# LATERALITY DIFFERENCES IN THE HUMAN VISUAL SYSTEM

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## ABSTRACT

Two techniques, a binocular matching task and a binocular rivalry task, were designed to yield relative dominance weights for the two eyes, the crossed and uncrossed visual pathways and the two cerebral hemispheres. Twenty subjects with normal vision were run on all conditions. Intercorrelations of the dominance weights of the two methods produced a number of hypotheses about visual functioning: (1) the left hemisphere appears more dominant for rivalry; (2) the right hemisphere appears more dominant for brightness matching; (3) the right hemisphere appears more dominant for lateral eye movements; (4) right-movers appear more often to have the left eye dominant, and left-movers the right eye dominant.

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## PURPOSE

Much current interest in neuropsychology is centered on the functional asymmetries of the two hemispheres. The old idea of the one dominant hemisphere, responsible for all functions is now seen to be an over-simplification, and the question today is what specific functions are initiated by which hemisphere.

The pioneer of cerebral function, Hughlings Jackson (1915) clearly emphasized that the so-called 'dominant' hemisphere, while apparently solely responsible for language, was not the exclusive agent in verbal behavior. The 'non-dominant' hemisphere also played a part -- in emotive language for example. Unfortunately, later workers ignored Jackson's observations and the dichotomy between the two hemispheres became a part of the 'conventional wisdom' of psychology. The 'dominant' hemisphere was mistakenly taken to dominate over <u>all</u> psychological functions not just over language.

Today the concept of dominance has been accepted as suggesting the greater influence of one hemisphere in mediating a specific function, with the understanding that the other hemisphere may also subserve the function to some, perhaps considerable, extent. The concept of dominance has been extended to describe the greater functional importance of one eye or ear compared to the other complementary organ. The dominant eye or ear may be thought of as somehow being more efficient or contributing more stimulus energy or being more favoured in attention than the other eye or ear, as judged by each eye or ear's separate performance in a perceptual task. In this study the concept of dominance is further extended to describe the possible differences between the crossed and uncrossed visual pathways. Differences between these pathways, corresponding to the nasal and temporal hemi-retinae, have been observed in some studies, as described in the next section.

The purpose of this study was to separate the relative dominance of the two eyes, the crossed and uncrossed visual pathways and the two hemispheres in the human visual system. The literature suggests that the concept of dominance is meaningful only with respect to a specific function or task, so in this study, dominance weights were obtained by two different methods to investigate the relationships between laterality differences and task characteristics. The use of different but comparable measures would reveal the extent of communality between different tasks. Such 'common factors' could relate to modes of functioning of the visual system. Differences between task characteristics could relate to differences in task performance. Such relationships, if they exist, might be expected to reveal new information on the differential functioning of the visual system.

## BACKGROUND

### Major Methods For Studying Laterality Differences

Currently, neurologists, physiologists and psychologists are re-examining the problem of the lateralization of cerebral functions in man. Four major lines of research are discernible:

#### Unihemispheric Lesions

Unihemisphere lesions often produce decrement in learned or familiar tasks. The interpretation given is that the greater the deficit produced by a lesion the greater the involvement of that locus in the function being tested. Often the exact locus of a lesion is less crucial than the hemisphere in which the lesion is situated. Thus, left hemisphere lesions almost anywhere in the temporal lobe cause disturbances in symbolic functions, while lesions of the corresponding areas in the right hemisphere produce greater loss of perceptual (e.g. visual, auditory and tactile) skills. One could describe this phenomenon by reasoning that the left hemisphere is dominant for language while the right hemisphere is dominant for perceptual skills. For examples of current work in this area one can refer to Mountcastle, (1962); Schulhoff and Goodglass, 1969; Milner, 1968; DeRenzi, 1968.

#### The Effects of Commisurectomy

From the time Sperry instituted the procedure of commisurectomy as effective treatment for severe epilepsy, investigations of such 'split-brain' patients has proceeded apace. The technique of commisurectomy in humans involves cutting of the forebrain commissural fibres - the corpus callosum and the anterior commissure, which connect opposite halves of the neocortex. Sometimes the hippocampal commissure is also severed, since it closely underlays the ocrpus callosum. With the commisural fibres severed the separate abilities of one hemisphere can be more precisely examined, free of the confounding involvement of the other hemisphere. Split-brain patients show evidence of clear functional independence of the hemispheres, as if they have two 'minds' in one body. The left hemisphere is almost invariably responsible for verbal functions while the right is usually incapable of verbal behavior, being essentially 'dumb' (Sperry, 1968). Evidence suggests that other higher functions, such as perceptual skills, may be lateralized, though less drastically than language. (Gazzaniga, 1970).

Electrophysiological Methods

Typically work in this area involves the measurement of EEG or evoked potentials in response to stimuli presented to one hemisphere or the other. Because differences between responses of the two hemispheres have not generally been of interest to researchers in the field of electrophysiology, most studies collect data from electrodes at the vertex of the head or on one side of the head only. The assumption is that both hemispheres behave in the same way with respect to the particular variable under investigation or else that the inter-hemispheric differences are not important or are not of interest.

Today more workers are interested in inter-hemispheric differences in response to various stimuli (e.g. verbal vs. non-verbal). Comparisons between the hemispheres of the evoked potentials can be made in terms of latency and amplitude of select components, consistency of the wave-shape within and across hemispheres and specific characteristics of the wave-shape. (Martin, 1970; Buchbaum & Fedio, 1969). Specifically, relationships between hemisphere differences in evoked potentials to visual stimuli and handedness have been found (Eason, Groves, White, & Oden, 1967).

EEG studies also point to differences between the hemispheres in terms of amount and amplitude of alpha and alpha blocking. These differences have also been related to other laterality differences such as handedness and lateral eye movements. (Lindsley, 1940; Giannitrapani, Sorkin, & Enenstein, 1966; Bakan, 1969).

Psychological Studies on Normal Subjects

Using normal subjects laterality differences have been demonstrated in several areas. Kimura's dichotic listening technique shows the lateralization of the processing of verbal and non-verbal auditory material (Kimura, 1964). Much work has been done on laterality differences in vision (White, 1969). Generally studies in this area have looked at differences in thresholds of recognition of stimuli presented to each eye or each visual field. Accuracy of recall of competing stimuli in different eyes or visual fields has also been studied as a method analogous to the dichotic listening technique, (Corballis, 1964; Sampson, 1964). A more detailed discussion of work in the area of laterality differences in vision follows in the next section on specific differences between parts of the visual system.

## Specific Laterality Differences in Vision

### Eye Differences

Considerable work has been done on eye dominance and eye differences judged on a variety of criteria. Much of the contribution has come from the field of optometry, where the study of abnormalities in vision has provided a greater understanding of the normal visual system.

The study of eye dominance reveals the lack of consistency among the various indices used. For example, the eye that is considered the best eye by a subject can often be poorest in acuity; the 'preferred' eye may not show dominance in a binocular rivalry test and so forth. The determination of eye dominance is dependent on the type of measure used. No consistently popular indices of eye dominance have emerged in the literature (Walls, 1952). One test that is easy to administer and intuitively appealing is the sighting test: the subject points at an object with a finger with both eyes open, and then closes one eye to discover which eye is actually aligned with the object and the finger -- this being taken as the dominant sighting eye. Another sighting test requires the subject to look through a tube at an object, thus forcing the choice of one eye. This is called the 'preferred eye'.

Such 'global' behavioural tests correlate weakly, though positively, with each other, and the relationship may be attributable to the 'motor' aspects that are common to the measures (Walls, 1952).

A few studies will be described to illustrate some of the experimental situations that reveal differences in ocular functioning. Such differences are found with measures of basic visual processes, such as contour formation and binocular rivalry and also with more cognitive tasks such as reaction time and recall measures.

Creed and Harding (1935) looked at the latencies of after-images of stimuli projected to each eye separately and found the right after-image latency consistently shorter than the left. They explain this by the assumption that preference in use for the right eye facilitates conduction of its stimulation.

Flom, Heath and Takahashi (1963) found contour interactions to be stronger in the "better seeing eye", even though no significant differences in acuity were found in their subjects. The authors interpret the results as suggesting "a dominant or stronger signal reaching the site of interaction from one eye".

Looking at eye differences in a more cognitive task, Minucci and Conner (1964) showed that reaction times differ depending on which eye is stimulated: reaction times are fastest to stimuli presented binocularly and slowest in response to stimuli presented to the non-dominant eye (dominance determined by a sighting test).

In a study of binocular rivalry and immediate memory, Sampson and Horrocks (1967) found that recall of different digits presented simultaneously to the two eyes was superior for digits presented to the dominant eye (dominance determined by the finger aiming test).

Since the physiological mechanisms underlying vision are little known, speculation on the reasons for differences between the eyes in various situations may not be fruitful here. However, it seems clear that each eye contributes information to the final percept partly independently of the other eye. The independent processes could take place at the retina or higher centers. Presumably the exact locus or loci of ocular interaction would depend on the nature of the task presented.

In the present study eye dominance is measured by a binocular rivalry task and a binocular brightness matching task. A third measure - a sighting test - is included to allow comparison with data from this and other studies, in which eye dominance is so determined.

Visual Pathway Differences

The data on differences between the crossed and uncrossed pathways is sparse, especially for humans. Phylogenetically it appears that the lower mammals may have stronger predominance of the crossed pathways while in the monkey and man the pathways are more nearly equal in influence. With cats, electrophysiological studies have demonstrated the numerical preponderance of crossed fibre in the visual system and of contralaterally dominated single units in the cat's cortex. (Burns, Heron & Grafstein, 1960; Hubel & Wiesel, 1962. In monkeys the greater influence of the crossed pathways is less obvious, but still apparent (Kruper, Boyle &

Patton, 1967).

With humans, a few binocular rivalry studies have investigated differences between visual fields. Bower & Haley (1964) found temporal differences in a rivalry situation, with the nasal hemi-retina having priority--the crossed pathways dominate at least temporally. These workers claim to detect four temporal stages in binocular vision (using digits exposed from 10 msec up to 650 msec.)

a. Read-in from nasal hemi-retinae.

b. Read-in from dominant eye.

c. Rivalry.

d. Binocular vision.

Crovitz and Lipscomb (1963) discuss the possibility of the dominance of the nasal hemi-retinae and the crossed-fibre system in binocular colour rivalry. They confirm Koellner's Effect which describes the initial dominance of the colour presented to the nasal hemi-retinae in rivalry. Crovitz and Lipscomb say their data "suggest the value of considering that the binocular field develops over time from the monocular fields with the crossed fibre system dominant at an early stage".

Several studies have reported faster reaction times of humans to stimuli presented to the nasal hemi-retinae, compared to stimuli presented to the temporal hemi-retinae (Woodworth & Schlosberg, 1965). More recently, Bower (1966) finds a difference of 1.5 msec between the conduction times (from eye to cortex) of impulses in the crossed and uncrossed pathways of man - the crossed being the faster.

Some workers (Wyke & Ettlinger, 1961; Hayashi & Bryden, 1967) here proposed that right field superiority in recall of tachistoscopically presented material is due to a combination of right eye dominance and crossed pathway dominance. This view is an alternative to postulating a left hemisphere influence in the recall task. In studies of laterality differences the dependent variable is often the amount of material recalled from the two visual fields under conditions of near-threshold exposure (Bryden, 1960; Heron 1957). The use of marginal stimulus conditions might give rise to a confounding variable in the form of differences between the crossed and uncrossed pathways. (Zurif & Bryden, 1969) Under more normal conditions of viewing, differences between these pathways may not be important. However, the present study was designed to uncover possible pathway differences, independent of eye or hemisphere differences, under conditions of viewing that might be considered normal in terms of the above threshold luminance levels of the stimuli.

Hemisphere Differences in Vision

As mentioned earlier, the dichotic presentation of auditory stimuli has shown in general a right ear superiority for recall of verbal material, and a left ear superiority for recall of non-verbal material, music (Kimura, 1964). These ear effects are interpreted as evidence of the lateralization of the processing of different types of aural material, assuming the dominance of the contralateral auditory pathways, over the ipsilateral. Verbal material is handled more effectively by the left hemisphere and non-verbal material by the right hemisphere, for the great majority of subjects.

With vision, no such analogous effect has been demonstrated, perhaps partly because of a less obvious difference between the crossed and uncrossed pathways in man. However a complicating factor in investigations of a hemisphere influence on the perception of visual stimuli is the possible presence of internal scanning mechanisms or attentional biases related to ocular scanning.

The importance of scanning mechanisms might be related to the cognitive complexity of the task as well as the type of stimuli used. The great majority of studies on hemisphere influences on vision have used recall of tachistoscopically-presented words as the dependent variable, ever since Mishkin and Forgays (1952) discovered that while English words presented briefly in left and right visual field to English speaking subjects showed greater recall accuracy in RVF, Yiddish words with Yiddish speaking subjects produced greater LVF accuracy. This study suggested a hemi-field difference attributable to reading habits. Heron (1957) extended the concept to postulate "directional post-exposure scanning" to account for the fact that recall superiority in LVF was found for verbal material (English) presented bilaterally (i.e., on both sides of the fixation point simultaneously), with RVF superiority for unilateral presentation (a word presented in either right or left of fixation point). Briefly, the hypothesis states that in reading unilateral presentations a conflict in scanning exists for the LVF--the eye has to move to the left to start the "sentence" but also tends to move to the right to read the "sentence" whereas for the RVF there is no such conflict because both tendencies are in the same direction -- to the right. This gives better accuracy scores for recall from RVF with unilateral presentation. With bilateral presentation, the LVF is favoured first in time, giving the material there the advantage of primacy.

While much evidence exists in favour of a reading set (or other scanning strategies), in processing near-threshold stimuli several studies point to a hemisphere factor with verbal material. Bryden &

Rainey (1963 found that when (English) alphabetical material was exposed unilaterally, a RVF superiority existed. This result is consistent with Heron's scanning hypothesis, but also with the involvement of the left hemisphere in processing the material in the RVF faster than in LVF due to the more direct visual pathways involved in the former. In attempting to eliminate the confounding influence of reading sets, Barton, Goodglass and Shai (1965) found a RVF superiority for 3-letter Yiddish words unilaterally presented at threshold exposure, vertically mounted in the hemifield. The rapid, near threshold durations and the vertical display could discourage the operation of any scanning tendency. Also the unilateral Yiddish words should create a LVF superiority according to Heron's scanning hypothesis. Hence the data strongly suggests the involvement of the left hemisphere in more effective processing of RVF verbal material.

The use of non-verbal material would discourage a reading set, and some evidence exists to suggest smaller hemifield differences with unilateral presentation of geometric forms. Bryden (1960) (also Bryden & Rainey 1963; Heron, 1957) found no difference between the hemifields for recall of geometric forms, presented unilaterally, while unilateral verbal material showed better RVF accuracy. This would mean that the scanning mechanism of Heron is specific to verbal material, or else suggest a hemispheric asymmetry with geometric stimuli in favour of the right hemisphere. With familiar (as opposed to abstract) forms (e.g. drawings of houses etc.) unilateral presentation shows a right visual field superiority (Bryden & Rainey, 1963; Wyke & Ettinger, 1961). The difference between familiar objects and abstract forms may be due to verbal labeling of familiar objects in processing and recall, hence the greater efficiency of the direct pathways from RVF to left hemisphere.

A relationship between field differences and handedness has been reported (Zurif & Bryden, 1969) strongly implicating a hemisphere factor.

However, the data in this field so far gathered is contradictory and generally confounded with many variables. No clear conclusions have so far been drawn as to the influence of hemisphereic dominance on laterality differences in recall, nor is evidence in clear support of the scanning mechanism (which seems to be highly stimulus-dependent anyway). M. J. White (1969) in a review of this field states: "Laterality differences in perception would appear to be a composite function of many factors. Whether a right or left field superiority in recall accuracy is found is dependent on (a) the type of stimulus presentation, unilateral or bilateral; (b) the amount, nature and spacing of the stimulus-information elements; (c) the intensity at which the information is shown (perhaps because the closer to threshold, the more important are 'structural', e.g. acuity, factors over processing factors); (d) the order in which the information is reported; (e) the viewing condition employed and the ocular dominance of the subjects; and (f) the handedness and lateralization of the subjects."

The studies cited suggest that severe difficulties exist in the interpretation of data in this field, mainly perhaps because of the following limitations:

(a) The use of meaningful material or stimuli encouraging the involvement of unknown scanning mechanisms.

(b) The use of the technique of recall, implicating unknown cognitive functions.

(c) The use of near-threshold presentations which create the problem of whether generalization of the data to more normal stimulus conditions is valid. (White, 1969)

(d) The confounding factors of eye and pathway asymmetries.

The present study was designed to overcome these disadvantages, as is explained in detail in the next section.

## Separating the Relative Contributions of the Eyes, Pathways and Hemispheres

Two techniques - brightness matching and binocular rivalry - were selected to overcome the disadvantages of previous studies on laterality differences in the visual system, as discussed above. An exposition of the binocular brightness matching and binocular rivalry paradigms follows. They are presented as alternative methods of finding the relative dominance of the three parts of the visual system: eye, pathway and hemisphere.

### Binocular Brightness Matching

The basic paradigm used in this study is that formulated by Levelt (1965) in examining the contribution of each eye's stimulus to the binocular brightness sensation. Levelt showed that the binocular sensation of brightness resulting from two monocular stimuli of differing luminance was not simply the addition of the brightness of each eye's stimulus, but a weighted average. The magnitude of the weights of each eye, i.e. the contribution of each eye to the intensity of the binocular sensation, depended on several factors:

Eye dominance. If the eyes are equal the weights are each 0.5; if unequal, the more dominant eye has the larger weight.

Relative contour information. The monocular stimulus that contains more contour than the other eye's stimulus leads to an increase in the magnitude of the weight for that eye.

Colour. The determinants are unspecified.

Temporal characteristics. An intermittent stimulus in one eye increases the dominance, hence the weight, for that eye.

Other determinants. Other factors such as degree of relative interest in the right and left eye stimuli also affect the relative balance between the two eyes.

In simple binocular brightness matching Levelt used bright circles as stimuli, one in each eye. One pair of circles of differing brightness were presented simultaneously, one in each eye, called (in the present study) the variable stimuli (V.S.), Two similar circles of equal brightness were presented simultaneously, one to each eye, called (in the present study) the standard stimuli (S.S.). The subject saw these pairs alternately and adjusted one of the variable stimuli until obtaining a match between the apparent brightness of the variables and standard pairs, in the binocular view. Levelt postulated his Law of Complementary Shares to describe the averaging process between the two unequal variable stimuli to produce the unified percept. The equations describing his law are:

(1) $W_L E_L + W_R E_R = C$

where $E_L$, $E_R$ are luminances of the left and right V.S. when the fused V.S. are matched for brightness with the fused S.S., in which $E_L = E_R$; $C$ = constant for any one value of S.S. intensity; $W_L$, $W_R$ represent the weighting coefficients reflecting eye dominance, and

(2) $W_L + W_R = 1$

Hence Levelt's law of complementary shares states that the weighting coefficients of each eye, describing binocular brightness summation, are proportions, i.e. they sum to unity.

Levelt's procedure of binocular brightness matching was followed in this study to obtain the weights that are used to define eye dominance.

To obtain the weights used to define the dominance of the crossed vs. uncrossed pathways the V.S. and S.S. are presented eccentrically, i.e. in one visual field or the other, by having the subject fixate a point, while matching the V.S. and S.S. for brightness. When the stimuli appear in the left visual field the weights $W_L$, $W_R$ will refer to the relative dominance of the crossed pathway from the left eye compared to the uncrossed pathway from the right eye (see Figure 1). When the stimuli appear in the right visual field, the weights $W_L$, $W_R$ will refer to the relative dominance of the uncrossed pathway of the left eye compared to the crossed pathway of the right eye.

The relative dominance of the hemispheres in the brightness sensation is obtained by presenting one pair of stimuli in one visual field and the other pair in the other. The one pair of stimuli, say the V.S., project to the right hemisphere, while the S.S. project to the left hemisphere. That hemisphere is defined in this study as dominant for brightness matching which needs the least light energy to make a match with the stimulus in the other hemisphere. This is determined by the value *C* in Levelt's equation. The *C* value for the V.S. and S.S. can be calculated and the hemisphere containing the stimuli with the lower *C* value is defined as 'dominant', since less light energy is required for that hemisphere to make a match.

The precise procedural details of this design are given in the Method Section.

<u>Binocular Rivalry</u>

In binocular rivalry the subject reports the phenomenal fluctuation of two different stimuli, one presented to each eye. The measure of dominance or 'strength' of a stimulus is the average time of appearance of that stimulus, compared to the average time of appearance of the rivaling stimulus. If one compares the relative appearance time of two equally dominant stimuli then one would obtain a measure of 'eye' dominance. This can be achieved by presenting the stimuli shown below:

Left Eye Right Eye

If the stimulus to the left eye, say, is seen for a longer time on average than that to the right eye, then one could say that the left eye is dominant in binocular rivalry. This is one basis of the definition of dominance in rivalry in this study. Though the physiological basis for differences in viewing time is still obscure, association of greater stimulus dominance with greater viewing time seems both intuitively and experimentally sound. (Kaplan & Metlay, 1964; Breese, 1909). Medical opinion also holds that the eye whose image is suppressed is the weaker eye (e.g. in amblyopia).

In this study, the above stimuli, called the 'single cross' (S.C.), were used to define eye dominance. In order to measure the dominance of the crossed vs. the uncrossed pathways a pair of stimuli that combined to yield two crosses were used, called the 'double cross' (D.C.).

Left Eye Right Eye

The subject is required to register the fluctuations of the two crosses simultaneously. The Method section contains the precise calculations involved in obtaining the dominance measures.

Hemisphere dominance is measured in this study by the relative rates of fluctuation of the bars of each cross. The cross in the left visual field of the binocular percept projects to the right hemisphere while the cross in the right visual field projects to the left hemisphere. The rationale for the use of this criterion is given in the section on Definitions of Dominance in the Method section.

The Advantages of the Two Methods: Brightness Matching and Rivalry

Several of the advantages of these two methods are apparent:

a. Both the brightness matching method and the binocular rivalry method are tasks that hopefully minimize or eliminate attentional bias or scanning mechanisms (Heron, 1957) related to the use of comparatively more cognitive tasks such as those involving recall of verbal material. (cf. P. 9, Hemisphere differences in vision) Scanning may refer to overt scanning of a stimulus or 'internal' scanning of the stimulus trace in the case of brief presentations. Scanning mechanisms may be due to reading habits or determined by task demands, as in signal detection. In this study both tasks required S to fixate a central point. In the rivalry task, S had to attend to the center of the field (with the single cross) or equally to both sides (with the double cross stimulus); in the brightness matching task, either central or eccentric deployment of attention was required of S, but a central fixation was maintained throughout. No external or internal scanning would seem to be necessary in the brightness matching or rivalry task. Hence this study should reflect laterality differences as related to more fundamental processes in the visual system, such as contour suppression in rivalry and brightness summation in the brightness matching task.

b. In the binocular brightness matching task particularly, the brightness summation process is probably independent of conscious attention since the subject is unaware of which eye receives which stimulus. In fact no subject reported noticing, at any time during the study, that each eye received a (variable) stimulus of differing brightness.

c. Both methods rely on the normal functioning of the visual system unlike those that use threshold measures for dependent variables. The use of threshold measures may produce results that are valid only under the marginal conditions of the experiment and do not reflect laterality differences under more normal visual functioning.

d. The methods chosen demand the functioning of the total visual system unlike some measures, such as acuity or reaction time, that may often be monocular tests and hence artificially require the use only of one half of the system at a time, thus disregarding the coordinated functioning of the inter-related parts of the system. With the rivalry method of introducing competitive input, the hope was that the measure would show clearer functional asymmetries, in a sense paralleling the dichotic listening task (Kimura, 1961).

e. Most studies on laterality differences use a recall measure as the dependent variable, which may introduce unknown cognitive functions to complicate interpretation. Both the rivalry and brightness matching tasks would be unlikely to involve such functions.

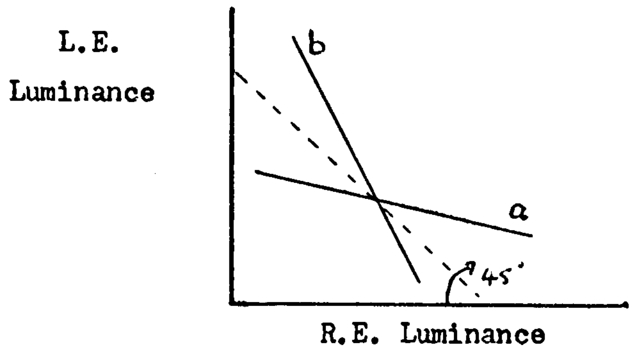
# METHOD

## Definitions of Dominance

The concept of dominance as it is applied to cerebral and sensory system functioning is open to attack as being vague and ill-defined. In terms of cerebral functioning, dominance refers to the lateralization or asymmetry of functions, implying that one hemisphere "controls" or has greater importance for a particular function (e.g., speech) than the other. In terms of the laterality differences of the visual system the term implies that one part of the visual system contributes more to the final percept than another part. How this dominance arises is not questioned at present, but the basic notion is that the 'dominant' part is somehow more sensitive to light energy than the non-dominant part, or processes the information more efficiently or 'weights' the energy more via attentional processes, or simply that the visual system has variable 'channel capacities' in its different parts. The operational definitions given below of each type of dominance are based on the above rationale. (Refer to pages 13-17 for the descriptions of the two methods of brightness matching and binocular rivalry)

### Eye Dominance

Brightness Matching. Within the brightness matching design, eye dominance was defined by the slope of the line determined by the luminances of the variable stimuli (V.S.), (page 13). For example, plotting left eye luminance along the ordinate and right luminance along the abcissa (as seen below) a slope of less than 45° (line a, in the diagram) implied left eye dominance i.e., less light was needed in the left eye to match the standard stimuli (S.S.). A slope of over 45° (line b, in the diagram) implied that the left eye needed more light to make the match and hence that the right eye was dominant.




The method of calculating the dominance weights of the brightness matching conditions is presented below.

The equation of the line describing binocular brightness summation (Levelt, 1965) is:

$$W_L E_L + W_R E_R = C$$

The weights $W_L$, $W_R$ were found by putting C = 8, the intensity value of S.S. and using the values of $E_L$, $E_R$ found for each subject in each condition. The solution for $W_L$, $W_R$ by matrix algebra is:

$$w = (E\ E)^{-1} E\ C$$

This solution gives the weights $W_L$, $W_R$ without the restriction that they sum to unity. The unrestricted weights were divided by their sum to convert them to proportions in accordance with Levelt's law of complementary shares. The weights then become relative weights. The unrestricted weights reflect the absolute values of the contributions of the eyes and pathways and hence permit inter-individual comparison and independent comparison of the pathways (see Page 37).

Rivalry. With a binocularly constituted single cross (SC) stimulus (see Page 16) the relative dominance of the two eyes was measured by the relative time that each eye's stimulus was seen (as recorded by key presses). The dominant eye was defined as the eye whose stimulus was seen the most often. Since Ss were instructed not to change their key press until they saw a definite change of stimulus any ambiguities of dominance were absorbed in the dominance times of one or the other eye's stimulus. Hence the dominance times of the two stimuli added up to the total time of presentation. The dominance times for each eye's stimulus was determined over four trials per subject; the trials were arranged to eliminate response and practice bias.

Pathway Dominance

Brightness matching. The same rationale as was used to obtain eye dominance weights (above) was used to calculate the relative dominance of LVF of each eye and RVF of each eye. In two separate conditions (LVF and RVF) the pairs of stimuli, V.S. and S.S., (see Page 15) are presented in LVF to obtain the dominance weights of LVF for the two eyes and in RVF to obtain dominance weights for RVF for the two eyes. The weights are obtained from the two lines fitted to the two sets of data points and they refer to a particular visual field of a particular eye. For example:

| Left Eye (L.E.) | | Right Eye (R.E.) | |
|---|---|---|---|
| LVF | RVF | LVF | RVF |
| 0.7 | 0.4 | 0.3 | 0.6 |

The weights of the LVF sum to unity as do the weights of the RVF, in accordance with Levelt's Law of Complementary Shares.

Rivalry. Using a binocularly constituted double cross (D.C.) stimulus (see Page 16), the relative dominance of the left field of one eye and the left field of the other was determined by the proportion of total time each left field stimulus was reported. The same method was employed to find the relative dominance of the right fields of each eye.

These proportions were obtained from the amount of time (measured as lines on Rustrak paper) that each rivaling stimulus was seen, totalled for the 4 response trials (see Page 35 ):

| | Left Eye | Right Eye | Nasal Fields | Temporal Fields |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Seen for: | X | Y | Z | W |

(arbitrary units of time, lines on Rustrak paper)

<u>Dominance Times obtained</u>:

| | | |
|---|---|---|
| Left visual field of left eye (LVF/LE) | = | X + Z |
| RVF/LE | = | X + W |
| LVF/RE | = | Y + W |
| RVF/RE | = | Y + Z |

The left fields sum to total time (X + Y + Z + W) as do the two right fields. The weights for relative dominance were simply the dominance times of each field of each eye divided by 2440 which represents the total time over the four trials. Each trial was 610 units or 90 seconds long. These weights were proportions as were the weights derived from brightness matching, i.e. they sum to unity.

<u>Hemisphere Dominance</u>

<u>Brightness Matching</u>. The Hemisphere condition described in the Method Section allowed a match of the relative intensities of two stimuli, each interpreted in a different hemisphere. The hemisphere needing the lesser light energy to match was the dominant hemisphere.

The intensity of the S.S. was 8 ft. L. and this was the value of

$C_S$ in the equation

$$W_L\ E_L + W_R\ E_R = C_S$$

for stimulus S.S.

For V.S. the constant $C_v$ can be calculated from the weights $W_L$, $W_R$ (obtained from the slope of the best-fitting line) and $E_L$, $E_R$. The constant $C_v$ was calculated as the mean of the constants derived by inserting each set of data points $E_L$, $E_R$ into the above equation.

$C_v$ was compared to 8 ftl., the value of $C_s$ in the opposite hemisphere. If $C_v$ was greater than $C_s$ then the hemisphere interpreting V.S. needed more light energy than the opposite hemisphere for the same subjective sensation. Thus the hemisphere mediating V.S. is the non-dominant hemisphere for brightness for that subject.

The weights of the hemispheres were obtained in this way: if V.S. was in RVF, the weight of the left hemisphere

$$W_{LH} = \frac{C_v}{16} \quad \text{and} \quad W_{RH} = 1 - \frac{C_v}{16}$$

If V.S. was in LVF, the weight of the right hemisphere

$$W_{RH} = \frac{C_v}{16} \quad \text{and} \quad W_{LH} = 1 - \frac{C_v}{16}$$

i.e. the hemisphere weights also sum to unity and center around 0.5.

Rivalry. The relative dominance of the hemispheres was calculated from the relative frequency of fluctuation of the bars of the two crosses in stimulus D.C. The cross in LVF refers to the right hemisphere and the cross in RVF to the left hemisphere. The hemisphere supporting the faster rate of fluctuation was defined as the dominant hemisphere. This definition is based on the following evidence.

(a) Alternation rate varies with the 'strength' of the stimuli. Increasing luminance levels of the rivaling stimuli will increase the rate of alternation (Kaplan & Metlay, 1964; Breese, 1909) and increasing the amount of contour in the stimulus to one or both eyes increases the alternation rate (Alexander, 1951). Alternation rate decreases with increase in the eccentricity of the stimuli, i.e. as the stimuli are projected more and more in the periphery of the retina. (Breese, 1909)

(b) The verbal hemisphere (usually the left) is probably more involved with attentional processes and arousal than the non-verbal hemisphere. Greater EEG alpha blocking is reported from the left hemisphere (Lindsley, 1940). Greater alpha amplitudes were found in the right hemisphere for right-handers while greater alpha amplitude was found in the left hemisphere for left handers (Subirana & Oller-Dourella, 1960). The expectation is that greater rate of alternation would reflect the greater state of arousal of the verbally dominant hemisphere. Johnson and Klintman, (1964) report a possible positive relationship between rate of fluctuation in binocular rivalry and arousal.

Lateral Eye Movement

S was asked 6 questions, described in the Procedure. The direction of the first lateral eye movement, as S reflected on the question, was recorded as 'left' or 'right'. For the purpose of scoring this variable the ratio of the number of left eye movements to total was used as the index of lateral eye movements. This phenomenon was included in this study because of a possible relationship between the direction of lateral eye movements and hemispheric dominance. (Bakan, 1969).

Handedness

Right handers who did not have any left handers in their family were scored 0, and the rest of the sample were given a score of 1. The scoring procedure separates 'pure' right handers from the rest. The former group might be expected to provide evidence of greatest lateralization.

Sighting Eye

The subject was asked to sight through a tube as if it were a telescope. The use of right or left eye for sighting was scored 0 or 1, respectively.

## Subjects

Twenty subjects were used, 4 women and 16 men, all students at Simon Fraser University, mostly between the ages of 19-23, with one male aged 29 and another aged 45. All claimed 20/20 vision or better on recent tests, without correction. Subjects were volunteers and paid $1.50 an hour, due to the length and rather arduous nature of the experiment (average duration 5 3/4 hrs. over several sessions).

## Apparatus

The apparatus consisted of a 6-channel binocular tachistoscope, Scientific Prototype, model G. B. Only four channels were used. Two 6" G.E. Cool White Lamps illuminated the stimuli in each channel. The lamps could be adjusted in intensity and controlled by electronic timers in a separate unit, one independent control circuit for each channel.

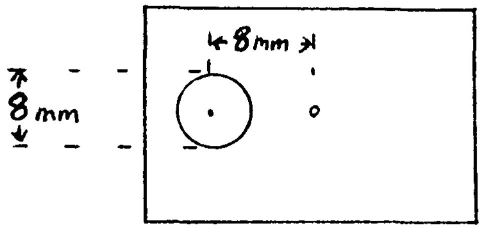
The input voltage to the timers and the lamps, was regulated at 115 volts by a voltage stabilizer. As a further protection against random intensity fluctuations a small photocell (model NSL 364) was placed in each channel, slightly to one side of the lamps and facing them. Changes in photocell resistance, due to changes in lamp luminance, would effect compensatory changes in the lamp's input voltage, thus maintaining a particularly steady intensity source. The sensitivity of the photocell feedback circuit could be controlled by a knob on the control unit, which enabled the photocell circuit to tap a variable voltage from the lamp circuit. The circuit is shown in Appendix 2. By these means, the lamps of the tachistoscope maintained a consistent intensity for hours at a time, despite being turned on and off every 3 seconds, as the brightness matching procedure demanded. Slight fluctuations in lamp intensity were recorded towards the end of a lamp's life and the lamp was then replaced.

Because of the uncertain quality of some of the lamps, and their variable life spans it was not practicable to calibrate them for luminance on the basis of input voltage. A photometer manufactured by Photo Research Corp., model 'Spectra' was used to take intensity readings in footlamberts on all brightness matches. The instrument was placed 2 1/2 meters from the eye-pieces of the tachistoscope and the telescope was focused onto the stimulus through the eye-piece. A 6 mm arc aperture in the photometer represented the measured area of illumination and was 1/8 the area of the stimulus circle (of the brightness matching task). This aperture, seen as a small black circle when looking through the telescope, was aimed at the center of the stimulus to measure the luminance. Slight errors in centering did not effect the luminance readings, as long as the aperture spot was contained within the area of the stimulus.

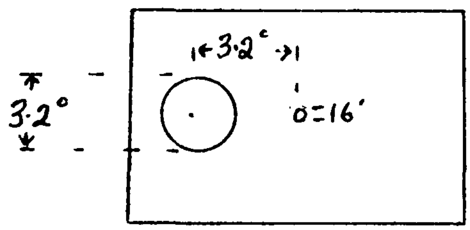
## Stimuli

For the brightness matching procedure, the stimulus was a bright circle, with or without a fixation point. The exact stimulus used for each condition, will be described later. The stimulus material was a Kodalith (high contrast) photographic transparency mounted on a conventional 36 x 24 mm photographic slide (Agfa Dia-Frames). The transparency was a negative photograph of a solid black (india ink) circle and fixation point drawn on a white card. The negative produces a transparent circle and an opaque surround. The opacity is inadequate for high illumination, but was quite sufficient at the intensity levels used in this experiment. At one stage in the pilot work, thin 1/32" sheet copper slides were tested, with holes made by a precision punch, but no difference in opacity could be detected by eye or photometer. Since the metal slides had slight irregularities around the edges of the holes, the Kodalith slides were used throughout this study. Agfa Dia-Frames slide mounts are glass protected and are ideal for quality slides, since the film is protected from dust and scratches. The adhesion inside maintains the film in a fixed position.

The physical dimensions of the stimulus are shown below:



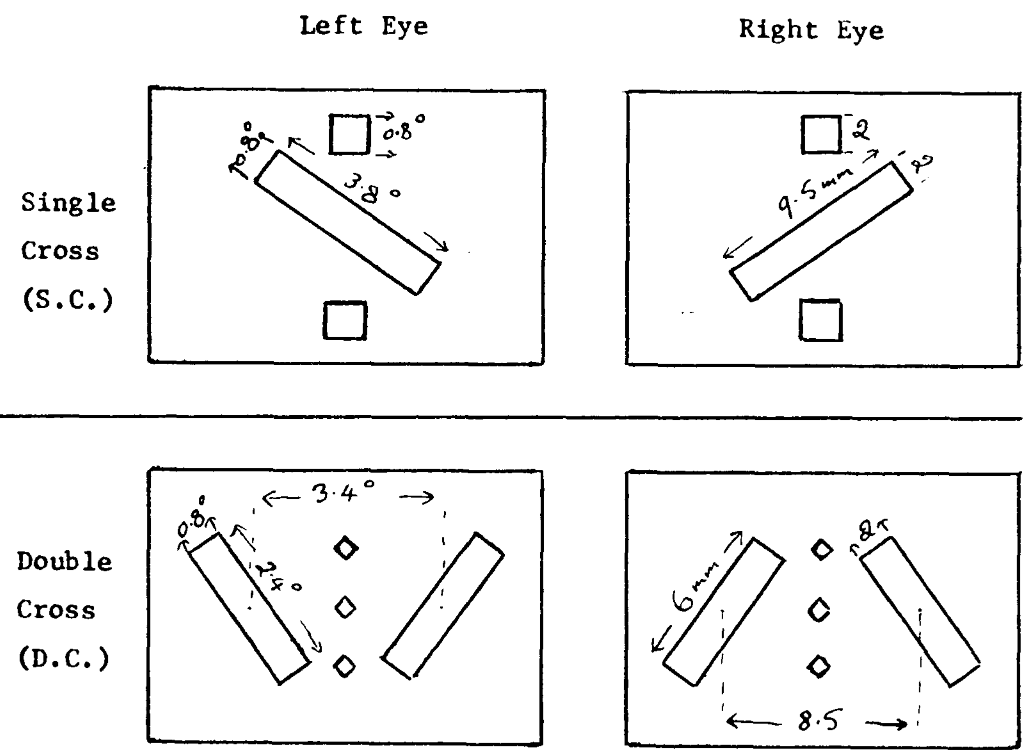

When placed in the tachistoscope, 145 mm from the plano-convex lens, f = 235 mm, the virtual image of the slide (magnified 2.68 times) subtends the angular dimensions shown below:




Internal reflection of light transmitted through the lens and the semi-reflecting mirrors cause some additional contours to be observed but these seemed negligible in their effects. No differences existed between the channels. (See Appendix 1). Additional light reflecting off the inside of the tachistoscope was eliminated by erecting black cardboard baffles at several points.

The background for the transparent circle was provided by commercial diffusing screen film-matt having one side of acetate. This surface produced a uniform light field. Extra filters equated the stimuli in each eye for spectral characteristics of white light. No colours were noticed by the Ss.

For the binocular rivalry part of the study, the stimuli consisted of a "single cross" and a "double cross" referring to the combined image shown below. These were also photographed on Kodalith film and the positive transparencies mounted on Agfa slides. The white background was the same as the interior of the luminous circles, described previously. The two squares in S.C. maintained the stability and symmetry of the combined image, due to the natural tendency of the eye to fuse like stimuli, as did the three "diamonds" in D.C. The subject fixated the center of the cross in S.C. and the center dot in D.C. throughout the stimulus presentation.




On the left side, dimensions are given as degrees of visual angle, on the right as millimeters. The actual stimuli are black figures on a white background.

The particular dimensions of stimuli were chosen for the following reasons:

(a) The size of the circles are comparable to those used by Levelt (1965). Obtaining dominance weights depended on the linear relationship postulated by Levelt to exist between the right and left eye brightness. It seemed appropriate to replicate that experiment as far as possible.

(b) The stimulus circles are large enough to sample a fair area of the para-foveal region and so the results would not reflect local irregularities in retinal sensitivity of individuals.

(c) The circles that are fixated eccentrically are centered $3.2^{o}$ from the fixation point so that slight errors of fixation will not involve stimulation of the wrong hemi-retina. Barlow (1952) in examining the errors of fixation found that human subjects could fixate with great accuracy - the scatter of individual fixation positions about the fixation point was as low as 5' arc. Also saccadic deviations from fixation were greatly reduced in number when the subject withdrew attention from the fixation point. These data suggest that in the present study the stimuli were being projected to the correct hemi-retina.

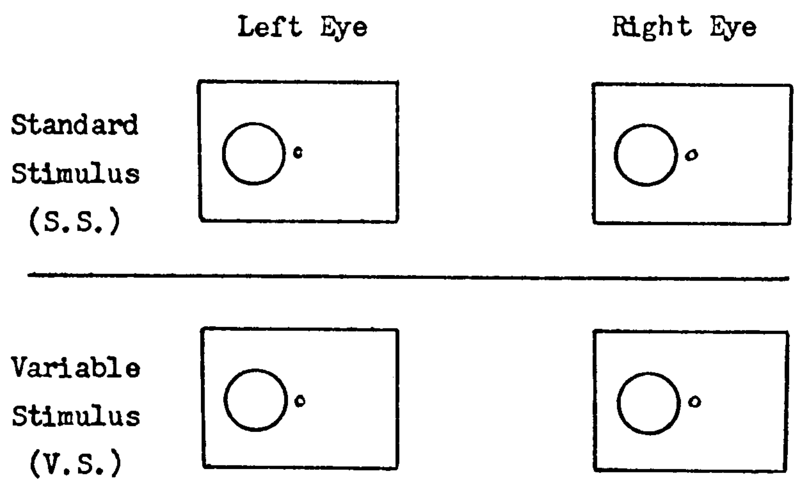
(d) The dimensions of the binocular rivalry stimuli were arranged to be comparable to the dimensions of the brightness matching stimuli.

## Procedure

Each subject was presented with each of the following six conditions. The brightness matching always preceded the rivalry conditions.

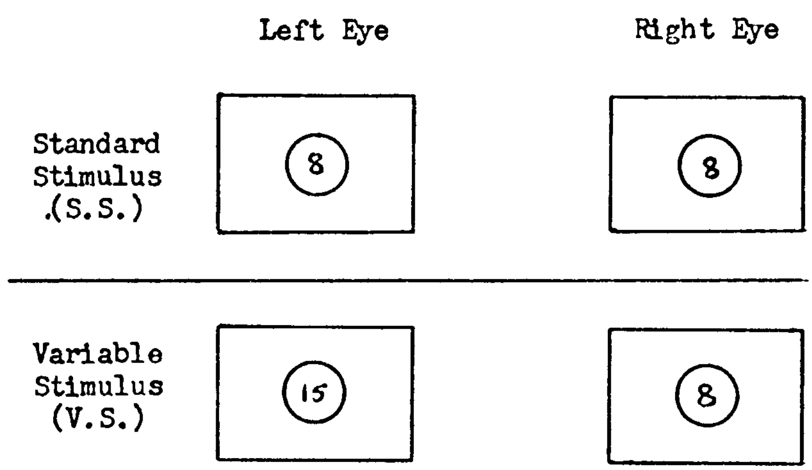
Central Circle (C.C.)

This condition was a replication of Levelt's design (1965). S saw a luminous circle against a completely dark background when looking into both eye-pieces of the tachistoscope. The circle was seen to alternate between two levels of brightness every three seconds. The diagram below explains how this was done.




These four stimulus slides were used for all brightness matching conditions.

For condition C.C. the fixation point was covered by black electrician's tape on the glass of the slide. The circles are in fact to one side of the center of the field as normally mounted in the tachistoscope, but this is unnoticeable to the subject, as everything else is black. Thus, for condition C.C. the stimuli were seen as:



The standard and variable stimuli were set initially at the brightness values shown by the numbers in the circles (the number for the left eye (V.S.) is approximate, since this is the adjusted stimulus for which the initial setting varied. The pairs of standard and variable stimuli (S.S. and V.S. respectively) alternated with a duration of 3 seconds each, and zero inter-stimulus interval.

S was given the following instructions as he sat down to the tachistoscope: "You will see a single circle changing in brightness. Do you see it? Good. I want you to respond, by simply saying 'brighter' or 'duller' depending on whether the circle has changed to brighter or duller than it was before. The brightness will change every 3 seconds. I will adjust the brightness after your response so that the change becomes less noticeable, until finally you will not be able to say the change is to brighter or to duller. When you feel you can't tell anymore, move your head away from the eye-piece and I will take a measurement of the intensity. It is important that you look at the center of the circle when judging, and all the time if possible. If your eyes get tired, don't move them around in the tachistoscope, but close them for a while--you do not have to respond to every brightness change".

S then had one practice trial during which the following instructions were given:

"You may notice that the change in brightness is more noticeable in one direction than the other, perhaps accompanied by a greater flash or glare. Try and ignore the change itself, when comparing the brightness and concentrate on the steady state, the last two seconds say. That is to say, don't try to use the change itself as a clue as to which is brighter or duller because this may be misleading. The lamps are switching on and off every three seconds and do not attain their true brightness as soon as they are switched on."

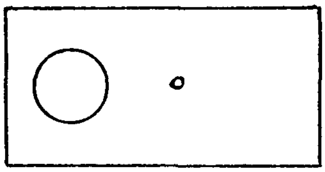
This latter instruction and its false rationale was given because the pilot work showed the disturbing effect of having circles of greatly different luminance in each eye. The onset of VS was disturbing presumably because a certain period of time is necessary to fuse the image from the two eyes. Ss in fact noted effects such as the VS circles (seen as single) appearing to contain flux or cloudy movement. These effects disappeared shortly after VS onset. Changing from VS to SS was less disturbing, presumably because the two eyes received circles of equal luminance.

S then proceeded to call 'brighter' and 'duller' and E adjusted the left eye V.S. luminance, towards the point of equality of VS and S.S., until S could not distinguish which was brighter (though a 'change' might still be noticed). In the early stages of adjustment E made a full turn of the brightness dial for each response from S, changing the intensity by roughly 1 footlambert; but as the S's time to respond increased, indicating greater difficulty in judging, E turned the dial only 1/2 of the way around, until finally small turns of 10 units were made. In order to standardize judgments as far as possible, E attempted to insure that roughly the same number of judgments of 'brighter' or 'duller' occurred, i.e., the starting point of the left eye VS was the same distance from the probable equality point for all trials. (Helson 1948)

Data: Two matching trials were conducted for each setting of the right eye V.S.: one with left eye V.S. brighter than needed to make a match and one with that stimulus dimmer than needed (randomized over trials). The right eye VS was varied in the following order (in footlamberts): 8, 9, 10, 11, 7, 6, 5. In general 14 matchings were obtained although in some cases more matchings were made according to the following criterion: if the second match differed from the first by more than 1 ftl. (for a given right eye V.S. setting) then two more trials were given.

Circle in Left Visual Field (L.V.F.)

In this condition, the fixation points were uncovered, and the slides arranged in their channels so that the circles appeared to the left of their fixation points: S saw the following:

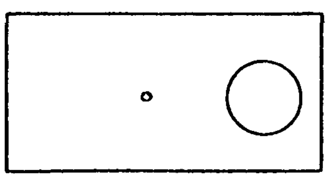


The instructions were the same as those in the first condition, except that S was asked to look at the fixation point only. It was strongly emphasized as essential to the study that the brightness match was not to be made by looking directly at the circles. When questioned, Ss maintained that they followed the instructions all the time, without too much difficulty. Parts of the instructions were repeated to S when E felt it was necessary. Some Ss had to be reminded to ignore the change in brightness several times, since it is an apparently obvious, though in this case often misleading, cue.

The same settings for right eye V.S. were made here as for C.C., with two trials for each setting (or more, according to the previous criterion).

Circle in Right Visual Field (RVF)

S saw the following:



The stimulus slides were simply turned around in the tachistoscope. This condition was randomly rotated in order with LVF conditions, over subjects.

<u>Circle in Right and Left Visual Field</u> (R/LVF)

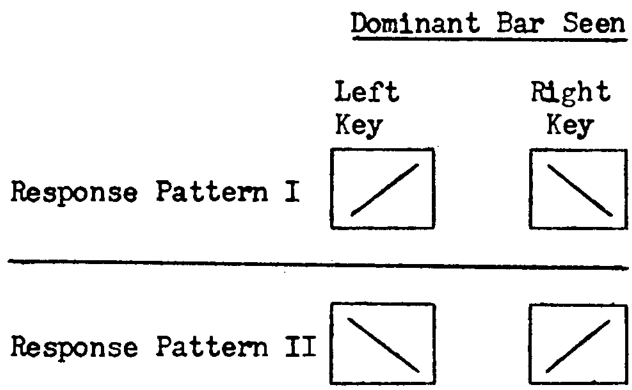
The SS and VS each alternated between one visual field and the other, with the fixation point remaining stationary. A slight phi phenomenon makes this condition a bit distracting but the real difficulty is in making a match, since one circle is going to one hemisphere, while the other goes to the opposite hemisphere. This condition was presented last, because of its greater difficulty.

<u>Single Cross (binocular rivalry) S.C.</u>

The stimuli are shown on page 28. S was asked to register the fluctuations in dominance of the rivaling bars of the cross by pressing one of two keys. Each key represented the dominance of one of the bars. The following instructions were given to S as he examined the stimuli.

"You will see a cross with a small square above it and another below it. Fixate the center of this cross, where the two bars intersect. You will notice the bars of the cross fluctuate with respect to each other; at one moment one bar appears stronger, blacker and in front of the other and then it will appear to fade and be replaced by the other bar. Do you notice that? Good. Now here are two keys. I want you to press these keys to record the fluctuations of the two bars. Press the left key when you see this bar ⧅ (or ⧄) as dominant, and press the right key when you see this bar ⧄ (or ⧅) as dominant. Keep the key pressed down as long as that bar is dominant and only lift your finger off (and press the other key) when you see the other bar as dominant. That is, you will always be pressing either one key or the other, never both and never none. Practice that for a minute. Use just your right hand to press the keys. This trial will last one minute." If S reported difficulty in 'holding' the cross (i.e. the eyes may tend to converge or diverge in following the fluctuations, causing the bars to separate) E adjusted one half of the tachistoscope into a more convergent or divergent position, depending on S's comfort and report of stimulus stability.

Response Bias. In order to overcome any response bias two response patterns were employed in the order shown:




To overcome possible bias due to practice and fatigue, both response patterns were repeated in the same order, giving four trials each lasting 1 minute. The data consisted of the totals of the dominance times for each bar in each response pattern.

Before the start of the trials, the two channels conveying the stimuli were equated for brightness, at 10 ftl.

Double Cross (binocular rivalry) D.C.

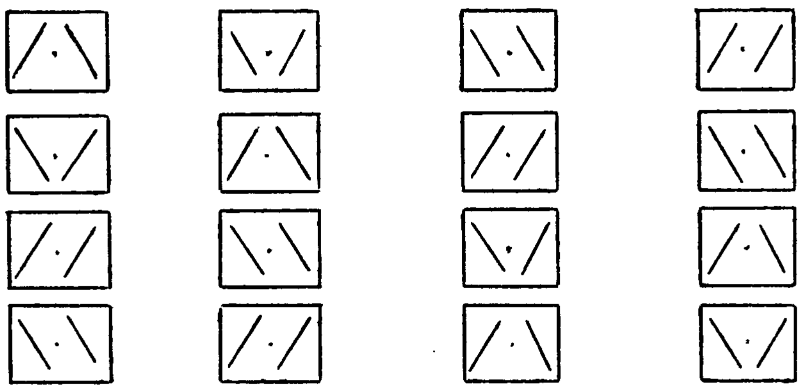
These stimuli - one presented to each eye - are shown on page 28. S was asked to register the fluctuations of the bars of the two crosses simultaneously. The task would be too difficult if S had to report each cross separately. However a simple response pattern overcame the difficulty of having to switch attention rapidly from one half of the visual field to the other. There were 4 response patterns (A-D below). The instructions are the same as for condition S.C., except that it was strongly emphasized to fixate the central spot while responding.

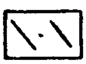
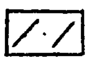
The four response patterns (A-D) are shown below:-

Dominant Bars Seen

KEY PRESS: Both Keys | None | Right Key | Left Key

Pattern: A, B, C, D



S was shown the above diagram and was told that the lines represented the dominant bars of the crosses and that he was to treat the rivaling stimuli as one configuration. (The four stimuli in the diagram represent the stimulus to the left eye , the right eye , the temporal fields , and the nasal fields ). S was asked to learn the first response pattern A. After practice, when S felt satisfied that he could follow the fluctuations, the trial began. (A Rustrak recorder marked the key presses on moving paper). Each response trial lasted for 90 seconds. The response patterns were learned and performed in the same order (A-D) for all subjects.

The data consisted of the total durations of the four stimulus patterns, over all four response patterns (A-D).

Other Laterality Data

Sighting Eye. S was asked to sight through a tube as if it were a telescope, as a test of eye dominance. No hesitation was observed with any Ss as to the choice of eye.

Handedness. S was asked which hand he used for writing and whether any of his immediate family used their left hand in writing.

Lateral Eye Movements. Eye movement direction in response to testing questions (Bakan, 1969) was examined. S was seated in a chiar, so as to squarely face E. Then six questions were put to him by E such as:

"What is 12 x 17?". "How many letters in the word 'Anthropology'?" "What is 'disease' spelt backwards?" "What is 13 x 19?"

When S became preoccupied with working out the solution, the direction of his first lateral eye movement (after looking at E) was recorded as 'right' or 'left'.

## Analysis of the Dominance Weights

Suppose ($W_{ij}$) represents the dominance weight for subject (i) derived under condition (j) (i.e. condition CC, RVF or LVF) then the transformation:

$$W_{ij} \rightarrow X_{ij} \text{ such that}$$

$$X_{ij} = 2W_{ij} - 1$$

centers the distribution around 0, instead of 0.5.

Then the Pearson product-moment coefficient $r_{jk}$ between the weights

$W_{ij}$, $W_{ik}$ under conditions j, k will be:

$$r_{jk} = \frac{\Sigma X_{ij} X_{ik}}{\sqrt{\Sigma X_{ij}^2 \; \Sigma X_{ik}^2}}$$

These correlations are presented in Table 3.

The unrestricted weights, obtained from the initial solution for $W_L$, $W_R$ from the line $W_L E_L + W_R E_R = C$ (see Page 20), are used as follows:

$W_L - W_R$, with unrestricted weights, is a measure of the absolute magnitude of the dominance difference between one eye or visual field over the corresponding eye or visual field. (This measure does not apply to the Hemisphere condition).

$W_L + W_R - 1$, with unrestricted weights, is a measure of the absolute total sensitivity of the two eyes or fields for that particular subject. The sum of the weights is centered around a mean of 1 and subtracting 1 centers the distribution around 0.

## RESULTS

Table 1 gives the dominance weights for each subject with respect to the left eye (whole eye, right and left field of the left eye) and left hemisphere. Familial handedness, eye movements and sighting eye data are also given with respect to the left hand, left eye direction and left eye respectively. Table 1 contains only left eye data because the dominance weights between left and right sum to unity, hence the weights for the right side give the same information, with signs reversed in the case of the correlations.

Table 2 gives the unrestricted weights obtained by the brightness matching procedure, and calculated as described on page 20.

Table 3 gives the correlations between the variables in Tables 1 and 2.

In order to simplify description, weights obtained by the binocular rivalry method will be designated by (R) and those obtained by the brightness matching method will be designated by (B).

In view of the number of variables (11) that are independently derived in the correlation matrix (Table 3) the possibility should be considered that several correlations may be significant by chance (Ryan, 1959, 1960). In fact, at the 0.05 level of significance the number of correlations that could be significant by chance (out of 55 correlations) is 0.05 x 55 = 2.75 or approximately 3. In general, the problem can be met by setting a higher significance level in proportion to the number of correlations in the matrix of independently derived variables (55). However no simple statistical solution is available, in view of the apparent interdependence of the variables. While clearly caution has to be exercised in accepting interpretations based on correlations bordering on nominal significance (0.05 level) the internal consistency of the data should add support to the interpretations. In addition, corroborative evidence is reported to support conclusions, both from within this study and from other studies.

## Eye Dominance

Eye dominance, determined by the rivalry method, reveals 9 out of the 20 subjects to be left eye dominant, 7 right eye dominant and 4 have equal dominance.

With the brightness matching definition only 3 out of 20 subjects are left eye dominant, 15 are right eye dominant, and 2 have equal dominance. A 't' test between the unrestricted weights representing the two eyes was significant ($t = 2.093$, $p<0.05$) showing the right eye to be dominant over the whole sample.

The correlation between the eye dominance weights established by the two methods is 0.01. Thus the two methods do not appear to be comparable, as regards eye dominance.

## Pathway Dominance

The rivalry method suggests that the uncrossed pathways are dominant in the visual system. Fifteen out of 20 subjects show the uncrossed pathways dominant (RVF greater than LVF, referring to the left eye, see Table 1). A 't' test between left and right field weights (R) of the left eye show a significant difference ($t = 2.407$, $p<0.05$) between the fields, with the right field dominant. This means that the uncrossed pathways are dominant in this sample.

The brightness matching results showed no clear evidence of pathway dominance. With the restricted weights, 11 out of 20 subjects have the crossed pathways dominant and the remaining 9 have the uncrossed pathways dominant. With the unrestricted weights only 3 out of 20 have the crossed pathways dominant, with another 12 with mixed pathway dominance i.e., one crossed pathway is stronger than the uncrossed for the same eye, and one uncrossed is stronger than the crossed pathway for the other eye. The remaining 5 have the uncrossed pathways dominant.

In the 'mixed' group, 7 had both pathways from the right eye dominant while 5 had both pathways from the left eye dominant. For these subjects, eye dominance appears to be of greater importance than pathway dominance.

No relationship was observed between the left visual field weights of the left eye derived from the two methods ($r = -0.03$). But for the right field weights the corresponding correlation is 0.60 ($p<0.01$).

A possible explanation for this significant correlation between the right field weights is the operation of an attentional bias relating to cerebral dominance. Because the verbally dominant hemisphere is almost always the left himsphere, the bias might be expected to operate in favor of the right visual field.

The possibility of a bias in the equipment cannot be sustained for the following reason; if there were, for example, a bias such that the luminance of the right field of the left eye was consistently underestimated by the photometer, then exactly the same underestimation would have to hold when the luminance level of the background of the D.C. stimulus was set at 10 ftl. However when setting the background luminance for the rivalry stimuli, S.C. and D.C., an aperture of 15' was used in the photometer and it was focussed at the center of the full field. So any bias in this reading would affect <u>both</u> right and left field equally. Also no extraneous cues were present in tachistoscope to emphasize the right visual field. (See Appendix 1).

## Hemisphere Dominance

The two methods of obtaining a hemisphere dominance factor show little relationship. The negative correlation (-0.33) may imply that rivalry and brightness matching may be mediated in different hemispheres. The tabulation below shows the extent of agreement (7 subjects) and disagreement (13 subjects) between the two hemisphere dominance measures. Neither measure shows significant asymmetries : by the rivalry method, 10 subjects are left and 10 right hemisphere dominant, while the brightness matching method shows 11 subjects as left and 9 as right hemisphere dominant.

| | | Rivalry | | |
|---|---|---|---|---|
| | | Left | Right | |
| | Left | 4 | 7 | 11 |
| B. M. | Right | 6 | 3 | 9 |
| | | 10 | 10 | 20 |

An interesting relationship exists between hemisphere dominance (R) and field dominance (R). As one might expect, left field (R) correlates negatively with hemisphere dominance (R): $r = -0.39$, while right field (R) correlates 0.44 ($p<0.05$) with hemisphere dominance (R). Thus, although the hemisphere dominance measure by the rivalry method does not seem to be related to any other variables it would appear to possess intrinsic validity. Further studies could be conducted relating this definition of hemisphere dominance to other likely variables, e.g., unilateral brain damage, since rate of alternation of a Necker cube is so related, Teuber (1962).

<u>Hemisphere Dominance and Handedness</u>

Hemisphere dominance (B) and handedness correlate 0.47 ($p<0.05$), implying that those subjects who were left handed or who had left handers in their immediate family tended to have left hemisphere dominance (B) while right handers with no familial left handers, tended to have the right hemisphere dominant for brightness. This suggests that brightness matching is influenced more by the hemisphere usually considered non-dominant and non-verbal.

Between handedness and hemisphere dominance (R), no relationship was observed, r = 0.06. (This may be because the visual system is well balanced with respect to the integrative processes involved between the visual areas in the two hemispheres. This would be important for binocular vision.)

<u>Hemisphere Dominance and Lateral Eye Movements</u>

No correlation exists between either measure of hemisphere dominance and the direction of lateral eye movements (LEM): r = -0.10 (R) and r = 0.05 (B).

<u>Visual Field Dominance and Lateral Eye Movements</u>

The direction of LEM correlates highly (r = -0.72) with left visual field dominance (B), but does not correlate with right visual field (B).

Rivalry measures of field dominance (right and left) do not correlate with LEM.

The relationship between left visual field and direction of LEM means that right movers (i.e. Ss who made predominantly right LEMs) have a dominant crossed pathway system and left movers have a dominant uncrossed pathway system, using the 'restricted weights' criterion.

The further implication can be drawn that the right hemisphere is more dominant in the control of eye movements.

With unrestricted weights the correlation between left visual field ($W_L - W_R$) and LEM is -0.44 ($p<0.05$), suggesting that the relationship might partly reflect sensitivity differences between the eyes.

Lateral Eye Movements and Eye Dominance

The direction of LEM and eye dominance (B) correlate -0.45 ($p<0.05$). The rivalry measure of eye dominance and LEM show no relationship.

This relationship means that right movers tend to have the left eye dominante (B) while left movers have the right eye dominant (B).

Lateral Eye Movements and Sighting Eye

No relationship exists between LEM and the eye used for sighting. ($r = 0.24$). This result is consistent with Duke (1968) who found a similar lack of relationship between LEM and dominant eye (dominance based on a sighting criterion).

Eye Dominance and Field Dominance

Eye dominance (R) correlates with right field (R) 0.53 ($p<0.01$) but not with left field (R): $r = 0.29$.

Eye dominance (B) correlates with left field (B) 0.58, but not with right field (B): $r = 0.10$.

One interpretation of this result might be that with the rivalry task the right field contributes the greater share to eye dominance, while with the brightness matching task, the left field contributes more to eye dominance. This supports the view that the left hemisphere may be more important than the right for binocular rivalry, while the right hemisphere may be more important than the left for brightness matching.

Some further interesting relationships exist: eye dominance (R) correlates not only with right field (R) as described above but also with right field (B) : $r = 0.50$. Consistent with this finding, eye dominance (B) correlates not only with left field (B) but also with left field (R): $r = 0.45$. This confirms the importance of the left field for eye dominance (B) and of the right field for eye dominance (R). Also, the reason for the lack of correlations between the eye dominance measures (R) and (B) is clear. The relationship is between one measure of eye dominance and dominance of the 'minor' field, in the other measure ('minor' in terms of its contribution to eye dominance by that measure). This finding suggests that the relationships between the brightness matching and rivalry tasks may be due to the common influence of a cortical factor.

For the difference measure ($W_L$ - $W_R$) with unrestricted weights, $W_L$, $W_R$, the above relationships also hold. Between left visual field (R) and ($W_L$ - $W_R$) for eyes the correlation is 0.45; between ($W_L$ - $W_R$) for eyes and left visual field (B) the correlation is 0.59 ($p<0.01$).

Employing the difference measure ($W_L$ - $W_R$) of field dominance and eye dominance shows a reduced correlation between eye and left visual field ($r = 0.37$) and no relationship between eye and right field ($r = 0.09$).

Absolute Sensitivities of the Eyes and Visual Fields

Since absolute sensitivity ($W_L + W_R - 1$) for 'eyes' correlates almost perfectly with the absolute sensitivities for both visual fields ($r = 0.99$ for left field and 1.00 for right field) this measure has good intrinsic validity.

Regarding the relationship between absolute sensitivity for eyes and the difference measure ($W_L$ - $W_R$) for both visual fields, the left visual field measures correlate 0.80 ($p<0.001$) while the right field measures are uncorrelated, $r = 0.08$ (cf. previous section).

A similar pattern of relationships exists between the absolute sensitivity of the left field and the difference measure for left field ($r = 0.78$) and right field ($r = 0.14$). Again, the absolute sensitivity of the right field correlates significantly with the difference measure for left field ($r = 0.80$), but not with the difference measure for right field ($r = 0.10$).

These consistent patterns of relationships suggest that in brightness matching efficient functioning of the eyes is concomittant with dominance (B) of the left field of the left eye, suggesting a greater involvement of the right hemisphere in brightness matching.

This conclusion is supported by the additonal finding that the difference between the total $(W_L + W_R - 1)$ for left and right visual fields is significant ($t = 2.093$, $p<0.05$) the left field (or right hemisphere) being the more sensitive.

Confirmation of the interpretation of $(W_L + W_R - 1)$ as an indicator of absolute sensitivity is provided from a study by White and Dallenbach (1932). These workers found that in judging the brightness of circles presented simultaneously in right and left visual fields, the left field brightness was overestimated. This supports the above finding of this study, using $(W_L + W_R - 1)$ as the measure of absolute sensitivity.

## DISCUSSION

The aim of this study was to examine the dominance relationships between the two eyes, the crossed and uncrossed pathways and the two hemispheres, found by brightness matching and binocular rivalry. The results show that no simple relationships exist between the two methods. Also, the hemisphere dominance weights obtained by either method may not reveal functional asymmetries, but the relationships between the dominance weights of the three parts of the visual system do reveal differences that can be interpreted in terms of the differential influence of the hemispheres in rivalry and brightness matching. In this section the results are related to relevant literature to explain and support the final conclusions.

### Asymmetry of Cortical Functioning of Brightness Matching

The results pertaining to hemisphere dominance can be seen as supporting the view that brightness discrimination is governed more by the right hemisphere. This interpretation is indirectly supported in studies of brain-injured cases, which show that lesions of the right hemisphere, particularly of the right temporal lobe, produce greater deficits in perceptual tasks, such as discriminations, than do similar lesions in the left hemisphere. (Weinstein, 1962; Milner, 1958; Dorff, Mirsky & Mishkin, 1965).

In monkeys the importance of both temporal lobes for all kinds of visual tasks is well established. Usually only bilateral lesions produce disruptive effects while in man, a right temporal lesion will have an equivalent effect, showing the greater lateralization of the human brain. (Chow, 1951; Mishkin & Pribram, 1954).

The brightness matching paradigm was designed to test for a hemisphere dominance bias in brightness matching. Such a bias would be independent of bias due to scanning mechanisms, particularly scanning mechanisms postulated to relate to asymmetries found with verbal stimuli. The results showing right hemisphere dominance for brightness matching suggest that the function is not related to verbal behavior. These data support the model proposed by Mishkin (1962) of the relationships between the striate areas and the inferotemporal areas of the cortex.

Asymmetry of Cortical Functioning in Binocular Rivalry

Binocular rivalry appears to involve mutual inhibition of the two rivaling stimuli. This action would probably take place in the striate area since it is here that the excitations from corresponding points of the two retinae converge onto common or adjacent cortical neurons. (Ogle, 1964; Hubel & Wiesel, 1968).

If, as we have found in this study, right field dominance (R) correlates with whole eye dominance (R) one might attribute the relationship to the dominance of the left hemisphere in binocular rivalry, since the fluctuations in rivalry of each eye's field is determined more by the fluctuations of the half-field projected to the left hemisphere. A possible bias of set due to the use of the right hand for recording the alternations might be considered.

However the original hypothesis underlying the rivalry definition of hemisphere dominance in this study was based on the notion that the dominant hemisphere for rivalry would produce faster alternation of the rivaling stimuli than the non-dominant hemisphere. No difference in frequency of alternation was found. However some relationship may exist between the rate of fluctuation of the rivaling stimuli in the right visual field (left hemisphere dominance (R)) and the dominance weights (R) for the right field ($r = 0.44$). A possible relationship might exist also between the rate of fluctuation in the left visual field (right hemisphere dominance (R)) and left field weights (B): $r = -0.39$. This reciprocity of relationship does not exist for the corresponding dominance measures determined by the brightness matching method.

An interesting observation by Goldstein (1967) of differences between the visual fields in terms of spontaneous fading of monocular stimuli (Troxler's effect) suggests a possible hemisphere involvement in this phenomenon which is generally considered to be due to retinal adaptation (Levelt, 1965). Specifically, Goldstein reports a greater frequency of fading of a monocular line figure in the right than in the left visual field, suggesting a bias in favour of the left hemisphere for reporting Troxler's effect. The lack of similar evidence of a left hemisphere bias in terms of frequency of alternation in this study may not be surprising in view of a possibly crucial difference between Goldstein's measure and the hemisphere dominance (R) measure used here. In this study, the rate of alternation was reported simultaneously in right and left half-fields with a rivaling stimulus in each field. The normal integrative action between each half-field of each eye's stimulus would tend to minimize differences between the visual fields. Perhaps a more sensitive method of verifying Goldstein's data for binocular rivalry would be to present a binocularly constituted single cross in one visual field only. Thus one could measure the rate of alternation in each (right or left) field, independently of the other field.

Thus it seems that the hemisphere dominance weights (R) do not in themselves reveal obvious asymmetry. The covariation of the hemisphere weights with the pathway (visual field) weights provides a clearer indication of the influence of the hemispheres in rivalry in their respective visual areas, while the stronger covariation of the right (than left) visual field weights with the eye weights suggests a functional asymmetry of a stronger left hemisphere influence on rivalry.

## Pathway Dominance

Three-quarters of the sample showed dominance in rivalry of the uncrossed over the crossed pathways. A significant difference was found between right field weights (R) and left field weights (R) for the left eye (Table 1) showing the right field to be dominant. ($t = 2.407$, $p<0.05$). This means that the uncrossed pathways are dominant taken over the whole sample. Corballis (1970) has confirmed this result, though Crovitz and Lipscomb (1963) found the opposite using color rivalry. It may be that stimulus characteristics are critical in rivalry dominance. Martin (1970) suggests the importance of stimulus characteristics in an electrophysiological study designed to separate the contribution of each eye to the wave-form elicited by binocular rivalry and fusion. This study is discussed later.

The brightness matching method showed no clear pattern of pathway dominance. Nearly equal numbers of subjects had crossed as had uncrossed pathways dominant with about half of mixed (one crossed and one uncrossed) dominance. The reason could be that the brightness matching method is too simple a task to put the visual system to a severe enough test to detect the slight functional differences involved. Alternately, a consistent pattern does not appear perhaps because a number of factors, uncorrelated with each other but correlated with the dependent variable, may give rise to apparently variable effects over subjects. Further research could examine this possibility by experimentally, or statistically controlling the confounding variables. The fact that significant and interpretable correlations exist between pathway dominance weights and other variables suggests that these weights are not the result of random influences. By this argument a larger sample might show a clear trend in pathway dominance. The present evidence rejects the view that the crossed pathways dominate the uncrossed pathways. Hence, such a dominance may not explain the superiority of the right visual field in right eye dominant subjects (Wyke & Ettlinger, 1961), though the task differences may be important in preventing over-generalization of this finding to studies involving recall of verbal material. Sampson & Spong (1964) did not find clear pathway differences in a procedure whereby S had to recall different letters flashed binocularly, so as to rival each other. So it appears that methodological factors may be important. In particular, the use of supra threshold stimuli may make pathway differences less critical in recall tasks.

Comparison of the Binocular Rivalry and Brightness Matching Paradigms

The two methods were expected to produce similar dominance weights because of the similarity between the processes of rivalry and fusion. However perhaps the task differences are crucial here. The rivalry task required the passive registration of the alternating percepts. The brightness matching task was more difficult - subjects took up to two or three minutes to make a satisfactory match according to their internal criteria of equality. This task involves discrimination of the stimuli to be compared. These functions seem to be focalized in the right temporal lobe in man (Milner, 1962; Warrington & Rabin, 1970).

An important difference between the two methods could be the type of response required: in the rivalry task S pressed keys with his right hand to register the dominance of the rivaling percepts, while in the brightness matching task, S gave a verbal response ('brighter' or 'duller'). The use of the right hand could bias hemisphere dominance (R) so as to produce as artifactual dominance of the left hemisphere as mentioned previously, since control of the right hand is effected by this hemisphere. This possibility could be examined further by randomizing the use of the hands over subjects. In this study it was decided that all Ss should use the right hand, regardless of handedness, because of the need to maintain uniform conditions across subjects as far as possible. Left-handers are usually not as severely lateralized as are right-handers (all left-handers in the sample reported using their right hand for some functions) so that a differential bias between right and left-handers in this study would be unlikely to affect the data significantly. This in fact seems to be the case.

Similarly producing a verbal response when matching brightness might be expected to bias dominance in favour of the left hemisphere, since this is generally the verbal hemisphere. Certainly the investigation of the effects of different responses on hemisphere dominance (B) could be fruitful in unravelling inter-hemispheric relations. One could also vary the type of stimuli to be matched for brightness, to examine the effects of differential hemispheric involvement in information processing (e.g. verbal vs. non-verbal stimuli).

Another important consideration in looking at the differences between the two methods is the <u>fact</u> of rivalry -- the phenomenal fluctuation between two dissimilar stimuli as against phenomenal fusion with brightness matching. Despite the apparent spontaneity of the fluctuations it is known that the subject can affect the dominance times of the stimuli in the two eyes by attending to one stimulus and not the other. The use of symmetrical geometric stimuli as in this study should eliminate such bias. Another possible bias is an attentional one favouring one visual <u>field</u> over the other. However the design of the rivalry technique in the present study allows a comparison of the visual fields in terms of their rates of alternation, which is used to define hemisphere dominance (R). Thus an attentional bias towards the right field could be related to left hemisphere dominance but no such bias was observed in this study in terms of frequency of alternation.

The Nature of Lateral Eye Movements

This study reveals relationships between lateral eye movements and two brightness matching variables - eye dominance (r = -0.45) and left field (r = -0.72). With handedness partialled out the latter correlation rises to -0.79, representing about half the variance. This substantial relationship, suggesting a hemispheric asymmetry related to eye movement, deserves further investigation. In this section some discussion is devoted to supporting the possible (weaker) relationship between eye dominance and lateral eye movement.

Lateral eye movements are elicited in a subject by asking him a question that requires some thought. (Day, 1967). The internalized state of attention produces lateral eye movements in a direction (right or left) that is characteristic of the individual. Day finds a basic difference in personality between right and left eye-movers:

"The right-mover describes anxiety as having an external locus and a 'fear in search of an object' quality. His description seems similar to the clinically descriptive label of "diffuse" anxiety. The left-mover describes anxiety as having definite internal locus. The quality is one of tension, arousal and 'loss of control of impulses'. His description approximates to the clinical label for 'manifest' of 'tensional' anxiety."

The locus of eye movements appears to be in the frontal lobes of the hemisphere contralateral to the direction of the eye movement. Robinson & Fuchs (1969) showed that stimulation of Brodman's area 8, called the frontal eye fields, produced eye movements in the direction contralateral to the hemisphero being stimulated. They used monkeys as subjects so one may generalize only cautiously to humans. In the awake animal, only saccades were elicited by frontal lobe stimulation while under light anesthesia slow and smooth eye movements are elicited. The great majority of elicited movements (95%) were in the direction contralateral to the hemisphere stimulated. Robinson and Fuchs show that smooth and saccadic movements are controlled by independent mechanisms, but in both types of movement the control center is in the hemisphere contralateral to the direction of the lateral eye movement. (Independent circuits were shown to exist for up and down movements too).

Eye movements then can be a simple indicator of attentional dominance. The bias in favor of the right or left hemisphere reflects the nature of a subject's thought processes perhaps. Bakan (1969) says:

"... a relatively more active right hemisphere, possibly indicated by the direction of eye movements, implies a syndrome consisting of greater use of pre-verbal activities such as imagery, greater hypnotic susceptibility, greater interest in humanistic subjects, less mathematical ability and more EEG alpha activity."

The correlations between direction of lateral eye movement and eye dominance (B) and left field dominance (B) leads to several conclusions that are mentioned in the Results section but are brought together here for convenience:

(a) Right-movers tend to have the left field of the left eye dominant over the left field of the right eye, and left-movers tend to have the left field of the right eye dominant over the left field of the left eye.

(b) Right-movers tend to have a dominant left eye.

(c) Right-movers tend to have the crossed pathways dominant over the uncrossed pathways, using the restricted weights criterion.

(d) The right hemisphere may be more important than the left hemisphere for the initiation of lateral eye movements in <u>both</u> directions.

The relationship between eye dominance and eye movement may be worth investigating further as it appears that the dominance concept has some significance in the functioning of the oculo-motor system. When the eyes converge on an object the subjective direction of the object is different for each eye, as can be seen in the apparent shift of the object when one eye is closed. The dominant eye is defined by Walls (1952) as the eye that determines the apparent direction of the object, i.e. the 'visual ego' is at the center of one of the eye-balls. Walls hypothesizes that the oculo-motor system has no need to maintain two records of innervation of the two eyes since the same pattern of innervation is sent to each eye. The records of the innervations of the dominant eye are preserved by the oculo-motor system but the record for the non-dominant eye is not. This would apply to all eye movements from a reflex-like fixation to the activity of maintaining fusion and voluntary eye movements. Walls calls this the "steering gear" hypothesis of eye movements in which "all voluntary innervation of the eye muscles perhaps goes to the muscles of one eye only".

If this is the case the relationship between eye dominance (B) and eye movements can be understood as the dominant eye (measured by brightness matching) guiding the non-dominant eye in the appropriate direction. One would only have to hypothesize that the left eye tends to be biased towards the right in making lateral eye movements while the right eye tends to be biased towards the left, i.e. both eyes tend to turn towards the NASAL field.

In order to support this hypothesis further one would need to investigate:

(a) the existence of a consistent difference between the eyes of the reception of innervation to the ocular muscles, and whether this difference relates to the direction of lateral eye movements and eye dominance as determined by sighting and other tests, and

(b) the presence of a bias in the direction in which the dominant eye (i.e. the eye that has prior innervation) moves under certain conditions of internalized attention. To be consistent with the data of this study the bias should be towards the nasal side of each eye.

Work done on the relative speed of the two eyes in vergence movements supports the hypothesis proposed here that eye dominance determines the direction of lateral eye movements and is consistent with the notion that right-movers tend to have greater left hemisphere dominance while left-movers tend to have greater right hemisphere dominance. Jasper (1932) found that the left eye tends to lead in the vergence movement with right-handers while with left-handers the right eye tends to lead. That is, generally the <u>non-dominant</u> eye (Sighting test) seems to start first. This finding is supported by Schoen and Scofield (1935) who found more rapid vergence movement with the non-dominant eye (dominance was measured by an alignment test).

For the data in the present study to be consistent with these findings we have to assume that eye dominance as measured by brightness matching is inversely correlated with eye dominance as measured by sighting tests. Although the data in the present study does not show any relationship between these variables (correlation between eye dominance (B) and sighting eye = 0.15) the literature shows that eye dominance is highly test specific. Using a different test, such as an alignment test instead of the Sighting test, might yield the expected relationship. For a wide review of the confused literature on eye dominance, see Walls (1952).

In terms of Walls "steering gear" hypothesis the 'leading' eye is the non-dominant eye as measured by gross behavioral indices (sighting, alignment).

Supporting evidence for the view that eye dominance (B) is possibly inversely related to eye dominance (sighting) comes from an electrophysiological study by Martin (1970). He compared the wave-forms of cortical evoked potentials to visual stimuli under conditions of binocular rivalry and binocular fusion. He says: "A particularly perplexing problem arises from the finding that the contributions from the generally perceptually non-dominant eye (i.e. the eye which in a far vision sighting test is less favoured) dominated the wave-form of the electrophysiological response of the majority of subjects, regardless of which pattern was perceived. Kaufman, Pitblado and Miller (1965) have obtained similar results and they stated that one eye's physiological "response will come to predominate over the other eye's response under fused binocular conditions, even though that eye may show a weaker response than the other eye when their monocular recordings are compared".

In view of the uncertain nature of eye dominance under different testing conditions we are led to the conclusion that eye dominance is not a unitary concept, and a variety of factors are involved in any one measure of eye dominance such as handedness, acuity, practice, and differential cortical functioning. In fact, what relationships exist between a wide variety of eye dominance tests, based on conventional indices such as sighting and other visual-motor tasks, could be ascribed to a 'motor factor' (Walls, 1952). An intriguing possibility is that hemisphere dominance may influence eye dominance independently of the over-riding effect of handedness.

In relation to lateral eye movements one could speculate on the possibility that effecting a momentary change in hemisphere activity (or dominance) may in turn affect the direction of lateral eye movement. One way of testing this may be to ask questions requiring verbal and non-verbal thought processes, and comparing the directions of the eye movements to the two types of questions. The difficulty is to find questions of a non-verbal nature. Presenting the subject with visual puzzles may be one solution - problems that he has to solve by visualizing, e.g. briefly present the subject with a simple maze and then ask him to imagine tracing his way out; or present a number of geometric shapes briefly and ask the subject to identify a target shape after the exposure. Essentially these are tests of short-term visual memory for patterns which is probably focalized in the right temporal lobe. (Warrington & Rabin, 1970). Other methods of changing hemisphere dominance momentarily may be considered, such as photic driving via one visual field or having the subject perform verbal tasks on material presented in the right visual field (to affect the left hemisphere).

If the relation between eye dominance and lateral eye movement is valid, one might expect to affect the direction of eye movement by changing the eye dominance, at least temporarily. A subject could wear an eye patch for a few days, and his eye movements before and after could be tested.

An observation of Crovitz and Daves (1962) suggests a possible relationship between eye dominance and lateral eye movements. With brief (100 msec.) stimulus exposures in a monocular recall task, subjects tended to show initial post-exposure eye movements to the left with the stimulus to the left eye, and to the right with the stimulus presented to the right eye. Since Levelt (1965) showed the dominance weight of the stimulated eye to be unity in monocular stimulation, these data indicate that the dominant (or stimulated) eye may tend to move in a temporal direction. This phenomenon is the reverse of that required by the data in this study. However the contradiction may be resolved by the consideration that, in the study by Crovitz and Daves, the subject's attention was externally directed towards a stimulus, while lateral eye movements as defined by Day are observed under conditions of internal attention. External and internal states of attention may produce eye movements in opposite directions. (Day, 1967).

## The Question of the Verbal Hemisphere

The relationship between eye movements and left field dominance (B) has been interpreted as indicative of a greater right hemisphere involvement in the initiation of eye movements. We have assumed throughout this Discussion that the right hemisphere is the non-verbal hemisphere. Milner, Branch and Rasmussen (1964) reported on patients with brain disorders whose language area was located by the sodium amytal test. Among right-handers, 90% were left dominant for language while 64% of left-handers were also left dominant for language. These figures would yield as estimate of 17 verbally left dominant subjects in our sample of 20. However the above figures may over-state the proportion of right language dominant people in the normal population, since Penfield and Roberts (1959) suggest that verbal functions are nearly always located in the left side regardless of handedness while the representation of speech in the right side is related more often to pathological causes. Such abnormal factors would be more likely to be present in the sample studied by Milner *et al*. So perhaps even fewer than 3 subjects could be expected to be right dominant for language in our sample, thus simplifying the problem of interpretation.

## The Multi-method Approach

The use of different methods to assess the functional asymmetries of the visual system is consistent with the recommendations of Campbell and Fiske (1959). These authors point to the possibility that the use of only one method confuses the influence of the method itself with the function being investigated, i.e. the results may be due mainly to method variance and may not reflect more general modes of functioning of the visual system. Comparing a number of methods enables the similarities and differences to be evaluated in terms of convergent and discriminant validity. A strong correlation between two methods on the same dimension would indicate the existence of communality that may reflect some underlying functional base, common to both methods. By comparing further measures of laterality differences in the visual system a pattern of interrelationships may be built up so that the interpretation of a consistent pattern of correlations may be more valid and reliable. Where convergence of the methods is found interpretative strength is gained. while the lack of convergence may lead to further theoretical insight. Discriminant validity can be achieved as far as possible if the factors considered to be distinguishable can be shown to be sufficiently uncorrelated with each other by the several methods used. In the case of the visual system this consideration might be important in evaluating the independent contributions to perception made by various parts of the system, such as the eyes, pathways and hemispheres, and higher cortical functions. The importance of converging operations in perception specifically has been discussed by Garner, Hake and Eriksen (1956).

# CONCLUSIONS

The following major conclusions can be derived from the data of this study:

(1) Eye dominance, measured by rivalry, is unrelated to eye dominance, measured by brightness matching.

(2) Eye dominance (rivalry) is correlated, ($r = .53$) with right visual field dominance (rivalry). This implies a relatively greater left hemisphere dominance for rivalry in this study.

(3) Eye dominance (brightness matching) is correlated ($r = .58$) with left visual field dominance (brightness matching). This implies a relatively greater right hemisphere dominance for brightness matching.

(4) For the majority of the sample (15 out of 20) the uncrossed pathways were more dominant in rivalry. The brightness matching criterion showed about equal numbers with the crossed and uncrossed pathways dominant.

(5) Direction of lateral eye movement relates to eye dominance ($r = -.45$): right-movers tend to have the left eye dominant, left-movers the right eye dominant.

(6) The right hemisphere may be more influential than the left in initiating lateral eye movements in both left and right directions, ($r = -.72$).

# BIBLIOGRAPHY


Alexander, L. T. The influence of figure-ground relationships in binocular rivalry. Journal of Experimental Psychology, 1951, 41, 376-381.

Bakan, P. Hypnotizability, Laterality of eye movements and functional asymmetry. Perceptual and Motor Skills, 1969, 28, 927-32.

Barlow, H. B. Eye movements during fixation. Journal of Physiology, 1952, 116, 290-306.

Barton, M.I., Goodglass, H. and Shai, A. Differential recognition of tachistoscopically presented English and Hebrew words in right and left visual fields. Perceptual Motor Skills, 1965, 21, 431-7.

Bower, T.G.R. A local sign for depth. Nature, 1966, 210, 1081-2

Bower, T.G.R. and Haley, L. J. Temporal effects in binorular vision. Psychonomic Science, 1964, 1, 409-10.

Breese, B. B. On binocular rivalry. Psychology Review, 1909, 16, 410-15.

Bryden, M. P. Tachistoscopic recognition of non-alphabetical material. Canadian Journal of Psychology, 1960, 14, 78-86.

Bryden, M. P. and Rainey, C.A. Left-right differences in tachistoscopic recognition. Journal of Experimental Psychology, 1963, 66, 568-71.

Buchsbaum, M. and Fedio, P. Visual information and evoked potentials from the left and right hemispheres. EEG and Clinical Neurophysiology, 1969, 26, 266-272.

Burns, B. D., Heron, W. and Grafstein, B. Responses of cerebral sortex to diffuse monocular and binocular stimulation. American Journal of Physiology, 1960, 198, 200-4.

Campbell, D. T. and Fiske, D. W. Convergent and discriminant validation by the multitrait-multimethod matrix. Psychological Bulletin, 1959, 56, 81-105.

Chow, K. L. Effects of partial extirpation of the posterior association cortex on visually mediated behavior in monkeys. Comparative Psychology Monograph 1951, 20, No. 3.

Corballis, M. Personal communication. 1970

Creed R. S. and Harding, R.D. Latency of after-images and interaction between the two retino-cerebral apparatuses in man. Journal of Physiology, 1935, 423-441.

Crovitz, H. F. and Daves, W. Tendencies to eye movement and perceptual accuracy. Journal of Experimental Psychology, 1962, 63, 495-8.

Crovitz, H. F. and Lipscomb, D. B. Dominance of the temporal visual fields at a short duration of stimulation. American Journal of Psychology, 1963, 76, 631-7.

Day, M. E. An eye-movement indicator of individual differences in the physiological organization of attentional processes and anxiety. Journal of Psychology, 1967, 66, 51-62.

De Renzi, E. Non-verbal memory and hemispheric side of lesion. Neuropsychologia, 6, 181-189.

Dorff, J. E., Mirsky, A. F. and Mishkin, M. Effects of unilateral temporal lobe removals in man on tachistoscopic recognition in the right and left visual fields. Neuropsychologia, 1965, 3, 39-51.

Duke, J. D. Lateral eye-movement behavior, Journal of General Psychology, 1968, 78, 189-195.

Eason, R. G., Groves, P, White, C. T. and Oden, D. Evoked potentials: relation to visual field and handedness. Science, 1967, 156, 1643-6.

Flom, M. C., Heath, G.G., and Takahashi, E. Contour interaction and visual resolution: contralateral effects. Science, 1963, 142, 979-80.

Garner, W. R., Hake, H. W. and Eriksen, C. W. Operationalism and the concepts of perception. Psychological Review, 1956, 63, 149-159.

Gazzaniga, M. S. The Bisected Brain. 1970. Appleton-Century-Crofts, N.Y.

Giannitrapani, D., Sorkin, A.I., and Enenstein, J. Laterality preference of children and adults as related to inter-hemisphere EEG phase activity. Journal of Neurological Science, 1966, 3, 139-50.

Goldstein, A.A. Retinal rivalry and Troxler's effect. Psychonomic Science, 1967, 7, 427-8.

Hayashi, T. and Bryden, M. P. Ocular dominance and perceptual asymmetry. Perceptual and Motor Skills, 1967, 25, 605-12.

Heron, W. Perception as a function of retinal locus and attention. American Journal of Psychology, 1957, 70, 38-48.

Hubel, D. H. and Wiesel, T.N. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. Journal of Physiology, 1962, 160, 106-154.

Hubel, D. H. and Wiesel, T. N. Receptive fields and functional architecture of monkey striate cortex. Journal of Physiology, 1968, 195, 215-243.

Jackson, H. On the nature of the duality of the brain. Brain, 1915, 38.

Jasper, H. H. A laboratory study of diagnostic indices of bilateral neuromuscular organization in stutters and normal speakers. Psychology Monograph, 1932, 43, No. 1, 72-174.

Johnson, G. and Klintman, H. Binocular rivalry as affected by simultaneous auditory stimulation. Psychology Research Bulletin, 1964, IV:10, 1-13, Lund Univ. Sweden.

Kaplan, I. T. and Metlay, W. Light intensity and binocular rivalry. Journal of Experimental Psychology, 1964, 67, 22-26.

Kaufman, L., Pitlado, C. and Miller,Jr. J.F. Perceptual phenomena and evoked potentials resulting from binocular stimulation with flickering light, 1965, Sperry-Rand Research Center, Systems Research Dept., Sudbury, Mass. SRRC-RR, 65-101.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 1961, 15, 166-171.

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-8.

Kruper, D. C., Boyle, B., and Patton, R. A. Eye preference in hemi-cerebectomized monkeys. Psychonomic Science, 1967, 7, 105-6.

Levelt, W. M. On Binocular Rivalry. 1965, Soesterberg: Institute for Perception RVO-TNO.

Lindsley, D. B. Bilateral differences in brain potentials from the two cerebral hemispheres in relation to laterality and stuttering. Journal of Experimental Psychology, 1940, 26, 211-225.

Martin, J. I. Effects of binocular fusion and binocular rivalry on cortically evoked potentials. EEG and Clinical Neurophysiology, 1970, 28, 190-201.

Milner, B. Psychological defects produced by temporal lobe excision. Research Publication of the Association for Nervous and Mental Diseases, 1958, 36, 244-57.

Milner, B. In Interhemispheric Relations and Cerebral Dominance. Ed. Mountcastle V.B., P.180. John Hopkins Press: Baltimore, 1962.

Milner, B. Visual recognition and recall after right temporal lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Milner, B., Branch, C. and Rasmussen, T. Observations of cerebral dominance. In Ciba Foundations symposium on disorders of language. Eds. A.V.S. de Rueck and M.O'Conner, London: Churchill., 1964.

Minucci and Conners, 1964, USN Subm. Med. Cent. Res. Rep. No. 33.

Mishkin, M. In Inter-Hemispheric relations and cerebral dominance (Ed) John Hopkins Press: Baltimore, 1962.

Mishkin, M. and Forgays, D. G. Word recognition as a function of retinal locus. Journal of Experimental Psychology, 1952, 43, 43-8.

Mishkin, M., and Pribram, K. H. Visual discrimination performance following partial ablations of the temporal lobe: I. Ventral vs. lateral. Journal of Comparative Physiological Psychology, 1954, 47, 14-20.

Mountcastle, V. B. Inter-hemispheric relations and cerebral dominance. (Ed) John Hopkins Press: Baltimore, 1962.

Ogle, K. N. Researches in binocular vision. 1964, Hafner Publ. Co. N.Y.

Penfield, W. and Roberts, L. Speech and Brain Mechanisms. Princeton: Princeton University Press, 1959.

Robinson, D. A. and Fuchs, A. F. Eye movements evoked by stimulation of frontal eye fields. Journal of Neurophysiology, 1969, 32, 637-48.

Ryan, T. A. Multiple comparisons in psychological research. Psychological Bulletin, 1959, 56, 26-47.

Ryan, T. A. Significance tests for multiple comparison of proportions, variances and other statistics. Psychological Bulletin, 1960, 57, 318-28.

Sampson, H. Immediate memory and simultaneous visual stimulation. Quarterly Journal of Experimental Psychology, 1964, 16, 1-10.

Sampson, H. and Horrocks, J. B. Binocular rivalry and immediate memory. Quarterly Journal of Experimental Psychology, 1967, 19, 224-31.

Sampson, H. and Spong, P. Handedness, eye dominance and immediate memory. Quarterly Journal of Experimental Psychology, 1961, 8, 173-80.

Schoen, Z. J., and Scofield, C. F. A study of the relative neuromuscular efficiency of the dominant and non-dominant eye in binocular vision. Journal of General Psychology, 1935, 12, 156-81.

Schulhoff, C. and Goodglass, H. Dichotic listening, side of brain injury and cerebral dominance. Neuropsychologia, 1969, 7, 149-160.

Sperry, R. W. Mental unity following surgical disconnection of the cerebral hemispheres. In, The Harvey Lectures. Series 62, 293-323, N.Y.: Academic Press, 1968.

Subirana, A. and Oller-Daurella, L. Laterality, maturity and EEG. Current problems in phonietrics, 1960, 1, 141.

Teuber, H.L. Interhemispheric Relations and Cerebral Dominance. Ed. Mountcastle, V.B. 1962, P. 146.

Walls, G. L. A theory of ocular dominance. AMA Archives of Ophthalmology. 1952.

Warrington, E. K. and Rabin, P. A preliminary investigation of the relation between visual perception and visual memory. Cortex, 1970, 6, 87.

Weinstein, S. Interhemispheric Relations and Cerebral Dominance. Ed. Mountcastle, V.B., John Hopkins Press: Baltimore, 1962.

White, M. J. Laterality differences in perception: a Review. Psychological Bulletin, 1969, 72, 387-405.

White, A. M., and Dallenback, K. M. Position vs. intensity as a determinant of the attention of left handed observers. American Journal of Psychology, 1932, 44, 175-9.

Wyke, M. and Ettlinger, G. Efficiency of recognition in left and right visual fields. Archives of Neurology, 1961, 5, 659-65.

Woodworth, R. S. and Schlosberg, D. Experimental Psychology, 1965, Holt: New York, P. 16-17.

Zurif, E. B. and Bryden, M. P. Familial handedness and left-right differences in auditory and visual perception. Neuropsychologica, 1969, 7, 179-187.

TABLE 1

Dominance Weights

(Left side only)

| Subject No. | Rivalry Method: Whole Eye | Rivalry Method: Left Field | Rivalry Method: Right Field | Rivalry Method: Hemi-sphere | Brightness Matching Method: Whole Eye | Brightness Matching Method: Left Field | Brightness Matching Method: Right Field | Brightness Matching Method: Hemi-sphere | Lateral Eye Move. | Handed-ness | Sighting Eye |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.55 | 0.51 | 0.56 | 0.47 | 0.45 | 0.46 | 0.44 | 0.45 | 0.67 | 0 | 1 |
| 2 | 0.55 | 0.46 | 0.49 | 0.53 | 0.50 | 0.53 | 0.50 | 0.55 | 0.50 | 1 | 1 |
| 3 | 1.00 | 0.52 | 0.59 | 0.49 | 0.45 | 0.42 | 0.57 | 0.52 | 0.67 | 1 | 1 |
| 4 | 0.47 | 0.45 | 0.59 | 0.53 | 0.46 | 0.51 | 0.52 | 0.47 | 0.33 | 1 | 0 |
| 5 | 0.52 | 0.53 | 0.53 | 0.50 | 0.58 | 0.50 | 0.47 | 0.59 | 0.33 | 1 | 0 |
| 6 | 0.56 | 0.44 | 0.53 | 0.50 | 0.53 | 0.51 | 0.52 | 0.51 | 0.17 | 1 | 1 |
| 7 | 0.59 | 0.47 | 0.51 | 0.51 | 0.41 | 0.41 | 0.47 | 0.51 | 0.83 | 1 | 1 |
| 8 | 0.44 | 0.47 | 0.45 | 0.47 | 0.43 | 0.36 | 0.45 | 0.52 | 1.00 | 0 | 0 |
| 9 | 0.44 | 0.35 | 0.30 | 0.47 | 0.45 | 0.49 | 0.44 | 0.48 | 0.33 | 0 | 0 |
| 10 | 0.50 | 0.46 | 0.53 | 0.51 | 0.48 | 0.49 | 0.57 | 0.53 | 0.67 | 1 | 0 |
| 11 | 0.56 | 0.48 | 0.53 | 0.50 | 0.50 | 0.49 | 0.51 | 0.53 | 0.33 | 0 | 0 |
| 12 | 0.45 | 0.54 | 0.45 | 0.51 | 0.49 | 0.50 | 0.43 | 0.55 | 0.53 | 1 | 0 |
| 13 | 0.54 | 0.52 | 0.51 | 0.48 | 0.48 | 0.53 | 0.50 | 0.49 | 0.33 | 0 | 0 |
| 14 | 0.11 | 0.40 | 0.41 | 0.48 | 0.44 | 0.54 | 0.42 | 0.45 | 0.33 | 0 | 0 |
| 15 | 0.50 | 0.51 | 0.52 | 0.51 | 0.49 | 0.54 | 0.47 | 0.47 | 0.33 | 0 | 0 |
| 16 | 0.50 | 0.31 | 0.59 | 0.66 | 0.49 | 0.53 | 0.52 | 0.42 | 0.50 | 0 | 0 |
| 17 | 0.50 | 0.41 | 0.54 | 0.48 | 0.45 | 0.47 | 0.61 | 0.49 | 0.67 | 0 | 0 |
| 18 | 0.56 | 0.51 | 0.54 | 0.53 | 0.48 | 0.48 | 0.55 | 0.48 | 0.33 | 0 | 0 |
| 19 | 0.43 | 0.40 | 0.45 | 0.48 | 0.43 | 0.49 | 0.46 | 0.58 | 0.33 | 0 | 0 |
| 20 | 0.47 | 0.46 | 0.50 | 0.51 | 0.55 | 0.56 | 0.47 | 0.52 | 0 | 1 | 0 |

TABLE 2

Unrestricted Dominance Weights

by Brightness Matching Method

| | Eyes | | Left Visual Field | | Right Visual Field | |
|---|---|---|---|---|---|---|
| Subject No. | Left Eye | Right Eye | Left Eye | Right Eye | Left Eye | Right Eye |
| 1 | 0.47 | 0.57 | 0.45 | 0.53 | 0.43 | 0.55 |
| 2 | 0.48 | 0.48 | 0.51 | 0.45 | 0.51 | 0.50 |
| 3 | 0.44 | 0.53 | 0.41 | 0.58 | 0.55 | 0.42 |
| 4 | 0.47 | 0.54 | 0.54 | 0.51 | 0.50 | 0.46 |
| 5 | 0.57 | 0.41 | 0.49 | 0.50 | 0.45 | 0.50 |
| 6 | 0.51 | 0.45 | 0.52 | 0.50 | 0.52 | 0.47 |
| 7 | 0.42 | 0.61 | 0.38 | 0.54 | 0.45 | 0.51 |
| 8 | 0.44 | 0.59 | 0.37 | 0.64 | 0.44 | 0.54 |
| 9 | 0.44 | 0.55 | 0.48 | 0.51 | 0.42 | 0.54 |
| 10 | 0.50 | 0.53 | 0.48 | 0.51 | 0.56 | 0.42 |
| 11 | 0.50 | 0.49 | 0.49 | 0.50 | 0.49 | 0.46 |
| 12 | 0.49 | 0.51 | 0.50 | 0.50 | 0.40 | 0.54 |
| 13 | 0.48 | 0.51 | 0.54 | 0.49 | 0.50 | 0.50 |
| 14 | 0.43 | 0.54 | 0.54 | 0.47 | 0.39 | 0.53 |
| 15 | 0.50 | 0.52 | 0.55 | 0.47 | 0.46 | 0.51 |
| 16 | 0.47 | 0.50 | 0.55 | 0.49 | 0.48 | 0.45 |
| 17 | 0.43 | 0.53 | 0.89 | 1.00 | 0.65 | 0.41 |
| 18 | 0.48 | 0.53 | 0.49 | 0.52 | 0.54 | 0.44 |
| 19 | 0.43 | 0.58 | 0.50 | 0.53 | 0.45 | 0.52 |
| 20 | 0.56 | 0.45 | 0.57 | 0.45 | 0.45 | 0.51 |

TABLE 3

Correlations of Dominance Weights

| | Variables 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Rivalry Method | | | | | | | | |
| 1 Whole Eye | 1.00 | | | | | | | |
| 2 Left Field | .29 | 1.00 | | | | | | |
| 3 Right Field | .53 | .23 | 1.00 | | | | | |
| 4 Hemisphere | .09 | -.39 | .44 | 1.00 | | | | |
| Brightness Matching Method | | | | | | | | |
| 5 Whole Eye | .01 | .45 | .17 | .11 | 1.00 | | | |
| 6 Left Field | -.39 | -.03 | -.02 | .30 | .58 | 1.00 | | |
| 7 Right Field | .50 | .05 | .60 | .23 | .10 | -.05 | 1.00 | |
| 8 Hemisphere | .18 | .23 | -.15 | -.33 | .20 | -.18 | -.06 | 1.00 |
| 9 Lateral Eye Move. | .18 | .20 | .03 | -.10 | -.45 | -.72 | .02 | .05 |
| 10 Handedness | .33 | .31 | .22 | .06 | .39 | .04 | .14 | .47 |
| 11 Sighting Eye | .42 | .41 | .16 | -.11 | .15 | -.14 | .09 | -.03 |
| Difference Measure ($W_L - W_R$) | | | | | | | | |
| 12 Whole Eye | .01 | .45 | .17 | .11 | 1.00 | .59 | .11 | .19 |
| 13 Left Field | -.18 | -.10 | -.05 | .32 | .35 | .70 | -.06 | .10 |
| 14 Right Field | .48 | .02 | .58 | .23 | .08 | -.04 | 1.00 | -.04 |
| Absolute Sensitivity ($W_L + W_R - 1$) | | | | | | | | |
| 15 Whole Eye | .07 | -.14 | -.04 | .18 | -.00 | .14 | .01 | .28 |
| 16 Left Field | .07 | -.17 | -.03 | .18 | -.02 | .13 | .06 | .28 |
| 17 Right Field | .07 | -.13 | -.04 | .18 | .01 | .14 | .02 | .28 |

Table 3 (Continued)

Correlations of Dominance Weights

| | Variables | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Rivalry Method | | | | | | | | | |
| 1 Whole Eye | | | | | | | | | |
| 2 Left Field | | | | | | | | | |
| 3 Right Field | | | | | | | | | |
| 4 Hemisphere | | | | | | | | | |
| Brightness Matching Method | | | | | | | | | |
| 5 Whole Eye | | | | | | | | | |
| 6 Left Field | | | | | | | | | |
| 7 Right Field | | | | | | | | | |
| 8 Hemisphere | | | | | | | | | |
| 9 Lateral Eye Move. | 1.00 | | | | | | | | |
| 10 Handedness | .03 | 1.00 | | | | | | | |
| 11 Sighting Eye | .24 | .40 | 1.00 | | | | | | |
| Difference Measure ($W_L$-$W_R$) | | | | | | | | | |
| 12 Whole Eye | -.45 | .39 | .15 | 1.00 | | | | | |
| 13 Left Field | -.44 | .20 | .09 | .37 | 1.00 | | | | |
| 14 Right Field | .26 | .14 | .09 | .09 | .00 | 1.00 | | | |
| Absolute Sensitivity ($W_L$+$W_R$-1) | | | | | | | | | |
| 15 Whole Eye | .00 | .22 | .01 | .01 | .80 | .08 | 1.00 | | |
| 16 Left Field | .01 | .20 | -.01 | -.01 | .78 | .14 | .99 | 1.00 | |
| 17 Right Field | .00 | .22 | .01 | .01 | .80 | .10 | 1.00 | 1.00 | 1.00 |

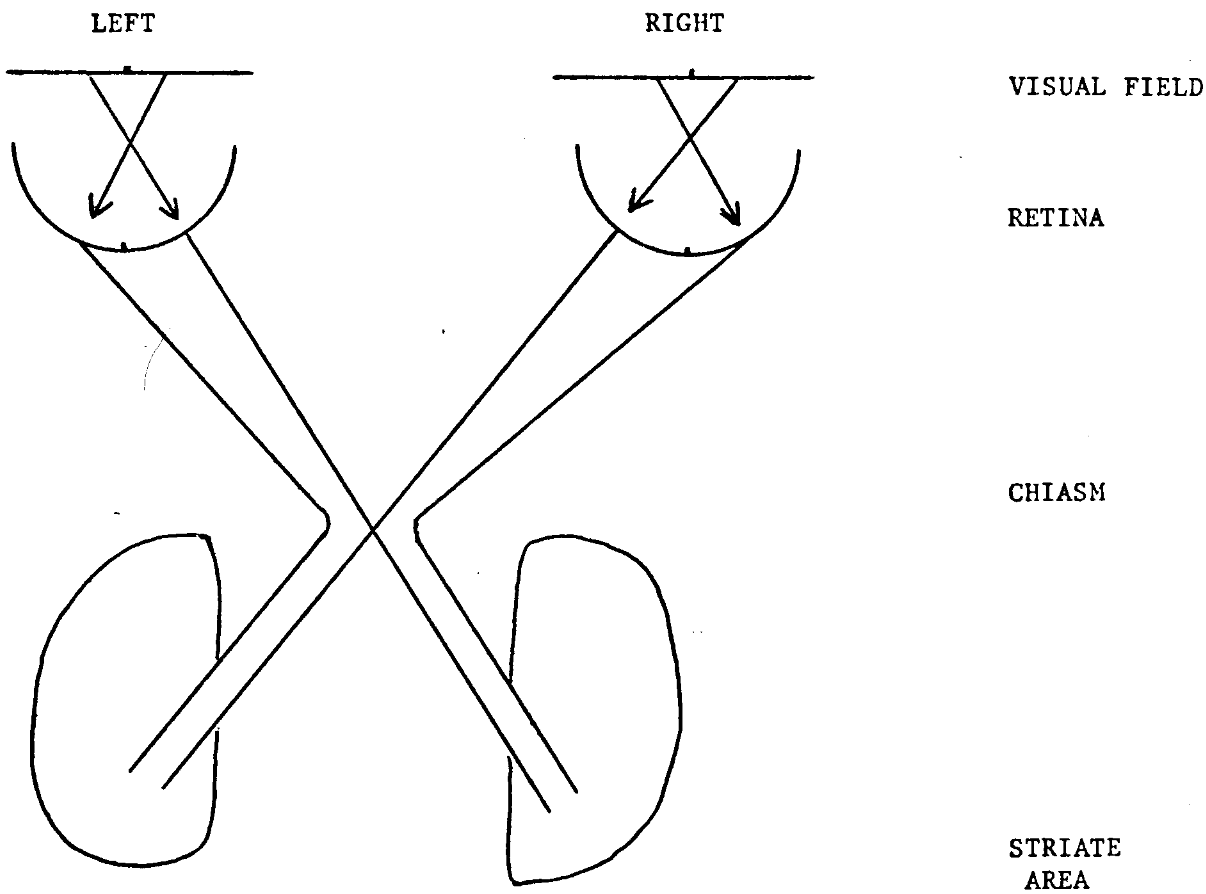
# APPENDIX I

In order to test the possibility that a bias may exist in the visual fields of the tachistoscope, the extent of the errors made in matching the brightness stimuli in the right and left fields were compared.

Since a simple linear regression program was readily available, regression lines were fitted to the data points of subjects in the brightness matching conditions RVF and LVF. The program gave the standard error of linear regression. The fixed V.S. was considered as the independent variable and the adjustable V.S. as the dependent variable for the purpose of fitting the regression line.

A 't' test for correlated samples showed the difference between the errors in the right and left field conditions to be non-significant ($t = 1.12$, $p < 0.20$, 19 degrees of freedom).

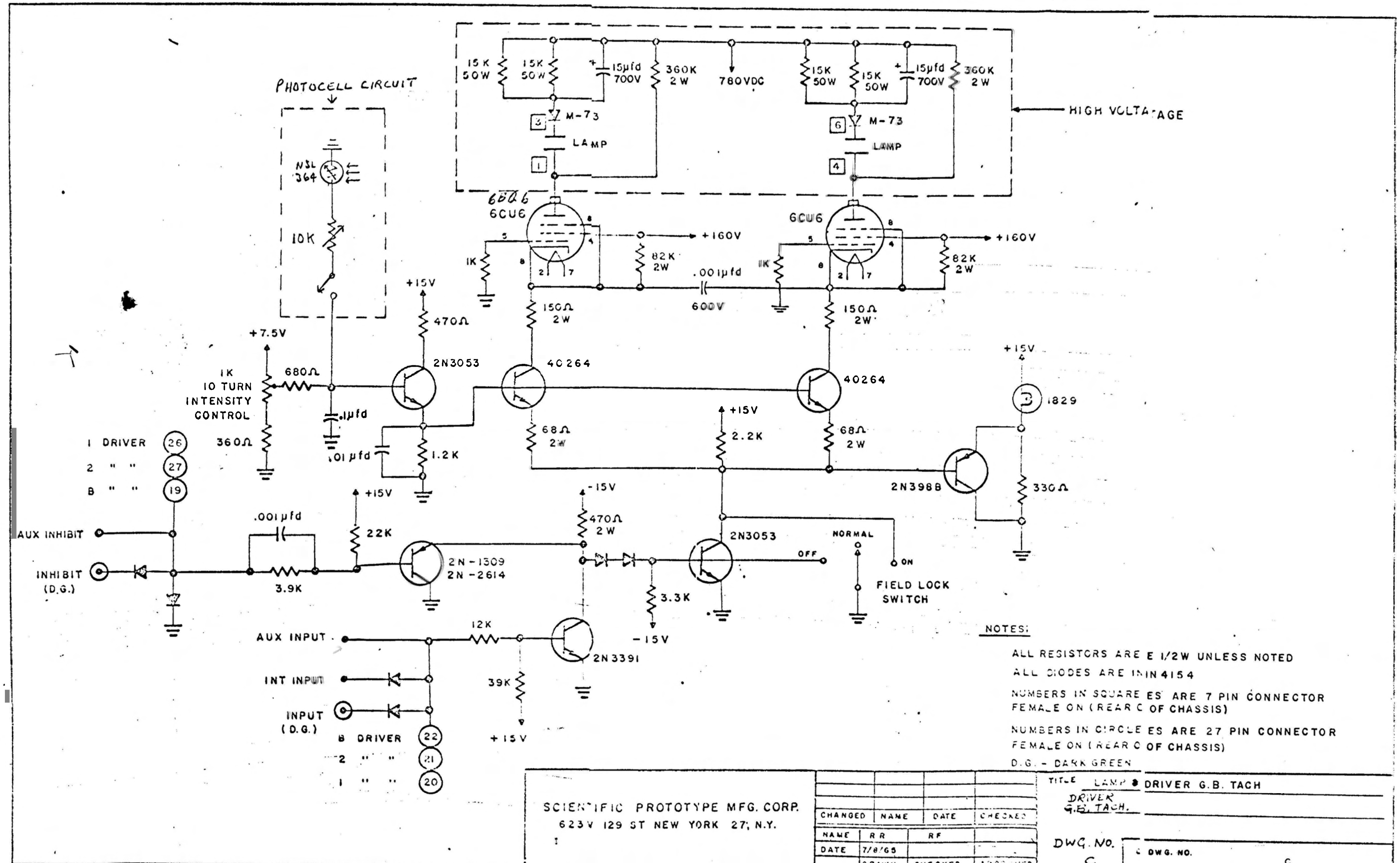
As far as the range of error in matching the brightness of the stimuli in the right and left fields is related to possible bias in the fields it appears that no bias exists between the two fields.




HUMAN VISUAL SYSTEM

Figure 1.

APPENDIX II


PHOTOCELL CIRCUIT
NSL 364
10K
HIGH VOLTAGE
15K 50W
15K 50W
15µfd 700V
360K 2W
780VDC
M-73
LAMP
6BQ6
6CU6
+160V
82K 2W
1K
.001µfd 600V
150Ω 2W
68Ω 2W
40264
2N3053
470Ω
+15V
+7.5V
680Ω
1K 10 TURN INTENSITY CONTROL
360Ω
.1µfd
.01µfd
1.2K
2.2K
1829
2N3988
330Ω
1 DRIVER 26
2 " " 27
B " " 19
AUX INHIBIT
INHIBIT (D.G.)
.001µfd
3.9K
22K
2N-1309 2N-2614
-15V
470Ω 2W
3.3K
2N3053
NORMAL
OFF
ON
FIELD LOCK SWITCH
AUX INPUT
12K
2N3391
INT INPUT
39K
INPUT (D.G.)
B DRIVER 22
2 " " 21
1 " " 20
+15V
NOTES:
ALL RESISTORS ARE 1/2W UNLESS NOTED
ALL DIODES ARE IN 4154
NUMBERS IN SQUARES ARE 7 PIN CONNECTOR FEMALE ON REAR OF CHASSIS)
NUMBERS IN CIRCLES ARE 27 PIN CONNECTOR FEMALE ON (REAR OF CHASSIS)
D.G. - DARK GREEN
SCIENTIFIC PROTOTYPE MFG. CORP.
623 W 129 ST NEW YORK 27, N.Y.
CHANGED NAME DATE CHECKED
NAME RR RF
DATE 7/8/65
DRAWN CHECKED APPROVED
TITLE LAMP DRIVER G.B. TACH
DWG. NO. C