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Cerebral Dominance, its Measurements and its Role in Letter Recognition and Spelling

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CEREBRAL DOMINANCE, ITS MEASUREMENTS AND ITS ROLE IN LETTER RECOGNITION AND SPELLING

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ABSTRACT

In this investigation, three methods of determining cerebral dominance were evaluated: dichotic listening, bilateral electroencephalogram, and response latencies for unilateral tachistoscopically presented letter pairs. Of the three, only the response latency method differentiated between right- and left-handed subjects (criterion validity). The Spearman-Brown split half reliability coefficient was .97.

The response latency methodology was used to determine the cerebral dominance of a group of poor spellers (N = 6) and a control group (N = 6) as a test of Orton's theory that speech disorders are caused by anomalous patterns of dominance. No such patterns of dominance were found. Orton's theory was not supported.

The experimental group was significantly slower ($p < .01$) and made more errors ($p < .05$) when responding with their right hands. It was theorized that the experimental group subjects encode verbal information kinesthetically and that their poor performance was due to interference of processing of the stimuli and the kinesthetic nature of the response, a key press. These results are seen as supporting Fernald's visual-auditory-kinesthetic theory of verbal learning.

CEREBRAL DOMINANCE, ITS MEASUREMENTS AND ITS ROLE IN LETTER RECOGNITION AND SPELLING

Chapter 1

Introduction

Man, throughout his history, has recognized that people are not functionally symmetrical; that is, they are more proficient in the use of their right or left hands. In spite of the widespread interest in handedness, there were no real scientific inquiries into its physiological or neurological causes until well into the nineteenth century.

Early research in medicine and human biology led to the conclusion that the two hemispheres of the brain controlled the contralateral sides of the body. It was established that control for each area of the body was, moreover, localized in a specific area of the contralateral cortex (Mountcastle, 1962). In 1836, Dax for the first time postulated what was to be called the doctrine of cerebral dominance: language in man is controlled by the cerebral hemisphere contralateral to the preferred hand (White, 1969).

The first systematic inquiry into the relationship between speech and cerebral function was conducted by Broca in the early part of the nineteenth century. He studied a number of right-handed inmates at a French mental hospital who had lost the ability to speak following a stroke. Autopsy revealed that in each case damage to the brain was confined to an area of the third frontal convolution of the left hemisphere. Broca's results (1861) led him to adopt the doctrine of cerebral dominance.

Later workers, notably DeJarine and Wernicke, studied slightly different types of speech disorders in right-handed patients caused by strokes (Geschwind, 1972) and found lesions confined to the left cerebral hemisphere. The bulk of evidence that had been amassed by the end of the nineteenth century had firmly established the doctrine of cerebral dominance, although some researchers believed that speech was controlled by the left hemisphere in all people regardless of handedness (Penfield & Roberts, 1959).

With the development of surgical techniques in this century, and in particular the development of brain surgery, researchers had been able to amass a body of data on speech control of the brain by more direct methods. This data is of two types: first, data on speech deficits following ablations of parts of the brain; and second, data from the direct electrical stimulation of the cortex during brain surgery. Most of this data indicates that Broca and the other early researchers were not far wrong. Penfield and Roberts (1959), who have collected information on more cases than any other researchers, have come to the conclusion that primary control of speech is localized in the left cerebral hemisphere for all right-handed and most left-handed people. They did find, however, that for some left-handed people control of speech functions resides in the right cerebral hemisphere and for others, speech control seems to be diffused to both hemispheres. Milner, Branch, and Rasmussen (1964) cite similar findings; they indicate that 90% of right-handed people were left dominant and 64% of left-handed people were left dominant.

During this period, while the question of cerebral localization of speech control was being investigated, a new related problem was being debated: the relationship between speech disorder, handedness, and cerebral dominance. Samuel Orton was one of the foremost researchers in this area during the first half of this century. He studied thousands of school-age children over the period of 15 years while directing the Iowa mobile mental hygiene clinic and later as director of the Iowa Psychopathic Hospital, Des Moines, Iowa. He collected carefully detailed case histories on hundreds of school children with reading problems. Orton's (1966) investigations into reading disabilities continued when he became a professor of neurology and neuropathology at Columbia University.

Orton (1937) noted that a significant number of children with speech problems that could not be explained by any usual pathology fit into a syndrome of defects for which he coined the term "strephosymbolia" or "twisted symbols." These children seemed to be functionally unable to use letters in any meaningful way, although they were able to perceive them. This syndrome was characterized by "verbal ability that is distinctly out of harmony with the child's skill in other fields--notably the ability to learn by hearing and to master arithmetic concepts [p. 73]." Reading and writing are poor and the problems usually encountered include reversals of direction while reading or writing, reversal of the order of words or syllables in words, or reversal of individual letters. Spelling and grammar are usually very poor and may be as much as 5 years behind achievement in other academic areas. The child's poor achievement in reading and writing may cause academic failure in other areas which stress reading proficiency such as social studies. In addition, these children usually have a great deal of trouble in learning a foreign language (Orton, 1928).

Orton (1937) found that in a significant number of cases of children exhibiting this syndrome, there was evidence of a crossed pattern of handedness and dominance, a history of the child having been changed in hand preference or a family history of speech defects and left-handedness. This led Orton to theorize that cerebral dominance is an inherited characteristic and that any failure of this inheritance to develop into a normal pattern of handedness (that is, with speech control in the hemisphere contralateral to the preferred hand) will cause the development of one or more of the symptoms characteristic of strephosymbolia.

Orton's clinical case histories and his deductions from the amassed data have led to a considerable amount of research in the fields of psychology, education, and medicine. The literature from this research is voluminous but inconclusive. In their general survey of the literature, Wussler and Barclay (1970) state that of those articles which are at least minimally acceptable from an experimental point of view, about half support Orton's theory and half reject it. The general level of the cited research is so poor, however, that they state that no conclusions can be drawn as to the validity of crossed dominance as a cause of speech problems.

In general, the same methodological problems are repeated in all of the above literature. In general, they attempt to measure a correlation between speech problems and crossed dominance using some sort of paper and pencil tests that are easily administered to a group. In a typical study (Chakrabarti, 1962), speech problems were inferred from scores on the Nelson-Denney reading test, specifically the subscores for vocabulary, comprehension, reading speed and so on. Handedness was measured by a four-item handedness questionnaire. Dominance was inferred from these same items which asked for the child's writing hand, throwing hand, kicking foot, and for any history of change or handedness in early childhood.

Chakrabarti's (1962) study, although typical of a great deal of the literature, is so poor as to be useless in determining the validity of Orton's theory. The Nelson-Denney reading test does not measure those specific things which Orton said are part of the strephosymbolia syndrome: that is, verbal skills that are distinctly below the level of other academic achievement characterized by reversals and very poor spelling.

A more damaging fault and one that is common to virtually all the research in this area is the inference of cerebral dominance from some sort of a handedness inventory. As Barnsley and Rabinovitch (1970) pointed out in their review article, handedness inventories, even good ones such as the Crovitz and Zener (1962) or the questionnaire developed by Davison (1948), cannot be used for anything other than determination of hand preference and hand use.

Definitive research in this area requires a method of directly determining cerebral dominance for speech that does not require subjective judgments on the part of the experimenter and does not involve procedures that could be damaging to the person being measured. Some methods have been developed in the past 20 years that are direct and appear to measure dominance reliably but cannot be used in research with humans because they are potentially damaging. These are the methods characterized by Kinsbourne (1973) as "invasive," that is, methods which require any direct intervention by the experimenter into the physical being of the subjects. These invasive techniques are undesirable for the following reasons: they require a degree of skill not usually available to the research psychologist, they are all potentially dangerous, and they are in violation of ethical standards for research in that they do not leave the subject unchanged and that the procedure is not justified by the expected results.

The oldest of these methods is the medical postmortem. Although this method was used extensively by early researchers as pointed out earlier, it is of very limited use since it requires one's subjects to die first. A second, more recent method, is surgical intervention into the brain, either electrical stimulation of the cortex or ablation of parts of the brain (Penfield & Roberts, 1959). These procedures are completely out of the question for normal researchers. The same objection holds for the split brain methodology developed by Sperry and Gazzaniga (1964); it is much too serious a procedure to use for research. Another objection to methodologies of this type is that in general, data gathered is a byproduct of an intervention to remediate a pathological condition (Penfield & Roberts, 1959).

The sodium amytal injection method of Wada (1949), although intrusive does not involve surgical procedures. In this method, sodium amytal is injected in the left- or right-carotid artery thereby anesthetizing one hemisphere at a time. Although this method has been widely used as a measure of lateralized cerebral function (Kimura, 1963), it has been widely characterized as too dangerous for use in normal experimentation (Milner & Rasmussen, 1964). This leaves only those methods which measure asymmetries of behavior and use them as indicators of dominance. There are several methods in the literature that may meet these requirements. They include measurement of specific orienting responses during verbal processing, unilateral superiority of one ear in a dichotic listening task, differential electroencephalograms (EEG) during verbal processing, and visual field superiority either in accuracy of report or speed of reaction time to tachistoscopically presented verbal material.

Orienting responses, usually eye and head turning (Kinsbourne, 1972), are measured during verbal processing on the theory that unilateral cerebral activity causes an overflow of activity into the motor centers of the same hemisphere, resulting in orienting responses in the direction away from the active hemisphere (Kinsbourne, 1973). Kinsbourne in his original study (1972), used three sets of 20 questions as stimuli. One list was verbal, one was made up of mathematical items, and the third was spatial. Eye motion and head turning were videotaped for each subject while the 60 test items were read aloud by the experimenter. The videotapes were later scored for magnitude of first eye motion and head orientation after presentation of the stimuli. Kinsbourne found that the 20 right-handed subjects turned their eyes and heads to the right significantly more often than to the left ($p < .0001$). Direction of eye and head motion for the 20 left-handed subjects was not significant.

This experimenter (1972) attempted to replicate Kinsbourne's study with the following modifications: no spatial stimuli were used, and eye motion was recorded using electrooculographic techniques described by Shackel (1967). No significant preference in direction of eye movement was observed for right- or left-handed subjects with verbal or mathematic stimuli. Other attempts to replicate Kinsbourne seem to have resulted in similar failure (Kinsbourne, 1973).

In dichotic listening tasks, different stimuli are presented to the two ears at the same time, either verbal stimuli, nonverbal clicks, or music. Since the primary projections from the ears are to the contralateral hemisphere, superiority of one ear for accuracy of report is used as an indicator of cerebral dominance (Kimura, 1964).

White (1969) in his survey of laterality differences states that a considerable amount of positive evidence has been collected indicating that the left temporal lobe is dominant for verbal material and the right temporal lobe for nonverbal material. Almost all of this evidence was amassed by experimenters using dichotic listening procedures (Gregory & Harriman, 1972; Kimura, 1963, 1964). This method is difficult to use because of the complexity of the stimuli and the precision with which they must be organized.

Electroencephalographic studies of functional asymmetries employ one of two related methods. The more popular, as measured by a number of experimenters in the literature, involves the measurement of bilateral evoked potentials following verbal or noise stimuli (Cohn, 1971; McAdam & Whitaker, 1971). The data from these studies using right-handed subjects agrees that verbal stimuli cause a higher amplitude evoked potential over the left hemisphere, and nonverbal noise stimuli cause larger evoked potentials over the right hemisphere. A second but less frequently utilized method is the recording of bilateral EEGs during verbal processing. The ratio of the amplitudes of the right and left EEG (Galin & Ornstein, 1972) or of some specific frequency component of the EEG (Gale & Penfold, 1971) is used as an indicator of locus of cerebral activity and hence dominance.

Visual field superiority in the perception of tachistoscopically presented stimuli may be an indicator of dominance (White, 1969). White states that the laterality differences in perception of these patterns are the result of a number of factors, one of which may be the specialization of the hemispheres for specific operations.

The visual field superiority methodology is an outgrowth of the early work of Mishkin and Forgays (1952) and the extension of their findings by Heron (1957). Tachistoscopic presentation of verbal material to the right or left of visual fixation gave rise to a clear superiority in the recall of the material presented in the right visual field (White, 1969). This right visual field (RVF) superiority with verbal stimuli (Harcum & Finkel, 1963) and with nonverbal patterns (McKeever & Hulling, 1970) was thought to be the result of post exposural scanning mechanisms (Harcum & Finkel, 1963).

Other researchers in an attempt to eliminate the problems of order of report and post exposural scanning began using reaction times for the recognition of unilaterally presented stimuli. Reaction times were measured from the presentation of the stimuli until the subject made a response indicating that the stimuli was or was not on a previously learned list of stimuli. Data from these studies show a RVF superiority for right-handed subjects and no superiority with left-handed subjects (Bryden, 1964; Filbey & Gazzaniga, 1969). Duane (1973) cites 21 studies of this type of which 17 showed a clear

RVF superiority for right-handed people.

Unilateral tachistoscopic presentation of nonverbal material such as faces (Geffen & Bradshaw, 1971; Rizzolatti, Umita, & Berlucchi, 1971) results in a left visual field (LVF) superiority. This is in agreement with the theory that the left cerebral hemisphere is specialized for speech and the right cerebral hemisphere is specialized for nonverbal spatial processing. These data also tend to support the theory that visual field superiority for reaction times is due to the nature of cerebral functioning rather than to a post exposural perceptual mechanism.

In a further modification of this methodology, subjects were asked to decide if the elements in a unilaterally presented pair of letters were the same or different (Egeth & Epstein, 1972). Reaction times for RVF presentations were faster for judgments of same and LVF presentations were faster for judgments of different. In both cases, the difference in reaction time between the RVF and the LVF was about 30 milliseconds. This is in agreement with observations of the time required for a neural impulse to travel from one hemisphere to the other (Geffen, Bradshaw, & Wallace, 1971).

The purpose of this research is twofold: first, to evaluate several of the above measures of asymmetry of behavior to see if any one or combination of measures can be used in an experimental setting to determine dominance for speech, and second, to use this derived methodology to test Orton's (1937) theory of crossed dominance as a causal factor in specific speech disorders. Crossed dominance for the purpose of this study is defined as a condition in which a person shows a clear hand preference for the right hand for motor activities but control for speech is not localized in the contralateral left hemisphere. According to Orton's theory, this causes speech related problems because commands from the speech center, instead of going to the contiguous motor centers for speech or writing must travel to the corresponding motor center of the other hemisphere (see Figure 1). The transmission of the command via synapses through the Corpus Callosum causes degradation of the neural information. The degradation in information is due in large part to the fact that the hemispheres are not totally connected and so each command must be encoded and then decoded (Geschwind, 1972). This degradation becomes especially bad for spelling during writing since a mental command originates in the speech center of the right hemisphere and is then synapsed to the motor center in the left hemisphere.

Therefore, it is hypothesized that people who exhibit a pattern of crossed dominance will also exhibit one or more of the speech defects characteristic of strephosymbolia. Dominance for speech in this study will be determined using the method of measurement of behavioral asymmetry selected by pretesting. Motor dominance will be determined by the hand used for writing. Spelling will be the specific speech defect studied. Spelling lends itself to this study for two reasons: first, it is a fairly simple neurological event compared with verbal speech, reading, and so on,

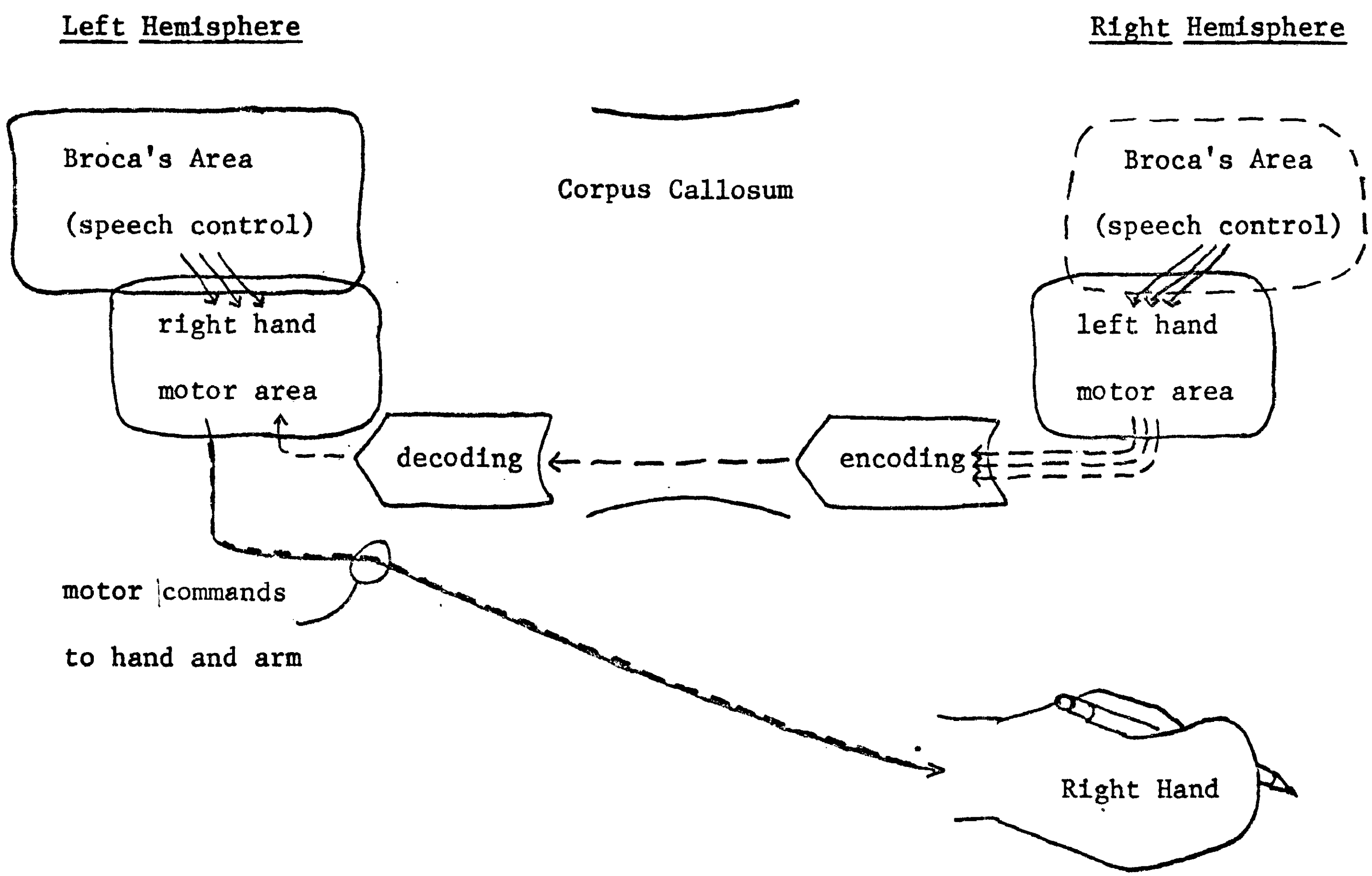

Fig. 1. Schematic representation of mental activity during writing for normal right-handed Ss (solid lines) and cross dominant Ss (broken lines).

and second, because it is the only speech defect that can be unambiguously scored. Specifically, it is predicted that college students who are very poor spellers will be right-handed but will be right hemisphere dominant for speech.

Chapter 2

Method

First Experiment

The three previously described methods of measuring behavioral asymmetry (dichotic listening, unilateral tachistoscopic presentation, and bilateral EEG), were evaluated in order to develop a measure for speech dominance. The criteria set for the acceptance of a test were first that it have criterion validity, second that it have reasonable reliability, and third that it produce results when conducted with a normal level of sophistication of technique.

Criterion validity was defined as the ability of the measure to correctly determine speech dominance in apparently normal right-handed control subjects. This standard was adopted because of the lack of any feasible method of directly determining dominance for speech and because of the high probability that any normal right-handed person is left hemisphere dominant for speech ($p > .90$).

Reliability was determined by the Spearman-Brown split-half reliability procedure (Anastasi, 1968). This was computed for those methods where the criterion validity seemed to warrant it.

A normal level of sophistication of technique was defined as a level of care and control in preparation of stimulus materials and equipment, and carrying out of experimental procedures that are not beyond the abilities of a careful and motivated researcher. All stimulus materials, for instance, were carefully developed and prepared by this researcher but none involved materials, equipment, or procedures not normally available in any moderately well-equipped experimental psychology laboratory.

Dichotic Listening Experiment

A short experiment was conducted to evaluate the dichotic listening methodology as developed by Kimura (1974). It was a measure of speech dominance.

Subjects

The experiment was conducted with the cooperation of 10 William and Mary undergraduate student volunteers. All 10 Ss were right-handed, 5 were male and 5 female.

Apparatus

A stimulus tape was recorded on Ampex recording tape using a Revox tape deck with a self-synch adapter and a Sony microphone. Playback of the tape was through the same tape deck and Koss Pro 4A stereo headphones.

The stimulus tape consisted of 45 numbered stimulus groups, each made up of a stimulus set followed by a test set. The stimulus set was made up of three dichotic pairs of two digit numbers, with one number from each pair going to the left ear and the other going to the right ear. During each stimulus set a different series of three numbers is presented to each ear. The test set was a single set of three numbers presented binaurally.

The numbers for the tape were taken from a random number table (Friedman, 1972). The test stimuli were either the same as the stimulus set presented to the left ear, the right ear, or neither (a set not previously heard). The order of matching of the test stimulus sets was randomized using the same random number table but with the constraint that there be an equal number of left, right, and neither.

All stimulus groups were identical temporally. The number of the group was presented binaurally followed by a 5-second pause and the stimulus set. The dichotic pairs were presented at a rate of about 2 seconds per pair or 6 seconds for the set. After another 5-second pause, the test set was presented at the same rate of 2 seconds per pair. After a 10-second pause, the next set began.

Procedure

Each S was tested individually. S was seated at a table containing the tape deck, headphones, and a response sheet. The task was explained to S, and S was instructed to indicate the correct match for the test set by circling L, R, or N on the answering sheet. S could stop and start the tape at any time but could not rewind it to repeat any of the groups.

Results

Only one of the Ss failed to do better than chance on this experiment. S number 5 got 15 out of 45 correct, exactly at chance level. The other nine Ss were significantly better than chance ($p < .05$) (Mendenhall & Ramey, 1973). The results for the nine Ss show a pattern that is consistent with the previously cited results of Kimura and others (see Table 1). The number of errors totaled

TABLE 1

Mean Errors of Recall in a Dichotic Listening Task

Subject number	Judgment		
	Left	Right	Neither
1	4	4	1
2	2	0	3
3	6	9	3
4	6	6	3
5	10	6	1
6	3	2	1
7	8	6	1
8	0	2	0
9	6	5	2

across Ss shows a small superiority of the right ear presentations for accuracy of recall. The superiority is about 10% which is very close to the value determined by Kimura (1973). These results only hold up when results are combined across Ss but not for individual Ss. Only five of the nine Ss show a right ear superiority, two show a left ear superiority, and the other two show no superiority.

Discussion

The results of these nine Ss taken as a whole tend to agree with the findings of other researchers using dichotic listening and with Kimura (1973) in particular. For group data, averaged across Ss, there seems to be a small superiority in recall of verbal information presented to the right ear. Since the right ear has most of its projections to the left hemisphere of the brain, it may be deduced that the left cerebral hemisphere is somehow more efficient at processing verbal information and it can be inferred that the left cerebral hemisphere is dominant for verbal processing.

The problem with these data becomes evident when an attempt is made to use the data from individual Ss to determine individual dominance for speech. The forced conclusion would be that only five out of nine right-handed Ss were left dominant, which seems highly unlikely.

Response Latency Experiment

Subjects

A total of 15 Ss took part in this experiment, 11 of whom were right-handed and 4 of whom were left-handed. All Ss were drawn from the population of The College of William and Mary in Virginia (undergraduate and graduate students and faculty).

Apparatus

The stimuli were pairs of letters arranged one above the other and separated by a distance that subtended a visual angle of about three degrees when viewed from the standard viewing distance. Each pair was located either to left or to the right of fixation, a distance that subtended a visual angle of five degrees. Stimuli consisted of 18 point futura bold dry transfer letters. The letters used were the same as those used by Egeth and Epstein (1972), A, I, O, U, X, V, and Y. There were a total of 80 stimulus pairs, 40 located to the left of fixation and 40 to the right of fixation. In half the stimulus pairs, the letters were the same and in half they were different. Stimulus pairs were made such that each of the six stimulus letters appeared the same number of times in each of the four letter positions and the same number of times in same pairs and different pairs. This meant that of the 80 stimulus pairs, 20 were right same, 20 were left same, 20 were right different, and 20 were left different.

Stimuli were presented using a Lafayette one-channel tachistoscope (Model 2500) modified so that it would trigger a Hunter timer (Model 120a). A bidirectional response key was connected to stop the timer and indicate S's response choice.

Procedure

Each S was tested individually in a test cubicle in which all the equipment was set up. At the beginning of the initial session, each S was told in detail about the design of the experiment and the experimental hypothesis. The equipment was demonstrated and S was allowed as many practice trials as desired to become proficient at responding.

At the beginning of each trial, the stimulus cards were randomized by shuffling. The 80 stimulus pairs were presented one at a time at a rate of about four per minute while S responded by means of the hand key as to whether he perceived the letters as same or different. Latency of response was recorded for each stimulus pair, and errors in same-different judgments were also recorded.

All 12 Ss were tested at least once responding with the left hand and once with the right hand. Most Ss were tested more than once with each hand to determine test-retest reliability.

Results

Due to problems with equipment during the early stages of this research, latencies for different judgments were not recorded for about half the Ss. Mean latencies for "same" judgments and the number of errors in each visual hemifield are shown in Table 2. Mean latency is the mean of all correct trials and errors are the

TABLE 2

Mean Reaction Times and Errors for "Same" Judgments for Stimuli Appearing in Left and Right Fields

	Mean reaction time			Errors		
	LVF[a]	RVF[a]	DIFF[a]	LVF	RVF	DIFF
Right-handers	455	411	44	2	0	2
	687	626	61	2	2	0
	380	323	57	2	1	1
	494	532	-37	4	1	3
	455	414	41	1	1	0
	399	376	23	1	1	0
	380	307	73	2	5	-3
	441	371	70	3	1	2
	338	270	67	6	1	5
	374	363	11	3	1	2
	467	470	- 3	5	1	4
Mean	437	411	27	2.8	1.5	1.3
Left-handers	625	657	-32	2	2	0
	305	317	-12	2	5	-3
	566	567	- 1	2	2	0
	370	408	-38	4	2	2
Mean	466	487	-21	2.5	2.75	-0.25

[a]LVF left visual field, RVF right visual field, DIFF difference.

number of times that S responded by identifying a "same" pair as "different."

For the 11 right-handed Ss, all but 2 showed a clear RVF superiority for latencies. Of the 4 left-handed Ss, 3 showed a LVF superiority. The grand mean for right-handed Ss showed a group RVF superiority of 27 milliseconds. This is only slightly lower than the predicted RVF superiority of 30 milliseconds. This difference was significant ($p < .01$) as tested by an analysis of variance (see Table 3).

The distribution of errors of response, responding that a stimulus pair was different when it was same or same when it was different, followed the pattern found in almost all unilateral tachistoscopic research (White, 1969). For right-handed Ss, there was a significant RVF superiority ($p < .05$). Left-handed Ss showed a slight nonsignificant LVF superiority. Although the RVF superiority is significant as determined by an analysis of variance (see Table 4), only 7 of the 11 right-handed Ss had fewer errors in their RVF and only 1 of the 4 left-handed Ss had fewer LVF errors.

A Spearman-Brown split half reliability coefficient was computed for the latency data. The reliability coefficient was .97, N = 14.

Discussion

This method seems to fit all three of the criteria stated earlier. It has criterion validity in that it can differentiate between left- and right-handed Ss, it has a high level of

TABLE 3

Analysis of Variance for First Experiment

Response Latencies--Right Handed

Subjects Only

Source	Degrees of freedom	Mean standard	*F* ratio	Level of significance
Visual field	1	.0075	11.90	$p < .01$
Between subjects	10	.0190	30.29	$p < .01$
Residuals	10	.0006		
Total	21			

TABLE 4

Analysis of Variance for

Errors--Right Handed

Subjects Only

Source	Degrees of freedom	Mean stan-dard	*F* ratio	Level of signif-icance
Visual field	1	11.636	5.203	$p < .05$
Between subjects	10	1.982	[a]	
Residuals	10	2.236		
Total	21			

[a]Not significant.

reliability, and it is reasonably easy to administer.

Bipolar Electroencephalographic Experiment

Subjects

The Ss in this study were 6 male College of William and Mary in Virginia undergraduate students selected from the group of 15 Ss who took part in the response latency experiment. They were selected on the basis of clearly defined dominance as measured by the preceding test, with 3 showing a clear RVF superiority (left dominant, right-handed) and 3 LVF superiority (right dominant, left-handed).

Apparatus

EEGs were recorded on a Grass Model 755 polygraph equipped with two Model 7P5A wide-band alternating current EEG preamplifiers and two tunable bandpass filters. Grass silver cup electrodes were located bilaterally in the temporal area corresponding to Broca's area and the speech motor areas as shown in Figure 2. The electrodes were placed on S's scalp over cotton wicks wet with a 5% NaCl solution and were held in place by an elastic headband.

A stimulus tape of 100 words was recorded on a cassette using a Sony Model 250 cassette recorder and a Sony Model 250M microphone. The words were taken from the American Standard Word Frequency Book (Carrol, Davies, & Richman, 1971) and were word number 301 to 400 with a mean frequency of about 300 per million in written language.

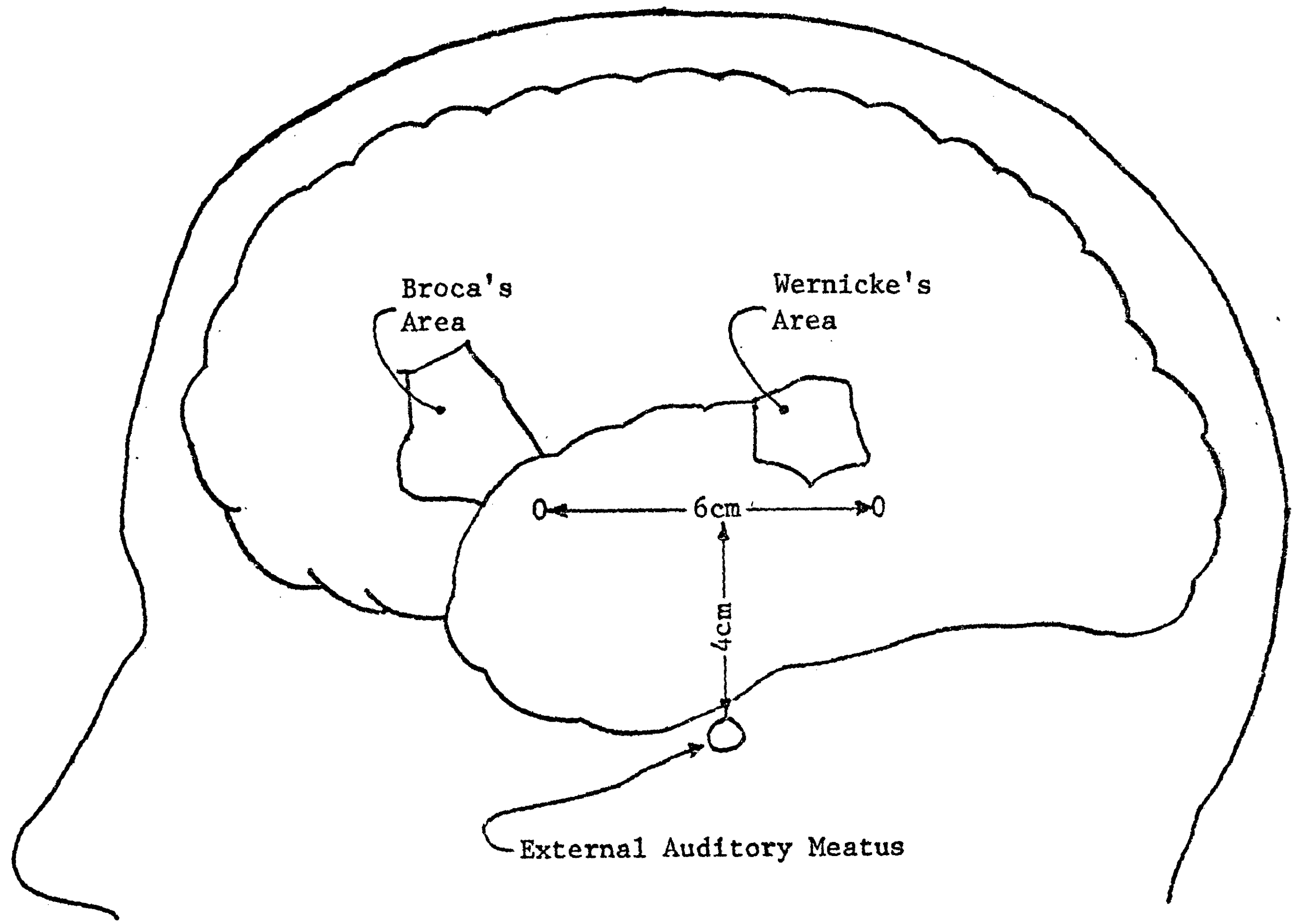

Fig. 2. Placement of bipolar electroencephalographic electrodes.

Procedure

Ss were seated in a room adjacent to the room containing the polygraph. The electrodes were connected and the S was given a 10-minute rest period. The stimulus word tape was played through a speaker placed 1 meter behind S's head. S was given a dummy hand-switch and was asked to press the switch each time he heard a noun. This was done to increase the attention level of S and theoretically to increase the level of EEG (Gale, Haslum, & Penfold, 1971).

The tunable filters were precalibrated and adjusted to pass the 20 Hz (Hertz) beta component of EEG. The EEG record for the 12-minute experimental period was scored by measuring the peak to peak amplitude of the record in millimeters at random points until 20 scores were recorded for both left- and right-hemisphere EEGs.

Results

The mean left- and right-hemisphere EEGs for six Ss are shown in Table 5. The differences in amplitude between left and right EEG is in the direction predicted but is not significant as measured by *t* tests. This is because of the large within-S variance.

Discussion

Of the three methods tested, it was demonstrated that only one, the response-latency task, met the stated requirements for a usable test of cerebral dominance for speech. The dichotic listening and bipolar EEG methodologies were eliminated because of the validity criterion (they could not discriminate between left- and

TABLE 5

Electroencephalographic

Amplitudes

Group	Hemispheres	
	Left	Right
Right hand	7.90	7.20
	6.20	5.20
	8.30	6.90
Subjects	7.46	6.43
Left hand	5.20	4.90
	9.30	6.40
	7.70	8.00
Subjects	7.40	6.43

right-handed Ss). The response latency method discriminated very well between these two groups and, in addition, was found to be reliable using split half comparisons. This method is also an easily-conducted procedure requiring no special skills on the part of E.

Second Experiment

Subjects

A second group of 12 right-handed Ss was selected from the same population used in the first experiment. The experimental group was selected on the basis of their self-reported bad spelling. The control group was made up of self-reported good spellers.

Apparatus

The apparatus was the same as that used in the Response Latency Experiment of the first experiment. (See page 21 of text.)

Procedure

The procedure was the same as that used in the Response Latency Experiment of the first experiment. Each S was tested using his preferred right hand for responding. After a period of at least one day, each S was retested using the same procedure but with responses made with the left hand.

Results

Mean reaction times were computed for each S for all combinations of the four independent variables, experimental-control group placement, response hand, stimulus pair type, and visual hemifield of presentation. The resulting mean reaction times (see Table 6) were subjected to an analysis of variance using a split plot factorial design with group placement as the between Ss variable and response hand, visual hemifield and stimulus pair type as repeated measures within Ss. The results of the analysis are shown in Table 7.

The difference between the grand mean reaction times for the experimental group ($\bar{X}$ = .880) and the control group ($\bar{X}$ = .591) was significant ($p < .01$). There was a significant difference ($p < .05$) between the grand means for right-handed responses ($\bar{X}$ = .822) and left-handed responses ($\bar{X}$ = .689). The reaction times for stimuli presented in the LVF ($\bar{X}$ = .748) and the RVF ($\bar{X}$ = .723) were significantly different ($p < .05$). (See Table 6.)

The interaction of stimulus pair type and hemifield of presentation was significant ($p < .05$). This interaction is the result of the predicted RVF superiority (Egeth & Epstein, 1972) for "same" judgments (LVF--RVF = 59 milliseconds) and the LVF superiority for "different" judgments (RVF--LVF = 23 milliseconds).

The interaction between experimental-control placement and the hand used to respond with was significant ($p < .01$). The means for the four cells (see Table 8) indicate that the interaction is due to longer reaction times for the experimental group, especially for right-handed responses. A test for significance of differences between means was run using the Neuman-Keuls Critical Value test (Mendenhall & Ramey, 1973). The results of this test (see Table 7)

TABLE 6

Mean Reaction Times

	Right hand response				Left hand response			
	Same		Different		Same		Different	
	LVF[a]	RVF[a]	LVF	RVF	LVF	RVF	LVF	RVF
Experimental group	1.062	.970	.943	1.015	.720	.796	.742	.770
	1.093	1.040	.864	.848	.510	.523	.542	.534
	1.017	.936	.956	1.020	.771	.624	.705	.704
	1.174	.996	1.005	1.121	.705	.652	.639	.676
	1.338	1.170	1.044	1.374	.933	.595	.731	.767
	.911	1.054	1.055	1.123	.862	.795	.798	.860
Grand mean	1.099	1.028	.978	1.084	.750	.664	.693	.719
Control group	.416	.314	.416	.422	.391	.364	.435	.380
	.628	.557	.547	.545	.600	.562	.547	.552
	.517	.539	.638	.589	.619	.575	.579	.536
	.656	.589	.635	.612	.617	.570	.526	.511
	.631	.616	.744	.717	.764	.737	.723	.763
	.750	.713	.742	.687	.766	.747	.652	.637
Grand mean	.600	.555	.620	.595	.626	.593	.577	.564

[a]LVF left visual field, RVF right visual field.

TABLE 7

Analysis of Variance for Mean

Reaction Times

Source	Degrees of freedom	Mean standard	F ratio	Level of significance
Between subjects	11	0.256		
A (group)	1	1.959	22.91	$p < .01$
Subjects within groups	10	0.085		
B (hand)	1	0.707	48.37	$p < .01$
C (stimulus)	1	0.004	0.94	
D (visual field)	1	0.010	8.28	$p < .05$
A X B	1	0.668	45.66	$p < .01$
A X C	1	0.001	0.27	
A X D	1	0.003	2.75	
B X C	1	0.003	0.66	
B X D	1	0.003	0.00	
A X B X C	1	0.012	3.27	
A X B X C	1	0.006	0.00	
A X C X D	1	0.023	0.25	
B X C X D	1	0.001	0.00	
A X B X C X D	1	0.001	0.00	
B X subjects within groups	10	0.015		

TABLE 7 (continued)

Source	Degrees of freedom	Mean standard	$\underline{F}$ ratio	Level of significance
C X subjects within groups	10	0.004		
D X subjects within groups	10	0.001		
B X C X subjects within groups	10	0.004		
B X D X subjects within groups	10	1.433		
C X D X subjects within groups	10	0.069		
B X C X D X subjects within groups	10	4.211		
Total	96			

TABLE 8

Neuman Keuls Test for Difference

between Mean Reaction Times

Group	Control left hand	Control right hand	Experimental left hand
Control right hand	0.008		
Experimental left hand	0.119*	0.117**	
Experimental right hand	0.462**	0.460**	0.343**

*$p < .05$.

**$p < .01$.

indicate that experimental group right-handed mean reaction time is significantly longer ($p < .01$) than the other three conditions. The mean reaction time for the experimental group is significantly longer than the mean reaction times for the control group using either right hand ($p < .01$) or left hand ($p < .05$).

A similar analysis was carried out for the numbers of errors made in judgments of "same" or "different." The analysis of variance used was a split plot factorial design (Kirk, 1968) with experimental versus control group placement as the between Ss variable and response hand and visual hemifield as within S measures. The number of errors was collapsed across the "same-different" conditions because more than 95% of the errors were errors in which a "same" stimulus pair was seen as "different" (see Table 9). The results of the analysis are shown in Table 10.

There was a significant difference ($p < .05$) between the number of errors made by Ss in the control group ($\overline{X} = 4.00$) and in the experimental group ($\overline{X} = 2.76$). The mean number of errors made for responses with the right hand ($\overline{X} = 4.12$) is significantly larger ($p < .05$) than the mean number of errors made while responding with the left hand ($\overline{X} = 2.633$). The interaction of these two factors, response hand and group, was not significant. There was a highly significant difference ($p < .01$) between the mean number of errors made for stimulus pairs presented in the LVF ($\overline{X} = 4.35$) and in the RVF ($\overline{X} = 2.40$).

TABLE 9

Number of Errors of Judgment

Group	Right hand: Left visual field	Right hand: Right visual field	Left hand: Left visual field	Left hand: Right visual field
Experimental	4	3	3	3
	7	5	5	1
	7	3	4	1
	9	9	3	2
	8	1	4	0
	6	2	4	2
Group mean	6.833	3.833	3.833	1.500
Control	7	2	3	6
	6	4	3	2
	1	2	4	3
	4	3	4	2
	1	2	5	2
	1	2	2	2
Group mean	3.333	2.500	3.500	1.800

TABLE 10

Analysis of Variance for Errors of Judgments

Source	Degrees of freedom	Mean standard	F ratio	Level of significance
Between subjects	11	4.20		
A (groups)	1	17.521	6.10	$p < .05$
Subjects within groups	10	2.871		
Within subjects	36			
B (hand)	1	25.521	5.58	$p < .05$
A X B	1	17.521	3.83	
B X subjects within groups	10	4.570		
C (visual field)	1	46.021	14.99	$p < .01$
C X subjects within groups	10	3.071		
B X C	1	0.021	0.02	
A X B X C	1	1.687	1.68	
B X C X subjects within groups	10	1.004		
Total	47			

Discussion

The analysis of the number of errors was carried out as a check on the methodology. Since these errors can be viewed as errors of recall or errors of report, as they are traditionally called in tachistoscopic tasks, this experiment can be directly compared with previous research reported in the literature. The results of this analysis compare favorably with the general literature as summarized by White (1969) and with the specific results of Egeth and Epstein (1972). The general results, replicated by this experiment, are that fewer errors are made for RVF presentations than for LVF presentations with a ratio of about 1:2. The percentage of errors over trials found in this experiment agrees in general with other research using letter pairs as stimuli, and is in the vicinity of 8%.

The interesting aspect of the distribution of errors is not the LVF--RVF difference which was expected, but rather the unexpected differences due to response hand and group placement. An examination of the pattern of mean errors for the experimental and control groups using left or right hand indicates that these differences are due almost exclusively to the large number of errors made by the experimental Ss responding with their right hand. The mean errors for the experimental group using their left hand and for the control group using either hand are almost identical.

It is also interesting to look at the distribution of errors within Ss. In the control group, the total errors are greater for right-hand response for three Ss and greater for left-hand responses for the other three, indicating that errors are not influenced by the choice of hand for response. In the experimental group, however, for all six Ss there were more errors for responses made with the right hand. In fact, five of the six experimental Ss made more than twice as many errors with their right hand than with the left.

The results of the analysis of reaction time results tends to replicate the results in the literature, especially Egeth and Epstein (1972). The interaction of visual field and same-different stimulus pairs is almost identical in magnitude and direction although in this research the visual field difference for "different" stimulus pairs was not significant.

The predicted pattern of interaction of visual field superiority with group placement did not materialize. There is virtually no difference in visual field superiority between the experimental and control groups with five Ss in each group showing a consistent RVF superiority for "same" stimulus pairs with either hand. Since visual field superiority is a measure of cerebral dominance, the pattern of crossed dominance predicted in the introduction has not been demonstrated. To the contrary, all 12 Ss, experiment as well as control, seem to be left hemisphere dominant for speech.

In the light of these results, it must be concluded that the hypothesis advanced in this thesis has not been supported. No pattern of crossed dominance or lack of dominance was indicated by the reaction time data nor for that matter by the error data.

In spite of this failure to support the hypothesis, an effect has emerged that differentiates significantly ($p < .01$) between experimental and control Ss. It is the interaction of group with response hand. This is true not only for the data collapsed across Ss but also for individual Ss. Each of the mean reaction times for the six experimental Ss in the right-hand condition is longer than any other mean reaction time in any of the other conditions.

The Ss who are poor spellers are also differentiated from the control group by the large difference between their reaction times using the right or left hand for responses. The right-hand and left-hand reaction times for the control Ss as a group and individually are almost identical.

Chapter 3

Conclusions

It must be concluded from these results that the dominance theory of speech defects has not been supported, at least for the sample of poor spellers examined in this study. It must also be concluded that there is some effect operating that caused the significantly slower reaction times for the poor spellers when responding with the right hand.

These results can be understood in light of the theory of verbal processing developed by Fernald, a contemporary of Orton. While working as a professor of Psychology at University of California--Los Angeles, Los Angeles, California, during the 1920s and 1930s, Fernald (1943) developed a method of remediating learning disabilities based on a trimodal theory of verbal learning.

Fernald's (1943) theory stated that not all people encode memories in the same way or memory mode. People tend to encode memories as visual images, auditory memories, or as kinesthetic traces. Her theory states further that each person tends to encode memories in only one mode--either visual, auditory, or kinesthetic--and since traditional teaching methods are exclusively visual and auditory, kinesthetic encoders cannot learn properly.

It can be theorized that the experimental Ss are poor spellers because they are kinesthetic encoders and their poor performance on the reaction time task is due to interference in processing caused by simultaneous processing of two kinesthetic tasks. During the period of time after the presentation of the stimuli the S must compare the kinesthetic memory traces of the two letters in the stimulus pair and process the response command which is obviously kinesthetic since it is a hand movement. This appears to be the same effect that causes the degradation of performance in a Stroop color-word task (Friedman & Derks, 1973).

For control Ss, processing of the letter pairs is carried on in a visual or auditory mode so there is no interference with the response which is kinesthetic. This is analogous to the Stroop task of counting colors (kinesthetic) and simultaneously reading the color names (visual).

The processing for the experimental Ss is analogous to the Stroop task of naming the colors and counting the words, both of which are processed in the same mode, causing interference and consequent degradation of performance. This interference is most pronounced for right-hand responses since right-hand responses are controlled by the left hemisphere of the brain and by the same general area of the cortex in which the kinesthetic memory traces are stored (Penfield & Roberts, 1959). Thus for right-hand responses, the processing and response are carried on not only in the same processing mode but also in the same cortical area. This causes a double interference and a consequent lengthening of reaction times. Reaction times for left-handed responses are less affected since the left hand is controlled by the right cerebral hemisphere. This means that different cortical areas are being used and the only interference will be due to processing mode.

This model can be used to explain the distribution of errors of judgments. Since these errors were virtually all errors in which "same" pairs were judged to be "different" we can theorize the following: first, the S judges the stimulus pair by comparing kinesthetic traces of the letters; second, the response is stored as kinesthetic traces that are different, that is, a hand movement to the right or to the left; and third, since the response traces interfere with the stimulus traces and the response traces are always "different," the interference will result in errors of the type found.

This theory could be checked by another experiment of the same design but substituting color patches for the letters in the stimulus pairs. Unless the poor spellers encode color kinesthetically, a concept that seems highly unlikely, the interference caused by simultaneously processing two things in the same mode should be eliminated. If results of this type were found, it would be strong support for Fernald's (1943) theory of learning and indirectly for her techniques of remediation of learning disorders.

More testing using this experimental method is indicated. Ideally, a large-scale study should be done using unselected elementary school children as Ss. The spelling ability of each child would be measured using a standardized spelling test and double blind experimental controls. This would allow a check of criterion validity in a population with a wider range of spelling ability.

If further testing indicates that this method has criterion validity that is as high as it appears from the results of this study, then this method can become a valuable diagnostic tool. If further research supports the kinesthetic encoding theory advanced to explain the results of this study, it will strengthen the empirical basis of the Fernald techniques of remediation.

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