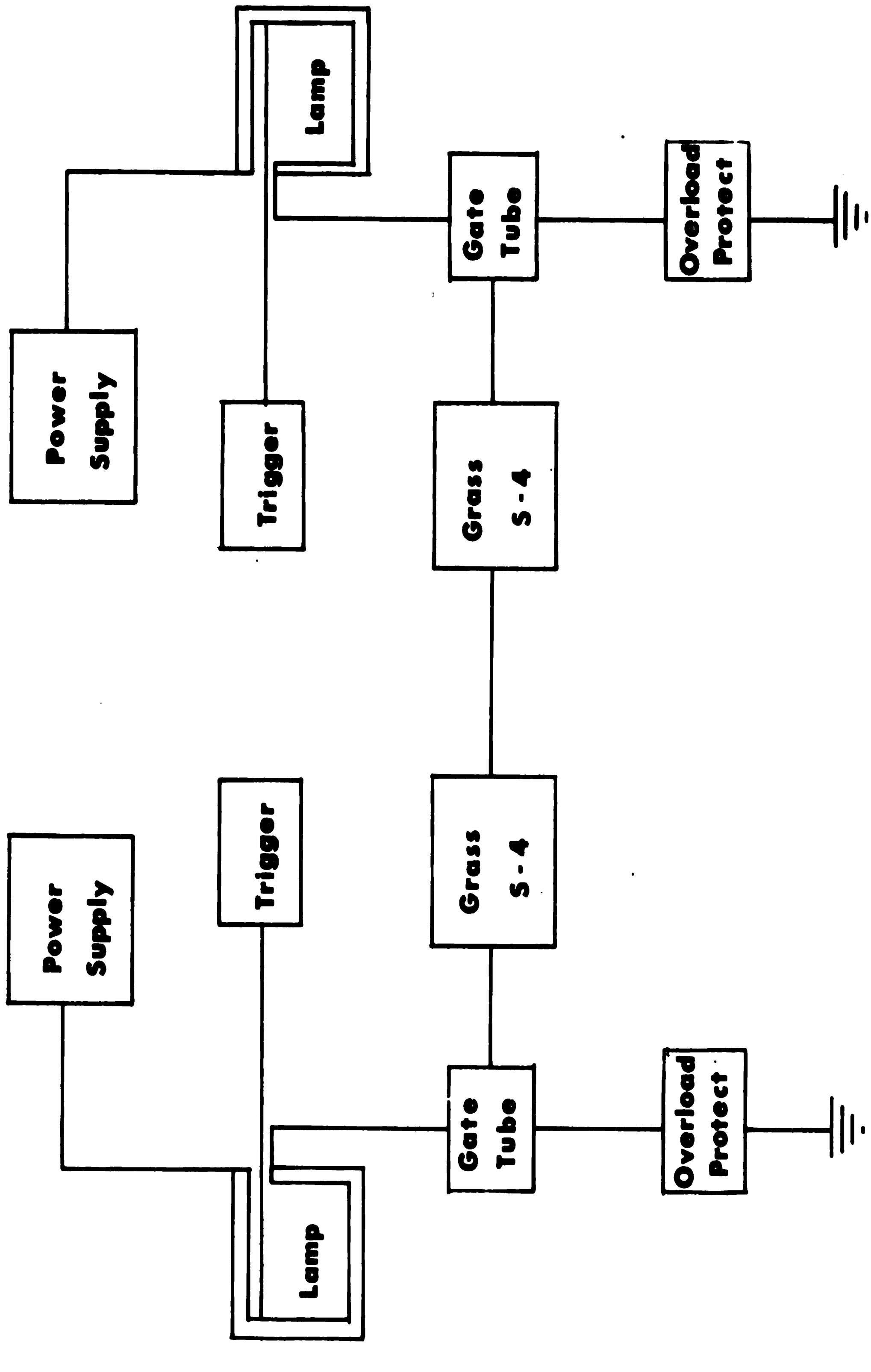

Power Supply
Trigger
Lamp
Gate Tube
Grass S - 4
Overload Protect
Grass S - 4
Power Supply
Trigger
Lamp
Gate Tube
Overload Protect

Figure 2

Fig. 3. Schematic diagram showing optical arrangement inside tachistoscope. A and A' are opaque baffles which form the stimulus configuration shown in Fig. 1. B and B' are the gas discharge tubes. C and C' are white poster boards which reflect the light through baffles A and A'. D is a semisilvered mirror. E is a .3 neutral density filter used to reduce the intensity of the disk and ring seen by the left eye. F is a circular neutral density wedge which regulates the intensity of the comparison disk seen by the right eye. G is a scale which indicates the setting of the circular neutral density wedge in per cent of transmission.

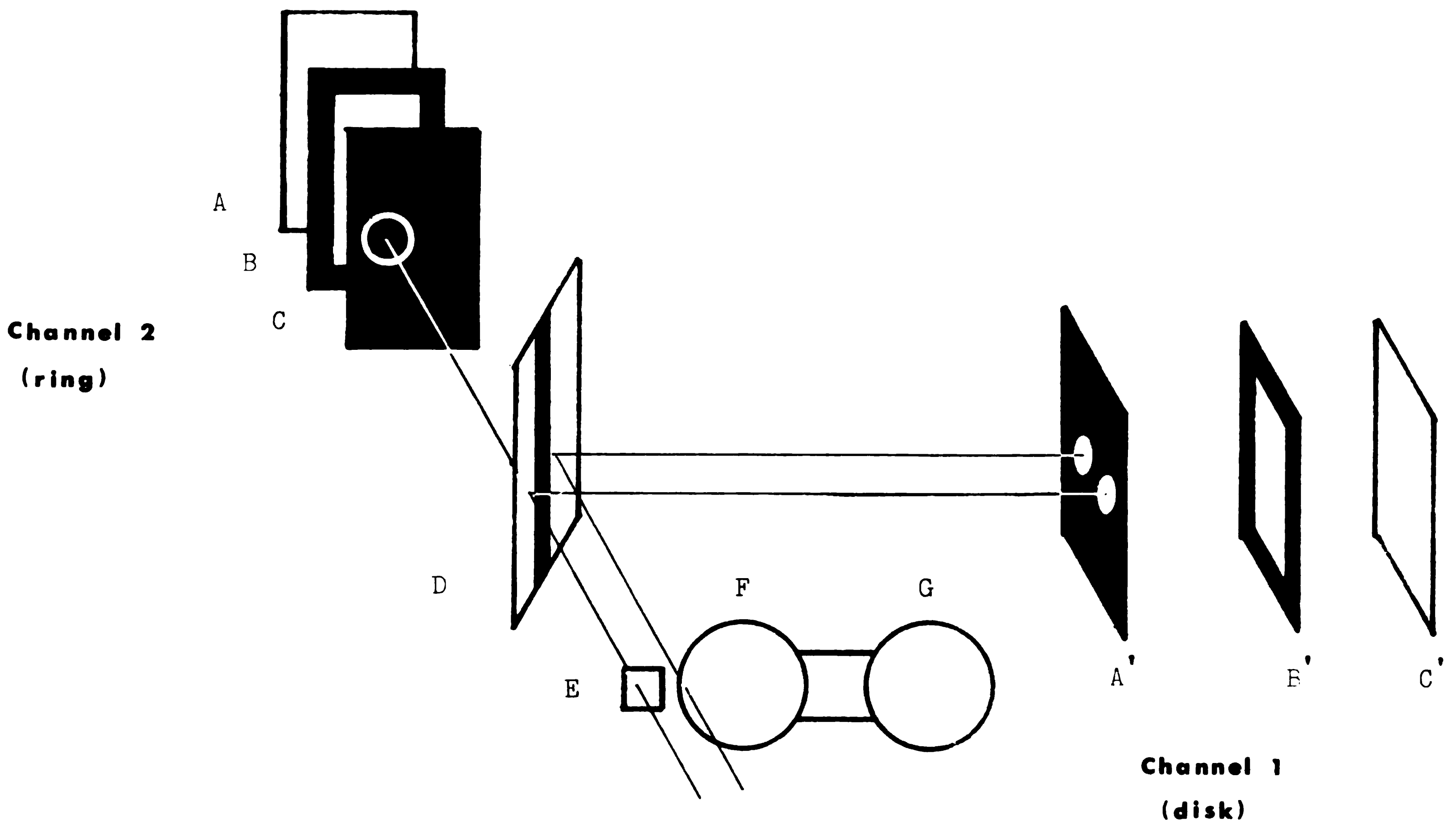


Figure 3

Fig. 4. Photograph of experimental apparatus. The tachistoscope is located on the left. The two Grass S-4's are in the center. On the right is the power supply to the gas discharge tubes.

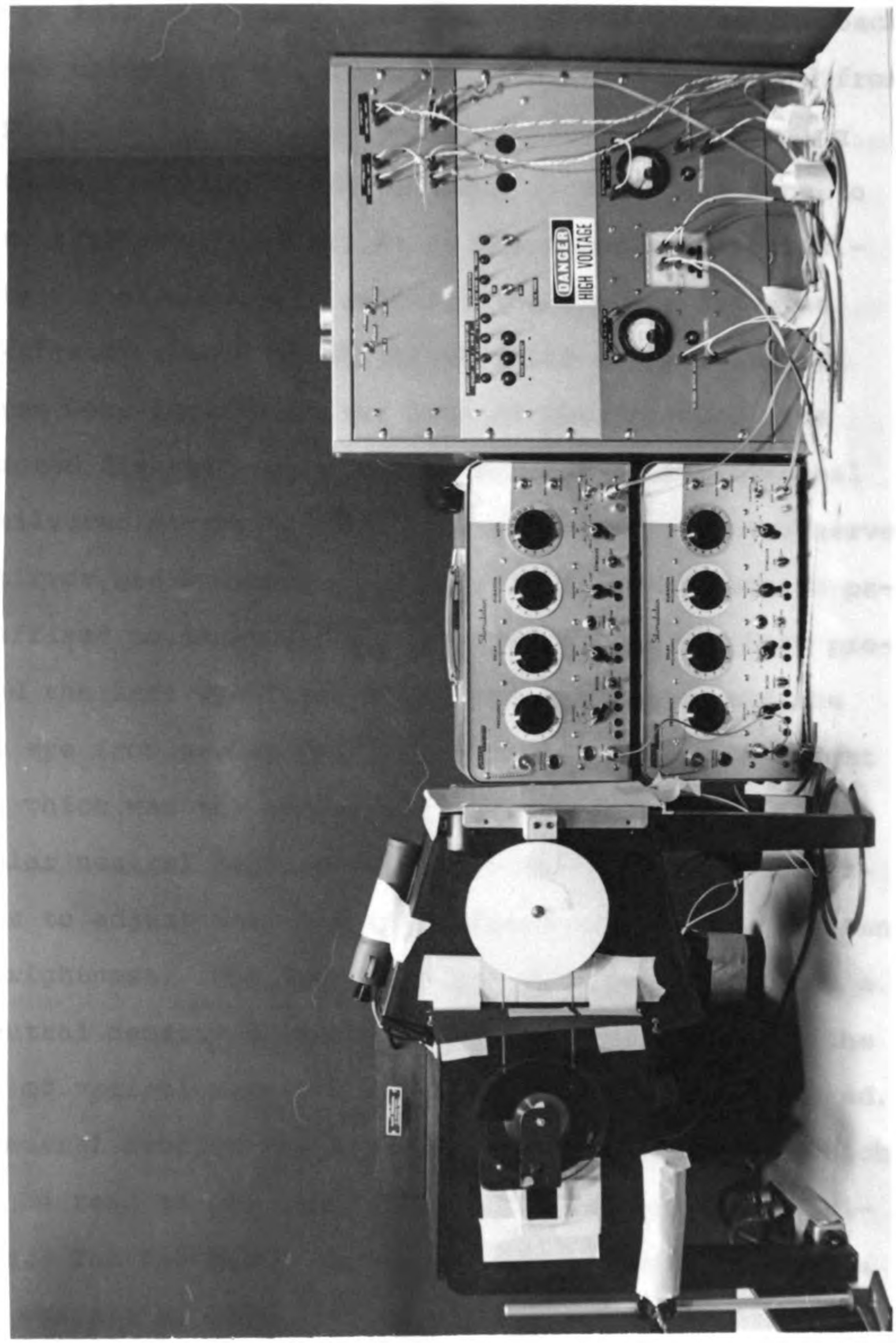

DANGER
HIGH VOLTAGE

Figure 3, the light from the gas tubes (B and B') was made to fall on white poster board (C and C') at the back of each channel of the T-scope. The light reflected from the poster board was then passed through image forming apertures in opaque baffle (A and A'). This was done to insure truly dark fields, as it was found that approximately 25% of the light reaching the eye was from the "dark field" when both the black field and the lighted figures were located at the back of the T-scope. The projected figures were brought together at the diagonal semisilvered mirror (D) and then passed on to the observer. The mirror had a vertical strip of black construction paper affixed to it which was located in a manner that prevented the left eye from seeing the right disk and the right eye from seeing the left disk and ring. The right disk, which was the comparison disk, passed through a circular neutral density wedge (F) which allowed the observer to adjust the intensity upward to 200% of the standard brightness. The left disk and ring passed through a .3 neutral density filter at the left so as to allow the range of variation in the comparison disk just discussed. The neutral density wedge was linked to a scale (G) which could be read in per cent of transmission by the experimenter. The two disks were of equal intensity when this scale was set at 100%.

Procedure

The task throughout this study was to match the apparent brightness of the left disk (which was not followed by the ring) by adjusting the intensity of the right disk (which was followed by a ring) until the two appeared to be of equal brightness.

Four different ring-disk color combinations were used: (1) blue disk-blue ring; (2) red disk-blue ring; (3) red disk-red ring; and (4) blue disk-red ring. Both the disk and the ring had a duration of 1000 milliseconds. A 2 second intertrial interval (onset of disks to onset of disks) was used for all conditions. Seven different interstimulus intervals (onset of disks to onset of ring) were utilized. They were 0, 40, 70, 100, 130, 160 and 210 milliseconds respectively. In addition, a condition where the ring was not presented was also used in order to ascertain the point at which the two disks appeared to be subjectively matched when presented alone.

In experiment 1a, observer J.W.W. made 100 observations for each of the 4 color combinations and 7 interstimulus intervals listed above. The color combinations were taken in the order listed. All the data was collected for each combination before going on to the next one. The 100 observations for each interstimulus interval were broken down into 10 sets of 10 matches each. Each set of matches consisted of 5 ascending and 5 descending matches, in accordance with the psychophysical method of limits. A set of 10 matches was made for all 7 intervals before starting over again. So that order effect might be minimized, each of the three experimenters were instructed to "randomize" the order in which they set up the interstimulus interval. Interspersed among each group of 7 sets of 10 matches was a set of 10 matches made between the right and the left disks without the ring. This was done to control for possible day to day fluctuations in matching criteria, etc.

In experiment 1b, observer R.J.B. made 40 matches on each of 4 disk-ring interstimulus intervals and two color combinations. The color combinations were red ring-red disk and blue ring-red disk. The interstimulus intervals used were 40 , 70, 100 and 130 milliseconds respectively. A disk only condition was also included. The procedure for collecting data was identical to that outlined in experiment 1a.

In experiment 2, observer J.W.W. was utilized to further evaluate the metacontrast effects obtained with the color combinations of red disk-blue ring and blue disk-red ring, for the 100 millisecond interstimulus interval and 10 millisecond stimulus duration. The blue disk-red ring combination was done first. The blue disk was maintained at a constant 1.90 foot lamberts. The red ring was alternately raised in intensity until it was noticeably brighter than the blue disk and lowered in intensity until it was noticeably dimmer than the blue disk. Ten groups of 10 matches each were taken for each condition. In addition, 10 groups of disk only matches were made for comparison purposes. The order in which these three different conditions were presented to the subject was varied by the experimenter, but one of each group was presented before repeating a condition.

The red disk-blue ring combination was done in much the same manner. The blue ring was maintained at a constant brightness and the red disk was alternately raised in intensity until noticeably brighter and lowered in intensity until noticeably dimmer. A comparison condition of disk only matches was taken, but since the red disk was varied in intensity, 5 groups of 10 matches were made at the high intensity condition and 5 were made at the low intensity condition.

RESULTS

The results of experiment 1a are graphically displayed in Figures 5, 6, 7 and 8. All data points are shown with brackets of ± 1 standard deviation. Figures 5 and 6 show the metacontrast effect obtained when the disk and ring are the same color. The blue disk-blue ring condition (Figure 5) produced maximum metacontrast at the interstimulus interval of 100 milliseconds. The 40, 70 and 130 millisecond interstimulus intervals also gave a marked reduction in brightness when compared to the disk only condition. The statistical significance of these deviations from the disk only condition can clearly be seen when it is noted that the ± 1 standard deviation units bracketing the data points represent ± 10 standard deviations of the mean (as each represents the average of 100 matches). Hence, any data points brackets that do not cross the disk only line can be considered to deviate from the disk only condition at a T level greater than 10.

The red disk-red ring condition showed an optimum metacontrast effect for an interstimulus interval of 100 milliseconds. The intervals 40, 70, 130 and 160 also showed significant reduction in brightness. It will be noted that the all red and the all blue stimulus configurations are very similar with the exception that the

Fig. 5. The apparent brightness of a blue disk when followed by a blue ring for seven different interstimulus intervals, Obs. J.W.W. Brightness index is the term used to represent the ratio of the luminosities of the two disks expresed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.

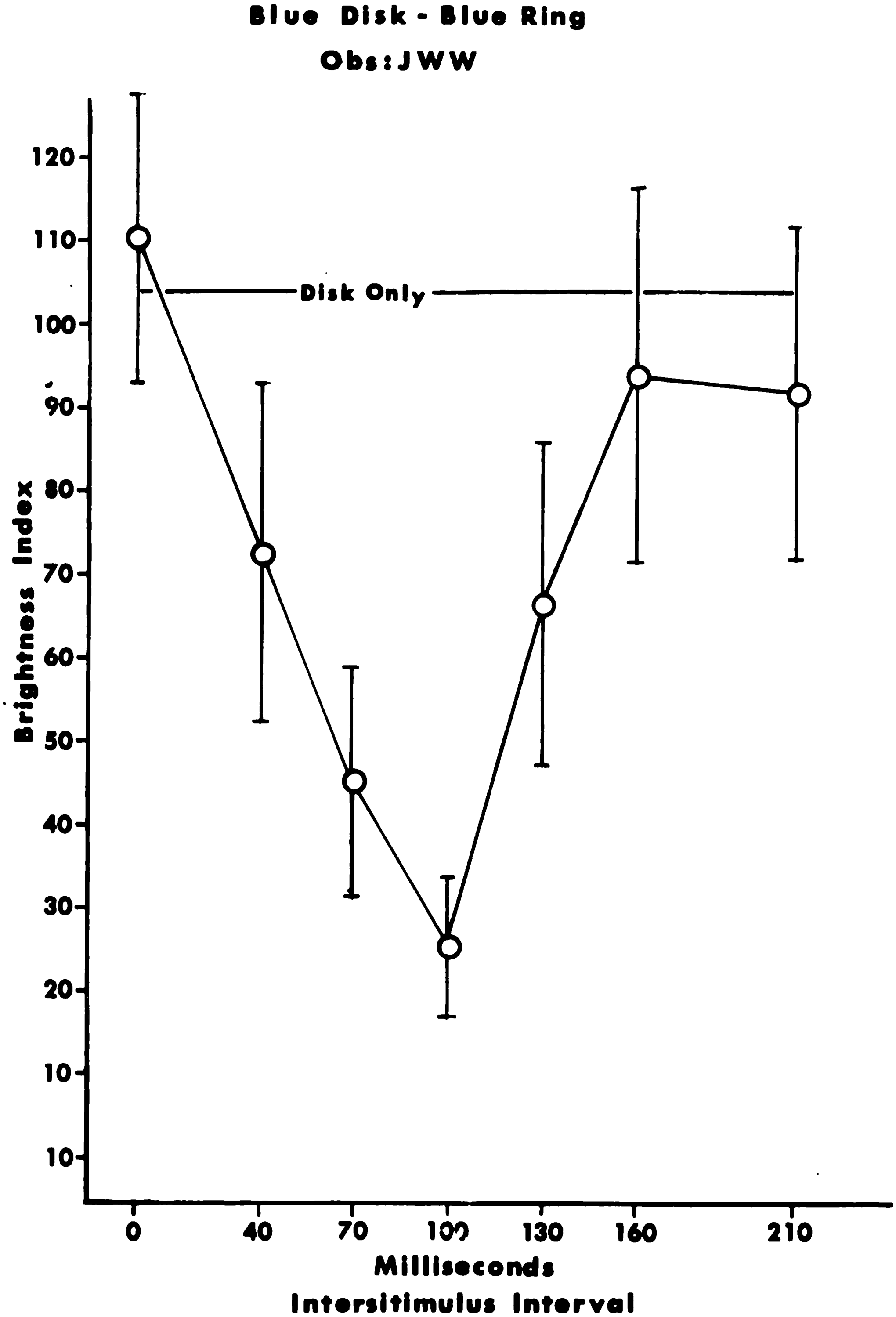
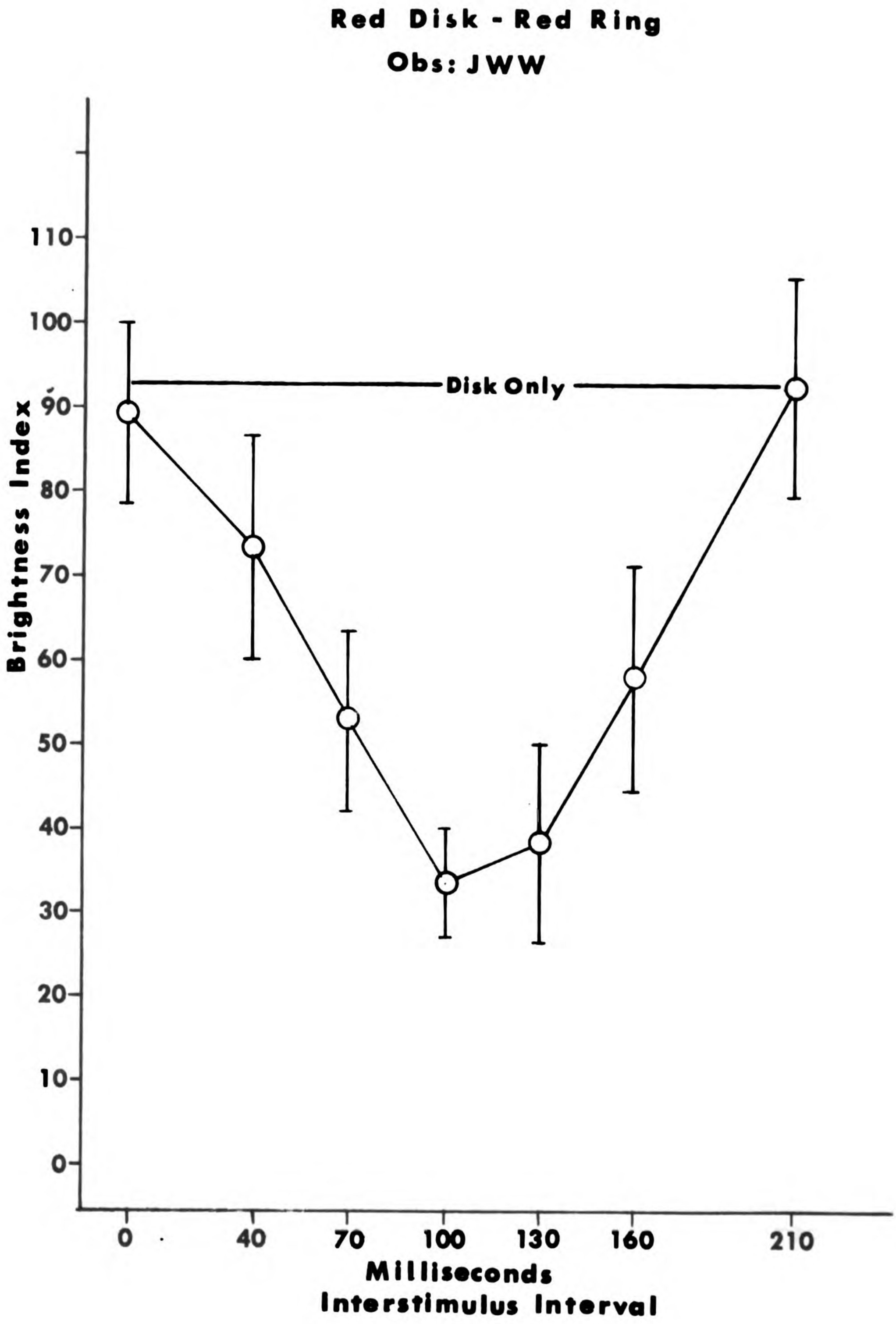

Blue Disk - Blue Ring
Obs: JWW
Disk Only
Brightness Index
120
110
100
90
80
70
60
50
40
30
20
10
10
0
40
70
100
130
160
210
Milliseconds
Intersitimulus Interval

Figure 5

Fig. 6. The apparent brightness of a red disk when followed by a red ring for seven different interstimulus intervals, Obs. J.W.W. Brightness index is the term used to represent the ratio of the luminosities of the two disks expressed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.



Red Disk - Red Ring
Obs: JWW
Brightness Index
110
100
90
80
70
60
50
40
30
20
10
0
Disk Only
0
40
70
100
130
160
210
Milliseconds
Interstimulus Interval

Figure 6

160 millisecond interstimulus interval was somewhat more effective for the all red than for the all blue condition.

Figures 7 and 8 depict the results obtained when a blue ring-red disk and a red ring-blue disk were utilized. The blue ring-red disk condition (Figure 7) produced no significant deviations from the disk only condition for any of the 7 interstimulus intervals used. The red ring-blue disk condition did produce moderate metacontrast effects for the interstimulus intervals of 70 and 100 milliseconds, however.

Experiment 1b was essentially an abbreviated form of experiment 1a, using another subject as observer. It will be recalled that in experiment 1b all the data points represent the means of 40 matches, hence the $\pm$ 1 standard deviation brackets can be considered to represent approximately $\pm$ 6.3 standard errors of the mean. Only two color conditions were utilized. They were red disk-red ring (Figure 9) and red disk-blue ring (Figure 10). With the exception that the disk only condition yielded lower values, the results of experiment 1b closely parallel those of experiment 1a. For the red disk-red ring condition, 70 and 100 milliseconds were found to be the most effective interstimulus intervals. When the blue ring-red disk condition was employed, no significant deviations below the disk only condition were found.

Fig. 7. The apparent brightness of a red disk when followed by a blue ring for seven different interstimulus intervals, Obs. J.W.W. Brightness index is the term used to represent the ratio of the luminosities of the two disks expressed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.

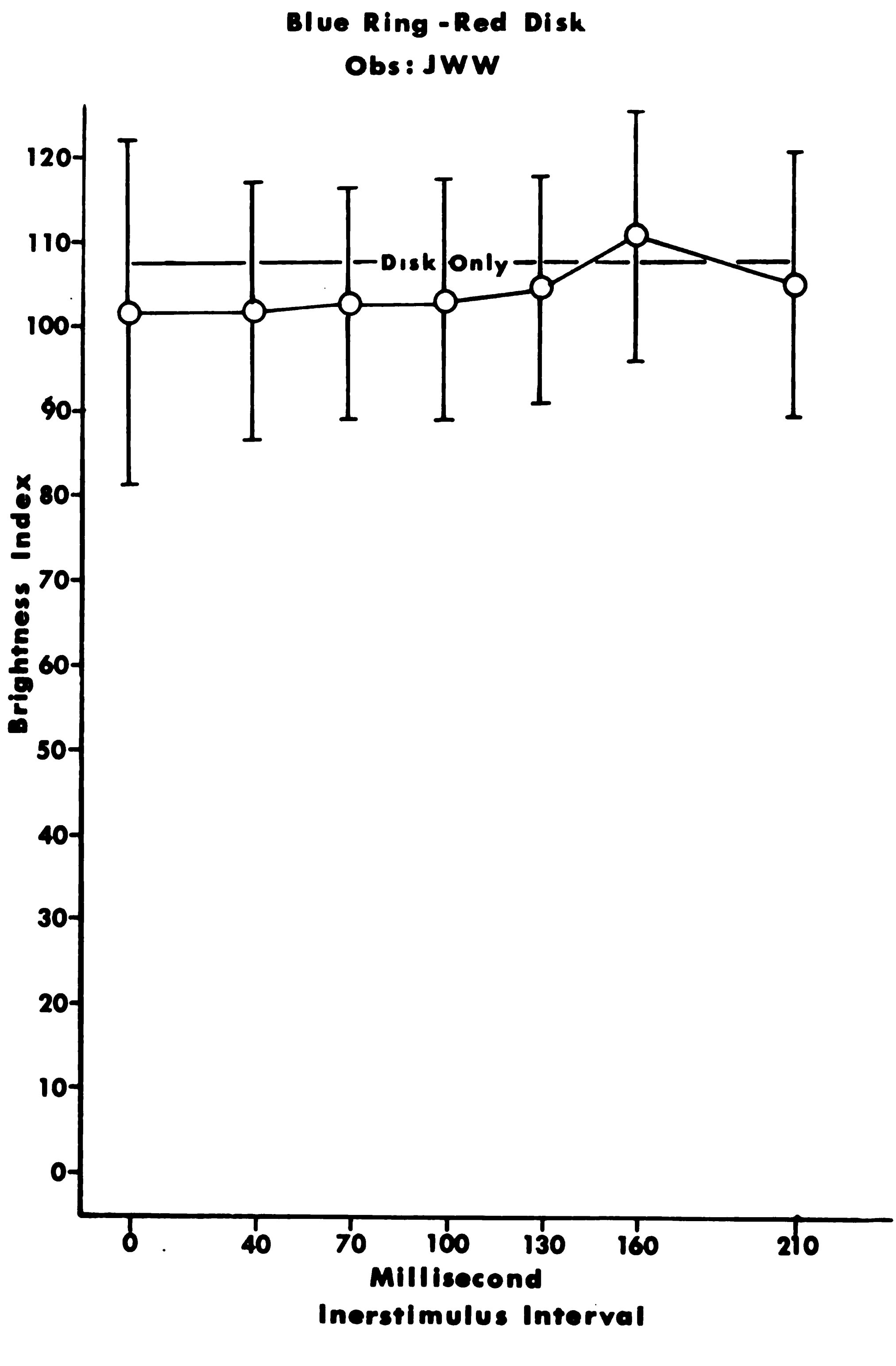

Blue Ring -Red Disk
Obs: JWW
Disk Only
Brightness Index
120
110
100
90
80
70
60
50
40
30
20
10
0
0
40
70
100
130
160
210
Millisecond
Inerstimulus Interval

Figure 7

Fig. 8. The apparent brightness of a blue disk when followed by a red ring for seven different interstimulus intervals, Obs. J.W.W. Brightness index is the term used to represent the ratio of the luminosities of the two disks expressed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.

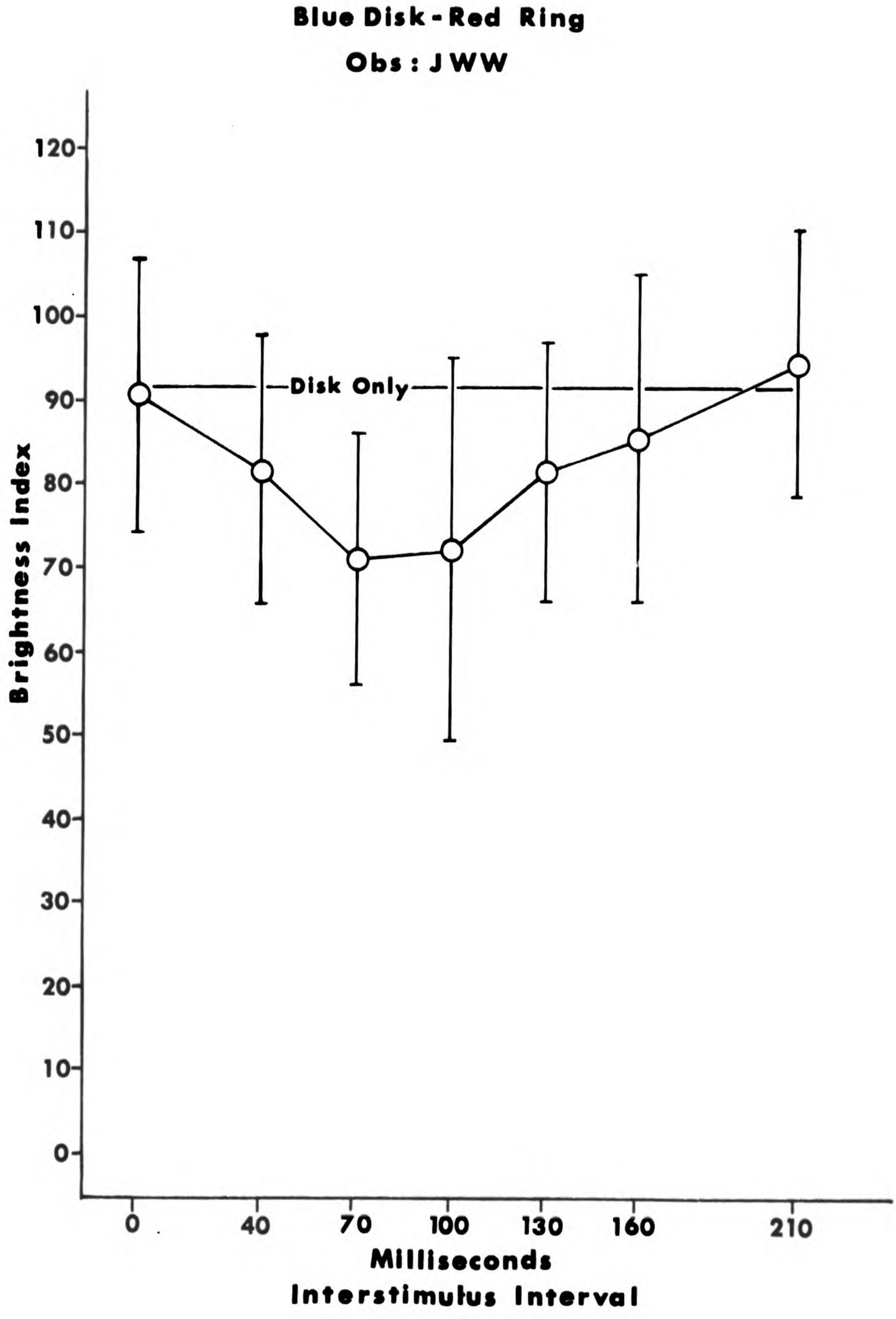

Blue Disk - Red Ring
Obs : JWW
Brightness Index
120
110
100
90
80
70
60
50
40
30
20
10
0
Disk Only
0
40
70
100
130
160
210
Milliseconds
Interstimulus Interval

Figure 8

Fig. 9. The apparent brightness of a red disk when followed by a red ring for four different interstimulus intervals, Obs. R.J.B. Brightness index is the term used to represent the ratio of the luminosities of the two disks expressed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.

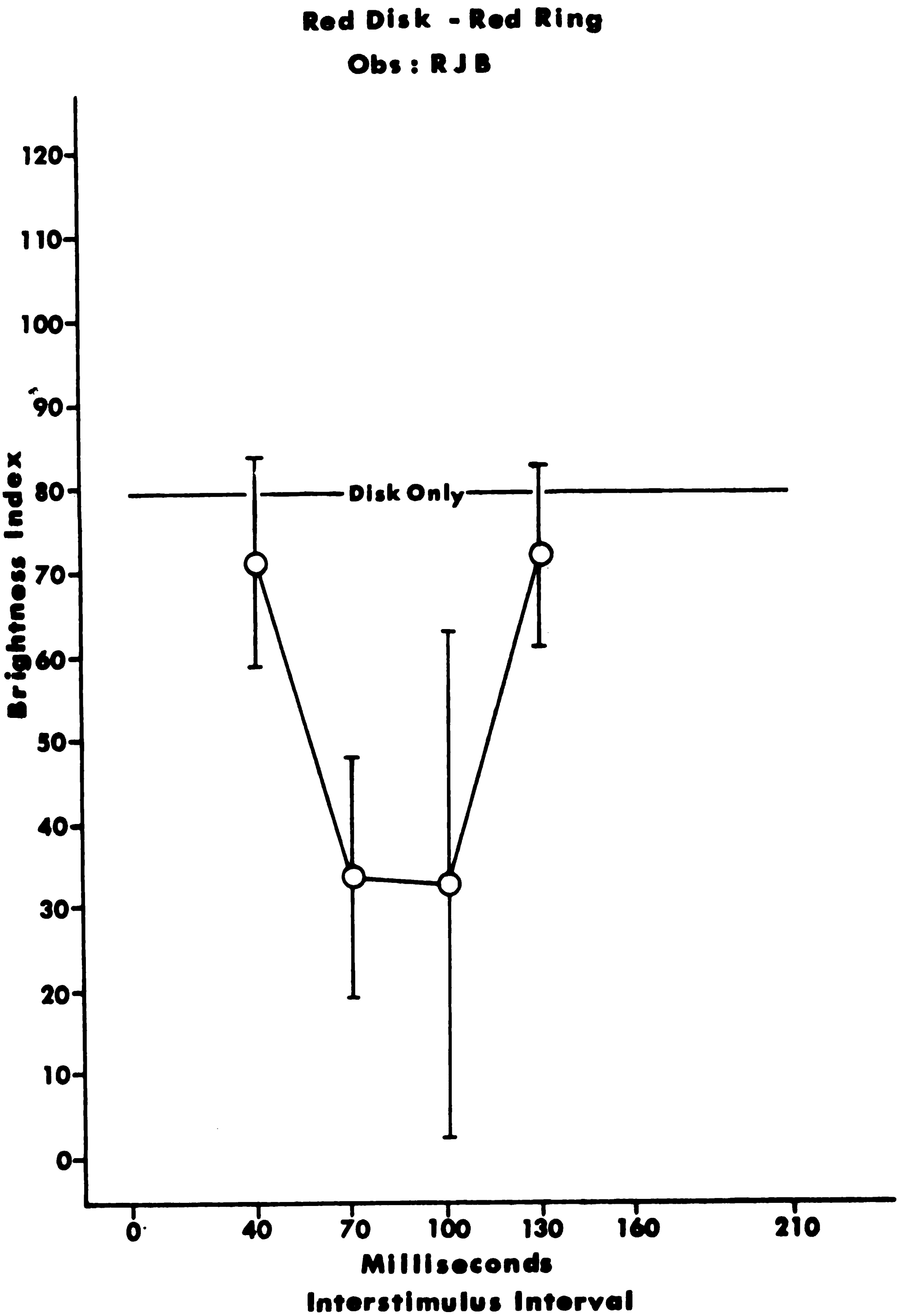

Red Disk - Red Ring
Obs : RJB
Brightness Index
120
110
100
90
80
70
60
50
40
30
20
10
0
Disk Only
0
40
70
100
130
160
210
Milliseconds
Interstimulus Interval

Figure 9

Fig. 10. The apparent brightness of a red disk when followed by a blue ring for four different interstimulus intervals, Obs. R.J.B. Brightness index is the term used to represent the ratio of the luminosities of the two disks expressed in per cent. The two disks were of equal intensity when the matching disk was set at 100%.

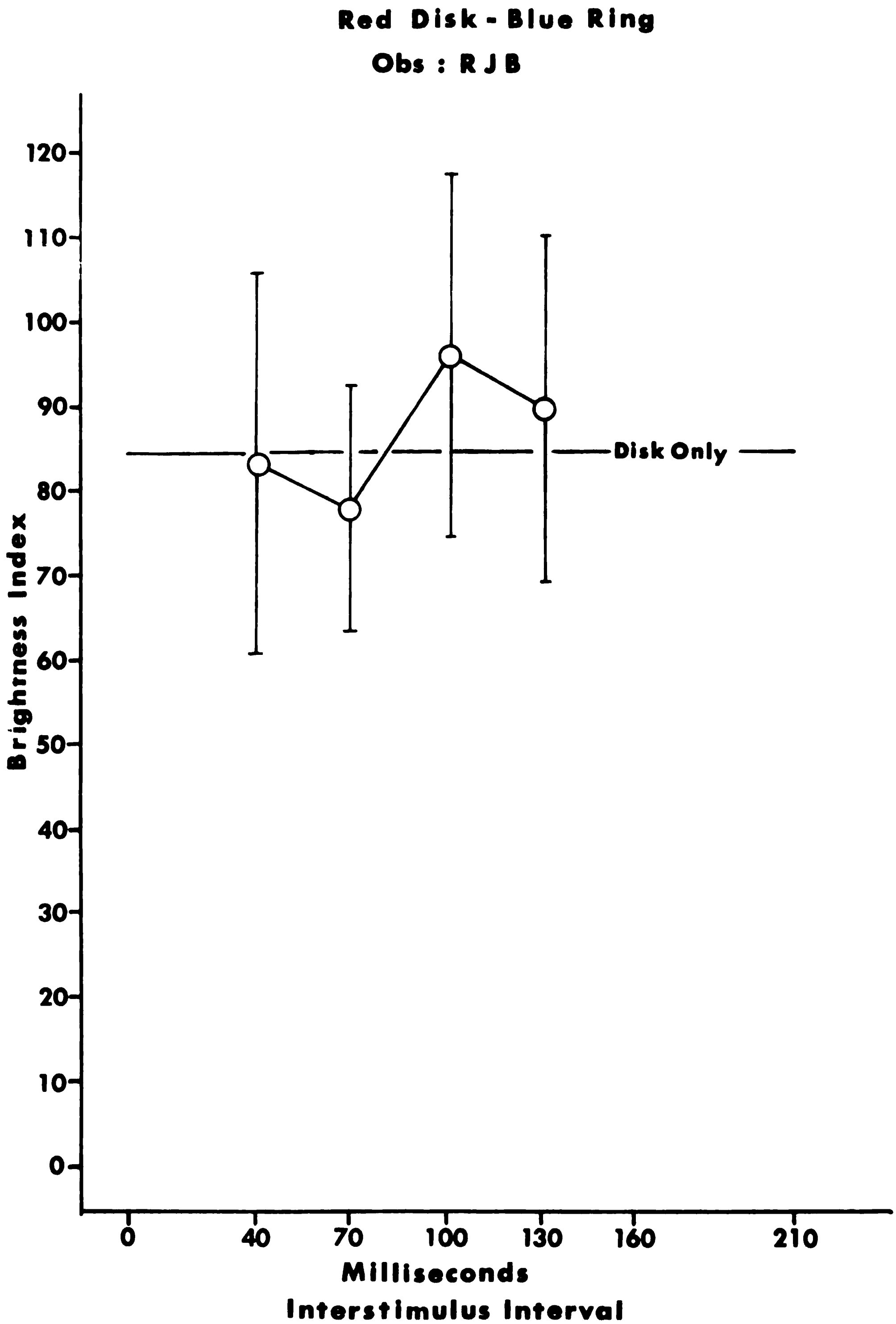
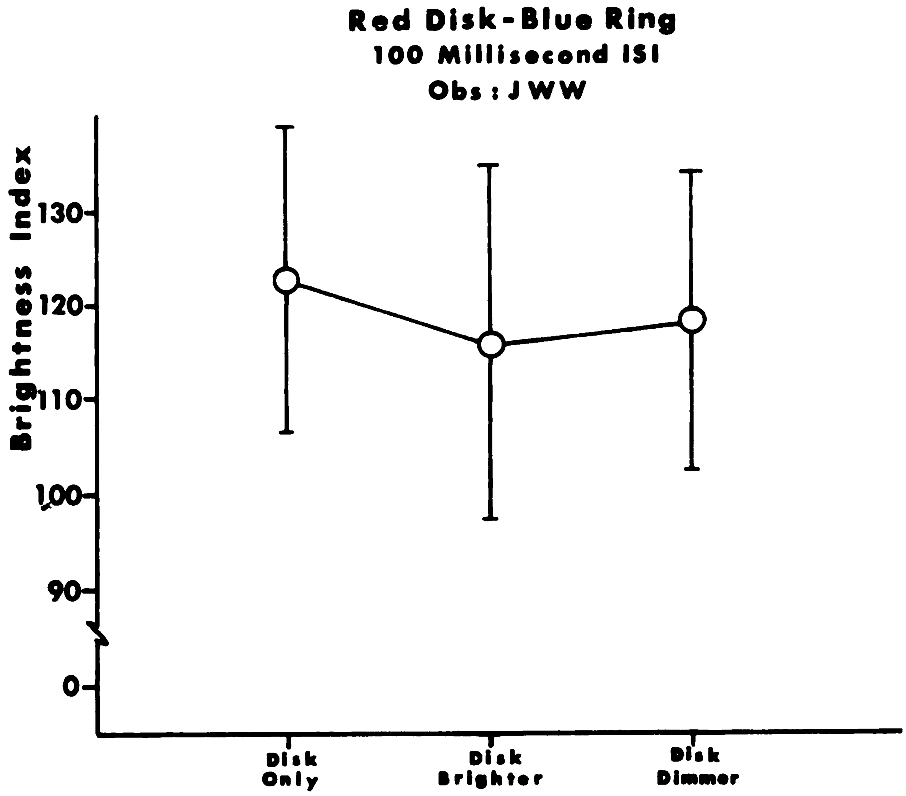

Red Disk - Blue Ring
Obs : R J B
120
110
100
90
80
70
60
50
40
30
20
10
0
Brightness Index
Disk Only
0
40
70
100
130
160
210
Milliseconds
Interstimulus Interval

Figure 10

Experiment 2 was devoted to the further investigation of the effects obtained with a red disk-blue ring condition as compared with a blue disk-red ring condition. It was shown in experiment 1a that the red disk-blue ring condition showed no metacontrast effects, but the blue disk-red ring condition did. In order to test for the possibility that these differential effects were due to a difference in brightness of the figures, both color conditions were run again with the brightness of the figure purposely altered as described in the procedure section. The results of these manipulations are depicted in Figures 11 and 12. Figure 11 shows that regardless of the brightness of the red disk relative to the blue ring, the blue ring had no depressing effect on the red disk. For the blue disk-red ring condition it was found that changing the brightness of the red ring relative to the blue disk did have a marked effect on the perceived brightness of the disk. When the red ring was noticeably brighter than the blue disk metacontrast was very marked. When the red ring was dimmer, a significant reduction in the perceived brightness of the disk was still observed, but it was not as great. This latter effect was approximately of the same magnitude reported for this color combination and interstimulus interval in experiment 1a. It can be concluded from experiment 2 that the differential effects found with red and blue figures are not due to relative

Fig. 11. The apparent brightness of a red disk when it is both brighter and dimmer than the blue ring which follows at an interstimulus interval of 100 milliseconds, Obs. J.W.W. The brightness of the blue ring was maintained at a constant 1.90 foot lamberts. The disk only condition was generated by matching the left and right disks with no ring present.

Fig. 12. The apparent brightness of a blue disk when followed by a red ring which is both brighter and dimmer than the blue disk, Obs. J.W.W. The interstimulus interval was 100 milliseconds for both conditions. The blue disk was maintained at a constant 1.90 foot lamberts. The disk only condition was generated by matching the left and right disks with no ring present.


Red Disk-Blue Ring
100 Millisecond ISI
Obs: JWW
Brightness Index
130
120
110
100
90
0
Disk Only
Disk Brighter
Disk Dimmer

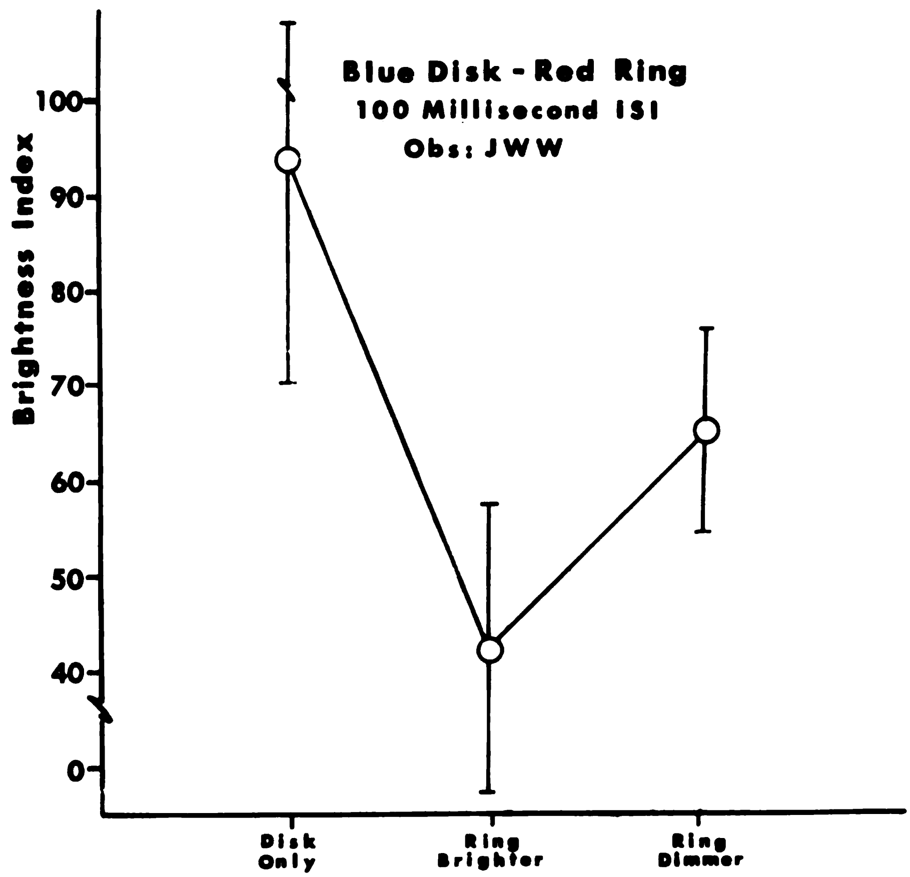

Blue Disk - Red Ring
100 Millisecond ISI
Obs: JWW
Brightness Index
100
90
80
70
60
50
40
0
Disk Only
Ring Brighter
Ring Dimmer

Figure 11 & 12

differences in brightness, but rather to the wavelength composition of the figures.

In addition to the above, some general observations should be noted here. The task of adjusting the intensity of the disk in the left eye, until it matched the perceived brightness of the disk in the right eye was an extremely difficult one. The observer, using the psychophysical method of limits, had to make small adjustments in the intensity of the right disk on the basis of his memory of the perceived brightness of two simultaneously presented 10 millisecond figures. He then had to wait 2 seconds for feedback from this adjustment which provided information which would indicate if any further adjustment needed to be made. This task was made even more complex because the brightness of the left (metacontrast) disk was being affected by an event occurring as much as 160 milliseconds after its cessation.

The task was perhaps best summed up by observer R.J.B. who said, in effect, that he could with some difficulty match the two disks on the basis of brightness, but that the two disks didn't really look the same. With this statement, observer J.W.W. concurs.

An additional difficulty was noted by observer J.W.W. This was that the presence of the blue matching disk in the right eye had a noticeable effect on the amount of perceived metacontrast in the left eye. Specifically, if the observer closed his right eye so that the comparison disk could not be seen, the metacontrast was not nearly as great as it was when both eyes were open. This phenomenon occurred even when great care was taken to maintain the fixation of the left eye on the point source provided for that purpose. This interference effect was not noted when red disks were being used.

DISCUSSION

Before attempting to evaluate the results of the foregoing experiments, some discussion of the apparatus and experimental design is in order. Gas discharge tubes were used as light sources in this study because they have very short rise and decay times (measured in nanoseconds). This property provided essentially square wave illumination of the figures. Gas discharge tubes also have the ability to provide the desired chromatic effects without sacrificing intensity. These tubes are not without their drawbacks, however. The light provided by the two sources used, neon and mercury vapor, was a composite of many emission lines of different wavelengths. Mercury's emission lines are predominantly blue, but it also produces visible lines well into the yellow. Neon's emission lines are predominantly red, but some are found in the green portion of the spectrum. Hence, any analysis of the results of these experiments on the basis of wavelength composition is somewhat restricted. It is felt by this author, however, that the larger wavelength dependent effects reported here can be assumed to be the result of the dominant wavelengths of the respective gas tubes used. Such an assumption will allow at least a qualitative interpretation of the data. A more quantitative analysis of these results will only come with more precise control of the chromatic composition of the light sources used.

A second problem encountered with the gas tubes was the result of their dependence on internal temperature. It was found that as the tubes heated up they became brighter. This characteristic of these tubes proved to be particularly troublesome when metering the tubes with the Pritchard photometer. The Pritchard is read in foot lamberts on a scale that has a considerably longer latency than the 10 millisecond stimulus duration used throughout this study. It was found that if the tubes were turned on continuously, the intensity would steadily rise for a period of several minutes. The procedure for metering the gas tubes had to be one where they were brought up to their normal heat by running them for 10 milliseconds every 2 seconds. They were then turned on steady and the meter was read as quickly as possible. After this was accomplished, the tubes were allowed to cool and the whole procedure was begun again. This was done until good agreement was found on several of the readings. It should be noted that the Pritchard, when used in this manner, was giving the brightness of the stimulus figures when they were on continuously. This means that they did not appear nearly as bright to the observer when they were on for only 10 milliseconds (Broca Sulzer phenomenon). It should also be noted that the Pritchard is a device which approximates the standard observer curve for chromatic brightness, but it does not fit it exactly. Hence the possibility that the red and blue tubes were not perfectly equated for brightness certainly exists. Even if the Pritchard exactly replicated the standard observer and no problems were encountered with measurement, the subjective matching point for any individual might still be different as a result of individual differences.

The above considerations provided the reason for undertaking experiment 2. Metacontrast is known to be affected by the relative brightness of the disk and ring (Alpern, 1954). If the disk is brighter than the ring, the effect is not as pronounced as it is when the disk is dimmer than the ring. If the red figures in experiment la and lb were actually brighter than the blue figures, one might expect the difference found between the blue disk-red ring condition and the red disk-blue ring condition. That the differences found were not the result of differences in brightness is borne out by experiment 2.

It has already been stated that the task of matching the two disks was a difficult one. Just how difficult is evidenced by the shifts in the disk only matches. The range of reported disk only averages is quite large, not only between observers but within observers as well. If one uses the 100% physical matching point as a comparison, the largest differences in the psychophysically determined matching points occur where much of the data was collected close together in time. For example, in experiment 2, the 300 matches for the red disk-blue ring condition were collected all on the same day. On that day all of the matches were relatively high, and consequently, the average for the disk only condition was 122.29. Similarly large discrepancies had been noted in the previous experiments, but over a period of several days, the disk only matches averaged to a mean relatively close to the 100% mark. That these discrepancies do occur, highlights the necessity for taking disk only matches along with the other data. Interpretation of the metacontrast effects based on the assumption that the disk only matches were always 100% would lead to some very erroneous conclusions.

Perhaps the most interesting results of this study are the differential effects obtained between the red ring-blue disk condition and the blue ring-red disk condition. It will be recalled that the former condition resulted in a reduction in brightness of the blue disk by approximately 30%, while the latter condition produced virtually no metacontrast effects. Several factors have been considered which might contribute to this difference.

If the red figures, due to an error in measurement, were significantly brighter than the blue figures, one might expect the kind of difference noted above on the basis of Alpern's findings (1954). This study showed that in a disk-ring situation, if the ring is brighter than the disk, metacontrast is enhanced, whereas if the disk is brighter than the ring, the amount of metacontrast is reduced. A consideration of experiment 2, however, clearly rules out the possibility that differences in brightness between the red and blue figures could be causing the different effects obtained with the blue disk-red ring condition as compared with the red disk-blue ring condition.

There is still another factor which could be considered as a possible contributor to the differences found between these two conditions. It will be recalled that observer J.W.W. reported an apparent increase in metacontrast when the blue matching disk was presented to the right eye, but a comparable effect was not noted when a matching red disk was used. This difference suggests that some kind of interoccular interference between the blue matching disk in the right eye and the blue metacontrast disk in the left eye may have been occuring. While this possibility has not been entirely eliminated, there are two pieces of evidence which suggest that interoccular interference does not adequately explain the perceived metacontrast in the red ring-blue disk condition. In the first place, there is no noticeable reduction in the brightness of the blue metacontrast disk when the red ring is not present and following the blue disk at the optimum interval of 70 to 100 milliseconds. Furthermore, manipulating the brightness of the red ring (Figure 2) had the expected effect on the amount of metacontrast perceived. Both of these facts lead one to the conclusion that the red ring is essential to the occurrence of metacontrast in the blue disk-red ring condition.

Secondly, the red ring was noted to have an effect on the blue disk when the blue matching disk was not present. This effect, though not as pronounced as when the matching disk was present, was particularly apparent when single presentations of the blue metacontrast disk were interspersed between presentations of the blue disk-red ring sequence. Under these conditions, the blue disk with no ring following it appeared brighter than the blue disk followed by a ring 70 to 100 milliseconds later. Consequently, it can be seen that the blue matching disk is not essential to the occurrence of metacontrast in the blue disk-red ring condition, while on the other hand the red ring is. Unfortunately, this latter method of observing metacontrast does not provide a means for quantifying the effect, hence the amount by which the blue metacontrast disk appeared reduced in brightness cannot be evaluated by this method.

In view of the above evidence it seems reasonable to assume that the differences noted between the blue disk-red ring sequence and the red disk-blue ring sequence are genuinely the result of the wavelength characteristics of the metacontrast disk and its concentric ring and are not an artifact generated by the method employed to measure metacontrast in this study. The nature of the mechanism responsible for these differences is not at all clear, however, just as an adequate model explaining the need for an optimum interstimulus interval has not been developed. It would be fruitless to speculate as to the nature of such a mechanism at this juncture. This is not to say that ideas do not come to mind. The suggestion that fundamentally scotopic and photopic visual mechanisms interact to produce the kind of effects obtained here is one such idea. No amount of speculation can serve as a substitute for experimental fact, however. The implication drawn from the present study, that wavelength is the important variable requires further study employing figures illuminated with sufficiently narrow wavelength bands to permit a more detailed analysis of interaction between figures of different wavelengths. If the suggestion that photopic and scotopic mechanisms are interacting to produce the kinds of effects obtained here is to be tested, figures illuminated in the range of 510 millimicrons (blue green) and 680+ millimicrons (deep red) would be desirable. In addition to these two wavelengths, it would also appear desirable to test as many wavelength combinations as possible in order to map possible interactions over a wide range of the spectrum.

The complication introduced by the presence of a matching disk in the alternate eye does not appear to be avoidable, as this method of judging the amount of metacontrast seems to be the best yet devised. In pilot studies done prior to this thesis it was found that making the matching disk steady rather than intermittent made the task of matching the two disks for brightness much more difficult. The complications introduced by putting both the metacontrast disk and the matching disk in the same eye are too many to permit such an arrangement. Neither does the method of adjusting the intensity of the metacontrast disk until it matches the ring in brightness appear feasible when the ring and disk are so markedly different in color.

Aside from introducing problems in quantifying the amount of metacontrast obtained, the apparent interaction between the disks in the left and right eyes suggests another line of investigation which might prove fruitful. The whole problem of under what conditions dichoptic metacontrast occurs is yet to be resolved. By dichoptic metacontrast it is meant the metacontrast effects obtained by presenting a disk in one eye and an apparently concentric ring in the other eye. Alpern (1952) reports that the phenomenon of dichoptic metacontrast is more difficult to obtain than is monoptic metacontrast. Werner (1940) and Kolers and Rosner (1960) have both obtained dichoptic metacontrast with dark disks and rings in lighted achromatic surrounds. Kolers and Rosner also have done some work with lighted figures in a dark field. Because only the blue disk in the present study appeared to produce any interoccular effects it would be interesting to determine if dichoptic metacontrast also proved to be wavelength specific not only for disks and rings of the same wavelength composition but for disks and rings of different wavelengths as well.

Finally there appears to be one more area where additional investigation needs to be done in order to fully bring into view the parameters bearing on this phenomenon. It will be recalled in the introduction of this thesis a good deal of time was spent defining metacontrast so as to include the effects obtained with the sequential presentation of black figures in a lighted surround as well as lighted figures in a dark surround. There have been differences noted in the results obtained using these two methods of presentation. Chief among these is the fact that while a lighted ring in a dark field interferes with the perception of a previously presented dark disk in a lighted field, the apparent converse of this, namely a lighted disk in a dark field followed by a dark ring in a lighted field produces no noticeable effects. The difficulty possibly arises out of the fact that successive presentations of lighted figures in a dark field is not the exact converse of presenting dark figures in a lighted field as it will be noted that the very critical null period separating the successively presented figures in both cases is not illuminated. In order for the presentation of dark figures in a lighted field to be the exact converse of the presentation of lighted figures in a dark field, it would seem logical to require that the null period in the former be filled with a blank illuminated field of the same intensity and wavelength composition as the surround for the dark figures. Whether this kind of addition will resolve the remaining differences between these two types of presentation remains to be seen.

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