REACTION TIME TO HEMIRETINAL STIMULATION

by

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For a number of years investigators have been searching for techniques of use in researching brain function in normal subjects as well as benign methods of detecting brain lesions in subjects who have possible brain damage. Dichotic listening is one such technique. Now that relationships have been demonstrated between the differential ear effect found in dichotic listening and functional anomalies formerly reported in a number of brain damaged patients further efforts have been directed to refining this technique as a method of discovering brain damage and determining undiscovered aspects of brain function in normal subjects. However, even before this correspondence could be made it was necessary to show that the contralateral auditory fibers "dominate" the auditory system. This was accomplished by drawing inferences from animal and human neurophysiological and antomical research and by conducting further investigations in this area.

The impetus for the study contained herein comes from the idea that tachistoscopic research provides another area useful in the study of brain-function relationships. Attempts to show a strong correspondence between the findings from tachistoscopic recognition and memory studies have, however, been beset with difficulty. This is due to the fact that differential field effects resulting from such studies are inconsistent and therefore have resulted in a variety of explanations other than that of lateral cerebral dominance. It is proposed that this is due to a lack of understanding of the role of contralateral/ipsilateral optic fiber relationships. The purpose of this study was to support the hypothesis that the contralaterial optic fibers "dominate" the ipsilateral optic fibers. This was accomplished by using reaction time to hemiretinal stimulation as a dependent variable in a "tachistoscopic type situation". Further, a preliminary study was conducted due to the belief that another problem contributing to the inconsistent tachistoscopic findings has been and is the lack of a good method for the control of fixation during stimulation.

In Experiment I a monocular lens mounted behind a stimulus screen was used to monitor fixation in a tachistoscopic recognition task. This technique was found superior to the often used "sideview" and as accurate as the method involving identification of a fixation stimulus. It was found that the "telescope technique" is preferable in those studies where presentation of a fixation stimulus might interfere with recognition or report of the experimental stimulus. This was the technique used to monitor fixation in Experiment II.

In Experiment II two independent Kodak carousel 35 mm projectors were used for stimulus presentation. Stimulus slides were presented with one projector while the other projector was used to present a symmetrical cross fixation marker in the center of the screen and to maintain a constant illumination level. The subject's task was to depress a standard telegraph key as rapidly as possible when he detected the presence of a small spot of light projected during monocular fixation of the central point. The stimulus was projected without warning and due to adequate auditory masking and projector position there was no possibility for anticipatory responses. The most important finding was a highly superior reaction time to contralateral as opposed to ipsilateral stimulation. The difference in reaction time due to contralateral/ipsilateral stimulation was significantly greater than the difference due to dominant/non-dominant hand reaction time.

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Introduction

The primary concern of this study was to demonstrate faster reaction time to contralateral optic fiber stimulation than to ipsilateral. This prediction was based on the hypothesis that the contralateral optic fibers are "superior" to ipsilateral which was in turn based on the premise that human functional neuroanatomy is of mainly contralateral organization. The hypothesis was tested in normal subjects.

The two cerebral hemispheres receive and transmit nervous impulses both ipsilaterally and contralaterally. Human functional neuroanatomy is, however, mainly of contralateral organization, particularly for the major systems. The pyramidal tract, serving to transmit efferent messages from the precentral gyrus to the muscles, consists of approximately eighty per cent crossed and twenty per cent uncrossed fibers. The uncrossed fibers of the anterior pyramidal tract are thought to end on the anterior horn, mostly on the motor neurons innervating the musculature of the trunk (Bucy, 1949), but the crossed fibers innervate the rest of the musculature. Afferent messages are also transmitted via the crossed fibers (Ruch and Patton, 1946).

The connections for audition and vision are more complex in that messages from each ear or eye pass to both sides of the brain. If one hypothesizes that the nervous system is predominately of contralateral organization it is of theoretical import to determine the relative strength of ipsilateral and contralateral contribution in such systems.

Knowledge of fiber connections has been used to make inferences about differential hemispheric functioning for tests such as tactual sensitivity of the palms, forearms and soles (Ghent, 1961; Ghent, Weinstein, Semmes and Teuber, 1955; Semmes, Weinstein, Ghent and Teuber, 1954; Weinstein, 1954, 1955 a, b; Weinstein and Sersen, 1961). Similarly, knowledge of the relative contributions of crossed (contralateral) or uncrossed (ipsilateral) auditory and optic fibers could strengthen and clarify the interpretation of findings in studies of these sense modalities.

Investigators in the area of audition in general, and dichotic listening in particular, have drawn inferences about brain functioning based on the assumption that the contralateral auditory fibers are 'stronger' than or 'superior' to the ipsilateral.

The dichotic listening paradigm consists of the simultaneous presentation of different stimuli to the two ears. Dichotic listening studies have shown that verbal stimuli such as words, letters or digits are more efficiently reported from the right ear (Bakker, 1967; Borkowski, Spreen and Statz, 1965; Broadbent and Gregory, 1961; Bryden, 1969; Kimura, 1961 a, b, 1963; Shankweiler, 1966). A left ear superiority has, on the other hand, been shown for melodies (Kimura, 1964; Shankweiler and Studdert-Kennedy, 1966; Spellacy, 1970), sonar sounds (Chaney and Webster, 1966), Morse signals (Bakker, 1967, 1970), environmental sounds (Curry, 1967) and music and tonal patterns (Spreen, Spellacy and Reid, 1970).

The right ear superiority for verbal material has been related to a left hemisphere cerebral dominance for speech while the left ear superiority for musical and other such non-verbal stimuli has been related to a right hemisphere dominance for such material. Since, the superior recognition of "verbal" and "non-verbal" stimuli occurs in the ear opposite to the hemisphere dominant for that function one must invoke the unifying assumption of a greater contralateral fiber "efficiency" (Kimura, 1961 a, b). This assumption is supported by neuroanatomical and physiological data (Ades and Brookkart, 1950; Rosenzweig, 1951; Rosenzweig and Wyers, 1955; Tunturi, 1946) which shows a superiority for the contralateral auditory fibers.

Known hemispheric functions in combination with auditory pathway transmission characteristics provide for an extremely powerful technique for the assessment of hemispheric laterality functions in both brain damaged and normal subjects. This is evidenced by the fact that dichotic listening is considered a useful technique for detecting lateralized lesion effects and for exploring the range of differential hemispheric functioning (Kimura, 1961 a, b). A similar conceptualization is proposed to account for differential tachistoscopic recognition.

The visual pathway and visual field projections are shown for monocular fixation in Figure 1. As shown, a stimulus in the right visual field traverses the contralaterlateral pathway of the right eye and the ipsilateral pathway of the left eye, to the left occipital cortex. Similarly, a stimulus in the left visual field traverses the contralateral pathway of the left eye and the ipsilateral pathway of the right eye, to the right occipital cortex.

The visual system like the auditory, is hypothesized to be dominated by the contralateral fibers. The nature of relative fiber superiority will be considered in terms of; (1) differential activation of cortical units, and; (2) speed of nervous transmission. Relative suppressive influences of one fiber group over the other will not be immediately considered in terms of electrophysiological and anatomical data. Some indirect evidence, indicating suppression of ipsilateral impulses by contralateral, will be considered subsequently in discussing simultaneous tachistoscopic visual stimulation.

There is some anatomical, and physiological evidence indicating that stimulation of the contralateral optic fibers leads to the activation of more cortical units in the contralateral hemisphere than does similar stimulation of the temporal projections to the ipsilateral hemisphere (Doty, 1958; Hubel and Weisel, 1959, 1962). Doty (1958) has found that the highest electrical response in the cat cortex, to both diffuse and punctiform photic stimuli, was in an area adjacent to area striata. The largest and earliest "on" potentials occurred more often for right field stimulation of the right eye and left field stimulation of the left eye. Stimuli presented in these areas are projected to the opposing cortex via the contralateral fibers for each eye respectively. Hubel and Wiesel (1959) found very little cortical unit driving from diffuse stimulation. However, for stimuli specific in form, size, position and orientation they found that "of the forty-five units studied, thirty-six were driven from only one eye, fifteen from the ipsilateral eye and twenty-one from the contralateral. The remaining nine could be driven from the two eyes independently (Hubel and Wiesel, 1959, p. 590)". There is some data indicating that the preceeding is the case for both "complex" and "simple" cortical units (Hubel and Wiesel, 1962). Greater activation of cortical units is consistent with the fact that the nasal fibers constitute approximately three-quarters of all the fibers (Polyak, 1957).

There are also indications that nervous transmission is more rapid

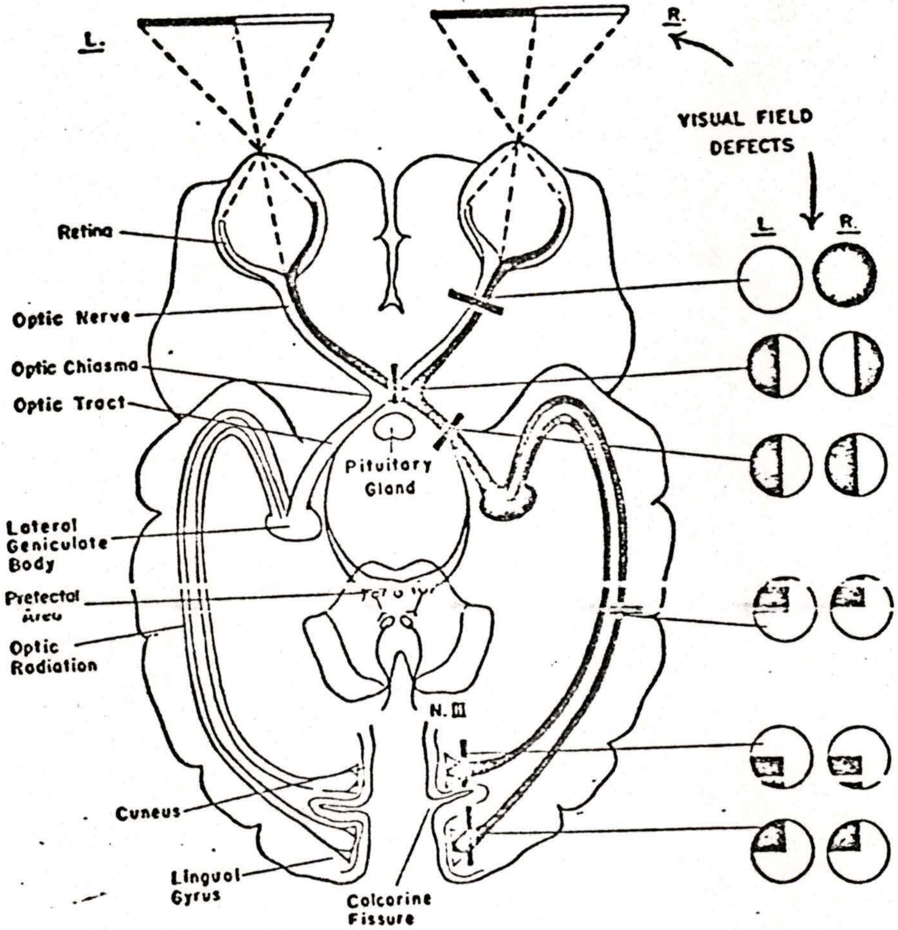

Fig. 1. The visual pathway. On the right are maps of the visual fields with areas of blindness darkened to show the effects of injuries in various locations. (Taken from Gatz, A. J. Manter's Essentials of Clinical Neuroanatomy and Neurophysiology. Philadepphia, F. A. Davis Co., 1970, page 85).

in the contralateral pathways. An estimate of nervous transmission speed has been obtained for human subjects by determining the probabilaties of a correct depth response from stereoline presentations at different relay times. Transmitting speed was inferred to be about 1.5 milliseconds faster for nasal fiber transmission (Bower, 1966).

Reaction time is consistent with more rapid contralateral nervous transmission since it is faster following nasal than temporal visual stimulation (Hall and Kries, 1897; Poffenberger, 1912). Reaction time data may also be consistent with relative cortical unit activation since it is both directly proportional to latency of evoked potentials and inversely proportional to amplitude of evoked potentials (Eason, Oden and White, 1967).

Regarding tachistoscopic research, most people show superior right field recognition for unilateral presentations of alphabetical stimuli (English) such as letters, nonsense syllables, and words, as well as for digits (Barton, Goodglass and Shai, 1965; Bryden, 1964, 1965, Forgays, 1953; Goodglass and Barton, 1963; Harcum and Finkle, 1963; Harcum and Jones, 1962; Heron, 1957; McKeever and Huling, 1970; Mangan, 1963; Mishkin and Forgays, 1952; Orbach, 1953, 1967; Terrace, 1959; Winnick and Dornbush, 1965). A right field superiority has also been shown for unilateral (Bryden and Rainey, 1963; Wyke and Ettlinger, 1961) and for bilateral (Wyke and Ettlinger, 1961) presentations of drawings of familiar objects. However, if letters, simple geometrical figures and nonsense forms are presented simultaneously on both sides they are identified more accurately in the left visual field (Bryden, 1960; Heron, 1957).

Left field superiority for right handers has been found for subjective attensity of circular areas (Dallenbach, 1923; Kirssin and Harcum, 1969), simultaneous exposure of both letters and forms (Bryden, 1960), and location of a dot on a spatial map (Kimura, 1969). Superior left field recognition, although usually non-significant, has also been found for Yiddish words and letters (Mishkin and Forgays, 1952; Orbach, 1953, 1967). Equal recognition scores have been found for nonsense forms (Heron, 1957), unfamiliar forms (Terrace, 1959; Bryden, 1960; Bryden and Rainey, 1963) and for familiar forms (Heron, 1957). Terrace, however did find a tendency for a left field superiority. Bryden and Rainey (1963) also presented letters, geometric forms and outline drawings, bilaterally, and found the subjects' recall to be considerably greater for elements appearing in the left visual field.

The basis for the differential tachistoscopic recognition has been examined in terms of cerebral dominance, selective retinal training, directional scanning, selective attention, stimulus structure, Koffka's (1935) anisotrophy of visual space, ocular dominance, visual acuity, and immediate memory. White (1969) covers most of these explanations and discusses relevant findings in his review. Each of these explanations is considered in "Dichotic Listening, Cerebral Dominance and The Tachistoscope" included in Appendix C. An attempt is made to add verisimilitude to a cerebral dominance-contralateral fiber superiority explanation. However, the purpose of this study is to consider the optic fibers themselves with the results finding theoretical relevance to the aforementioned controversy. More of the above data can be accounted for by a cerebral dominance explanation assuming the contralateral optic fibers dominate the ipsilaterial. Hence, the purpose of the study is to demonstrate contralateral superiority.

Simultaneous tachistoscopic exposure of a series of paired visual stimuli is analogous in form to the dichotic listening procedure. Simultaneous binocular presentation creates an input competition which, of course, does not occur in successive prsentation. Bower and Haley (1964) presented ten digit pairs, one of each pair to opposite eyes simultaneously, the subjects' task being to report all the digits they could see. The results showed that the digits reported were either ones projected to the nasal hemiretinae or to the dominant eye. Resolution in favour of the dominant eye has also been found by Anderson and Crosland (1933), Sampson and Horrocks (1967) and Sampson (1969). The relative ineffectiveness in recall for digits projected to the non-dominant eye when eight digits in four pairs were presented simultaneously, one to each eye (Sampson, 1969) has been attributed to the inefficient recall of digits projected to the left temporal retina. Sampson (1969), confirming Bower and Haley (1964) also found significantly better recall for digits projected to the nasal retinae. The order of efficiency of recall was right nasal, left nasal, right temporal, and left temporal (Sampson, 1969).

A superior nasal sensitivity has also been indicated for complex stimulus patterns in which the subject's task was to attempt a reproduction of the pattern which was presented in the left and right halves of the visual field during central fixation (Harcum and Dyer, (1962). In accordance with findings mentioned earlier for pattern-type stimuli, there was superior accuracy for the left-field elements.

Sampson and Spong (1961 a) report results for simultaneous exposure of four digit pairs during binocular fixation. Significantly more digits were recalled from the right eye (the dominant for all subjects) but this was only in a non-fixation control condition. There was no difference during central fixation. Recall was best from binocular fixation and nasal projection. Furthermore, digits projected to the left eye were reported significantly more slowly than those from the right eye. These results are in line with a cerebral dominance-contralateral fiber superiority explanation.

The relative efficiency of different retinal fibers has also been considered in monocular tachistoscopic experiments. Overton and Wiener (1966) have attributed a right field superiority for words to a more sensitive temporal hemi-retina of the left eye. This was based on the finding that words in the right field showed better recognition for the left eye, but there was no difference between the fields for the right eye. This finding is probably anomalous since Goodglass and Barton (1962), Goodglass and Shai (1966) and McKeever and Huling (1970 a, b) have all found significantly superior right field recognition for both eyes. McKeever and Huling (1970 b) report the same result with children.

McKeever and Huling (1970 a) found that crossed optic nerve fibers resulted in poorer recognition scores than uncrossed for words. It is important to note, however, that "actually this inferiority was restricted to the right hemisphere since the mean score for nasal fibers was actually slightly higher than for temporal fibers to the left hemisphere. Although the right hemisphere fiber score difference was fairly large, it was also quite variable and not significant by t test

(McKeever and Huling, 1970 a)." McKeever and Huling (1970 b) did not find a strong "fiber effect" although their data indicate a superior crossed connection since there was a slightly greater field differential in the right eye than in the left eye.

These findings, in combination with the differential superiorities observed in dichotic listening studies, are consistent with the postulate that the left and right hemispheres differ on a verbal - non-verbal dimension. In any case, it appears that invoking a cerebral dominance/ contralateral fiber superiority hypothesis to account for differential tachistoscopic recognition results in unification of the findings from clinical observations of the results of brain lesions, dichotic listening studies, and tachistoscopic recognition.

The purpose of this study was to re-affirm findings (Hall and Kries, 1897; Poffenberger, 1912) which show faster reaction time to contralateral stimulation than to ipsilateral by using a more powerful experimental design due to a greater number of subjects and improved apparatus.

The Hall and Kries (1897) study was considered by Poffenberger (1912) to be only an indication of superior reaction time to contralateral stimulation. The author states: "The number of reactions from which the averages are calculated and the mean variations are not given. No statement is made as to whether or not the value for each position is an average of the two eyes for that position (page 43)." Furthermore the previous authors made no effort to either control the stimulus and surround light intensity or record the values. Despite Poffenberger's improvements on the aforementioned points further experimentation was considered necessary for the following reasons:

(1) The surround illumination varied slightly as a function of the time of day and therefore the intensity of light entering through two windows. In this study the surround illumination remained constant.

(2) Stimulation of different points on the subject's retina was achieved by rotation of the subject's body in a revolving reaction chair. In this study the subject remained in the same position at all times. Stimulation of different points on the retina was achieved by the tachistoscope shutter. This was thought to eliminate errors in fixation due to differences in eyeball muscle tension and body movement and errors in retinal stimulation position.

(3) The preparatory signals were verbal and variant whereas in this study they were non-verbal (a tone) automated and invariant.

(4) The device used for stimulation was a circular drum which revolved by means of an electric motor and v-belt. This device was visible to the subject as well as audible which would create unnecessary distraction. The nature of the device would create errors in exposure time and drum revolution time. A more accurate device to be described was used in this study. It was neither visible nor audible to the subject.

(5) A Hipp chronoscope was used to record reaction time. A more accurate timer, standardized against an oscilloscope was used to record reaction time in this study.

(6) Poffenberger used no method for monitoring fixation. A new method for monitoring fixation was used in this study.

(7) Poffenberger repeatedly tested four subjects two of whom were well trained in reaction time work and two of whom had served as subjects at various other times. This study involved forty subjects equally divided into four different groups according to handedness and eyed-ness. This

was done to allow more generalization. Further, these subjects received adequate practise but were not repeatedly tested. This was to demonstrate that the hypothesized contralateral fiber "superiority" would occur in the time usually alloted for a subject in a tachistoscopic test of laterality and despite the variability doubtless incurred from minimally adequate practise.

Furthermore, since the hypothesis under test was considered to be an important variable in tachistoscope research it was thought necessary to demonstrate it under conditions similar to tachistoscopic tests of laterality involving such considerations as distance from the screen, laterality of stimulation and apparatus.

The design of this study allowed for a more adequate statistical analysis than did the Poffenberger study.

Hypotheses

Hypothesis One

There is no difference in reaction time between right handed and left handed subject groups.

Hypothesis Two

There is no difference in reaction time between right eye and left eye dominant subject groups.

Hypothesis Three

The above between subject factors do not interact.

Hypothesis Four

Reaction time is significantly faster to contralateral than to ipsilateral stimulation.

Hypothesis Five

Reaction time is significantly faster when a subject is reacting with his dominant versus his non-dominant hand.

Hypothesis Six

The above within subject factors do not show a significant interaction of optic fiber X reacting hand meaning that there is not a differential effect on contralateral optic fiber X reacting hand. Moreover, it it is hypothesized that the eye fiber factor is of greater importance than the reacting hand factor. This results in the prediction that reaction times show the order contralateral X dominant hand < contralateral X non-dominant hand < ipsilateral X dominant hand < ipsilateral X non-dominant hand where (<) indicates faster reaction times.

Experiment I

AN IMPROVED TECHNIQUE FOR MONITORING FIXATION IN TACHISTOSCOPE STUDIES

A number of research problems, such as those concerned with differential visual perception and memory, involve the presentation of visual stimuli to various portions of the retina (see White, 1969, for a review). Such procedures require that the subject look at a fixation point during visual stimulation. Since there is no way to force the subject to fixate for every trial, some method must be used to identify and eliminate those trials for which the subject was not fixated.

One technique, adapted from Sperry (1968), requires that the subject identify numbers projected at the fixation point. The stimulus duration for these numbers is usually above threshold but below the latency of eye movements to a stimulus lateral to fixation. The latter latency is between 125 and 235 milliseconds (Woodworth, 1938; Crovitz and Daves, 1962). Therefore unless the subject is looking at the fixation point he cannot report the fixation stimulus. The trials in which the subject cannot report the stimulus are rejected (for example, see McKeever and Huling, 1970 a, b; 1971).

Another procedure is to have an observer watch the subject from a position slightly to the side and in front of him. Presentation in which, in the opinion of the observer, the subject was not fixated are rejected (for example, see Mishkin and Forgays, 1952; Forgays, 1953; Orbach, 1953, 1967).

While the first procedure is generally considered to be more accurate, it has a major disadvantage. The naming of the fixation stimulus might interfere with the subject's recognition or report of the experimental stimulus so that it would be undesirable for the subject to have a fixation stimulus presented.

This report describes a method of checking fixation that is as accurate as the fixation stimulus technique, yet requires neither a fixation stimulus nor any response by the subject. A monocular lens was mounted behind a hole in the screen. The subject was required to fixate a small spot of reflected light on the center of the lens face. By viewing the subject through the lens the experimenter was able to accurately observe movements of the subject's pupil, changes in head or eye position, and eye blinking.

Method

Subjects

The subjects were 12 male university students with normal and equal eye acuity (20/20 ± 10). Eight were in Part I and four were in Part II which was a replication of Part I with observer's positions reversed.

Apparatus

The experiment was conducted in a flat black "perception tunnel."

A projection tachistoscope (LaFayette Model T-2K) was used for stimulus presentation at six-second intervals. This tachistoscope consisted of two Kodak carousel 35 mm projectors with 500 watt bulbs. The projectors were adjusted so that the projection field of each completely coincided with projection field dimensions of 48.26 x 78.74 cm. The distance from the projector to the screen was 1.83 m. Stimulus slides were presented with one projector, while the other projector was used to present a symmetrical cross fixation marker in the center of the screen and to maintain constant illumination. Each bar of the cross was 4 cm. long by 1 cm. wide.

The stimuli were projected by a Kodak carousel 750 projector through a special shutter which is controlled by a Gerbrands "300" Series Digital Millisecond Timer. This device allows for stimulus durations as short as

5 milliseconds (± .005%).

The projectors were placed on top of a 152 cm. high, 122 cm. x 122 cm. metal enclosure. A one-inch piece of foam rubber, completely covering the top of the enclosure was placed between the metal and projectors in order to mask vibrations. A desk was attached to the front of the stationary enclosure. The subject sat within the enclosure, with his head held stable by means of Haag/Strat chin-rest and forehead brace mounted on the desk. This arrangement allowed for the projectors to be the same distance to the screen as were the subject's eyes and yet be completely hidden from view.

The actuation of the stimulus shutter initiated a four-second interval in a Hunter Decade Interval Timer (Model 111C). This timer actuated a second timer (Model 111C) which in turn actuated a .75 second fixation warning tone.

The warning tone was presented to the subject through Telex ST-20 Stereo-twin headphones by an EICO-Model 377 Audio Generator. The tone, a 40 db sine wave, interrupted the otherwise continuous white noise used to mask the shutter sounds. The white noise (40 db) was produced by a Marietta Apparatus Company (Style NA-36) White Noise Generator amplified by an EICO (HFIZA) amplifier. The shutter sounds were masked in order to control for auditory anticipation. The tone and white noise intensities were measured with a Scott 200 Sound Level Meter, pressed against the inside of the earphones. There were 37 presentation slides 11 of which were blank. The blank slides were positioned randomly among the 26 actual stimulus slides. The stimulus slides consisted of the numbers 1 through 9 placed on the slides so as to overlay the fixation cross if both were flashed on the screen simultaneously. There were three slides of each number except for the number 1 for which there were two. The stimulus slides were presented in the same randomly selected order for each subject.

The stimuli were presented on a stationary flat black screen affixed to a vertical wood panel. A hole was cut in the screen corresponding with the dimensions of the fixation cross at the fixation point. The hole was large enough to admit an approximately 15 power telescope. The telescope was constructed from a 135 mm. F2.6 Telephoto lens viewed through an Accura T-scope. The front of the telescope lens was in the same plane as the screen. The technique of viewing the subject through the telescope is hereafter referred to as the "Telescope Technique." The telescope allowed one observer to view the pupil of either of the subject's eyes from the same height as the subject's eyes and from the exact spot of required fixation. A 150 watt reflector flood lamp was directed upon the subject from 50^o above and to the side. This provided clear illumination of the subject's pupil.

The second observer ("Side View Technique") sat three feet in front of and to the left of the subject.

Procedure

The subject was first given an eye test (Snellen E Letter Chart; Imperial Optical Limited, Number 2). Subjects who did not have normal and equal-eye acuity ($20/20\pm10$) were eliminated.

The subject was seated immediately beneath the projectors and his head was adjusted to a standard chin rest, so that the corner of each eye was level with a white dot on the sides of the forehead brace. The height of these dots (and, therefore, the subject's eyes) from the floor corresponded exactly to the height from the center of fixation to the floor.

An obliquely raised platform was placed on the desk directly in front of the subject so that he could mark down his response to stimuli, as instructed, without moving his head in the chin rest. The subject was instructed to put a number down if he saw and recognized a number and to put an X down if he did not see or did not recognize a number. Since the subject was marking something down on the sheet every time, neither observer could tell whether or not he had fixated by watching his response to stimuli. For each stimulus, each observer marked on his own recording sheet that the subject was either fixated or not fixated. Furthermore, as an additional control, neither observer could see the other.

Prior to the start of experimental trials the subject was read the instructions for the task and was given a series of five practice trials with a stimulus exposure of 10 msec. The exposure duration was increased by 1 msec. until the subject could correctly report a series of 5 numbers. When the subject reached this criterion, the digital timer was increased by 2 msec. for the experimental trials. This procedure resulted in experimental presentation durations of between 15 and 19 msec. depending on the particular subject.

The definition of subject fixation was a correct report of the number by the subject. The definition of non-fixation was the recording of an X by the subject. There were no ambiguous decisions to make in scoring because examination of the subject's responses revealed that every time a number was marked it was in fact the correct number.

The observer's decision was deemed "correct" when it was consistent with the subject's response, and "incorrect" when it was not. Thus the observer was correct when he classified the subject as fixated and the subject recorded the number, or when he classified the subject as not fixated and the subject recorded and X.

In Part II, the observers switched techniques but the procedure remained as outlined above.

Results

Part I: Original Observer Position

The observer who used the telescope technique was consistently superior in noting whether or not the subject was fixated during presentation. This superiority was due to a difference between the two techniques, rather than a difference in observer ability since the "replication with observer positions reversed" again resulted in superior performance by the telescope observer.

Table 1 presents the number of correct and incorrect decisions made by the sideview observer and the telescope observer. Since there were a number of trials made within each subject the decisions were paired by trials for analysis by the sign test. Those trials for which both observers were correct or incorrect were eliminated. Those trials for which the sideview observer was correct and the telescope observer incorrect were assigned minuses. Those trials for which the telescope observer was correct and the sideview observer incorrect were assigned pluses.

Table 1, Part A, shows that the sideview observer was incorrect a total of 24 times out of 208 trials while the telescope observer was incorrect only 4 times. This difference is particularly striking because in each of 4 times that the telescope observer was incorrect, the sideview observer was also incorrect which resulted in 0 minuses and 20 pluses

($p <.000001$). Furthermore, 3 of the 4 telescope observer errors were made when the subject was fixated and only 1 when he was not fixated. This indicates that the telescope observer was more conservative and, more important, that he was better able to detect non-fixation. A breakdown in terms of paired decisions resulted in 0 minuses with 9 pluses for the fixated trials ($p < .002$) and 0 minuses with 11 pluses for the non-fixated trials ($p <.0005$).

Table 1

Part I: Original Observer Position

Number of correct and incorrect decisions
made by the sideview and telescope observers

	(a)		(b)		(c)	
	Totals		Fixated Trials		Non-fixated Trials	
	Incorrect	Correct	Incorrect	Correct	Incorrect	Correct
SIDEVIEW	24	184	12	180	12	4
TELESCOPE	4	204	3	189	1	15

Part II: Replication with Observer Positions Reversed

	(a)		(b)		(c)	
	Totals		Fixated Trials		Non-fixated Trials	
SIDEVIEW	13	91	7	91	6	0
TELESCOPE	2	102	2	96	0	6

Part II: Replication with Observer Positions Reversed

Table 1, Part 2, presents the number of correct and incorrect decisions made by the sideview observer and the telescope observer after they had reversed positions. The data show a superior performance by the telescope observer. The sideview observer was incorrect a total of 13 times out of 104 trials while the telescope observer was incorrect only twice. This resulted in 2 minuses and 14 pluses ($\underline{p} < .002$). The telescope observer was incorrect only when the subject was fixated indicating the same conservative direction of error and superior detection of non-fixation found in Part I. A breakdown in terms of paired decisions resulted in an insignificant 2 minuses with 8 pluses for the fixated trials ($\underline{p} = .055$) and a significant 0 minuses and 6 pluses for the non-fixated trials ($\underline{p} < .02$).

Discussion

This experiment clearly demonstrates that improved reliability can be obtained using the telescope method. The data further suggests that the side observer is much less sensitive to departures from the fixation point.

The replication with observer positions reversed eliminated the possibility that the results of Experiment I were due to a difference between observers. For both observers the telescope method was superior to the sideview method. This superiority was demonstrated for each of the 12 subjects.

On the basis of these results, it is strongly recommended that the "Telescope Technique" be used to monitor fixation in studies that need such a control. Since the number of errors made by the telescope observer is within the number of errors one would expect from a subject, it is as accurate as the method used by McKeever and Huling (1970a, b; 1971), yet allows accurate identification of fixation without requiring any response from the subject. It is expected that the telescope method will find wide application in tachistoscopic studies.

Experiment II

Reaction Time to Hemiretinal Stimulation

There is some anatomical and physiological evidence indicating that stimulation of the contralateral optic fibers leads to the activation of more cortical units in the contralateral hemisphere than does similar stimulation of the temporal projections to the ipsilateral hemisphere (Doty, 1958; Hubel and Weisel, 1959, 1962). Greater activation of cortical units is consistent with the fact that the nasal fibers constitute approximately three-quarters of all the fibers (Last, 1961; Polyak, 1957).

There are also indications that nervous transmission is more rapid in the contralateral pathways. An estimate of nervous transmission speed has been obtained for human subjects by determining the probabilities of a correct depth response from stereo-line presentations at different relay times. Transmitting speed was inferred to be about 1.5 milliseconds faster for nasal fiber transmission (Bower, 1966).

Reaction time data is consistent with more rapid contralateral nervous transmission since it is faster following nasal than temporal visual stimulation (Hall and Kries, 1897; Poffenberger, 1912). Difference in reaction time, however, may also be consistent with relative cortical unit activation since reaction time is both directly proportional to latency of evoked potentials and inversely proportional to amplitude of evoked potentials (Eason, Oden and White, 1967).

The purpose of this study was to re-affirm the findings (Hall and Kries, 1897; Poffenberger, 1912) which showed faster reaction time to contralateral stimulation than to ipsilateral by using a more powerful experimental design due to a greater number of subjects and improved apparatus.

The Hall and Kries (1897) study was considered by Poffenberger (1912) to be only an indication of superior reaction time to contralateral stimulation. The author states: "The number of reactions from which the averages are calculated and the mean variations are not given. No statement is made as to whether or not the value for each position is an average of the two eyes for that position (page 43)." Furthermore the previous authors made no effort to either control the stimulus and surround light intensity or record the values. Despite Poffenberger's improvements on the aforementioned points further experimentation was considered necessary for the following reasons:

(1) The surround illumination varied slightly as a function of the time of day and therefore the intensity of light entering through two windows. In this study the surround illumination remained constant.

(2) Stimulation of different points on the subject's retina was achieved by rotation of the subject's body in a revolving reaction chair. In this study the subject remained in the same position at all times. Stimulation of different points on the retina was achieved by the tachistoscope shutter. This was thought to eliminate errors in fixation due to differences in eyeball muscle tension and body movement and errors in retinal stimulation position.

(3) The preparatory signals were verbal and variant whereas in this study they were non-verbal (a tone) automated and invariant.

(4) The device used for stimulation was a circular drum which revolved by means of an electric motor and v-belt. This device was visible to the

subject as well as audible which would create unnecessary distraction. The nature of the device would create errors in exposure time and drum revolution time. A more accurate device to be described was used in this study. It was neither visible nor audible to the subject.

(5) A Hipp chronoscope was used to record reaction time. A more accurate timer, standardized against an oscilloscope was used to record reaction time in this study.

(6) Poffenberger used no method for monitoring fixation. A new method for monitoring fixation was used in this study.

(7) Poffenberger repeatedly tested four subjects two of whom were well trained in reaction time work and two of whom had served as subjects at various other times. This study involved forty subjects equally divided into four different groups according to handedness and eyed-ness. This was done to allow more generalization. Further, these subjects received adequate practise but were not repeatedly tested. This was to demonstrate that the hypothesized contralateral fiber "superiority" would occur in the time usually alloted for a subject in a tachistoscopic test of laterality and despite the variability doubtless incurred from minimally adequate practise.

Furthermore, since the hypothesis under test was considered to be an important variable in tachistoscope research it was thought necessary to demonstrate it under conditions similar to tachistoscopic tests of laterality involving such considerations as distance from the screen, laterality of stimulation and apparatus.

The design of this study allowed for a more adequate statistical analysis than the Poffenberger study.

Method

Subjects

The subjects were 40 male university students with normal and equal eye acuity (20/20 ± 10). There were 10 subjects in each of four groups which consisted of individuals who were either right handed-right eye dominant (RH-RED), right handed - left eye dominant (RH-LED) left-handed-right eye dominant (LH-RED), or left-handed-left eye dominant (LH-LED). Handedness was determined by an individually administered Crovitz and Zener (1962) handedness questionnaire and a finger tapping dexterity task. Eyedness was determined by the finger aiming test (Buxton and Crosland, 1937) and by the A-B-C Test for Ocular Dominance (Miles, 1929).

Apparatus

The experiment was conducted in a flat black "perception tunnel".

Two independent Kodak carousel 35 mm projectors with 500 watt bulbs were used for stimulus presentation. The projectors were adjusted so that the projection field of each completely coincided with projection field dimensions of 48.26 x 78.74 cm. The distance from the projectors to the screen was 1.83 m. Stimulus slides were presented with one projector, while the other projector was used to present a symmetrical cross fixation marker in the center of the screen and to maintain a constant illumination level. Each bar of the cross was 4 cm long by 1 cm wide.

The projectors were placed on top of a 152 cm high, 122 cm x 122 cm metal enclosure. A one-inch piece of foam rubber, completely covering the top of the enclosure was placed between the metal and projectors to mask vibrations. A standard telegraph key was directly in front of the subject on a desk attached to the front of the stationary enclosure.

The subject sat within the enclosure, with his head held stable by means of a Haag/Strat chin-rest and forehead brace mounted on the desk. This arrangement allowed for the projectors to be the same distance to the screen as were the subject's eyes and yet be completely hidden from view.

The digital timer conrolling the stimulus duration was initiated by one tape of a dual tape programmer. The other tape actuated a timer which initiated a .75 second fixation warning tone prior to stimulus presentation. There were 23 randomly selected intervals ranging from 2 to 6 seconds between the fixation warning tone and stimulus presentation. The tape programmer was initiated by remote control allowing the experimenter to begin the stimulus presentation series from behind the screen.

The warning tone was presented to the subject through Telex ST-20 Stereo-twin headphones by an EICO-Model 377 Audio Generator. The tone, a 40 db sine wave, interrupted the otherwise continuous white noise used to mask the shutter sounds. The white noise (40 db) was produced by a Marietta Apparatus Company (Style NA-36) White Noise Generator amplifed by an EICO (HFIZA) amplifier. The shutter sounds were masked in order to control for auditory anticipation. The tone and white noise intensities were measured with a Scott 200 Sound Level Meter, pressed against the inside of the earphones.

There were 80 presentation slides with 76 stimulus slides and 4 slides which directed the subject to use either his left or right hand or his left or right eye. The stimulus slides consisted of 3 mm diameter holes punched in the exposed and developed film used to make the slides. The stimuli appeared on the screen as bright spots of light 17 cm to the right or left of fixation and therefore subtended 4° of visual angle.

All timuli were projected 39 cm above fixation. The stimuli were all of the same size and appeared in the same position to the right or left of fixation.

The stimuli were presented on a stationary flat black screen affixed to a vertical wood panel. A hole was cut in the screen corresponding with the dimensions of the fixation cross at the fixation point. The hole was large enough to admit an approximately 15 power telescope. The telescope was constructed from a 135 mm F2.6 Telephoto lens viewed through an Accura T-scope. The front of the telescope lens was in the same plane as the screen but was positioned 5.08 cm behind the panel so that reflected light from the stimulus presentation did not appear on the face of the lens. If this had not been done the subject might have reached to foveal stimulation rather than to the intended lateral retinal stimulation. The telescope allowed the experimenter to view the pupil of either of the subject's eyes from the same hight as the subjects eyes and from the exact spot of required fixation. A 150 watt reflector flood lamp was directed upon the subject from 53° above and to the side. This provided clear illumination of the subjects pupil.

The actuation of the stimulus shutter initiated a Hunter Klockounter (Model 120A, Series D). Full depression of the telegraph key stopped the Klockounter.

Procedure

The subject was first given an eye test (Sneller E Letter Chart; Imperial Optical Limited, Number 2). Subjects who did not have normal and equal-eye acuity (20/20 ± 10) were eliminated. Then the subject was given the A-B-C Test for Ocular Dominance (Miles, 1929) followed by the finger aiming test (Buxton and Crosland, 1937). If the results of these two tests were consistent the subject was considered acceptable regardless of the "degree" of dominance dictated by ratio obtained from the Miles Test. No subjects were rejected because of inconsistent eyedness responses. To determine handedness the subject was given the Crovitz and Zener (1962) hand preference questionnaire and a finger tapping test of manual dexterity. The dexterity task consisted in having the subject press a key attached to a mechanical counter as many times as possible with the index finger during a ten second interval. Each hand was tested twice. If the results of these two tests were consistent the subject was considered acceptable regardless of the "degree" of handedness ascertained from either measure. Two subjects were rejected because of inconsistent preference and dexterity responses. Each of these rejected subjects preferred his left hand but was in fact more dextrous with his right.

The subject was seated immediately beneath the projectors and his head was adjusted to a standard chin rest, so that the corner of each eye was level with a white dot on the sides of the forehead brace. The height of these dots (and, therefore, the subject's eyes) from the floor corresponded exactly to the height from the center of fixation to the floor.

Prior to the start of experimental trials the subject was read the instructions for the task and was given a series of 36 practice trials. There were 4 slides consisting of the hand or eye directions mentioned previously. The subject was asked to fixate carefully on a small spot of stationary light in the center of the cross as soon as he heard the warning tone. This fixation spot was actually a reflection in the face of the lens caused by the light emitted from the "screen projection carousel. It must be re-emphasized that no other light reflections appeared on the telescope face during stimulation. The subject was further instructed to dpress the key completely and as rapidly as possible when the stimulus light appeared while maintaining constant fixation. To further impress the need for constant fixation upon the subject he was told that the experimenter would be behind the screen carefully monitoring fixation through a telescope and recording his reaction times. If the subject was not fixated or if he blinked during a stimulus exposure that trial was rejected.

The stimulus exposure was 100 msec for all subjects and for all presentations. This duration is less than the time necessary to make lateral eye movements (125-235 msec; Woodworth, 1938; Crovitz and Daves, 1962) and yet was long enough to allow the subject to read the direction slides.

Design

There were four stimulus situations. The stimulus was projected to the right visual field for half the trials and to the left visual field for the other half. The subject used his right hand-left eye (ipsilateral) and right hand - right eye (contralateral) during right visual field stimulation. He used his left hand - right eye (ipsilateral) and left hand - left eye (contralateral) during left visual field stimulation. This was done so that the hemisphere of stimulation was the main hemisphere controlling the reacting hand. This would, then, be the hemisphere contralateral to that hand. The resulting conditions formed a 2 x 2 within design consisting of the factors contralateral versus ipsilateral and dominant hand versus non-dominant hand. There were 9 repeated measures under each condition. However, the median score was extracted for analysis so that each subject had only one score per condition.

Groups formed a 2 x 2 between design with the factors being right - versus left - eye dominant and right - versus - left-hand dominant subjects. These four different groups were included as a control balance to demonstrate the contralateral - ipsilateral effect over and above the effects due to differences in the dominant and non-dominant hand or eye.

The original reaction time scores were analyzed by a 2 x 2 x 2 x 2 analysis of variance excluding the confounded effect due to eyedness. Inclusion of eyedness as a factor would have resulted in an incomplete design with confounded analysis since each subject would occur in only 4 out of 8 possible within combinations. This is due to the 4 particular treatment combinations of eye and hand used here. For example, the first and second effects might be contralateral - dominant hand - dominant eye and contralateral dominant-hand - non-dominant eye respectively. A subject from Group 1 (RH-RED) would have a score for the first within condition but none for the second. Group 2 (RH-LED) would have a score for the second but not the first, and so on.

The particular order of conditions for any of the 40 subjects was chosen at random from a list of the 24 possible treatment orders.

Results

The results showed no difference between right handed and left handed subjects but right eye dominant subjects showed faster reaction times than left eye dominant subjects. Reaction time was faster to contralateral stimulation than to ipsilateral stimulation and for the dominant hand over the non-dominant hand. There were no significant interactions.

Table 2 shows the reaction time means and variances for the between main effects of hand and eye dominance and the within main effects of retinal stimulation and reaction hand. The means for all main effects and interactions are shown in Table 6, Appendix.

Table 2

Reaction Time Means in Milliseconds: Main Effects

Main Effects	Means
Right Hand Dominant	415.750
Left Hand Dominant	434.075
Right Eye Dominant	405.600
Left Eye Dominant	444.255
Contralateral Stimulation	412.563
Ipsilateral Stimulation	437.263
Dominant Hand Reaction	418.638
Non-dominant Hand Reaction	431.188

As shown in Table 2 all mean reaction times for main effects were in the low to mid-400 milliseconds. Right hand dominant subjects were 20 milliseconds faster than left hand dominant subjects and right eye dominant subjects were 39 milliseconds faster than left eye dominant subjects. Reaction time was faster to contralateral stimulation than to ipsilateral stimulation by 25 milliseconds while the dominant hand was faster than the non-dominant hand by about 13 milliseconds. Although the difference in mean reaction time is larger for the between subjects effects the within effects are shown to be of greater importance due to the smaller treatment error variance.

Table 3

Summary Analysis of Variance Table: I

Source	Df	MS	F	
Subject	39			
B1 (Right handed/left handed)	1	13432.23	1.328	
B2 (Right eyed/left eyed)	1	59675.63	5.899	*
B12	1	4687.22	0.463	
EB12	36	10116.17		
W1 (Contralteral/Ipsilateral)	1	24403.60	59.772	**
W1B1	1	14.40	0.035	
W1B2	1	1488.40	3.646	
W1B12	1	240.10	0.588	
EW1B12	36	408.28		
W2 (Dominant hand/Non-dominant hand)	1	6300.10	22.218	***
W2B1	1	1.60	0.006	
W2B2	1	57.60	0.203	
W2B12	1	490.00	1.728	
EW2B12	36	283.56		
W12	1	24.02	0.023	
W1ZB1	1	2.03	0.002	
W1ZB2	1	308.03	0.292	
W1ZB12	1	87.02	0.082	
EW1ZB12	36	1056.62		
W	120			
TSQ/N =	28888101.23	N = 160	SST = 538338.78	

$* P < .05$
$** P < .000001$
$*** P < .000036$

A summary of the 2 x 2 x 2 x 2 analysis of variance is presented in Table 3 above. Right eye dominant subjects showed faster reaction times than left eye dominant subjects ($p < .05$) but there was no sifnificant difference in mean reaction time between right handed and left handed subjects. The hand dominance x eye dominance interaction was not sifnificant.

Contralateral stimulation resulted in faster reaction times than did ipsilateral stimulation ($p < .000001$) as shown in Table 3. Reaction time was also faster when the subject used his dominant hand than when he used his non-dominant hand ($p = < .000036$). There were no significant interactions. The significant within effects of contralateral/ipsilateral stimulation and dominant hand/non-dominant hand reaction are presented in Figure 2 for a visual comparison.

Figure 2. Reaction time means in milliseconds for between and within main effects.

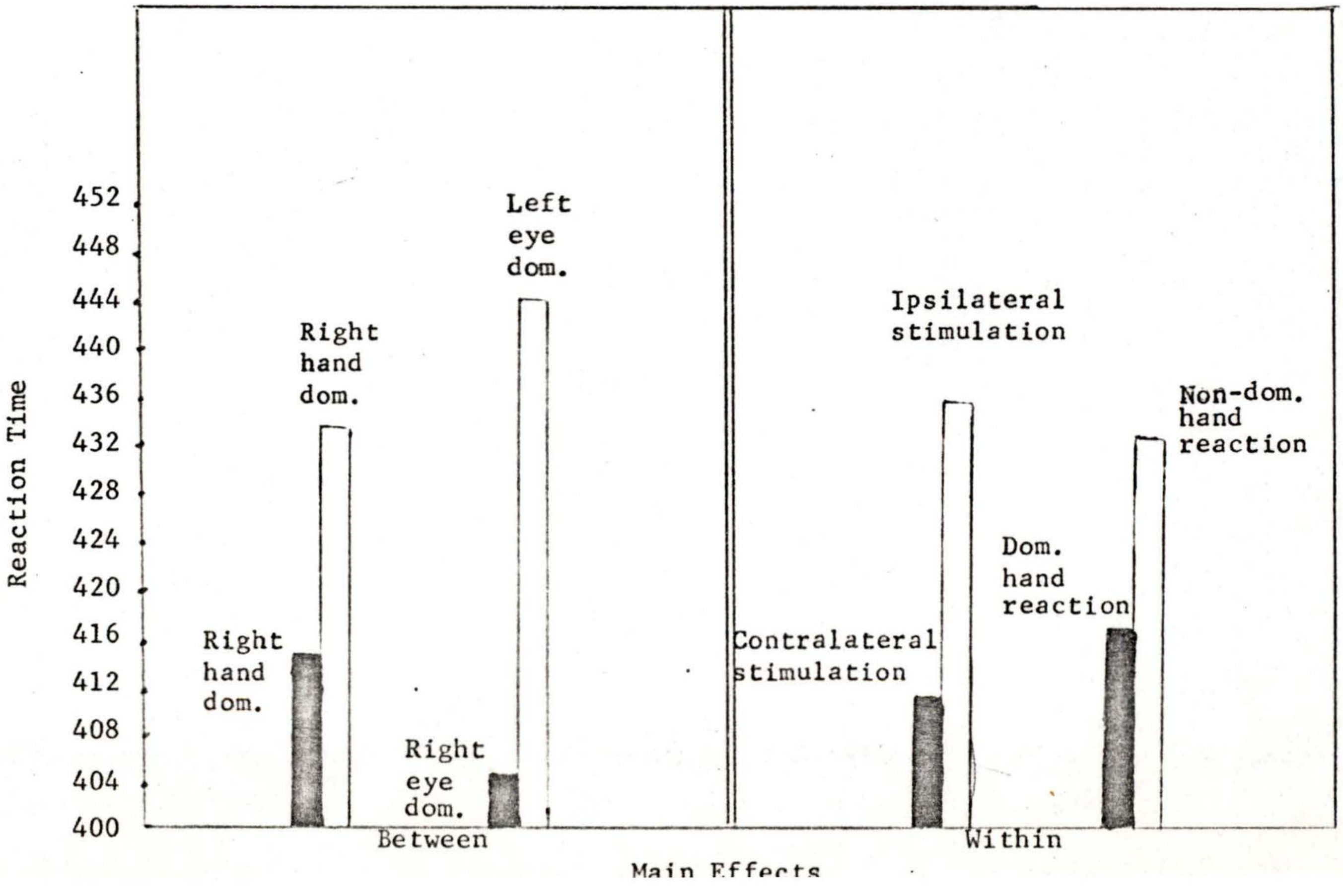

Table 4 shows the mean reaction times for the insignificant retinal stimulation x reacting hand interaction. The means show the hypothesized (6) order of contralateral x dominant hand $<$ contralateral x non-dominant hand $<$ ipsilateral x dominant hand $<$ ipsilateral x non-dominant hand where ($<$) indicates faster reaction times ($p < .001$). The mean difference between contralateral and ipsilateral was 24.700 milliseconds while the mean difference between dominant and non-dominant hands was 12.550. The difference between these two mean differences was significant by t-test ($p < .001$) indicating that the eye fiber effect was of greater influence on reaction time than the hand dominance effect.

Table 4

Reaction Time Means in Milliseconds for the Contralateral/Ipsilateral x Dominant hand/Non-Dominant Hand Interaction

	Dominant Hand	Non-dominant Hand	Average
Contralateral	406.675	418.450	412.562
Ipsilateral	430.600	443.925	437.262
Average	418.637	431.187	

Discussion

Hypothesis (1), (3), (4), (5) and (6) were confirmed but hypothesis (2) was not confirmed.

1. Hypothesis One

Hypothesis one stated that there is no difference in reaction time between right handed and left handed subject groups. As predicted, there was no significant difference in reaction time between these groups.

2. Hypothesis Two

Hypothesis two stated that there is no difference in reaction time between right eye dominant and left eye dominant subject groups. This hypothesis was not confirmed since right eye dominant subjects were significantly faster than left eye dominant subjects ($p < .05$). There is no explanation offered for this difference since eye dominance was not a significant factor when the results were analyzed with dominant versus non-dominant eye stimulation substituted for dominant versus non-dominant hand reactions. (See Table 5 Appendix A). The latter is more in line with expectation particularly in view of an exposure duration well above threshold. Furthermore, the subjects were of equal eye acuity and the selection was random for all subjects. There was no equating for "degree" of eyedness but this should not be an important factor since the subjects were neither required to differentially react to complex stimuli nor asked to do more than merely detect the presence of an easily discernable spot of light.

3. Hypothesis Three

The between subjects interaction was not significant indicating that handedness did not differentially affect eyedness in terms of reaction time. This was as predicted.

4. Hypothesis Four

Hypothesis four stated that reaction time is faster to contralateral than to ipsilateral stimulation. This was the primary purpose of the study. As predicted, reaction time was significantly faster to contralateral stimulation ($p < .000001$). This result re-affirms with greater power of effect, the findings of Hall and Kries (1897) and Poffenberger (1912) which showed faster reaction time to contralateral stimulation than to ipsilateral.

This finding is taken as further evidence that the contralateral optic fibers are "superior" to or more "efficient" than the ipsilateral optic fibers. This is consistent with the anatomical and physiological evidence indicating that stimulation of the contralateral projections leads to the activation of more cortical units in the contralateral hemisphere than does similar stimulation of the temporal projections to the ipsilateral hemisphere (Doty, 1958; Hubel and Weisel, 1959, 1962). Reaction time is considered consistent with relative cortical unit activation since it is inversly proportional to amplitude of evoked potentials (Eason, Oden and White, 1967). Greater activation of cortical units is also consistent with the fact that the nasal (contralateral) fibers constitute approximately three-quarters of all the fibers (Last, 1961; Polyak 1957).

The differential fiber reaction time is also consistent with the indication that nervous transmission is more rapid in the contralateral pathways indirectly determined by Bower (1966). The reason for this consideration is that reaction time is directly proportional to latency of evoked potentials (Eason, Oden and White, 1967).

On the basis of this evidence as well as the earlier findings the basic postulate of "superiority" or "efficiency" of the contralateral over ipsilateral visual fibers is considered more tenable. The terms "superiority" and "efficiency" are considered synonymous and refer to; (1) relative cortical unit activation; and (2) relative rapidity of signal transmission.

5. Hypothesis Five

Hypothesis five stated that reaction time would be significantly faster when subjects were reacting with their dominant versus their non-dominant hand. This hypothesis was confirmed ($p < .000036$) as expected on the basis of the imposed conformity beyween the hand preference questionnaire and dexterity task.

6. Hypothesis Six

Hypothesis six stated that the within factors of contralateral/ipsilateral and dominant hand/non-dominant hand would not show a significant interaction. It was hypothesized that the eye fiber factor would be of greater importance than the reacting hand factor. This resulted in the prediction that reaction time would show the order contralateral x dominant hand $>$ contralateral x non-dominant hand $>$ ipsilateral x dominant hand $>$ ipsilateral x non-dominant hand where ($>$) indicates faster reaction times. This order hypothesis was as predicted ($p < .001$). Further evidence comes from the finding that the difference between the reaction time fiber differential was greater than the reacting hand differential ($p < .001$).

Summary

The results of this study conclusively support the major hypothesis of the study which was that reaction time to contralateral stimulation is faster than reaction time to ipsilateral stimulation as demonstrated by Hall and Kries (1897) and Poffenberger (1912). The extremely powerful difference demonstrated was probably due to the increase in power obtained by using a greater number of subjects and improved apparatus and design. Furthermore, this finding was demonstrated in four different groups of subjects thereby increasing generalization. The effect occurred despite the greater variability doubtless incurred from less practice and therefore less stabilized reaction times. On the basis of these findings it is considered important to be cognizant of the effects of area of retinal stimulation in tachistoscopic recognition tasks.

Appendix A

Analysis of Variance with Eye Stimulated Substituted for Reacting Hand as the Second Within Factor

As mentioned in the design section of Experiment II, the within factor of dominant eye stimulation versus non-dominant eye stimulation was not included in the analysis. Inclusion of this as a factor would have resulted in any one subject having a score for only four out of eight possible treatment combinations according to the imposed definition of manner of stimulation. Furthermore, the subject groups of RH-RED & LH-LED, would fill different cells than the subject groups of RH-LED despite exactly the same treatment combinations. This would have resulted in an appropriate test of all main effects but completely confounded tests of the interactions. For these reasons a second 2 x 2 x 2 x 2 analysis of variance was conducted such that the only difference between Table 3 and Table 5 below is that on Table 5 dominant eye/non-dominant eye stimulation has been substituted for dominant hand/ non-dominant hand reaction.

Table 5

Summary Analysis of Variance Table: 2

Source	Df	MS	F	
Subject	39			
B1 (Right handed/left handed)	1	13,432.23	1.328	
B2 (Right eyed/left eyed)	1	59,675.63	5.099	*
B12	1	4,687.22	0.463	
EB12	36	10,116.17		
W1 (Contralateral/Ipsilateral)	1	24,403.60	59.722	**
W1B1	1	14.40	0.035	
W1B2	1	1,488.40	3.646	
W1B12	1	240.10	0.588	
EW1B12	36	408.28		
W2 (Dominant eye/Non-dominant eye)	1	87.03	0.082	
W2B1	1	308.02	0.292	
W2B2	1	2.02	0.002	
W2B12	1	24.03	0.023	
EW2B12	36	1,056.62		
W12	1	490.00	1.728	
W12B1	1	57.60	0.023	
W12B2	1	1.60	0.006	
W12B12	1	6,300.10	22.216	***
EW12B12	36	283.56		

W

TSQ/N = 28,888,101.23 N = 160 SST = 538,338.78

* $P<.05$

** $P<.000001$

*** $P<.000036$

Results

The results show exactly the same mean squares and F-values for the between effects and for the within effect of contralateral/ipsilateral stimulation. The within effect of dominant eye/non-dominant eye stimulation is, however, not significant.

The four-way interaction of retinal stimulation x eye of stimulation x handedness x eyedness was significant (p = .000036). This interaction is not considered worthy of examination. Comparison of Tables 3 and 5 reveals that the main effect mean square for dominant hand/non-dominant hand has merely been exchanged for the four-way interaction. Table 3 shows that when the second within factor is reacting hand the hidden effect of eye stimulated does not create enough disturbance to result in a significant interaction. However, when the second within factor is eye stimulated the mean square and F-value shown for the four-way interaction in Table 3 now becomes the main effect mean square and F-value shown in Table 5. Furthermore, the main effect mean square and F-value shown in Table 3 for reacting hand now becomes the four-way interaction mean square and F-value shown in Table 5 where hand stimulated is the hidden factor.

Although this is an inappropriate analysis from both the statistical and discussion viewpoint this is considered sufficient evidence that, at the least, the eye stimulated is not as important a variable as reacting hand. This is as expected in light of the treatment methodology (i.e., stimulus duration of well above threshold, a highly visible stimulus, no requirement for differential responding, and peripheral retinal stimulation). Furthermore, the subjects were not required to make differential type responses on the basis of eye stimulated and there was no minimum cut-off criterion for "degree" of eye dominance laterality in subject selection except a greater (6/10) number of responses to the Miles Test with one over the other eye.

Appendix B

Reaction Time Means in Milliseconds:
Main Effects and Interactions

Table 6

Reaction Time Means in Milliseconds: Main Effects and Interactions

GRAND MEAN

424.913

Between

Source			
		RH Group	LH Group
B1 (Right handers/left handers)		415.750	434.075
		RED Group	LED Group
B2 (Right eyed/left eyed)		405.600	444.225
B12		RED	LED
	RH	391.025	440.475
	LH	420.175	447.975

Within

		Contralateral	Ipsilateral
W1 (Contralateral/Ipsilateral)		412.563	437.263
WIBI			
	RH	403.700	427.800
	LH	421.425	446.725
W1B2			
	RED	390.200	421.000
	LED	434.925	453.525

Table 6 (continued)

W1B12				
	RH	RED	374.700	407.350
		LED	432.700	448.250
	LH	RED	405.700	434.650
		LED	437.150	458.800

W2 (Dominant Hand/Non-Dominant Hand)

			Dominant Hand	Non-Dominant Hand
			418.638	431.188
W2B1	RH		409.575	421.925
	LH		427.700	440.450
W2B2		RED	399.925	411.275
		LED	437.350	451.100
W2B12	RH	RED	383.700	398.350
		LED	435.450	445.500
	LH	RED	416.150	424.200
		LED	439.250	456.700
W12				
	Contralateral		406.675	418.450
	Ipsilateral		430.600	443.925

Table 6 (continued)

W12B1				
	RH	Contralateral	397.800	409.600
		Ipsilateral	421.350	434.250
	LH	Contralateral	415.550	427.300
		Ipsilateral	439.850	453.600
W12B2				
	RED	Contralateral	386.300	394.100
		Ipsilateral	413.550	428.450
	LED	Contralateral	427.050	442.800
		Ipsilateral	447.650	459.400
W12B12				
	RH-RED	Contralateral	386.300	381.100
		Ipsilateral	399.100	415.600
	RH-LED	Contralateral	427.300	438.100
		Ipsilateral	443.600	452.900
	LH-RED	Contralateral	404.300	407.100
		Ipsilateral	428.000	441.300
	LH-LED	Contralateral	426.800	447.500
		Ipsilateral	451.700	465.900

Appendix C

Cerebral Dominance, Dichotic Listening and the Tachistoscope

The present paper grew out of an attempt to determine the relation between two widely used techniques for studying normal subject perception and immediate memory; (1) dichotic listening and; (2) tachistoscopic visual presentation. Results from studies using the dichotic listening procedure are generally considered consistent with cerebral lateral asymmetry of function. In fact, this technique is considered useful for detecting lateralized lesion effects and for exploring the range of differential hemispheric functioning. (Kimura, 1961 a, b). Laterality differences resulting from tachistoscopic presentation, on the other hand, have usually been related to the development of reading skills (Mishkin and Forgays, 1952; Heron, 1957). The latter emphasis has resulted in a lack of investigation into the relation between tachistoscopic recognition and cerebral dominance (Bryden, 1965).

It is proposed that lateral cerebral dominance has a strong relationship to differential tachistoscopic recognition as well as to ear differences found in dichotic listening. To provide a link between these two procedures, human functional neuroanatomy is considered to be a system of mainly contralateral organization. The use of one basic explanation to account for data from these two techniques is believed to be more cogent than the variety of explanations currently being adopted.

The purpose then, is to demonstrate a relationship between dichotic listening and tachistoscopic presentation based on considerations involving lateral cerebral dominance and the pathways by which information passes from the eye or ear to the brain.

HEMISPHERIC CEREBRAL DOMINANCE

The concept of hemispheric dominance dates back to Broca's observation of a relation between left frontal lobe damage and the occurrence of aphasia in 1861 (Benton, 1965). Subsequently, a mass of evidence has accumulated indicating that verbal functions such as speech and writing are commonly mediated by the left cerebral hemisphere (Penfield and Roberts, 1959; Wada and Rasmussen, 1960). Verbal learning and retention deficits have been found in left temporal lobe damaged patients all of whom had demonstrated left hemisphere dominance for speech (Fedio and Mirsky, 1969; Kimura, 1968; Milner, 1958, 1968; Milner and Teuber, 1968). These deficits increase following left temporal lobectomy for removal of the epileptogenic foci (Meyer and Yates, 1955; Milner, 1958).

Lesions in the left cerebral hemisphere have also resulted in certain forms of apraxia (e.g., ideomotor apraxia: Ajuriaguerra, Hecaen and Angelergues, 1960), a group of symptoms termed the 'Gerstmann Syndrome' (Ajuriaguerra, Hecaen and Angelergues, 1960; Benton, 1961; Gerstmann, 1927; Heimberger, DeMyer and Reitan, 1964) and other 'orientational' deficits such as right-left disorientation (McFie and Zangwill, 1960).

The 'non-dominant' or 'minor' right hemisphere is definitely subordinate, then, for speech and writing. Nevertheless, there is likely some degree of minor hemisphere participation in language functions (Gazzaniga, 1967). Patients in whom the hemispheres have been surgically separated by commissurotomy can make words from letters put in the left hand (Levy, Nebes and Sperry, 1971). This is consistent with data showing slight changes in evoked cortical potentials recorded over the right hemisphere during tachistoscopic word discrimination (Fedio and Buchshaum, 1971). It has been suggested that the minor hemisphere might be more important for speech, than it usually is, if the major hemisphere were not so dominant for the motor channels of speech (Levy, Nebes and Sperry, 1971; Smith, 1966). Furthermore, the minor hemisphere is actually dominant for a number of 'non-verbal' functions.

Right hemispheric lesions have been found to result in greater dificits in visuo-constructive ability (McFie and Zangwill, 1960; McFie, Piercy and Zangwill, 1950), visuo-spatial ability (Brain, 1941; Paterson and Zangwill, 1944; Milner and Teuber, 1968), as well as apraxia for dressing and inattention to one visual half-field (Critchley, 1953; Hecaen, 1962; Hecaen and Ajuriaguerra, 1945; Hecaen, Ajuriaguerra and Massonet, 1951). Similarly, in a study covering a period of ten years the apractognostic syndrome of the minor hemisphere was found to include; (1) disturbances of body scheme (anosogosia, etc.); (2) Apraxia for dressing; (3) visuo-constructive disabilities; (4) unilateral spatial agnosia and disturbances of topographical relationship, and, although less conclusively; (5) loss of topographical memory (Hecaen, Penfield, Bertrand and Malmo, 1956). General deficits in spatial and constructional praxis performance following lesions in the non-dominant hemisphere have been found by Benton (1962 a, b) and by Milner (1954).

Right hemispheric lesions, in a variety of areas, have resulted in significantly poorer scores on the performance subtest of the Wechsler-Bellevue Scale, than similar lesions in the left (Anderson, 1951; Heilbrunn, 1956; McFie and Piercy, 1952; Reitan, 1955; Weisenberg and McBride, 1936). The loss in performance scores for right hemisphere damaged andpost-operative patients has been attributed mainly to right temporal lobe damage or removal (Hebb, 1939; Milner, 1958).

Right parietal damage has resulted in greater impairment, than left parietal damage, on visual perception of Gollin Figures, incomplete shapes, incomplete letters, and greater impairment on a non-representational visual retention test made up of five block squares variously positioned on a four by four white ground (Warrington and James, 1967). Defects in visual identification, discrimation, retention and in closure have also been found to be primarily associated with lesions in the temporal lobe of the non-dominant hemisphere (Kimura, 1963; Lansdell, 1968; Meier and French, 1965; Milner, 1968). Similarly, for patients with demonstrated left hemispheric dominance for speech, damage in the right temporal lobe results in clear impairment in accuracy and speed of response on the McGill Picture Anomaly Series, whereas left temporal damage does not (Milner, 1958). Milner found that these defects were augmented when the epileptogenic focii were removed by right temporal lobectomy.

Unilateral right temporal lobectomy results in an increase in errors on the tonal memory, loudness discrimination and pitch discrimination tasks of the Seashore Measures of Musical Talents but no consistent increase in errors was found following left temporal lobectomy (Milner, 1958, 1962). Shankweiler (1966) has found that non-dominant temporal lobe lesions result in significantly more severe defects, than dominant temporal lobe lesions, in the naming and repetition of well known musical tunes. Similarly, the recognition of meaningful, non-verbal sounds is impaired by right hemisphere damage (Spreen, Benton and Fincham, 1965; Wortis and Pfeffer, 1948) as is spatial orientation in the auditory sphere (Wortis and Pfeffer, 1948).

The preceeding lesion and test results indicate that the functions of the two cerebral hemispheres differ on a "verbal/non-verbal" dimension. For the purposes of this paper these words will be defined in terms of the dichotic and tachistoscopic stimulus material to be covered. Hence, "lateral cerebral dominance" is taken to mean the following:

A. Left hemispheric involvement for verbal material. Verbal material is defined specifically as single and multiple-letter stimuli (i.e., letters, words, nonsense syllables, and non-word letter series), digits, alphanumeric stimuli (i.e. combinations of letters and digits, words and digits, etc.) and rather vaguely, familiar objects presumed to involve almost automatic verbal labelling. This will apply to both the visual and auditory modes.

B. Right hemispheric involvement for non-verbal material. Non-verbal material is defined specifically as dots, unfamiliar geometrical and nonsense forms (to a lesser extent familiar geometrical forms), and "spatial maps" for the visual mode. For the auditory mode non-verbal will be defined in terms of such stimuli as melodies, sonar sounds, Morse Signals, and music and tonal patterns.

Cases for which the other hemisphere is dominant, for either A or B, will be clearly noted.

Generally, the left hemisphere is considered synonymous with "dominant" or "major" hemisphere. The right hemisphere is considered synonymous with "non-dominant" or "minor" hemisphere. Specifically, however, the dominant or major hemisphere is the hemisphere dominant for speech whether it be the right or left. The non-dominant or minor hemisphere is the other.

These terms grew out of laterality preference considerations such as handedness. Since studies often use handedness as a measure from which cerebral dominance is inferred this relationship will be considered.

HANDEDNESS AND CEREBRAL DOMINANCE

The left hemisphere is not always dominant for speech. Broca and others had noticed that right hemispheric dominance for speech occurred mainly in left-handers and, consequently, postulated a relationship between handedness and speech dominance. Although there were exceptions, this postulate " .... has come down to us as the classical doctrine of hemispheric cerebral dominance for language -- the left hemisphere is crucial for language in the right-handed person, the right hemisphere in the left-handed person (Benton, 1965, p. 334)". Experimental study has, unfortunately, not verified this clear-cut relationship.

Subjects are often classified into left or right speech dominant groups according to self-reports of handedness. Left-handers are placed in a right speech dominant group while right-handers are placed in a left speech dominant group. Conclusions based on a difference (or no difference) between these groups should, however, be considered cautiously. Although left-hemispheric speech representation is significantly lower for sinistrals than for dextrals, a left-hander is still more likely to have a dominant left, rather than right, hemisphere for speech. Left hemispheric speech representation has been demonstrated for ninety-three per cent of right-handed and sixty-five per cent of left-handed patients tested by Wada's (1949) intracarotid sodium amytal test (Branch, Milner and Rasmussen, 1964; Milner, Branch and Rasmussen, 1964). Furthermore, these authors found that another fifteen per cent of the left-handers had bilateral speech representation, leaving only ten per cent of the left-handers with unilateral right hemispheric speech dominance.

These findings, combined with a lack of relationship between self-reports of left-handedness and manual dexterity (Benton, Meyers and Polder, 1962; Burt, 1912; Satz, Achenback and Fennell, 1967), indicated the inadequacy of testing cerebral dominance on the basis of self-reported handedness. Nevertheless, one would expect some difference between right - and left-handers, in a random sample from a normal population, since it is likely that left-handers would be less strongly left hemisphere dominant for speech than right-handers.

Further separation between right - and left-handers might be achieved by placing familial left-handers in the right-hand, left-hemisphere dominant group. Bryden (1965), Staz, Achenbach and Fennell (1967), and Weinstein and Sersen (1961) have found indications of a relationship between familial left-handedness and ipsilateral (left) cerebral dominance for speech in normal subjects. However, even this association must be considered tenuous since brain-damaged patients indicate that familial left-handedness is more strongly associated with cerebral ambilaterality than with either left or right hemispheric dominance for speech (Hecaen and Sauguet, 1971).

SUPERIORITY OF CONTRALATERAL BRAIN-BODY FIBER CONNECTIONS

The two cerebral hemispheres receive and transmit nervous impulses both ipsilaterally and contralaterally. Human functional neuroanatomy is, however, mainly of contralateral organization, particularly for the major systems. The pyramidal tract, serving to transmit efferent messages from the precentral gyrus to the muscles, consists of approximately eighty per cent crossed and twenty per cent uncrossed fibers. The uncrossed fibers of the anterior pyramidal tract are thought to end on the anterior horn, mostly on the motor neurons innervating the musculature of the trunk (Bucy, 1949), but the crossed fibers innervate the rest of the musculature including that of the mobile limbs.

Exteroceptive and proprioceptive somesthetic messages concerning touch, temperature, and pain proceed from the left side of the face or body to the right postcentral gyrus or from the right side of the face or body to the left postcentral gyrus. Taste sensations from one side of the tongue are relayed via the arcuate nucleus of the thalamus to the infraparietal plane or the medial side of the parietal operculum of the opposite side of the brain (Ruch and Patton, 1946). Therefore, most afferent transmission for the somesthetic, taste, and olfactory senses is exclusively contralateral as is most efferent transmission of motor impulses.

The fibre connections for audition and vision are more complex in that fibers from each ear or eye pass to both sides of the brain in approximately equal number (relative to the above). If one hypothesizes that the nervous system is predominantly of contralateral organization it is of theoretical import to determine the relative strength of ipsilateral and contralateral contribution in such systems.

Inferences About Brain Functioning

Knowledge of fiber connections has been used to make inferences about differential hemispheric functioning. For example, Weinstein and Sersen (1961) tested 136 subjects for pressure sensitivity of the palms, forearms, and soles. A majority of these subjects showed greater sensitivity on the left side than on the right (see also Ghent, 1961). This was particularly true for familial and strongly dextral subjects. Conversely, strongly sinistral subjects showed greater pressure sensitivity on the right side of the body. In view of the contralaterality of somesthetic and motoric brain-body fiber connections other studies may be centered on the hypothesis of tactual sensitivity as a function of the "minor" hemisphere (Weinstein, 1954; Semmes, Weinstein, Ghent and Teuber, 1954; Weinstein, 1955 a, b; Ghent, Weinstein, Semmes and Teuber, 1955).

Similarly, knowledge of the relative contributions of crossed and uncrossed auditory and optic fibers could strengthen and clarify the interpretation of findings in studies of these sense modalities.

Auditory Fibers

Investigators in the area of audition in general, and dichotic listening in particular, have drawn inferences about brain functioning based on the assumption that the contralateral auditory fibers are stronger than the ipsilateral. This assumption receives some support from electrophysiological and anatomical data.

Tunturi (1946) applied successive electrical stimuli to corresponding groups of nerve fibers in the opposing coclea of dogs. For both ipsilateral and contralateral stimuli the responsive areas in one or the two cerebral hemisphere corresponded in latency, duration, wave form, and initial sign. However, the amplitudes of contralateral responses were slightly greater than those of ipsilateral. When successive electrical stimuli were applied to the same spot on the bony spiral an absolutely unresponsive period from twenty to one hundred milliseconds occurred, the longer periods often occurring after ipsilateral stimulation. This was followed by an interval of from one hundred to two hundred and fifty milliseconds during which the response to a second stimulus gradually increased to its former magnitude. In some experiments the second response had recovered only fifty per cent of its original size in two hundred and fifty milliseconds. This was most frequent following ipsilateral stimulation, implying that the contralateral pathways can handle a larger amount of information more rapidly than the ipsilateral.

Ades and Brookhart (1950) have concluded that there is one more synapse in the ipsilateral pathway, thereby increasing the time necessary for a nervous impulse to reach the brain. Rosenzweig and Wyers (1955) did not find evidence for an extra ipsilateral synapse although they did observe the greater amplitudes for contralateral responses found by Tunturi (1946) at the collicular level in the cat following click stimulation. In addition, Rosenzweig (1951) has indicated that there may be a slightly greater number of contralateral auditory fibers resulting in greater contralateral "efficiency". Rosenzweig has also indicated a possible point of overlap between the two pathways at which the contralateral pathways exert suppressive influence over the ipsilateral.

Taken together, the electrophysiological and anatomical results indicate a more "efficient" contralateral ear-brain connection. However, the differences appear small and the additional factor of suppression due to competition might be involved as well. A few contralateral fibers, shown in a secondary cross-over at the inferior colliculi, are likely the suppressor fibers.

Since the postulate of concern is that human functional neuroanatomy is of mainly contralateral organization it would be germane, at this point, to consider the nature of the term "efficiency" for those cases in which there is no competition. Disregarding suppression, then, "efficiency" might occur in at least two possible ways; (1) greater activation of cortical units following contralateral stimulation, or (2) greater rapidity of signal transmission in contralateral fibers. The direct electrophysiological and anatomical data mentioned indicates the former. Although rapidity of signal transmission has not been given much attention, one study will be mentioned which, if nothing else, indicates a way in which this question might be investigated, indirectly, in normal subjects.

Simon (1967) tested simple reaction time to a 1,000-cps tone presented to either the left ear, the right ear, or to both ears simultaneously. The findings may have a bearing on the so-called efficiency of the auditory fibers. Although Simon was not specifically interested in reaction time relative to the fibers, his data appear to indicate that reaction time is more rapid to the contralateral nerve impulses. The right ear trials showed significantly faster reaction times than the left ear trials, but a sign test for correlated samples indicated that right-ear superiority was significantly more frequent on the right hand trials. For the right-handed subjects this would indicate faster contralateral auditory signal transmission in view of the fact that the right hand is controlled by the left hemisphere. If contralateral auditory signal transmission is faster, then the converse should be true; left-handed (at least strongly left-handed subjects should show faster reactions with left ear stimulation. However, Simon (1967) found that even strongly left-handed subjects showed a right ear superiority, although it was not as marked for left-handed males. This may not be antithetical to the above interpretation of superior contralateral auditory signal transmission since all of Simon's "strongly-left" - handed subjects performed one or two of the five hand preferences questioned with the right hand. Satz, Achenbach and Fennell (1967) found that even strongly left-handed subjects, test-classified in this manner, often performed manual dexterity-type tasks better with the right hand. It should be mentioned that there was no difference between the ears when the subject was informed, in advance, as to which ear would be stimulated. Obviously, interpreting Simon's data as evidence for faster auditory signal transmission in contralateral fibers is tenuous and cannot be used to make any firm generalizations. Nevertheless, the evidence suggests that contralateral efficiency might be interpreted in terms of rapidity of signal transmission. Both activation and transmission speed, then, appear to be factors influencing the relative fiber "efficiency" for non-competition situations.

On the basis of the evidence presented in this section, the "superiority" or "efficiency" of the contralateral over ipsilateral auditory fibers is considered a basic postulate. The terms "superiority" or "efficiency" have been the most generally used terms in the literature to describe this situation, but what is meant by these terms is usually not made clear. It is proposed that these terms are synonymous and refer to; (1) relative cortical unit activation; (2) relative rapidity of signal transmission for non-competition (successive) stimulus situations, and; (3) suppression in competition (simultaneous) stimulus presentations. Also taken as a basic postulate, due to the preceding evidence, is that the auditory mode is a "system of mainly contralateral organization".

Visual Fibers

The visual pathway and visual field projections are shown for monocular fixation (Figure 4) and for binocular fixation of a central point (Figure 5). As shown, a stimulus in the right visual field traverses the contralateral pathway of the right eye and the ipsilateral pathway of the left eye, to the left occipital cortex. Similarly, a stimulus in the left visual field traverses the contralateral pathway of the left eye and the ipsilateral pathway of the right eye, to the right occipital cortex.

The visual system is also considered to be dominated by the contralateral fibers. Like the auditory system, the nature of relative fiber superiority will be considered in terms of; (1) differential activation of cortical units, and; (2) speed of nervous transmission. Unlike the auditory system, relative suppressive influences of one fiber group over the other will not be considered in this section, since, there is a definite dearth of electrophysiological and anatomical data concerning this relationship. Some indirect evidence, indicating suppression of ipsilateral impulses by contralateral, will be considered in the discussion on simultaneous tachistoscopic visual stimulation.

There is some anatomical and physiological evidence indicating that stimulation of the nasal (crossed) optic fibers leads to the activation

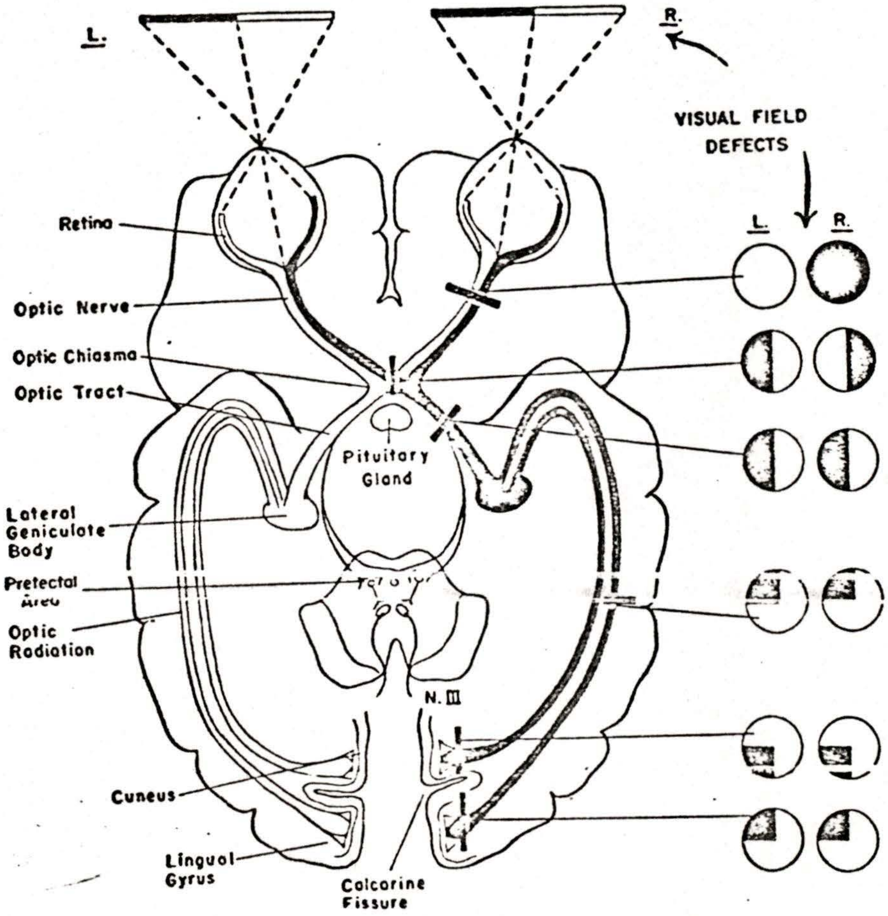

Figure 3. The visual pathway. On the right are maps of the visual fields with areas of blindness darkened to show the effects of injuries in various locations. (Taken from Gatz, A. J. Manter's Essentials of Clinical Neuroantomy and Neurophysiology. Philadelphia, F. A. Davis Co., 1970, page 85.

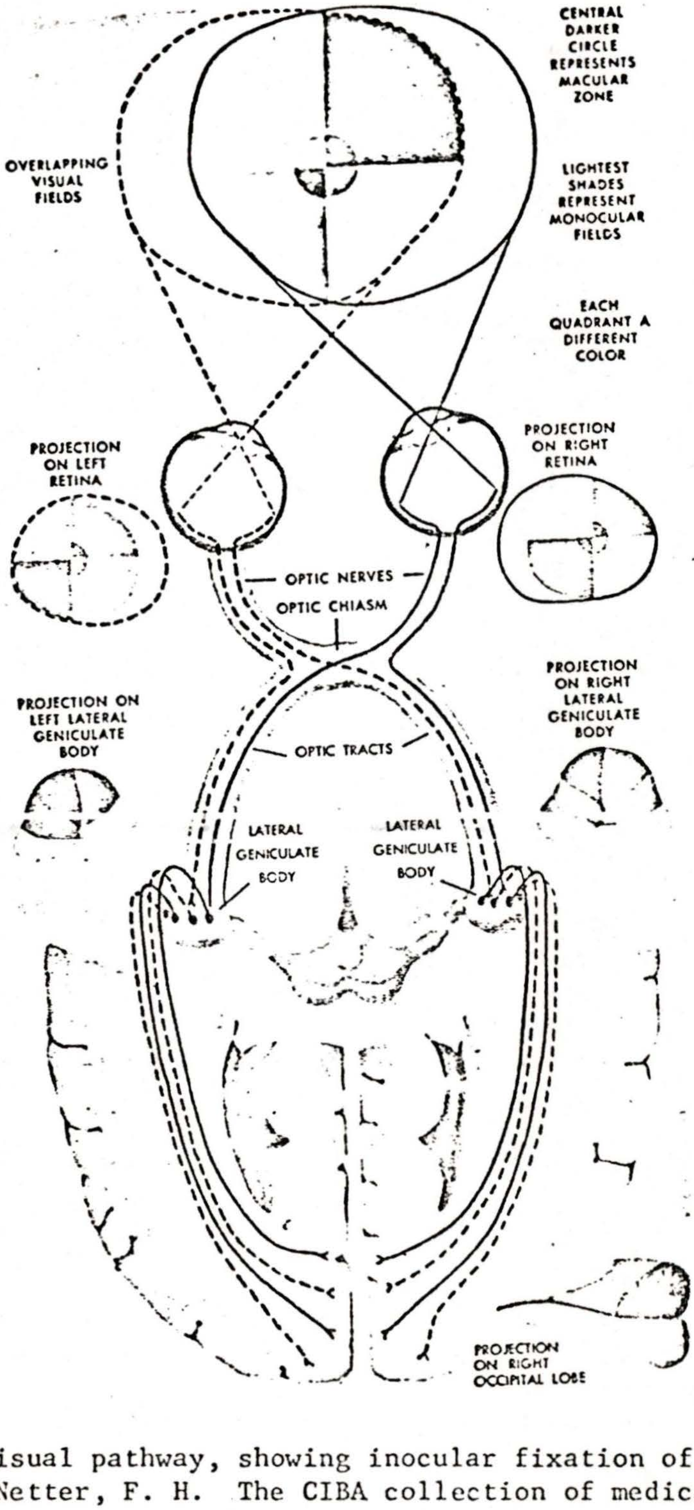

Figure 4. The visual pathway, showing inocular fixation of a central point. From Netter, F. H. The CIBA collection of medical illustrations. Nervous system. CIBA Pharmaceutical Company, 1962, Volume 1, page 63.

of more cortical units in the contralateral hemisphere than does similar stimulation of the temporal projections to the ipsilateral hemisphere (Doty, 1958; Hubel and Weisel, 1959, 1962).

Doty (1958) has found that the highest electrical response in the cat cortex, to both diffuse and punctiform photic stimuli, was in an area adjacent to area striata. The largest and earliest "on" potentials occurred more often for right field stimulation of the right eye and left field stimulation of the left eye. Stimuli presented in these areas are projected to the opposing cortex via the contralateral fibers for each eye respectively. Hubel and Wiesel (1959) found very little cortical unit driving from diffuse stimulation. However, for stimuli specific in form, size, position and orientation they found that "of the forty-five units studied, thirty-six were driven from only one eye, fifteen from the ipsilateral eye and twenty-one from the contralateral; the remaining nine could be driven from the two eyes independently (Hubel and Wiesel, 1959, page 590)". There is some data indicating that the preceding is the case for both "complex" and "simple" cortical units (Hubel and Wiesel, 1962). Greater activation of cortical units is consistent with the fact that the nasal fibers constitute approximately three-quarters of all the fibers (Polyak, 1957).

There are also indications that nervous transmission is more rapid in the contralateral pathways. An estimate of nervous transmission speed has been obtained for human subjects by determining the probabilities of a correct depth response from stereo-line presentations at different relay times. Transmitting speed was inferred to be about 1.5 millisecondsfaster for faster nasal fiber transmission (Bower, 1966).

Reaction time is consistent with more rapid contralateral nervous transmission since it is faster following nasal than temporal visual stimulation (Hall and Kries, 1897; Poffenberger, 1912). Reaction time, however, may also be consistent with relative cortical unit activation since it is both directly proportional to latency of evoked potentials and inversely proportional to amplitude of evoked potentials (Eason, Oden and White, 1967).

As for the auditory system, on the basis of the evidence presented in this section, the "superiority" or "efficiency" of the contralateral over ipsilateral visual fibers is considered a basic postulate. Again, "superiority" and "efficiency" are considered synonymous and refer to; (1) relative cortical unit activation; and (2) relative rapidity of signal transmission for non-competition (successive) stimulus situations. However, as mentioned, suppression of ipsilateral by contralateral fibers during competition (simultaneous) presentations will be considered later. Also taken as a basic postulate, due to the preceding evidence, is that the visual mode is a "system of mainly contralateral organization".

DICHOTIC LISTENING

The dichotic listening paradigm consists of the simultaneous presentation of different stimuli to the two ears. When different verbal stimuli such as words, digits, or letters are presented to the two ears those stimuli which arrive at the ear opposite the dominant hemisphere for speech are more "efficiently" reported (Kimura, 1961 a, b). Kimura (1961 a) and Shankweiler (1966) have found that unilateral left temporal-lobe damage impairs the recognition of digits arriving at the contralateral ear. However, these significant losses occurred only in simultaneous, as opposed to successive, presentations. Further investigation (Kimura, 1961 b) showed that when speech is represented in the left hemisphere (determined by Wada's (1949) intracarotid sodium amytal test), recognition of digits is superior at the right ear, and when speech is represented in the right hemisphere, the left-ear recognition is superior. This appears to be a true preceptual difference since right-ear superiority for digits prevails even when subjects are required to report the left-ear digits first (Bryden, 1969). The latter was, as in many other dichotic studies, a random sample uncontrolled for handedness, in which the majority of the subjects would be left-hemisphere-dominant for speech. Any right hemisphere subjects in Bryden's (1969) group would have had a negative influence on the results. Kimura (1963) has demonstrated this right ear effect for digits for boys and girls as early as age four, although Bakker (1967) has found a decrease in right ear superiority at age seven, no difference between the ears between ages seven and ten and an increase at age eleven in right ear performance. There is no apparent reason for the discrepancy.

Dichotic listening studies, then, have shown that verbal stimuli such as words, letters, or digits are more efficiently reported from the right ear (Bakker, 1967; Borkowski, Spreen and Statz, 1965; Broadbent and Gregory, 1961; Bryden, 1969; Kimura, 1961 a, b; Kimura, 1963; Shankweiler, 1966). A left ear superiority has, on the other hand, been shown for melodies (Kimura, 1964; Shankweiler and Studdert-Kennedy, 1966; Spellacy, 1970), sonar sounds (Chaney and Webster, 1966). Morse signals (Bakker, 1967, 1970), environmental sounds (Curry, 1967) and music and tonal patterns (Spreen, Spellacy and Reid, 1970).

The right ear superiority for verbal material has been related to a left hemisphere cerebral dominance for speech while the left ear superiority for musical and other such non-verbal stimuli has been related to a right hemisphere dominance for such material. Left-hemispheric dominance for speech has been demonstrated unequivocally by the clinical studies of unilateral lesions. The right hemisphere, on the other hand, appears to be dominant for non-verbal stimuli of the type mentioned above. Right temporal lobectomy results, in an increase in errors at the left ear on the Seashore Measures of Musical Talents. No increase in errors was found following left temporal lobectomy (Milner, 1962; Shankweiler, 1966). Similarly, the recognition of meaningful, non-verbal sounds, is impaired by right hemisphere damage (Wortis and Pfeffer, 1948; Spreen, Benton and Fincham, 1965).

Further correspondence with cerebral dominance comes from direct physiological measures of summated auditory evoked cortical responses which demonstrate a greater amplitude of initial output over the right hemisphere for click notes, and equal or higher amplitudes of output over the left hemisphere for verbal stimuli. Cohn (1971) presented two types of stimuli, through earphones, at a rate of one per second; (1) a ten msec. square wave pulse that generated a loud click, and (2) single syllable words with a decrementing duration of about 150 msec. The stimulus recording for clicks showed a definite positive peak with a latency of about fourteen msec. over the right hemisphere and, simultaneously, a somewhat delayed complex-formed, notched or multiphasic wave, generally of lower amplitude over the left hemisphere. The initial responses from the left hemisphere varied but the 14 msec. right hemisphere responses were invariant for four other randomly selected subjects. Responses recorded for verbal stimuli showed a negative deflection followed by succeeding positive waves for both hemispheres. For twenty of the subjects the summated evoked cortical responses showed equal-hemisphere amplitudes, but seventeen subjects showed a greater output amplitude over the left hemisphere.

The differential ear effect, then, has a strong relationship to cerebral dominance, particularly in view of Cohn's (1971) direct measures. Since, the superior recognition of "verbal" and "non-verbal" stimuli occurs in the ear opposite to the hemisphere dominant for that function one must, of course, invoke the unifying assumption of a greater contralateral fiber "efficiency" (Kimura, 1961 a, b). This assumption is supported by the neuroanatomical and physiological data presented earlier (Tunturi, 1946; Ades and Brookhart, 1950; Rosenzweig and Wyers, 1955; Rosenzweigh, 1951) which shows a superiority for the contralateral auditory fibers.

However, merely hypothesizing a greater contralateral efficiency has not been found adequate to deal with the data showing significant losses in right ear recognition of digits following left temporal lobectomy for simultaneous but not for successive presentation (Kimura, 1961 a). Consequently, Kimura (1967) hypothesizes that in addition to more efficiency in the contralateral pathways (possibly due to a slightly greater number of contralateral fibers) there is a point of overlap between the two pathways, suggested by Rosenzweig (1951), at which the contralateral pathways may exert a suppressive influence on the ipsilateral during competition.. Central occlusion has been suggested as well as afferent overlap (Kimura, 1967). A thorough investigation of the effects of competition and division of attention indicates that competition in dichotic listening tasks, as suggested by Kimura(1967), is both necessary and sufficient to get laterality-ear differences (Bryden, 1969), as does a study on intraindividual threshold comparisons (Palmer, 1964). The preceding model, nevertheless, needs some further elaboration.

Kimura's model explains a right ear superiority for alphanumeric stimuli but does not explain why an injury in either hemisphere impairs an alphanumeric message from the contralateral ear. Sparks, Goodglass and Nickel (1970) found that, through their own calculations, Kimura (1961 b) had reported results indicating that unilateral temporal lobe lesions introduced an additional deficit of about 8 per cent in the ear contralateral to the lesion. Inclusion of Heschl's gyrus in the excision brought the total deficit of the contralateral ear to about 21 per cent of the mean score of the pooled ears. Removal of the left anterior temporal lobe produced more severe impairment in both ears than a similar removal on the right.

Section of the anterior commissure and corpus callosum results in almost complete loss of left-ear information under dichotic conditions (Sparks and Geshwind, 1968; Milner, Taylor and Sperry, 1968). Kimura's model would not predict this since the ipsilateral connection from the left ear to the left hemisphere remains intact under these conditons. To Kimura's hypothesis, that under dichotic conditions, the ipsilateral ear input to each hemisphere is virtually suppressed by the contralateral input, Sparks and Geshwind (1968) have added a second postulate; that there is competition for report by the left hemisphere speech system between the information from the right ear arriving directly via the decussating route and information from the left which followed the decussating pathway to the right hemisphere and has then followed a transcallosal pathway across to the left auditory association area. This model more adequately accounts for both the normal cerebral dominance effect and for left ear extinction in cases of callosal section.

Under normal dichotic listening the left ear input, degraded relative to the right ear input by an extra synaptic step, is at a disadvantage in competing for oral report. After callosal section, the elimination of the principal pathway bringing left ear information to the left hemisphere leaves only the right ear input available for oral report.

Sparks, Goodglass and Nickel (1970) provide data supporting a slight modification of this hypothesis. A dichotic listening procedure was used to present digit pairs and monosyllabic word pairs to left brain-damaged aphasic and right brain-damaged nonaphasic male patients. All of the subjects were right-handed and had unilateral lesions determined by clinical examination, electroencephalographic recordings and brain scan results. Mean scores for both ears pooled showed significantly higher scores for right brain-injured subjects than left brain-injured both in digit sets and in words. Comparison between ears, pooling scores for digits and words, showed the right ear to be insignificantly inferior for the left hemisphere group and the left ear significantly inferior for the right hemisphere group.

Both hemisphere-impaired groups show the familiar "lesion effect" in which the ear contralateral to cortical injury loses effectiveness. However, the differences between ears is greater for the right hemisphere group than the left (approaches significance, $p < .10$). The insignificant inferiority of the right ear for the left-hemisphere group is due to the fact that a large proportion of them showed an inferior performance by the ear ipsilateral to the lesion. Sparks, Goodglass and Nickel (1970) have hypothesized the model shown in Figure 6 to account for dichotic listening findings.

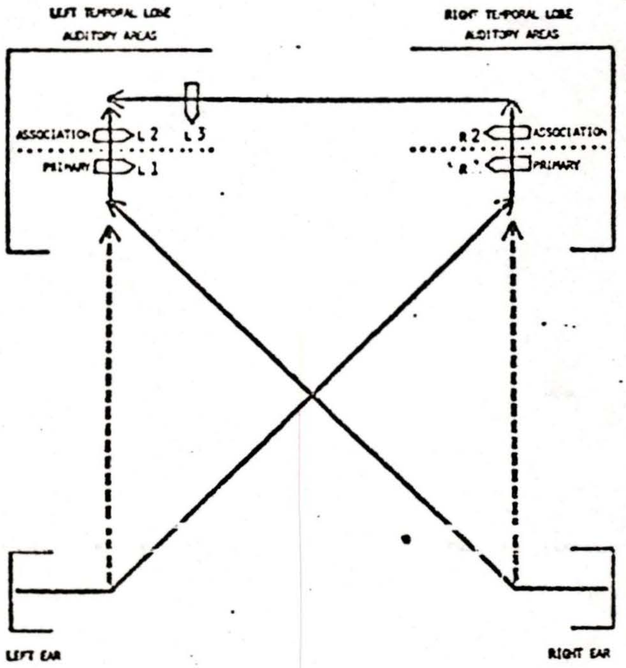

Figure 5. Diagrammatic representation of decussating auditory pathways to the temporal lobes. Areas L1, L2, R1 and R2 represent lesions producing extinction. The broken lines represent the less important ipsilateral routes. Taken from Sparks, R., Goodglass, H. and Nickel, B. Ipsilateral Versus Contralateral Extinction in Dichotic Listening Resulting from Hemisphere Lesions. Cortex, 1970, VI, 249-260.

According to this model, a lesion in the left temporal cortex degrades the dominant right ear signal both at the primary sensory and at the association area levels, while affecting the dominant left ear signal only at the association area level in the left temporal lobe after it has crossed the corpus callosum. Right hemisphere lesions result in left ear extinction because verbal signals from the left ear to the right hemisphere via the dominant decussating route must be returned to the dominant left temporal lobe for decoding. It is not possible, according to this model, to obtain ipsilateral extinction as a result of right temporal lobe damage because the only pathway required for the processing of right ear information is the undamaged decussating route directly to the left temporal lobe. A lesion in the left hemisphere causing ipsilateral left ear extinction is suggested to be located at the point where the auditory pathway after crossing the corpus callosum from the minor auditory association area of the right temporal lobe has arrived in the dominant association area of the left temporal lobe. This is shown in Figure 4 as L3 and offers further explanation why ipsilateral extinction considered significant is restricted to subjects with left hemisphere lesions.

Dichotic listening studies have, then, shown better right ear performance for the aforementioned non-verbal stimuli in the population. ? The right ear superiority for verbal material has been related to a left hemisphere cerebral dominance for speech while the left ear superiority for musical stimuli has been related to a right hemisphere involvement in certain non-verbal functions. These proposals are, of course, based on the unifying assumption of greater contralateral auditory fiber efficiency whether it be greater amplitude or speed of contralateral nervous response or suppression of ipsilateral nervous activity by contralateral fibers under competition situations.

To more adequately account for both the normal cerebral dominance effect and for left ear extinction in cases of callosal section it is also postulated that there is competition for report by the left hemisphere speech system between the information from the right ear arriving directly via the decussating route and information from the left which followed the decussating pathway to the right hemisphere and has then followed a transcallosal pathway across to the left auditory association area.

This direction of inference, from known hemispheric functions to pathway transmission characteristics provides an extremely powerful technique for the assessment of hemispheric laterality functions. This is evidenced by the fact that dichotic listening is consided useful for detecting lateralized lesion effects and for exploring the range of differential hemispheric functioning (Kimura, 1961 a, b).

A similar model is proposed to account for differential tachistoscopic recognition. Although it is not necessary, in most cases, to do more than present material in either one or the other visual field to demonstrate differential recognition, it will be seen that the "either-or" situation and the "simultaneous" or "competing" situation can be encompassed by one model. The latter procedure, involving presentation of material to the right and left visual fields simultaneously, is quite analogous to dichotic listening experimentation. As expressed by Bryden (1965):

> "One task is visual while the other is auditory, and there may be some dissociation of laterality effects in the two modalities. Secondly, in the dichotic listening task, where the numbers are

> clearly audible, the major problem is to remember all the material during recall, while the tachistoscopic recognition situation, with its extremely brief exposure duration, is primarily a problem of obtaining enough information to make the proper identification. Laterality effects in the tachistoscopic task, therefore may be due to differences in the ease of activating a stimulus trace or cell assembly, while laterality effects in the dichotic listening task may be due to differences in the ease of retrieval, or in the rate of decay of the stimulus trace. I.e., one task may be an input problem while the other is an output problem."

However, in the sequel several experiments will be reported in which the procedure was to simultaneously present several pairs of stimuli to be subsequently reported. This type of tachistoscopic presentation is quite similar to the dichotic listening procedure.

TACHISTOSCOPIC VISUAL RESEARCH

Regarding tachistoscopic research, most people show superior right field recognition for alphabetical stimuli (English) such as letters, nonsense syllables, and words, as well as to digits (Bárton, Goodglass and Shai, 1965; Bryden, 1964; Bryden, 1968; Forgays, 1953; Goodglass and Barton, 1963; Harcum and Finkle, 1963; Harcum and Jones, 1962; Heron, 1957; Mangan, 1963; Mishkin and Forgays, 1952; McKeever and Huling, 1970; Orbach, 1953, 1967; Terrace, 1959; Winnick and Dornbush, 1965). A right field superiority has also been shown for unilateral (Wyke and Ettlinger, 1961; Bryden and Rainey, 1963) and for bilateral (Wyke and Ettlinger, 1961) presentations of drawings of familiar objects. However, if letters, simple geometrical figures, and nonsense forms are presented simultaneously on both sides they are identified more accurately in the left visual field (Bryden, 1960; Heron, 1957).

Left field superiority for right handers has been found for subjective attensity of circular areas (Dallenbach, 1923; Kirssin and Harcum, 1969), simultaneous exposre of both letters and forms (Bryden, 1960), and location of a dot on a spatial map (Kimura, 1969). Superior left field recognition, although usually non-significant, has also been found for Yiddish words and letters (Mishkin and Forgays, 1952; Orbach, 1953, 1967). Equal recognition scores have been found for nonsense forms (Heron, 1957), unfamiliar forms (Terrace, 1959; Bryden, 1960; Bryden and Rainey, 1963) and for familiar forms (Heron, 1957). Terrace (1959), however, did find a tendency for a left field superiority. Bryden and Rainey (1963) also presented letters, geometric forms, and outline drawings, bilaterally, and found the subjects' recall to be consistently greater for elements appearing in the left visual field.

The basis for this differential tachistoscopic recognition has been examined in terms of cerebral dominance, selective retinal training, directional scanning, selective attention, stimulus structure, Koffka's (1935) anisotropy of visual space, ocular dominance, visual acuity, and immediate memory. Each of these explanations will be considered but an attempt will be made to add verisimilitude to a cerebral dominance - contralateral optic fiber superiority explanation.

Selective Retinal Training

Mishkin and Forgays (1952) have attempted to account for differential tachistoscopic recognition by an explanation based on reading experience.

They hypothesized that, due to the left-to-right organization of the English language, reading English is a mainly right visual field activity. Therefore, reading English would selectively train the left hemi-retinae. Conversely, reading Yiddish, in which the letters run in the reverse order, is a left visual field activity which, then, selectively trains the right hemi-retinae. Consequently, a la Hebb (1949), a more effective neural organization develops in the left hemisphere for English and right for Yiddish. This training, due to reading, was thought to be of major influence in tachistoscopic recognition. As predicted, Yiddish is more easily recognized in the left visual field by bilinguals who, at the same time, show greater recognition in the right for English words (Mishkin and Forgays, 1952; Orbach, 1953, 1967). The data were not completely consistent with the hypothesis since the recognition differential was significant for English but not for Yiddish. However, the relatively small differential recognition of Yiddish may in fact be consistent with the selective retinal training hypothesis when subjects are considered in terms of the first language learned.

Orbach (1953) found that subjects who had learned English first, recognized Yiddish words better in the right visual field, whereas, those who had learned Yiddish first showed better recognition in the left visual field. Furthermore, there appears to be a difference in the degree of selective retinal training in Hebrew and English cultures. A native Hebrew does, generally, read some material from left-to-right regardless of whether or not he learns English.

> "Although Hebrew has numerals which are composed of Hebrew letter-forms, these are infrequently taught as numerals and seldom utilized in newspapers and books.

> Instead, as in English, the Arabic numerals are used. In arithmetic especially, the child is taught to calculate with Arabic numerals and long numbers are read in the left-to-right direction. Music, too, is written from left to right. These considerations suggest that the left hemi-retina may get a considerable amount of training even in Hebrew-reading youngsters while right hemi-retinal development is proceeding. Thus, the right-to-left habit would be less decisively established in Hebrew readers than the left-to-right habit in English readers. (Orbach, 1967, page 133)."

Cerebral dominance, despite the apparent importance of reading habits, cannot be completely eliminated. Testing native Hebrew readers, Orbach (1967) found better recognition of English in the right visual field though right-handers showed a greater recognition differential than left-handers. No significant recognition differential was obtained using Hebrew words. However, further analysis of a significant interaction showed that right-handers recognized more Hebrew words in the right visual field and left-handers identified more Hebrew words in the left. Furthermore, presentation of Yiddish and English words vertically through a monocular tachistoscope to bilinguals, for whom Hebrew was the first learned and most fluent language, has shown lower right visual field thresholds for both languages (Barton, Goodglass and Shai, 1965). This indicates a lateral dominance effect, although Goodglass and Barton (1963) have found significantly lower thresholds in the right visual field for both left and right-handed English speaking subjects presented with monocularly exposed English words. Despite these results, Barton, Goodglass and Shai (1965) argue for an explanation based on the language dominance of the left hemisphere.

If the right field superiority for words is due to retinal training from reading, then the degree of right field superiority should vary as a function of reading experience. Forgays (1953) studied the degree of right field superiority as a function of educational grade level (grades 2 through 10 and each of the first three college years) and found that the superior recognition of words presented to the right of fixation is significantly related to educational grade level. Since the total recognition of words increased significantly with educational level, it seems reasonable to consider reading as a variable increasing with education. This is, however, also not inconsistent with the lateral dominance hypothesis since there were essentially no field differences until grade eight. Thereafter a difference developed which remained essentially constant. The selective retinal training hypothesis would actually be more in line with a gradual increment between grades two through seven. In fact the development of cerebral dominance seems to be more important than reading per se, since seventh graders reading at a normal level show equal right field superiority to those reading at a third grade level (McKeever and Huling, 1970 b). To account for the discrepancy Forgays (1953) experiment has been criticized on exposure duration, subject distraction and poor fixation control (McKeever and Huling, 1970 b).

By the same line of reasoning (more education, more reading), Kimura (1959) compared army personnel, with an average of eight years of schooling, to college students on letter recognition. Fixation was directed to the center of a square with one letter in each quadrant of the square. Both the army personnel and college students showed decreasing recognition scores from the upper left square to the lower right. However, when increasingly larger gaps were introduced between letters the army personnel recognized more letters in the upper right than the upper left, whereas the college students showed no change in ordering. This supposedly indicates that reading experience affects tachistoscopic recognition but more in terms of "creating" a left-to-right set than in terms of a selective retinal training; an effect found earlier by Heron (1957).

Selective Attention

Reading experience may affect tachistoscopic recognition in two ways: if one assumes that reading somehow "sensitizes" the left hemi-retinae and that superior right field recognition is due to the sensitivity *per se*, it would be necessary to demonstrate that the right field superiority was not due to selective eye movements during stimulus exposure. However, if one hypothesizes that reading "creates" a set to attend to verbal stimuli from left to right it would be necessary to consider some sort of "post-exposural process" (Heron, 1957) facilitating the perception of stimuli in the right visual field while debilitating perception in the left.

Heron (1957) demonstrated that the right-field superiority for alphabetical material is only obtained when the material is exposed in one or the other field. If letters are exposed to each field simultaneously, more are recognized in the left. Furthermore, when four letters are exposed in a square on either the left or right of fixation the frequency of correct recognitions is in the order upper left, upper right, lower left, then lower right. There were no significant differences between the mean scores, for either nonsense or familiar forms exposed in the right field and those exposed in the left. Successive exposure resulted in more letters being perceived in the right than in the left visual field in both an informed and uninformed condition. That is to say, it made no difference whether or not the subject knew the field of presentation. Heron (1957) developed a hypothesis in terms of an attentional process. Exposure of the stimulus excites corresponding traces, via feedback from the oculomotor centers, in the order in which the letters would normally be fixated during reading. The first letter or word of the stimulus is attended to and the remainder of the stimulus is scanned. For stimuli on the right side of the fixation point only one direction of scanning is necessary; on the left two directions are necessary, first to the left, then to the right. Since geometrical forms or nonsense figures are not usually read in unidirectional sequences they should be recognized equally in both fields.

To support Heron's (1957) hypothesis it is necessary (1) to show that eye movement does occur during fixation, (2) that the eye movement is systematically related to differential accuracy, (3) that the first word or letter of the word is tantamount to perception, (4) that discrimination occurs before a "post-exposure" process or scan, and (5) that the recognition of forms is equal in each visual field.

(1) Eye movement during fixation

That there are involuntary eye movements during fixation has been convincingly demonstrated. Three types of movements have been reported relative to the eyeball as a whole; (1) irregular movement of high frequency (30-70 cycles per second) with a small range (approximately 20" arc) (Adler and

Fliegelman, 1934; Ratliff and Riggs, 1950); (2) rapid flicks each of a few minutes of arc lasting about 0.02 sec. and occurring at regular intervals of about 1 sec. (Adler and Fliegelman, 1934; Lord and Wright, 1948; Ratliff and Riggs, 1950; Lord, 1951); (3) slow irregular movements (Adler and Fliegelman, 1934; Ratliff and Riggs, 1950). Ditchburn and Ginsborg (1953) used a plane mirror attached to a contact lens to photographically record the displacement of the image relative to the retina. This displacement was a result of the total angular movement of the eye due both to movements of the eye in its orbit and eye as a whole. Three types of movement similar to, but more accurate than, the above were reported; (a) a tremor of 10-30" arc, 30-80 cycles per second; (b) flicks 1-20' arc, occupying 0.025 sec. at intervals of 0.03-5.0 sec.; (c) drifts up to 6' in an interface period. The involuntary movements were co-ordinated in both monocular and binocular fixation. If these eye movements can be seen as systematic further support will be added to Heron's (1957) hypothesis.

(2) Systematic eye movement

Bryden (1961) has found a significant relation between eye movements and locus of recognition for both alphabetical and geometrical material. No relation was observed between eye movements and order of report. Similarly, presentation of a row of numerals across the visual field has resulted in a congruence between the direction of initial eye movement and the visual field more accurately perceived (Crovitz and Daves, 1962). Both of these studies support Heron's (1957) hypothesis in that differential tendencies to eye movement are associated with differential accuracy.

(3) Importance of the first element to perception

(i.e., stimulus structure)

Mishkin and Forgays (1952) have denied that the beginning of a word is a better cue than any other part for recognition. They demonstrated that recognition was just as good when the first half of the word was blurred as when the second half was blurred. On the other hand, Harcum and Jones (1962) have found the distribution of recognition errors to be relatively symmetrical among letter positions to the left of fixation, while the distribution on the right increased from fixation. That scanning need not always proceed from left to right, but rather from beginning to end, is indicated by better recognition for mirror-image words in the left visual field (Harcum and Finkle, 1963). Therefore, despite the discrepant results, the beginning part of the word is likely the most important for correct perception.

(4) Discrimination before scanning

Heron's (1957) hypothesis implies that discrimination of the stimulus arrangement must take place before the selective mechanism operates (Kimura, 1959). In a second experiment (subsequent to the one reported earlier) Kimura (1959) tested the relation between duration of stimulus (20 msec. and 40 msec.) and the effect of letter position. Some support was found for the prediction derived from Heron's (1957) hypothesis. There was a tendency (insignificant) for letter recognition to be better in the right visual field in the 40 msec. condition but not in the 20 msec. condition.

(5) Equal field form recognition

Heron (1957) had reported results showing equal left and right field recognition for familiar and nonsense forms. Similarly, Terrace (1959) and Bryden and Rainey (1963) have found the difference between scores for word recognition to be significantly greater in the right visual field while the differences for unfamiliar forms were not significant. Terrace (1959), however, did find a higher mean recognition on the left which is in the direction predicted by cerebral dominance.

Furthermore Heron's (1957) results are difficult to reconcile with data from Wyke and Ettlinger (1961) and Bryden and Rainey (1963) which show that recognition of familiar objects, viewed for brief periods, is more efficient in the right visual field.

These results are not inconsistent with the cerebral dominance hypothesis. The recognition of familiar forms and objects might be confounded by a naming factor in that familiar objects might automatically be named by subjects, resulting in a right field superiority as shown for words. Forms are, perhaps, a little more difficult to name. This is, of course, conjectural until an experiment is performed on tachistoscopic recognition as a function of ease of verbal labelling. At any rate, the argument for a cerebral dominance explanation becomes more cogent in view of the factthat for a patient with a right temporal lobe lesion the threshold for recognition of pictures on the left side of the binocular field was considerably higher than that on the right when two stimulus figures were presented simultaneously on either side of the fixation point (Wyke and Ettlinger, 1961).

Another possibility for the discrepancy is the difference in procedure. Wyke and Ettlinger (1961) used an increasing stimulus duration until the subject recognized the form, while Heron (1957) used a constant exposure duration obtaining a score for number of items correctly recognized. Nevertheless, the discrepancy may be real since both Bryden (1960) and Kimura (1959) have found a tendency to report forms in a left to right order. Bryden (1960) found both letters and forms to be recognized more accurately in the left visual field than in the right when the material was exposed in both visual fields simultaneously. When forms were exposed successively in one visual field or the other, they were recognized with equal facility in the two fields. Kimura's (1959) first experiment, although unmentioned previously, also involved fixation in the center of a square of forms and for letters with geometrical forms added. As with squares of only letters, squares with geometrical forms and squares of letters with geometrical forms added showed decreasing recognition scores from upper left to lower right. These results suggest that Heron's (1957) hypothesis is inadequate even though there is some evidence that left-to-right reporting of forms is not a strong effect (Bryden, 1960).

Furthermore, Heron's hypothesis is dubious on more general objections. His most basic finding in support of the hypothesis was that the simultaneous exposure of words led to left visual field superiority. McKeever and Huling (1971 a), in direct opposition, report the other effect; right visual field superiority with bilateral exposure. This was found to be true even when the stimulus in the left visual field led the stimulus from the right by as much as twenty milliseconds (McKeever and Huling, 1971 b). Since interhemispheric transfer time is approximately six milliseconds (Poffenberger, 1912; Efron, 1963; Jeeves and Dickson, 1970) the twenty millisecond lead would allow the stimulus from the left visual field to get to the language (left) hemisphere before that from the right. These results, then, speak strongly against those of Heron. It was suggested that the discrepancy is due to Heron's lack of fixation control (McKeever and Huling, 1970 b).

Immediate Memory

Bryden (1960) has found that when subjects were given instructions to report forms or letters either from left to right or from right to left immediately after exposure of the material, the locus of optimal recognition for the forms changed, but that for letters did not. When the order of report was from left to right, more forms were reported in the left visual field, while more were reported in the right when the order was from right to left. While confirming Heron's (1957) finding that more letters are perceived in the right than in the left visual field, regardles of whether or not the subject knew the exposure field, the results also indicate that immediate memory is an important factor determining which objects are correctly reported after a tachistoscopic presentation (Bryden, 1960). In addition, the processes involved in the recognition of letters seem to be strongly polarized in a left-to-right direction while those involved with forms are not. Bryden (1960) suggests that a central association model is more successful in dealing with the general problem of serial order than is a "scanning mechanism".

The use of multiple-letter stimuli, showing results in favour of Heron's (1957) hypothesis, might be obscuring the effects of cerebral dominance. Bryden (1964) randomly presented either single-letter or multiple-letter stimuli to test this idea. The data were insignificant for single-letter stimuli but the trend indicated that the superior field of recognition is dependent on the dominant hemisphere for speech. Multiple-letter stimuli, however, did not show any relation to cerebral dominance. Bryden (1964) proposed that highly directional reading habits (Heron, 1957) override cerebral dominance with multiple-letter stimuli. The subjects in this experiment were classified according to writing hand. To obtain more conclusive results, Bryden (1965) used a dichotic listening test, along with a handedness questionnaire. Dichotic listening has been found a better technique than self-report measures of handedness for the classification of normal subjects according to cerebral dominance (Kimura, 1961 a, b; 1967). For twenty second exposures, Bryden (1965) found better identification for letters in the right visual field by right-handers and approximately equal right and left visual field identification by left-handers. General right-field superiority was not observed at a twenty-five second exposure. Consideration of the findings by Branch, Milner and Rasmussen (1964) and Milner, Branch and Rasmussen (1966), reported earlier, leads to the conclusion that Bryden's (1968) results are in line with the cerebral dominance prediction.

Neurophysiological observations indicate that the temporal lobes might play an important role in memory (Penfield, 1958). Further, Milner's psychological examination (1958) of temporal-lobe patients has suggested that the dominant lobe may be primarily associated with verbal memory, whereas the minor temporal lobe may be concerned with rapid visual identification.

Cerebral Dominance and Left Visual Field Superiority

Experiments showing a left visual field superiority for certain non-verbal stimuli are best explained by a minor hemispheric dominance for these functions.

Dallenbach (1923) has found that circular areas in the left visual field require less intense illumination when right-handed subjects are required to match two circular areas, one in each visual field, for attributive clearness. Correctly assuming that most right-handed people are left hemisphere dominant for speech, Dallenbach (1923) attributed the results to less interference in the right hemisphere for this type of material. Kirssin and Harcum (1967) tested Dallenbach's (1923) hypothesis for both left-handers and right-handers. As predicted, right handers showed left-field superiority (i.e., less illumination was necessary) in conjunction with a right-field superiority for left handers. However, since there were several large negative scores, the data were not considered as positive evidence for Dallenbach's (1923) hypothesis (Kirssin and Harcum, 1967).

Kirssin and Harcum (1969) also attempted to determine whether the hemifield of greater attensity was correlated with differential accuracy in the perception of binary pattern elements. All subjects, regardless of handedness, showed superior left field reproduction for binary patterns exposed across the visual field. Kirssin and Harcum (1967) interpreted this as inconsistent with the hypothesis of lateral dominance in terms of a stable structural difference. However, this is probably an incorrect interpretation in view of the reports on handedness and cerebral dominance for language (Branch, Milner and Rasmussen, 1964; Milner, Branch and Rasmussen, 1966) and the reports on the lack of relationship between self-reports of laterality and manual dexterity (Benton, Meyers and Polder, 1962; Satz, Achenbach and Fennell, 1967).

A somewhat related finding is that recognition of a dot on a spatial map is more accurate when presented in the left visual field (Kimura, 1969). Kimura (1969) presented a series of dots, tachistoscopically, in either the left or right visual field, the subjects' task being to locate the dot on a spatial map depicting all of the dot locations presented. Kimura (1969) hypothesized that the results were due to the operation of a "spatial-coordinate" system in the right hemisphere. Julez (1965), using random dot patterns generated by a computer, has found spatial factors to be important in form discrimination. Therefore, one might invoke Kimura's (1969) "spatial-co-ordinate" hypothesis in an attempt to account for the tachistoscopic recognition of such stimuli as nonsense and unfamiliar forms, geometrical figures, circles and dots. That is, one would predict superior recognition of such forms in the visual field corresponding to the non-dominant hemisphere for speech which would adequately account for Kirssin and Harcum's (1967) data assuming, of course, the slight relationship between handedness and cerebral dominance previously indicated.

Kimura's (1969) hypothesis receives support from several of the clinical lesion studies reported earlier. Right hemispheric lesions have been found to result in greater deficits in visuoconstructive ability (McFie, Piercy and Zangwill, 1950; McFie and Zangwill, 1960) and visuospatial ability (Brain, 1941; Paterson and Zangwill, 1944; Milner and Teuber, 1968). Kimura (1969) also cites evidence showing that the estimation of dots presented tachistoscopically is superior in the left visual field in normals but is radically disrupted by temporal and parietal lesions in the right hemisphere. Lesions in similar regions of the left hemisphere cause little loss in accuracy (Kimura, 1966; Warrington and James, 1967). Kirssin and Harcum's (1967) data still, however, could be considered consistent with the tendency of subjects to report forms in a left-to-right manner found by Kimura (1959) and Bryden (1960). Bryden's (1960) data appear to be adequately explained by cerebral dominance. Kimura's (1959) experiment, which involved the central fixation of a square, appears to indicate that something more than cerebral dominance is operating.

Sampson and Spong (1961 a) have reported evidence indicating that the recall of eight digits presented successively in four pairs (one to each eye) is dependent on a "central mechanism which temporally groups stimuli when taxed". This finding is in agreement with Bryden's (1960) central association model based on immediate memory and, in addition, appears to explain why there is difference between visual fields for forms presented successively. Therefore, one might propose that the importance of cerebral dominance is diminished when successive presentation taxes the immediate memory span. Bryden (1964) has proposed that highly directional reading habits (Heron, 1957) override cerebral dominance for multiple-letter stimuli. As indicated, the recognition of most multiple-letter stimuli such as words, is adequately accounted for by cerebral dominance since there is a right visual field superiority. It is possible that for these experiments, the central memory mechanism has not been taxed, since a few other particular cases of multiple-letter presentation show a left-field superiority (Kimura, 1959; Bryden, 1960, 1964). This immediate memory may explain why subjects showed decreasing recognition scores from upper left, to upper right and lower left to lower right if one assumes that the subjects are actually "scanning" the square in this manner. However, it still does not explain why the subjects would scan forms in this manner to begin with, since, as indicated, we are not usually trained to read forms.

Cerebral Dominance, Eye Dominance, and Contralateral Fiber Superiority

It has not been necessary, as yet, to invoke the postulate of contralateral optic fiber superiority. However, the tachistoscopic literature covered has not been strictly analogous to the dichotic listening paradigm. Simultaneous tachistoscopic exposure of a series of paired visual stimuli to be reported is quite analogous. To explain these results one must consider eye dominance and contralateral fiber superiority an explanation which fits nicely into the cerebral dominance explanation.

It is, therefore, of interest to determine why temporal grouping apparently does not occur for simultaneous presentation. Simultaneous binocular presentation creates an input competition which, of course, does not occur in successive presentation. Bower and Haley (1964) presented ten digit pairs, one of each pair to opposite eyes simultaneously, the subjects' task being to report all the digits they could see. The results showed that the digits reported were either ones projected to the nasal hemiretinae or to the dominant eye. Resolution in favour of the dominant eye has also been found by Anderson and Crosland (1933), Sampson and Horrocks (1967) and Sampson (1969). The relative ineffectiveness in recall for digits projected to the non-dominant eye when eight digits in four pairs were presented simultaneously, one to each eye (Sampson, 1969) has been attributed to the inefficient recall of digits projected to the left temporal retina. Sampson (1969), confirming Bower and Haley (1964) also found significantly better recall for digits projected to the nasal retinae. The order of efficiency of recall was right nasal, left nasal, right temporal, and left temporal (Sampson, 1969).

A superior nasal sensitivity has also been indicated for complex stimulus patterns in which the subject's task was to attempt a reproduction of the pattern which was presented in the left and right halves of the visual field during central fixation (Harcum and Dyer, 1962). In accordance with findings presented earlier for pattern-type stimuli, there was superior accuracy for the left-field elements.

Sampson and Spong (1961 a) report results for simultaneous exposure of four digit pairs during binocular fixation. Significantly more digits were recalled from the right eye (the dominant for all subjects) but this was only in a non-fixation control condition. There was no difference during central fixation. Recall was best from binocular fixation and nasal projection. Furthermore, digits projected to the left eye were reported significantly more slowly than those from the right eye. These results are in line with the cerebral dominance - contralateral superiority explanation. The authors state:

> "This analysis leads to the general conclusion that temporal grouping of responses occurs when a limited capacity central integrating mechanism is taxed, and that pairing of responses represents the action of the central mechanism and does not depend only upon the spatial arrangement of the stimuli. It is feasible that the tendency to order responses from left-to-right originated from eye-movements in reading, but in these adult subjects eye-movements could have played no part in organizing responses in this experiment. The conclusion, then, that temporal grouping is particularly symptomatic of the taxing of a limited capacity central mechanism accords well with previous ones from auditory experiments and those using the reaction time procedure (Sampson and Spong, 1961 a)."

The superiority of nasal fibers involved in recall (Sampson, 1969), in recognition (Bower and Haley, 1964) and in the reproduction of complex patterns (Harcum and Dyer, 1962), combined with these authors' concomitant findings of a superior right field for digits and left for patterns, indicates another possible interpretation for Kimura's (1959) perplexing finding. One might hypothesize that the form in the upper left is recognized more easily since it traverses the nasal retina of the left eye and temporal retina of the right, the nasal retina of the left eye being the fastest route to the non-dominant hemisphere for speech. The form next recognized is the one in the upper right square. Since it traverses different fibers (left-temporal, right-nasal) to the left hemisphere the impulse would have to cross the corpus callosum to the right hemisphere. Presumably, this happens before the bottom half form reaches the right hemisphere. The same reasoning applies to the bottom two figures. It is, of course, necessary to hypothesize that two different impulses cannot traverse the same retinal fibers at the same time. Otherwise, recognition in terms of cerebral dominance and superior nasal transmission would be better for both left figures. This hypothesis, so far, does not explain the superior recognition of upper over lower forms. At any rate, Kimura's (1959) findings are difficult to reconcile with those of Mishkin and Forgays (1952) who found the best recognition for words to the right and below fixation. An experimental manipulation will be included in the proposed experiment to determine whether or not there is differential reaction time to upper-versus-lower stimulation.

The superiority of retinal fibers has also been considered in monocular tachistoscopic experiments. Overton and Wiener (1966) have attributed a right field superiority for words to a more sensitive temporal hemi-retina of the left eye. This was based on the finding that words in the right field showed better recognition for the left eye, but there was no difference between the fields for the right eye. This finding is probably anomalous since Goodglass and Barton (1963), Barton, Goodglass and Shai (1965) and

McKeever and Huling (1970 a, b) have all found significantly superior right field recognition for both eyes. McKeever and Huling (1970 b) report the same result with children.

McKeever and Huling (1970 a) found that crossed optic nerve fibers mediated poorer recognition than uncrossed. It is important to note, however, that "actually this inferiority was restricted to the right hemisphere since the mean score for nasal fibers was actually slightly higher than for temporal fibers to the left hemisphere. Although the right hemisphere fiber score difference was fairly large, it was also quite variable and not significant by t test (McKeever and Huling, 1970 a)." McKeever and Huling (1970 b) did not find a "fiber effect" although their data indicate a superior crossed connection since there was a slightly greater field differential in the right eye than in the left eye).

Consideration of these findings, in combination with the differential superiorities observed in dichotic listening studies, indicates that the left and right hemispheres differ on a verbal-non-verbal dimension. In any case, it appears that invoking a cerebral dominance hypothesis to account for differential tachistoscopic recognition results in unification of the findings from clinical observations of the results of brain lesions, dichotic listening studies, and tachistoscopic recognition. Greater activation of cortical units and greater speed of signal transmission due to contralateral optic pathways form a basis for this hypothesis.

Further correspondence with cerebral dominance comes from direct physiological measures of averaged visual evoked cortical responses. Fedio and Buchsbaum (1971) tachistoscopically presented words or random dot patterns to both normals and temporal lobe damaged patients and recorded the evoked potentials. For the normal group they found that word material produced a higher discrimination index score than dot stimuli from the left hemisphere while dot patterns produced a greater discrimination index than words from right hemisphere evoked responses. This finding is in line with a cerebral dominance explanation of differential tachistoscopic recognition since all of these subjects were right handed and left hemisphere dominant for speech (determined by such methods as the intracarotid amytal test, cortical speech mapping and psychometric test). To attain a higher degree of confidence Fedio and Buchsbaum ran the same test on a different group of subjects who had undergone unilateral right or left temporal lobectomies. In line with the above the expected verbal impairment for left temporal lobectomy cases was expressed in less different averaged evoked response waveforms evoked by right and left field presentation of verbal stimuli. The nonverbal deficit associated with right temporal surgery was expressed by undifferentiated averaged evoked response waveforms recorded during perception of nonsense dot patterns (Fedio and Buchsbaum, 1971)."

The major explanations for the results of tachistoscopic visual stimulation have been considered. The remaining explanations, of those mentioned, are in terms of Koffka's (1935) anisotropy of visual space and visual acuity. Directional scanning was integrated into the discussion on the selective attention explanation.

Koffka's (1935) Anisotropy of Visual Space

Anisotropy of visual space refers to the possibility that stimuli are seen in one visual field over the other due to greater clarity in that field. Mishkin and Forgays (1952) offered this as a possible explanation for the right visual field superiority shown for words but rejected it by showing that Yiddish was better recognized in the left visual field. This explanation has not received any support and will be disregarded.

Visual Acuity

Differential visual acuity is often controlled as a nuisance variable or ignored. Hayashi and Bryden (1967) have, however, found that acuity dominance has a significant effect on recognition during binocular fixation. The authors believe that stimuli reaching the acuity dominant eye is stronger and less distorted. Furthermore, there are more left acuity dominant than right acuity dominant people (Crovitz, 1961). This might have contributed to the results obtained in experiments not controlled for acuity or for which acuity was ignored. Acuity dominance in these cases likely is related to contralateral fiber superiority and cerebral dominance (Hayashi and Bryden, 1967; Wyke and Ettlinger, 1961). That is, differential recognition may be increased or decreased in relation to the material, the dominant hemisphere and the eye which is dominant.

SUMMARY

An attempt has been made to indicate a relation between dichotic listening and tachistoscopic visual presentation. The emphasis has been to explain the results of studies in these areas in terms of cerebral dominance and its relation to a postulate of human functional neuroanatomy as a system of mainly contralateral organization. The use of one basic explanation to account for data from these two techniques is believed to be more cogent than the variety of explanations currently being adopted. By doing so, both tachistoscopic visual presentation and dichotic listening are considered potentially useful techniques for exploring the range of differential hemispheric functioning in normal humans.

Cerebral dominance is a concept which might best be seen as varying along a verbal-non-verbal dimension. One hemisphere (usually the left) is dominant for various types of verbal functions, while the other is dominant (usually the right) for non-verbal functions.

Since the results of dichotic listening studies are usually explained in terms of cerebral dominance and contralateral auditory fiber superiority (relative transmission speed, relative cortical unit activation and suppressive influences), the purpose was merely to organize and present the major findings. Dichotic listening studies have shown that verbal stimuli such as words, letters, or digits are more efficiently reported from the right ear. A left ear superiority has been found for such non-verbal stimuli as melodies, sonar sounds, Morse signals, environmental sounds, and music and tonal patterns. The right ear superiority for verbal material has been related to a left hemisphere cerebral dominance for speech while the left ear superiority for musical and other such non-verbal stimuli has been related to a right hemisphere dominance for such material. Since the superior recognition of verbal and non-verbal stimuli occurs in the ear opposite to the hemisphere dominant for that function it is necessary to invoke the unifying assumption of contralateral fiber "superiority". To more adequately account for both the normal cerebral dominance effect and for left ear extinction in cases of callosal section it is also postulated that there is competition for report by the left hemisphere speech system between the information from the right ear arriving directly via the decussating route and information from the left which followed the pathway to the right hemisphere and has then followed a transcallosal pathway across to the left auditory association area.

A similar approach was taken for differential tachistoscopic recognition.

The "either-or" situation and the "simultaneous" or "competing" situation were encompassed by the cerebral dominance-contralateral optic fiber superiority explanation.

Koffka's anisotropy of visual space is of little value as a predictor of differential recognition. Selective attention, stimulus structure, and immediate memory are considered relevant to the "directional scanning" hypothesis. Directional scanning, selective retinal training, ocular dominance and acuity, and cerebral dominance have all contributed to explanations for the data although ocular dominance and acuity show a relationship to cerebral dominance. Directional scanning appears to have its strongest basis from multiple-letter presentation. Cerebral dominance, to a certain extent, has been of explanatory value in most experiments but does not appear to explain a left visual field superiority for Yiddish. The "selective retinal training hypothesis" has received the greatest attention due to this finding. Nevertheless, cerebral dominance cannot be completely ruled out in view of results showing superior left field recognition for Yiddish by left-handers and superior right field recognition by right-handers. One might entertain the possibility that left cerebral dominance for language is actually "created" by a left-to-right language. Once established, lateral dominance is of major importance. The right hemisphere then becomes relatively more important for "non-verbal" type stimuli by virtue of the fact that it is unencumbered by language.

The hypothesis of an intimate relationship between cerebral dominance for language might be testable in terms of ipsilateral and contralateral optic fibers. Ocular dominance has been found to influence binocular, simultaneous stimulation by digits but this has been found due mainly to the relative inferiority of the left temporal retina. Right field superiority, found with monocular stimulation by words, has been attributed to a more sensitive temporal retina in the left eye. However, the weight of the evidence indicates a differential effect in the right as well as the left eye favouring a nasal fiber superiority.

Instruction for Experiment I

"You will be wearing headphones through which you will hear a hissing noise interrupted, occasionally, by a short tone. Each time the tone occurs you are to look directly at this cross on the screen in front of you. More specifically, I would like you to look directly at a small spot of light in the center of the cross."

"At various intervals following the tone a number will be flashed on the screen right over the fixation cross or close to it. If you see and recognize the number please write it on the sheet in front of you. If you do not recognize the number or do not see a number please mark an X. You will have plenty of time, after the stimulus, to look down, record the number or X and look up. After marking a number or an X please do not close your eyes except to blink. Please do not look up to the right because the flood lamp will likely annoy you.

Again be sure and return to the fixation point when you hear the tone. However, AND I WOULD LIKE TO EMPHASIZE THIS, I WOULD LIKE YOU TO OCCASIONALLY FIXATE AT SOME POINT OTHER THAN THE CROSS. It is worth discovering for yourself that you probably cannot report the number if you fixate at some other spot. SINCE I WOULD LIKE TO KNOW WHETHER OR NOT I CAN TELL IF YOU ARE FIXATING PLEASE DO NOT INDICATE WHEN YOU ARE GOING TO FIXATE AT SOME POINT OTHER THAN THE CROSS. Only mark down a number if you see and recognize one. As a matter of fact some of the slides do not have a number. I will now give you a few practice trials. See if you can report the numbers. O.K.? Finally, there will be two experimenters watching you during the test period; Steve will be sitting (here) and I will be behind the screen."

Instructions for Experiment II

In this experiment I'm interested in your reaction times after seeing a spot of light in different parts of the visual field.

The task is quite simple. You will be wearing headphones through which you will hear white noise. At various intervals you will hear a tone. When the tone occurs please look at this spot of light in the center of the cross. At random intervals following the tone a spot of light will appear somewhere on the screen. When the light appears depress the key as rapidly as possible. Make sure that they key is fully depressed before releasing it.

It is extremely important to me that you do not move your eyes from the center of the screen when reacting to the light because I have set the equipment up to be able to stimulate particular portions of your eye.

Occasionally you will see directions on the screen which will say .....

Cover Right Eye   Cover Left Eye   Use Right Hand   Use Left Hand

Now I'll give you some practice trials. After the practice trials I'll stop the apparatus and put on the experimental tray. Please remain seated and in the headrest. Once the practice trials are over and the new tray inserted I'll go behind the screen to observe your pupils through a telescope, monitor fixation, and record your reaction times.

PLEASE REMEMBER TO FIXATE CAREFULLY FOLLOWING THE TONE AND NOT MOVE YOUR YOUR EYES TO THE SPOT OF LIGHT

YOU SHOULD PERHAPS BLINK A LITTLE MORE THAN USUAL TO AVOID TIRING YOUR EYES

TRY AND IGNORE ME DURING THE PRACTICE TRIALS. I'LL BE MOVING ABOUT TO MAKE SURE THAT EVERYTHING IS WORKING CORRECTLY

MAKE SURE THAT YOUR INDEX FINGER IS LIGHTLY RESTING ON THE KEY WITH THE KEY FULLY UP. DO THIS THE SAME WAY EACH TIME (i.e. do not on some trials have your finger above the key and on others have the key partially depressed.

Handedness Questionnaire

For each item, circle the letters to the left which best describe your hand preference for that task.

Explanation of letters:

Ra = right hand always

Rm = right hand most of the time

E = both hands equally often

Lm = left hand most of the time

La = left hand always

X = do not know which hand

(1) Ra Rm E Lm La X: is used to write with.

(2) Ra Rm E Lm La X: to hold a nail while hammering.

(3) Ra Rm E Lm La X: to throw a ball.

(4) Ra Rm E Lm La X: to hold bottle while removing top.

(5) Ra Rm E Lm La X: is used to draw with.

(6) Ra Rm E Lm La X: to hold potato while peeling.

(7) Ra Rm E Lm La X: to hold pitcher when pouring out of it.

(8) Ra Rm E Lm La X: to hold scissors when cutting.

(9) Ra Rm E Lm La X: to hold knife when cutting food.

(10) Ra Rm E Lm La X: to hold needle when threading.

(11) Ra Rm E Lm La X: to hold drinking glass when drinking.

(12) Ra Rm E Lm La X: to hold tooth brush when brushing teeth.

(13) Ra Rm E Lm La X: to hold dish when wiping.

(14) Ra Rm E Lm La X: to hold tennis racquet when playing.

Do you consider yourself to be left handed or right handed?

Please indicate which members of your direct family. i.e. parents and brothers and sisters are left handed ______________________________

Footedness Questionnaire

Using the letters above, please answer the questions below in the way which best describes your foot preference for each task.

(1) Ra Rm E Lm La X: to stamp out a fire.

(2) Ra Rm E Lm La X: to kick a football.

Instructions for A-B-C. Test for Ocular Dominance (Miles, 1929).

"I will expose a card for a moment while you look at it through the V-Scope. You will tell me which of the two spots on the card is larger and which is darker. The two spots will always differ from each other in size and darkness. Press the V-Scope open with both hands and when I count 'one, two, up' bring it up and look through it at the card."

Instructions for Finger Tapping Test

"Please put your palm on this board and your index finger on this tab. When I say go I would like you to depress the key as many times as you possibly can until I say stop. We'll do each hand twice starting with your left. Please practice a few taps with each hand. Notice that the key must be allowed to come completely back up after depression or the counter will not count the tap."

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