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An Investigation of the Relationship Between Cerebral Dominance and Intelligence.

Allan Berman
Louisiana State University and Agricultural & Mechanical College

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in

The Department of Psychology

by

Allan Berman
B.A., University of Massachusetts, 1962
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ABSTRACT

A battery of tasks designed to measure both the direction and the degree of cerebral dominance was assembled. Care was taken to insure that items were included which tested not only preference, but also control and function laterality: in addition, tasks measured not simply handedness, but also laterality of foot, eye, and ear. A scoring system was devised which appropriately weighted the tasks and assigned a differential score termed the Index of Cerebral Dominance. The ICD, along with the Columbia Mental Maturity Scale, was administered to 100 subjects, arranged into 5 groups of 20 subjects each. Groups included (1) individuals with superior intelligence, with no brain damage; (2) individuals with average intelligence, with no brain damage; (3) individuals with retarded intelligence, with no brain damage; (4) individuals with average intelligence, with brain damage; (5) individuals with retarded intelligence, with brain damage. The presence or absence of brain damage was determined after surveying results of psychological and neurological examinations.

Results indicated a correlation of .81 between intelligence scores and ICD scores, for subjects with no brain damage. The correlation was .43 for individuals with brain damage. Both of these correlations were significant, as was the difference between the correlations. These results were interpreted as support for the hypotheses that there is a significant relationship between cerebral dominance and intelligence, and that such a relationship is more
predictable for individuals without other brain disorders than it is for individuals who are so damaged.

It was also found that ICD scores of individuals with retarded intelligence but no brain damage, were the lowest of any group, and significantly lower than scores of a group with similar intelligence, but who had brain damage. These results apparently supplied evidence that cerebral dominance is not only related to intelligence, but might play a role in determining intelligence.

Cerebral dominance is seen as an indicator of neurological organization. A theory developed during the paper explains a conception illustrating the operation of this organization. Central to the foundation of the theory is that verbal and symbolic behavior are mediated by a dual memory trace, involving a sensory component and an emotional component. The theory asserts that cerebral dominance is necessary to be established for proper neural connections to develop, and for verbal and symbolic behavior to progress normally. Results of this research are support for such a theory.

Future research should be devised to help answer the questions of the cause of dominance disturbances, their potential for effecting emotional as well as intellectual components, and the possibilities of changing or correcting dominance patterns.

Reliability of the battery of dominance tasks was tested, and a test-retest correlation of .86 was found. This correlation compared favorably with scattered results on the only widely used physiological dominance measurement, the Wada Test. If practically feasible, comparative studies between the Wada Test and the ICD might be profitable.
Limitations of the present study involved the restrictions posed by the age limits of the sample. Suggestions were made for further methodological improvement of cerebral dominance research, as well as for replications of the present study.
CHAPTER I

INTRODUCTION

To provide historical perspective as well as a theoretical basis for formulation of hypotheses concerning cerebral dominance, physiological and neuroanatomical research will first be considered, as they are related to verbal function and symbolic behavior. Secondly, that research specifically involving measurement and effects of disturbed cerebral dominance will be surveyed. Finally, literature concerned with relationships among cerebral dominance, verbal ability and higher mental functioning will be reviewed.

A. Physiological Research and Concepts of Verbal Function

The history of research on speech and verbal disorders dates from 30 A.D., when Valerius Maximus described a learned man of Athens who lost his memory for letters after he was struck on the head with a stone.

In modern times, Gall (1807) made the first significant attempt at localization of function when he ascribed speech to the convolutions in the inferior aspect of the frontal lobe. Bouillard (1825), who accepted Gall's views, advanced the opinion that there were two ways in which a cerebral lesion could affect speech: by destruction of the center of memory for words, or by damage to, or alteration of, neurological pathways governing movements of speech.

Dax (1836) was the first investigator to conclude that the left
hemisphere of the brain was important for speech function. Broca (1861), who studied autopsies of brains from individuals with verbal disorders, concluded that a lesion in the frontal lobe was the primary cause for loss of speech, but that areas of the temporal and parietal lobes were also involved. Broca confirmed Dax's hypothesis that the left side of the brain was the only significant hemisphere for speech.

A major deficiency in research on verbal function until this time was a lack of specific description of exactly what types of disorders were being localized. Gall, Bouillard and Broca combined verbal difficulties as one basic defect; hence, localization was necessarily only an approximation.

It was Hughlings Jackson (1932) who made the first genuine attempt to discover just what functions were being lost in verbal disorders. Among other things, he maintained that since speech is required for thinking about novel or complex things, thinking in the speechless person was inferior in symbolization to that of the normal person. Jackson also concluded from the data of Dax and Broca that there must be a dominant hemisphere of the brain.

Earlier, Wernicke (1881) had located the seat of "sound-memories" in the temporal lobe and had placed the conceptual basis for speech in Broca's area. Broca's and Wernicke's ideas remained unchallenged until Pierre Marie (1906) attacked some of their previously long-accepted conclusions. Marie re-examined the brains of Broca's first two patients in search of evidence that the frontal lobe was important in verbal ability, as Broca had claimed. He concluded that the frontal area had no function in speech, a conception that was
also incorrect. However, Marie's rejections of Broca's formulations stimulated research in the area. Marie also attacked Bouillard's distinction between sensory and motor aphasia, and stated that every aphasic patient showed some defect of comprehension, and that in every patient intellectual activity was diminished.

This early research suffered greatly from conceptual inaccuracy. Terms such as speech, verbal function, and aphasia were used without definition, often interchangeably. Subsequent researchers went to the opposite extreme, breaking down verbal function into a multitude of parts. Each researcher defined his own terms and did not consider whether his terms overlapped or coincided with those of others. This terminological confusion, combined with unsophisticated experimental methodology which lacked proper controls, plagued research in the area until the middle of the 1930's. Until that time only one consistent finding had emerged upon which there was agreement--that only one side of the brain was concerned with verbal functions, particularly speech, and that this side of the brain was considered dominant because of that distinction.

Subsequent researchers made the basic assumption that complete cerebral laterality for speech and verbal function existed, and their research was predicated upon that original assumption.

Henry Head (1935, 1920) first attempted to clarify the confusion. He believed that there was no reason for the assumption that many terms previously used represented different functions; they all involved use of language, and efforts were necessary to determine the
cause of the basic language defect. Faults of reading, speaking and writing, he believed, did not consist of disturbances of separate groups of human functions: they were all language disorders that became disturbed no matter what primary defect was involved. Weisenberg (1934) and Weisenberg and McBride (1935) criticized some of the tests from which Head derived his conclusions, on the basis that not all of the tests could be performed satisfactorily by normal subjects, a fact which contaminated Head's results.

Most researchers agreed that lesions in specific localities definitely produced clinically different types of verbal disorders. Proximity of the lesion to Broca's area (posterior part of the third frontal convolution) determined the greater or lesser involvement of the motor components of speech. If the lesion were nearer the vicinity of the junction of the parietal, occipital and temporal lobes, the more that reading and writing functions were affected. Finally, the greater the involvement of the posterior, superior temporal region, the greater the difficulty in comprehension of spoken words (Penfield and Roberts, 1959). All these researchers assumed that lesions were always in the dominant hemisphere.

According to nearly all investigations until 1945, areas of the brain involved in verbal function included: (1) the posterior, inferior part of the frontal lobe; (2) the posterior half of the first and second temporal gyri; (3) the angular gyrus; and (4) the temporo-parieto-occipital junction. All of these areas were found to be significant only on the dominant side.
Despite such apparent unity, none of the theories of physiological correlates of verbal function gained general acceptance.

Neilson (1946) corrected an assumption that had caused conflicting experimental results for decades. He argued that the minor (non-dominant) hemisphere may be involved in verbal function. Using the autopsy method, he concluded:

(1) The minor cerebral hemisphere will sometimes assume the function of the dominant hemisphere, but not in every patient.

(2) Language disfunctions, if only partial in nature, do not usually transfer to the minor side in toto; visual, auditory or motor functions may transfer separately or not at all.

(3) An artificial writing mechanism may be formed at times on the minor side by training; even if this happens, the entire verbal mechanism does not necessarily transfer.

(4) Speech functions have many pathways, and it is unsafe to localize a lesion solely on the basis of verbal disorder.

There are many serious criticisms of Neilson's work. The most serious was his assumption that brain disorders found at autopsy were responsible for the language defect. No apparent consideration was given to the possibility that the observed lesion might have caused an unrelated, unrecognized symptom.

Secondly, Neilson used a type of "probability theory," in which he assumed that as long as most autopsies gave the same results, the findings were valid. He maintained that a few variations were expected due to individual differences and to the widespread pathways of verbal function.
Nielson's work was, however, a milestone in specifically defining speech disturbances. He accomplished a type of gross cortical localization of language function. Because of the above criticisms, very little may be definitively deduced from his findings except that lesions were found within one of the four areas noted previously as common to most early findings.

Some of Nielson's findings agreed with Lashley's earlier (1929) concept of equipotentiality. By this, Lashley meant that different parts of a given sensory system are interchangeable in their roles in learning. Nielson's evidence that speech function, within separate sense modalities, may transfer to the opposite cortex, involved the equipotentiality principle. Later work has found, however, that Lashley's concept may not always be correct (Morgan, 1965).

A more careful approach, with different methodology and more meticulous attention to detail, was used by Penfield and Roberts (1959). They dealt first with the problem of the relationship between handedness and dominance. "In almost one hundred years, only 140 cases have been reported with aphasia resulting from involvement of only the right hemisphere. It seems clear that the left hemisphere is usually dominant for speech, regardless of handedness. The reason why the right hemisphere is sometimes dominant is unclear, but it is not related to handedness" (p. 102).

Following injury, if other areas in the left hemisphere are capable of functioning during speech they will assume this function. After a complete removal of the left hemisphere, the right hemisphere
assumes these functions. An additional finding was that speech returned more rapidly if the injury or removal occurred early in life.

Following these dominance studies, Penfield performed brain surgery and used electrical stimulation on the surface of the cortex during operation to map language responses that occurred. During these procedures the patient was conscious but could not see the surgeon. There was an observer, usually the anesthetist, who was seated near the patient, transmitting reactions to the surgeon and to the "cartographer". The anesthetist could not see the surgeon, and did not know when or where stimulation was applied (Penfield and Roberts, 1959).

Results showed that electrical stimulation could have either a positive effect upon speech (i.e., causing vocalization), or a negative effect (i.e., interrupting vocalization). There were several kinds of negative effects, involving various speech disorders from total arrest of speech to distortions, confusion and perseveration. Observation of points where stimulation caused any type of speech disturbance revealed that these points corresponded quite closely to areas previously mentioned as being significant for verbal function. All points were on the dominant side of the brain (Penfield and Roberts, 1959). "We believe that the most important area for speech is the posterior temporo-parietal region (of the dominant lobe). . . ." (p. 188).

Penfield and Roberts' conception of speech function, resulting from the above research, may be summarized as follows:

Comprehension of speech occurs after receiving auditory impulses in both hemispheres and in the higher brain stem (HBS), and during the interaction of impulses between the HBS and the dominant temporo-parieto-occipital region. . . . Impulses produced after
interaction between HBS and the dominant hemisphere may be transferred to the motor cortex of either hemisphere, and thence to the final common pathway to the muscles used in speaking" (pp. 188-190).

If the auditory area of one hemisphere is destroyed then the corresponding area of the other hemisphere is used alone. Transient disorders would result only if lesions were on the left (dominant) side, and cells or pathways to the HBS were effected. Persistent disorder would occur if the latter pathways were functioning abnormally or if the lesion was very extensive.

The memory trace for speech must lie somewhere along the HBS-temporo-parieto-occipital pathway of the dominant hemisphere, where Penfield and Roberts stated that comprehension occurred. Using the method of ablation, they stated that mediation of verbal neural impulses must be integrated through a subcortical center, in their opinion most likely the thalamus.

Using the hypothesis that the thalamus serves an organizing role for verbal functions (as it does for other functions) it may be easier to understand the 1959 finding of Penfield and Roberts that a partial lesion of the posterior speech cortex produced aphasia which was followed, after a time lapse, by recovery without displacement of speech function to the other hemisphere. The thalamic speech center is suggested as the means of providing ideational mechanisms by changing previously unemployed areas in the cortex of the same hemisphere.

The hypothesis of Penfield and Roberts is in disagreement with Nielson's view that speech functions will transfer separately to the minor side following an injury. An inference from the research of
Penfield and Roberts is that speech function will not transfer to the minor side unless there is severe injury to the dominant cortex—and then it is transferred completely. That the same side of the cortex will be used when possible is also supported by Goldstein (1936). It appears that Penfield and Roberts, with superior clinical techniques, and ability to confirm hypotheses by physiological examination, have corroborated some of the armchair speculations made by Pierre Marie over half a century earlier.

Most recent findings concerning the physiological basis of speech function are best represented by the theory elaborated by Norman Geschwind (1965), whose interest in verbal behavior is a by-product of his more general concern with inter-hemispheric connections.

Geschwind viewed the situation of cortical connections in man as complicated by two basic facts: (1) As we ascend the phylogenetic scale, associative activities become separated from receptive activities. Large association areas are more clearly distinguishable in the brain and are the only connections to the primary receptive areas. (2) In addition, in man there is the introduction of a new anatomical structure, the posterior parietal lobule, including the angular and supramarginal gyri. These areas cannot be recognized in lower species, even as high as the macaque (Crosby, et al., 1962). In addition to these factors, others which distinguish the posterior parietal lobule are:

(a) The gyri of the area are highly variable.

(b) It is one of the latest zones to myelinate.
(c) It has relatively few thalamic afferents.
(d) It appears to have many afferents from other cortical areas.
(e) The area is located not in apposition to any primary receptive area, but at the point of junction of visual, auditory and somesthetic association areas.

Thus, in man, the existence of this strategically located and highly differentiated region of the posterior parietal lobule makes possible a large amount of intermodal associations, and language is dependent upon formations of associations between audition and other modalities. The ability to acquire speech, according to Geschwind, depends upon this capacity to form cross-modal associations.

Disturbances of language ability will result from any disorder that cuts off the posterior parietal lobule (Wernicke's area, Penfield's posterior speech area) from other association areas or from primary areas. Lesions which isolate this area from the motor areas will also affect speech.

Geschwind pointed out that a lesion in the posterior parietal lobule on the dominant side impaired not only speech, but also verbal comprehension. He believed that the area is the storehouse for all verbal associations. Geschwind for the most part neglected subcortical connections, but did state that verbal abilities involved only nonlimbic associations.

The persistent neglect of the limbic system by researchers in the area is difficult to understand. The effects of emotion upon speech are well known. (Stuttering, for example.) Motivation influences the
child's first efforts in learning to speak. Furthermore, distortions of speech occurring in individuals who are highly excited or in a tense emotional state are common. The emotions can have a variety of excitatory and inhibitory effects upon the individual's use of language. It is likely that the limbic system must interact with the primary speech associations somewhere along the circuit.

Figure 1 represents a conceptual system of cerebral organization for language function which describes how such an interaction as that considered above may take place. The figure uses the auditory system as an example, since most verbal associations involve that system. However, it must be remembered that essentially the same mechanism could exist for any sensory system.

Figure 1. Schematic diagram of a proposed pathway for speech.
Initial verbal stimulation enters and proceeds to the primary projection area, and thence to the appropriate association areas of the cortex. From there, on both sides of the brain, impulses travel to that part of the temporal cortex designated "TE" by Geschwind. The association area on the dominant side, however, sends collateral fibers to the parietal speech area, which is believed to be an association area for speech. The parietal association area sends impulses directly to the thalamus (probably the posterior section called the pulvinar, since Penfield's brain dissections showed that the posterior speech area sent afferent fibers to this area of the brain only). Meanwhile, impulses have simultaneously gone from TE through the limbic system and to the thalamus. In the thalamus, a combination of associations is effected. Verbal associations from the parietal area interact with the emotional associations arriving from the limbic system. It is here--after emotional "filtering" has taken place--that the final response is determined. The thalamus then integrates the combined association and sends response instructions to the motor area of the cortex.

There are many implications arising from such a theory, which form the conceptual framework basic to the hypotheses to be made later in this paper:

1. Speech function is composed not only of a single association, but of at least two interacting associations. It has been the unfounded assumption of a single association that has hindered research in the language area.

2. One of these associations is strictly sensory, coming from
the parietal speech area on the dominant side; the other may be an emotional association from the limbic system.

(3) Therefore there are at least two memory traces involved in speech: a sensory trace recalling the concept related to the word(s); and an emotional trace, acting as a kind of filter for the total association.

(4) Only the sensory association, from the dominant side of the parietal cortex, is absolutely necessary for speech to occur. It is not necessary that emotional filtering take place, but it usually does.

(5) In some individuals, cerebral disorders may cause a disturbance so that the two associations do not reach the thalamus together. If something happens along the pathway of the emotional association, inappropriateness of affect may result. If the lesion or disfunction is along the sensory pathway (mostly confined to the dominant side), intellectual damage involving verbal abilities will result.

(6) Memory traces are located along the pathways transmitting various associations. For the sensory association, relating the word to a concept, the memory trace is along the parietal-thalamic pathway of the dominant side; for the emotional association, the memory trace is somewhere along the TF-thalamic pathway. It is difficult to ascertain from previous research as to whether the emotional association is restricted to the dominant side also, since little is known about subcortical laterality. There is some probability that the emotional trace comes from the dominant side, but this has not been studied enough to state with any degree of certainty.
A disorder of cerebral dominance, causing improper communication between dominant parietal speech areas and the thalamus, will have destructive effects upon verbal ability, and may possibly also have effects upon the emotional components of language. Such disorders result probably from brain damage and may be apparent upon examination, or they may be an inherent part of the brain structure due to disturbed neurological organization, and not be amenable to diagnosis by current methods. Such disorders vary widely in intensity depending, among other things, upon degree of failure of one side or the other to gain dominance.

It does not matter which side is dominant, so long as one side has attained dominance.

That the pathways described in Figure 1 and subsequent discussion actually exist is substantiated by the work of Geschwind (1965), Penfield and Roberts (1959), Krieg (1963), Lassek (1957), Walker (1938) and Kappers, et al., (1936).

Research that has involved the effects of incomplete or mixed dominance will now be reviewed.

B. Research on the Effects of Disturbed Cerebral Dominance

For the remainder of this investigation, "dominant" will apply to that side of the brain which has assumed the primary role for verbal and symbolic behavior. Because physiological evidence of dominance is so difficult to obtain, nearly all research on cerebral dominance has been done using behavioral indices. These behavioral techniques have been derived from physiological and psychological experiments. Until
Penfield and Roberts' work in 1959, early research was based primarily on the assumption that handedness was a reliable indicator of cerebral dominance. These experiments related handedness or "eyedness" to reading ability, with quite simple criteria for establishing dominance. The simplicity and experimental naiveté of the early work led to confusing results. There were studies that positively related handedness (or eyedness) and reading ability: Stromberg (1934), Bennett (1933), Dearborn (1933, 1931, 1930, 1925), Monroe (1932), Anderson and Kelley (1931), and Hincks (1926). There were also many studies which reported a negative relationship: Johnston (1942), Bennett (1938), Gates and Bond (1936), Witty and Kopel (1936), Van Riper (1935), and Woody and Phillips (1932).

A basic problem throughout the research has been the development of appropriate and reliable techniques for measurement of dominance. Such techniques have often been oversimplified in design or too cumbersome in construction (Ojemann, 1930; Downey, 1930, 1927; Rife, 1922). Another difficulty has been the use of apparatus and measurement devices that were too limited in application or merely inadequate (Grider, 1935; Durost, 1934; Koch, 1933; Lund, 1932; Giff, 1931).

Despite accumulating evidence that different patterns and combinations of handedness existed in different individuals, and sometimes even within the same person at different times, not until the middle of the 1930's did this realization become reflected in the necessary revision of experimental procedures. (Hildreth, 1949; Brain, 1945; Burt, 1937; Durost, 1934; Koch, 1933; Twitmeyer and Nathanson, 1933; Haefner, 1929).
During that decade and the next, research was directed less toward specific reading difficulties and more toward intellectual deficits. Burt (1937) found that superiority of the right hand was far less marked among mentally defective patients than among merely dull patients, and less in the dull than in normal and bright subjects. Selzer (1933) earlier had found unidextrality to be more pronounced in normal than in dull children. Mintz (1947) found a slightly greater percentage of left-handedness among mentally subnormal boys. In addition, the dominant eye came in for more attention. Robinson (1946) and Gahagan (1933) found no relationship between eye dominance and any other measure of visual efficiency, indicating that the preferred eye was not necessarily superior in vision.

Since 1945, attention has turned to other aspects of laterality, particularly the relationship between hand and eye dominance. But here results were also conflicting. Koos (1964), Leavall (1954) and Berner and Berner (1953) all found a discrepancy in hand-eye laterality to be associated with reading difficulty, while Balow and Balow (1964), Balow (1963), Silver and Hagin (1960), Smith (1949), Fernald (1943), and Fendrick (1935) all found negative results. Held and Hein (1958), Held (1956) and Gottlieb (1958) have hypothesized that lack of hand-eye coordination could be due to displacement of the retinal image, and that the only correction is continual sensory stimulation ("re-afference") to cause adaptation. Kimura (1961a, 1961b, 1959) has studied ear laterality and found that when verbal stimuli of a different nature are presented to the two ears, those stimuli which arrive at the ear opposite the dominant hemisphere are more easily recognized.
There were several factors which may have accounted for the multiplicity of results. These factors were related to faulty experimental design which failed to take into account relevant variables, or mere carelessness in development of measurement procedures. As a result, very little may be deduced from the data so far presented.

One of the factors that has contributed to differential results is variability of subject age. Hildreth (1949) discussed the importance of age in determining lateral dominance, but in general, subsequent researchers tended to ignore his findings. Belmont and Birch (1963) later found that hand preference was not reliably established until at least eight or nine years of age. Below that age, considerable mixed handedness occurred. Eye preference did not become stabilized until age ten. Coleman and Deutsch (1964) attributed a considerable amount of experimentally conflicting results to the fact that various researchers used subjects of different ages.

Zangwill (1960), Goodglass and Quadfasel (1954) and Humphrey and Zangwill (1952) have all studied dominance with relationship to age, and their findings indicated not only age differences in cerebral dominance, but also corroborated earlier evidence that unilateral specialization for handedness, as well as language, varied among individuals. They also believed that cerebral laterality for language, and handedness, were not directly linked. They stated that at birth the two hemispheres have an equal potentiality for localization of speech function, but that most people develop speech centers in the left cerebrum, independent of handedness. Dreifuss (1963) reported that production of meaningful
words occurs in the child at 18 to 24 months, independent of dominance. It is significant that this occurs during the same period when the child first develops hand preference (Zangwill, 1960; Ingram, 1959; Karlin, 1959; Goody and Mckissock, 1951; McCarthy, 1946; Brain, 1945).

Support for the idea that dominance is not yet established during the first few years of life may be found in the research showing that when lesions of the dominant hemisphere disturb speech early in life recovery is quite rapid; while if damage occurs after full development of speech, the verbal disorder will be lasting. This observation is thought to reflect the capacity of the brain, before a critical age, to shift cerebral dominance after injury (Byers and McLean, 1962; Carmichael, 1954; Tizard, 1953; Ford, 1952; Guttmann, 1942; Basser, 1941). Age at which dominance is finally established (and, by implication, unchangeable) is a subject of much conjecture. Forgays (1953) believed that not until adulthood or late adolescence is accuracy of word perception related to the side of the field of vision in which words are presented, and thus that eye dominance, at least, is not established until that time (Mishkin and Forgays, 1952). S. Adler (1964), however, stated that cerebral laterality is usually determined by age six. Delacato (1963) concurred that dominance becomes complete between the ages of six and eight years. The latter two authors cite considerable experimental and anecdotal evidence to support their views.

It definitely appears that age of subject is of considerable importance in determining dominance, and in many studies it has been ignored. Clark (1959) criticized another methodological error in dominance studies, involving group selection. He believed that uncautious
selection of subjects was the probable cause of confusion in research results. He stated that neither left-handedness, left-eyedness or crossed laterality in themselves were important causes of language differences in groups. This view was somewhat supported by Vernon (1957). Vernon (1957) maintained that dominance varies according to the way it is measured. The most reliable tests should have many tasks. Even then, evidence as to the existence of complete or incomplete dominance is difficult to obtain. The relationships of eye, ear, foot and hand laterality to cerebral dominance is obscure. Certainly, he stated, no one is justified in concluding that everyone is either completely right- or completely left-sided. Vernon emphasized two difficulties prevalent in earlier research: (1) The necessity for developing dominance tests that involve many tasks and that have established reliability; and (2) the necessity for establishing measures that discriminate among various degrees of dominance, without assuming total left or right dominance. Benton (1962) has commented that in many studies no distinction has been made between fully lateralized subjects and those who use both sides to some degree, and he has warned that there are frequent discrepancies between self-classification of handedness and actual performance laterality.

Luria (1966) confirmed that dominance of one hemisphere in relation to speech functions has not proved so absolute as was originally assumed. Research has shown that degree of dominance varies from subject to subject and from function to function. Luria considered that higher mental functions, including speech, resulted from combined action of both hemispheres, with each making its own, but not equal,
contribution. Speech functions do show a marked degree of lateralization and dependence upon a dominant hemisphere. But Zangwill (1960), Jackson and Zangwill (1956), Ettlinger and Jackson (1955), Goodglass and Quadfasel (1954), and Humphrey and Zangwill (1952), have all shown that lesions of the left hemisphere in left-handed individuals lead to definite disturbances of speech and related processes. However, these results may be spurious due to the continued confusion of handedness with dominance.

Nevertheless the literature at best is still confusing. With lesions of the dominant hemisphere, speech and related functions are disturbed to a different degree in different subjects, and may be restored in some subjects but not in others. These apparent contradictions cannot be explained by severity of the lesions, size of the focus, or complicating factors. "It is evident that the degree of dominance in relation to lateralized processes such as speech varies considerably from case to case" (Luria, 1966, p. 91).

Yet Luria failed to take into account some factors already mentioned to explain the variable results, such as subject age and, more importantly, probable unreliability of measurement devices. Nearly all experimenters used only a few tests for dominance. Harris (1957), who used a battery of items, consistently reported positive results when dominance was related to reading ability.

Delacato (1963) has discussed at length the types of tasks necessary for a reliable instrument to discriminate. True dominance is composed not only of preference, but also of control and function. In the
completely lateralized individual these three aspects are accomplished by the same limb (or eye or ear). In the individual with disturbed dominance, there may be laterality differences occurring which upset the uniformity of dominance among preference, control and function. Dominance tests must include tasks measuring all three of these factors.

Besides problems involved in the measurement of dominance, other methodological difficulties involved sample selection. Groups of "normals" have not been properly controlled. There has been inadequate (or complete absence of) matching for age, intelligence, or verbally-related intellectual factors that do not vary. Brain-damaged groups have not been separated according to age, intelligence or localization of focus. The large group of retarded individuals with no observable brain damage has been almost entirely ignored.

The area of dominance as it relates to verbal abilities has been studied extensively by researchers in medicine, psychology, education and speech pathology. Each of these groups has been concerned with a specific aspect of the problem, and has narrowed the scope of research to fit only that area, failing to include results from other areas, and generally neglecting to adopt widely accepted practices of experimental design. Theorists have speculated upon reasons for conflicting results, discarding one theory or supporting another, and generally tending to explain confused results not by examination of experimental procedures, but by proposing still more theories. New research, carefully designed to examine some of the more venerable existing theories, should have priority over new theories.
First, however, it will be necessary to examine still another area of research which bears upon the problem.

C. Relationships among Dominance, Verbal Ability and Intelligence

The relationship between verbal ability and intelligence has been one of the most controversial areas in the history of measurement of human differences. Many "intelligence" tests are almost entirely dependent upon verbal ability; others require little or no verbal fluency. One reason for difficulty has been a lack of a widely accepted definition of intelligence. A more accepted view currently is that intelligence is, in part at least, the ability to think in terms of abstract ideas, the relative capacity to form concepts and to relate concepts to diverse situations (Terman, 1937). According to this view, language is the shorthand of higher mental functions, and thus ability with language is the single most important determinant of IQ. The idea that abstract or conceptual ability is basic to intelligence is accepted by many; the argument remains over whether verbal ability is necessary in order to have adequate conceptual ability. The controversy is reminiscent of early debates by members of the Wurzburg School over the existence of imageless thoughts (Boring, 1950).

Favoring the view that language is necessary for conceptual functioning is the fact that, since the work of Broca and Wernicke, investigators have found that lesions in the dominant hemisphere which impaired language also impaired general abstract or conceptual ability—the so-called higher mental functions. Goldstein (1948) believed that development of dominance of one hemisphere paralleled the development
of the higher mental functions. After one hemisphere has attained dominance, all new abilities are particularly related to that hemisphere and differences between the two hemispheres become more outstanding. Thus, according to Goldstein's implication, failure to attain dominance would result not only in language difficulties, but also in generalized abstract and conceptual deficits.

S. Adler (1964) maintained that language capacity is divided between the two hemispheres, with concrete language functions in the left hemisphere and abstract functions on the right side, regardless of laterality. Penfield and Roberts (1959), however, in their detailed research, intimately connected speech functions with conceptual ability.

As time passes, there is formed within the brain the ganglionic equivalent of a word and the ganglionic equivalent of a concept. Experience over the years continues to reinforce the back-and-forth neuronal relationship between the two... The... neuronal conductions between the ganglionic equivalent of a word and the ganglionic equivalent of an idea are so facilitated as to be fixed for life (p. 230 ff.).

Thus the ganglionic equivalents of words are established as conditioned reflexes, with the word as the CS and the concept as the CR. The process also works in reverse. Therefore as soon as the idea has been selected by the individual the word is normally forthcoming, and the individual, by conscious action, may speak, write, or silently formulate the word. When an individual is listening or reading, the word immediately summons the corresponding idea. The speech mechanism is probably physiologically separable from the conceptual storehouse, but the possibility of functional separation is unknown.

Actually, Penfield and Roberts did not actually come to grips
with localization, since their conception of language function did not necessarily mean that verbal and conceptual abilities are located in the same area, only that they are mutually dependent.

Many researchers have believed that verbal and nonverbal intelligence are distinctly different, and Anderson (1951, 1950) maintained that the two types of ability may each be represented in one hemisphere. He found that a group with damage to the dominant hemisphere showed greater loss of verbal ability, while a group with damage in the nondominant hemisphere had greater losses on performance items. He made the interpretation that the dominant hemisphere is responsible for determining what to do, while the nondominant hemisphere determines how to do it. Reitan (1960) has suggested that, in disphasic patients, problem solving and other adaptive abilities (as well as complex physiological tasks not involving language) do not suffer. However, Reitan's study did not involve subjects with complete loss of language function. In addition, his brain-damaged patients performed more poorly than controls on measures of intellectual function such as Halstead's Test of Biological Intelligence and the Wechsler-Bellevue. These results support earlier work by Kennedy and Wolf (1936), who claimed that aphasia is a mere loss of a linguistic tool, and that intellect can survive without it. Head (1963), however, interpreted data to indicate that aphasia is a manifestation of a primary intellectual loss. McFie and Piercy (1952) supported Anderson's (1951, 1950) results, stating that verbal and performance differences depended upon which hemisphere was damaged, while Reitan (1959) found that some aphasics even show certain superiority on nonverbal tests. Such findings imply that language loss is an
independent deficit and not indicative of loss of intellectual function. Weisenberg and McBride (1936), though, had evidence that aphasics tend to produce inferior results on nonverbal as well as verbal tests. This finding is supported by Hebb (1942). There is also considerable evidence that nonaphasic, brain-injured individuals will perform worse on nonverbal tests than aphasics (McFie, 1960; Heilbrun, 1956; Bauer and Becka, 1954). Finally, recent research by Milner (1965), Teuber (1965), and Weinstein (1965), has shown that greater deficiencies in performance of human subjects may occur after damage to a given region of one cerebral hemisphere than after similar damage to the corresponding region of the opposite hemisphere. Importantly, these differences are not limited to tasks involving the use of language.

One basic problem with many of the above studies is that they compared groups of aphasic individuals with groups of normals and did no more than point out that some aphasics may have other deficits in addition to verbal losses, while others may not.

Piercy (1964) believed that much confusion rests in the fact that it is too easy to simplify the problem of the relationship between speech and intelligence by regarding either or both as unitary entities. Some structures may underlie both speech and intellectual ability and create a situation where certain lesions will produce certain types of aphasia associated with specific intellectual deficits, while other lesions may create different clinical pictures.

It is very difficult to separate the consequences of language disability from the effects of damage to cerebral structures in
brain-damaged patients who have aphasic disturbances. For instance, Teuber and Weinstein (1956) have shown that all brain-injured people tend to do worse than normals on a test of perceiving hidden figures—whether aphasic or not—but that aphasics do worse than non-aphasics. This would imply that both the brain-damage and the aphasia are contributing separately to the loss. Also, Weinstein, et al. (1955) showed that aphasics do significantly worse than non-aphasics on tests of conditional reaction to combinations of visual shapes and backgrounds. Both of these studies show apparently worse performance by aphasics on nonverbal items, and argue that the failure of aphasics cannot be explained on the basis of intellectual impairment alone. This supports Piercy's (1964) hypothesis that it is cerebral damage causing the disorders, and also possibly causing associated intellectual losses, but that mere loss of speech, in itself, is not the basis for intellectual deficit.

Piercy and Smith (1962) found that unselected groups of aphasics showed greater impairment than any other group of brain-injured patients on verbal intelligence tests. They also have patients with lesions in the posterior nondominant hemisphere who showed greater deficiencies on spatial tasks than did aphasic patients. But left-hemisphere damaged aphasics did worse than other brain-injured patients on all other tasks.

Finally there are the reports of patients with left hemisphere damage, without clinical aphasia, who did worse than their right-hemisphere damaged counterparts on tests of verbal intelligence and memory (Reitan, 1959; Milner, 1958; Meyer and Jones, 1957; Meyer and Yates, 1955; McFie and Piercy, 1952). These studies would argue that perhaps
there are some structures on the dominant side responsible for intellectual factors, apart from verbal functions.

Looking at the total picture, the results are quite confusing. The consensus of data support the fact that if the dominant hemisphere is damaged, verbal disorders are definitely produced. However, verbal disorders may or may not be accompanied by intellectual losses, depending in part upon the structures involved, severity and type of damage, and the definition of intelligence being used. It is not clear whether conceptual disorder, when it does occur, is due to damaged structures, or due to neurological disorganization resulting from interference with established brain dominance. Another complicating factor is that it is difficult to establish, with any safe degree of reliability, the specific focal laterality of brain damage. Neurologists themselves do not have enough faith in their diagnostic techniques to state definitely whether they can pinpoint reliably that brain damage is or is not on the dominant side (Lilly, 1967).

Further research is necessary to investigate the effects of disturbed dominance apart from the effects of damaged cerebral structures, and to separate the effects of these two types of disorders from the effects of verbal disability alone. Research findings until this point have not adequately determined either the extent and type of disorders involved, nor exactly what is causing the observed losses. Also, despite the wealth of conjecture and inference concerning the issue, there has as yet been no research specifically exploring the nature of the relationship between cerebral dominance and intelligence, apart from
associated brain damage. Weinstein (1965) has studied the intellectual effects of brain wounds in each hemisphere. He found that individuals with right hemisphere lesions suffered from perceptual impairment, but not significant intellectual impairment; those with left parieto-temporal lesions had intellectual impairment but no loss in perceptual (tactile or visual) judgement.

It will be the purpose of this research to examine thoroughly the relationship between cerebral dominance and intelligence, both with and without diagnosed brain damage, using a methodology enabling as reliable a measurement of dominance as possible with present knowledge, and with adequate sampling procedures to enable determination of the cause of intellectual deficits.
CHAPTER II

THE PROBLEM

A necessary beginning to research in this area was the assessment of cerebral dominance using behavioral indices that were reliable and that were numerous enough to permit specific determination of degree of dominance, and not merely to designate whether the subject was right- or left-sided. This involved using measures to determine hand, foot, eye and ear dominance, with care focused on the issue of assessing not only preference, but also control and function laterality.

Using a measurement battery of this type, a comprehensive study of dominance characteristics of various groups was undertaken: individuals of normal intelligence, with and without brain damage; retarded individuals, with and without brain damage; and superior individuals, without brain damage, were used. It was also necessary to set specific age limits, due to previous research indicating the importance of the age variable in measurements of dominance.

Using such measurement devices and sampling techniques, the main purpose of this research was to investigate dominance characteristics of the various groups. In addition, the following hypotheses, derived from conclusions in previous sections, were tested:

(1) Most individuals do not have complete right or left cerebral dominance, but tend to have varying degrees of dominance.

(2) There is a relationship between the degree to which the individual has attained complete dominance, and intellectual factors:
that is, individuals of superior intelligence score significantly higher on dominance measurements than do normal individuals, and normal individuals score higher than retarded individuals.

(3) It is not important whether an individual has attained either right- or left-hemisphere dominance, so long as one side has achieved a discriminable degree of dominance over the other.

(4) The effect of brain damage upon intelligence depends upon the degree to which it has interfered with the maintenance of cerebral dominance. The characteristics of dominance scores of brain-damaged individuals are not as clearly related to intelligence as the scores of individuals without brain damage. Differences may be attributable to the effects of brain damage.

(5) Retarded individuals with no detectable brain damage show more disturbed dominance than any other group, with such disturbance being directly related to the severity of the retardation. Failure of one side to gain dominance is seen as symptomatic of disturbed neurological organization. In the absence of other verified brain damage in retarded individuals, it is assumed that the disturbed neurological organization alone has caused the retardation.
CHAPTER III

METHOD

A. Subjects

All subjects had passed their eighth birthday but had not reached their fourteenth birthday. Subjects were classified as having normal intelligence with IQ's from 88-110, superior intelligence from 120 and above, and in the category of retarded intelligence from 45-75 IQ. Individuals with IQ of 111-119 and those having IQ's of 76-87 were not used in order to eliminate borderline subjects where interpretation would not be clear. Children with temporary physical hindrances such as braces, casts or crutches, were not used. Children who had allied disabilities, other than those under study, were not used.

B. Measurements

The Columbia Mental Maturity Scale, a short, reliable intelligence measure, was used. Tasks used to measure dominance are listed below. They were obtained from those used, and found to be reliable, by Luria (1966), Coleman and Deutsch (1964), Delacato (1963), Greenberg (1960), Harris (1957, 1955), Lieben (1951), and Van Riper (1935, 1934). Tasks were randomized to determine order of presentation, and are listed in order of administration. Subjects were given the following instructions:

I want to see how well you can follow directions. Listen carefully and make sure you do exactly as I say. If you don't understand something, or if you want me to repeat it, don't be afraid to ask.
(1) "Fold your hands like this." (Demonstration of folding with interlocking fingers. Dominant hand indicated by outermost thumb. One measurement.)

(2) "Draw a circle. . . . Now do it with your other hand. . . . Now do it with both hands at the same time." (Record which hand was used first, and which circle was more accurately drawn. Two measurements.)

(3) "Let me see you hop on one leg." (Record which leg was used. One measurement.)

(4) "Hold this pencil in your hand right here (10 inches directly in front of S’s nose). Now close one eye. Now open that eye and close the other. When did the pencil look like it was higher?" (E may repeat if necessary. Record which hand was used, and which eye was closed when pencil seemed higher. Two measurements.)

(5) Administration of the Purdue Pegboard for right hand, left hand, and both hands together, using directions and standardized norms provided with that test. (Record which hand achieved better score separately, and which hand achieved better score when both were used together. Two measurements.)

(6) "Put your ear against that wall and tell me if you hear anything. (Motion to wall to S’s right.) Now put your ear against that wall and tell me if you hear anything." (Motion to wall to S’s left. Record which ear was used each time. Two measurements.)

(7) "Stand up. Close your eyes and put your feet together. Now lift up your arms and hold them straight out in front of you." (Record which arm was higher. One measurement.)
(8) "See if you can throw this ball into the basket from here (10 feet away). Now try it with your other hand." (Record which hand was used first and which was more accurate. Two measurements.)

(9) "Fold your arms like this." (Demonstrate. Record which arm was uppermost. One measurement.)

(10) "Step up on this chair. Now step down." (Record which foot was used to step down. One measurement.)

(11) "Put your arms on the table with your hands together like this. Now push as hard as you can with both hands." (Record hand opposite direction of tilt. One measurement.)

(12) "Can you write your name? Do the best you can." (While S wrote, E noticed from rear the direction of head tilt. Record opposite eye as dominant. One measurement.)

(13) "I want to see how well you can kick. Stand here (10 feet away) and see if you can kick the ball to me. (Ball placed two feet to left of S.) Now try again. (Ball placed directly in front of S.) Now once more." (Ball placed two feet to right of S. Record foot used each time. Three measurements.)

(14) "Let me see you cut this paper on that line with the scissors. Now try it with the other hand." (Record which hand was used first and which was more accurate. Two measurements.)

(15) "Draw a square. Now do it with the other hand. Now do it with both hands at the same time." (Record which hand was used first and which drew the more accurate square. Two measurements.)

(16) "Kneel down on one knee." (Record which knee. One measurement.)
(17) "Put this paper in front of you so that you can see the 'X' clearly. Now take this (3 1/2") tube in one hand and look through it so you can see the 'X.' Now bring the tube up to one eye so that you can still see the 'X.'" (Record which hand was used and which eye was used. Two measurements.)

(18) "Walk over to the door. Stop facing the door. Now when you come back, walk backwards." (Record foot used first walking forward and foot used first walking backward. Two measurements.)

(19) "Aim this rifle and pretend you're going to shoot me." (Record which hand was used for trigger and which eye was used for sighting. Two measurements.)

(20) "Put some beads on this string. Now do it with the other hand." (This was timed, using Stanford-Binet beads. Record which hand was used first and which hand strung more beads in one minute. Two measurements.)

(21) "Hold this pencil in your hand like this. Now place the pencil so it is even with the line on that wall. Now close one eye. Does the pencil move? Now close the other eye. Did the pencil move that time?" (Record which hand was used, which eye was closed first, and which eye caused movement of the pencil when closed. Three measurements.)

(22) "Write your name. Now do it with the other hand. Now do it with both hands together." (Record which hand was used first, and which hand was better controlled. Two measurements.)

(23) "Take this paper in one hand and hold it straight out so
you can see that red mark on the wall through this hole in the paper.
Now bring the paper up to your eye so you can still see the red mark."
(Record hand and eye used. Two measurements.)

(24) (Stopwatch was placed on table two feet to left of S.)
"Put your ear down on this watch and listen to the ticking. (Watch
was moved to a position directly in front of S.) Now listen once more.
(Watch was moved to two feet to right of S.) Now listen again."
(Record which ear used each time. Three measurements.)

(25) "Hold this (10") tube up to your eye with one hand so
you can see that red spot on the wall." (Record which hand was used
and which eye was used. Two measurements.)

(26) "See if you can break this paper cup with your foot.
(Cup placed two feet to right of S.) Now break this one. (Cup placed
directly in front of S.) Now this one." (Cup placed two feet to left
of S. Record which foot was used each time. Three measurements.)

(27) "Let me show you how to wind this stopwatch. Now you do
it for me. Now try it with the other hand." (Record which hand was
used first and which was more efficient. Two measurements.)

(28) "Step up onto this chair." (S was placed directly in
front of chair with feet together prior to directions. Record which
foot was used to step up. One measurement.)

(29) "Hammer this nail into the board. Now try it with the
other hand." (Record which hand was used first and which was more
accurate. Two measurements.)

(30) (Boys) "Swing this bat for me." (Girls) "Show me how
you sweep the floor with this broom." (Record which hand was used as
power hand. One measurement.)

C. Procedure

$S$ was brought into the room with the examiner and time was taken until he appeared comfortable. The Columbia Mental Maturity Scale was administered. Following conclusion of the CMMS, a few more minutes intervened while $E$ quickly determined if $S$'s IQ fell within the desired range. If so, then $E$ gave the instructions and proceeded with the dominance tasks as given above. Dominance tasks were administered twice through. The entire procedure took from 30 to 45 minutes per subject. All subjects were tested individually.

Scores on the Index of Cerebral Dominance (ICD) were computed as follows. There were 30 tasks involving 54 measurements, each administered twice, for a total of 108 measurements. Twenty-nine of the items were for hand dominance, 12 were for foot dominance, 8 were for eye dominance, and 5 were for ear dominance (all administered twice). Total right and left responses for hand, foot, eye, and ear were summed separately, and right minus left difference scores for each body area were calculated. This produced a total differential dominance score for each body area measured. To compensate for differences in numbers of tasks, the foot dominance differential was multiplied by 2.4, the eye differential by 3.7, and the ear differential by 5.8. This allowed a maximum score of 58.0 for each body area, and a total score of 232.0 possible if all responses for all tasks were on the same side of the body.

In addition to the differential scores for each body area, the sum of these scores (also a difference score) resulted in a total
dominance score. In many instances individuals used different sides of the body for hand, foot, eye and ear. Scores were reported in terms of a numerical figure, indicating degree of dominance attainment, and a letter (R or L) indicating direction of dominance.

There were seven tasks (administered twice for a total of 14) which required hand-eye coordination. Since many studies have indicated that unilateral hand-eye coordination is quite important, a measure of this variable was also obtained by simply summing the number of times out of 14 that the individual used unilateral hand-eye coordination.
CHAPTER IV

RESULTS

A correlation matrix was obtained between the various scores on the ICD, and the intelligence score obtained by the subjects. Correlations were obtained for the entire group of subjects, for subjects without any brain damage, and for those subjects with brain damage. This matrix is summarized in Table 1. The correlation obtained between total ICD score and intelligence of non-brain-damaged individuals was .81. A scatter diagram of this correlation may be found in Appendix C. A similar correlation between ICD score and intelligence test scores of brain-damaged individuals was .43. While both of these correlations were statistically significant beyond the .01 level, the correlation obtained for brain-damaged individuals was significantly lower than that for subjects without brain damage. Inspection of the data indicated that ICD scores apparently were distributed normally within all groups.

To elucidate the findings further, mean ICD scores for the various groups were obtained on all dominance measures, and analyses of variance were performed (Tables 2 through 9). Analyses indicated that all of the measures, with the exception of ear dominance, varied significantly between groups. Using the Duncan Multiple Range Test, means of the groups were compared and results showed that the total ICD mean score for individuals in Group 3 (retarded, no brain damage) was the lowest of any group and significantly lower than the next lowest ICD mean, that of Group 5 (retarded, with brain damage).
### Table 1

**Correlations of Dominance Variables as Measured on ICD, with Intelligence Scores Obtained from CMMS for Normal and Brain Damaged Subjects**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total r (N=100)</th>
<th>Brain-Damaged r (N=40)#</th>
<th>Normals r (N=60)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Dominance</td>
<td>.66</td>
<td>.57</td>
<td>.68</td>
</tr>
<tr>
<td>Foot Dominance</td>
<td>.65</td>
<td>.36</td>
<td>.67</td>
</tr>
<tr>
<td>Eye Dominance</td>
<td>.19</td>
<td>.25</td>
<td>.16</td>
</tr>
<tr>
<td>Ear Dominance</td>
<td>.14</td>
<td>.12</td>
<td>.19</td>
</tr>
<tr>
<td>Total R-L</td>
<td>.79</td>
<td>.57</td>
<td>.83</td>
</tr>
<tr>
<td>Hand-Eye Coordination</td>
<td>.51</td>
<td>.18</td>
<td>.56</td>
</tr>
<tr>
<td>ICD, Single Admin.</td>
<td>.53</td>
<td>.43</td>
<td>.54</td>
</tr>
<tr>
<td>Total ICD Score</td>
<td>.74</td>
<td>.43</td>
<td>.81</td>
</tr>
</tbody>
</table>

#Includes Ss from IQ 45-110.

*Includes Ss from IQ 45-145 with no diagnosable brain damage.

### Table 2

**Mean ICD Scores of Various Groups for Separate Dominance Variables and for Total Score**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1*</th>
<th>Group 2*</th>
<th>Group 3*</th>
<th>Group 4*</th>
<th>Group 5*</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Dominance</td>
<td>49.8</td>
<td>38.1</td>
<td>26.9</td>
<td>38.0</td>
<td>22.3</td>
<td>35.0</td>
</tr>
<tr>
<td>Foot Dominance</td>
<td>46.5</td>
<td>23.3</td>
<td>14.4</td>
<td>19.6</td>
<td>10.6</td>
<td>22.9</td>
</tr>
<tr>
<td>Eye Dominance</td>
<td>83.4</td>
<td>27.2</td>
<td>24.7</td>
<td>24.4</td>
<td>19.2</td>
<td>35.8</td>
</tr>
<tr>
<td>Ear Dominance</td>
<td>23.8</td>
<td>18.6</td>
<td>16.2</td>
<td>23.2</td>
<td>18.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Total R-L</td>
<td>82.4</td>
<td>48.4</td>
<td>25.6</td>
<td>46.0</td>
<td>26.5</td>
<td>45.8</td>
</tr>
<tr>
<td>Hand-Eye Coordination</td>
<td>11.7</td>
<td>7.7</td>
<td>6.4</td>
<td>6.9</td>
<td>5.9</td>
<td>7.7</td>
</tr>
<tr>
<td>ICD Total</td>
<td>148.1</td>
<td>75.6</td>
<td>37.2</td>
<td>69.1</td>
<td>45.4</td>
<td>75.1</td>
</tr>
</tbody>
</table>

*Group 1 = Superior IQ, no brain damage

Group 2 = Normal IQ, no brain damage

Group 3 = Retarded IQ, no brain damage

Group 4 = Normal IQ, brain damage

Group 5 = Retarded IQ, with brain damage
### Table 3

**Summary Table for Analysis of Variance of Hand Dominance Scores Between Groups**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Squares</th>
<th>df</th>
<th>Mean Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between</td>
<td>929096.0000</td>
<td>4</td>
<td>232274.0000</td>
<td>18.59</td>
<td>.001</td>
</tr>
<tr>
<td>Within</td>
<td>1187300.0000</td>
<td>95</td>
<td>12497.8947</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2116396.0000</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4

**Summary Table for Analysis of Variance of Foot Dominance Scores Between Groups**

<table>
<thead>
<tr>
<th>Source</th>
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<tr>
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### Table 5

**Summary Table for Analysis of Variance of Eye Dominance Scores Between Groups**

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### TABLE 6
SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF EAR DOMINANCE SCORES BETWEEN GROUPS

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### TABLE 7
SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF RIGHT MINUS LEFT TOTAL SCORES BETWEEN GROUPS

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### TABLE 8
SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF HAND-EYE SCORES BETWEEN GROUPS

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TABLE 9
SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF TOTAL INDEX OF CEREBRAL DOMINANCE SCORES BETWEEN GROUPS

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<thead>
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A point biserial correlation was performed on the data from right- and left-sided individuals (as determined by IGD scores). A correlation of .20 was obtained between sidedness and dominance scores, which was significant at the .05 level.

Complete right or left dominance would have been indicated by an IGD score of 232.0. The highest score obtained by any individual was 212.0, and the mean score for Group 1 (superior intelligence) was 148.1.

To test the reliability of the IGD as a measure of dominance, a test-retest correlation was performed, correlating the first and second administrations of the IGD for each subject, which resulted in a reliability coefficient of .86. Computations for the point biserial and for the reliability coefficient are shown in the Appendix.
The primary hypothesis under consideration, concerning the relationship between cerebral dominance and intelligence, has been confirmed by the present data. The correlation of .81 between dominance and intelligence is unexpectedly high, and would indicate that about 65% of the variance in intelligence scores may be related to differences in dominance. The very high correlation was unexpected in this research since earlier results in this area had been so contradictory and inconclusive. It is believed that there are several reasons for the conclusiveness of the above correlation. First of all, the measure of dominance used was carefully constructed and administered and found to have high reliability. Very few previous studies have provided any reliability data along with results. In addition, the dominance measure was constructed not to provide a haphazard, token measurement of laterality or handedness, but to indicate the total dominance configuration of the individual.

Another factor contributing to the favorable results has probably been the care taken in selection of subjects. No subject was included in either of the brain-damaged groups unless there existed specific neurological and psychological examination data indicating brain damage. No individual was included in Group 3 (retarded without brain damage) unless complete neurological and psychological examinations had been completed and showed no evidence of such damage. Where it was
suspected that a subject's scores were for some reason unreliable (i.e., unfavorable testing conditions) the subject was excluded from the sample. In addition, ages of the children within the groups were held relatively constant, with all groups including subjects from 8 to 13 years of age.

Another contributing factor was the specific intelligence test used. Individuals with dominance difficulties often have speech disturbances or other language disturbances. If an intellectual measure which depended upon language had been used, spurious indications of intellectual ability might have been obtained for some groups. The Columbia Mental Maturity Scale is a completely nonverbal test, so language problems associated with poor dominance could not have contributed to the results.

Finally, and perhaps the most pertinent reason why these results have been so much more definite than earlier work, is the fact that this is the only research which has attempted to correlate a comprehensive, reliable measure of dominance with intellectual ability as measured by a standardized, widely accepted test. Despite the wealth of conjecture upon the issue, no other experimentally controlled research of this kind has been found.

There were several interesting sidelights contained in Table 1, in addition to the primary correlation under consideration. The first factor that appears is the difference existing between correlations of partial scores for hand and foot dominance, as opposed to correlations of scores for eye and ear dominance. This would indicate that hand and
foot dominance contributed most to the overall dominance score, while eye and ear dominance contributed very little. In subsequent analysis (Table 5) it was determined that eye dominance did differ significantly between groups, while ear dominance did not (Table 6). Inspection of the data introduced the possibility that ear dominance scores were unreliable, and might possibly be left out of the dominance battery. To test for this possibility, the entire table of correlation matrices was recomputed, this time correlating intelligence scores with ICD scores made up only of hand, foot and eye dominance tasks. Results of this computation indicated that all correlations were found to be reduced, and the reliability of the total ICD score was also lower. Both findings were significant. Thus it appeared that ear dominance, while not itself highly correlated with intelligence, added something to the total dominance score which made the dominance score not only more highly correlated with intelligence, but also more reliable.

These are interesting results, since they suggest that earlier research which attempted to correlate handedness alone with verbal or intellectual functions was decidedly wrong in approach (Johnston, 1942; Bennett, 1938; Gates and Bond, 1936; Witty and Kopel, 1936; Van Riper, 1935; Gates, 1935; Stromberg, 1934; Kirk, 1934; Bennett, 1933; Dearborn, 1933, 1931, 1930, 1925; Woody and Phillips, 1932; Monroe, 1932; Anderson and Kelley, 1931). Present data indicate rather conclusively that handedness alone, while an important indicator of dominance, is by no means the most reliable indicator. To obtain a reliable indicator of dominance, all body lateralization must be considered.
In view of the considerable research on hand-eye coordination (Koos, 1964; Balow and Balow, 1964; Balow, 1963; Silver and Hangin, 1960; Leavall, 1954; Berner and Berner, 1953; Smith, 1949; Fernald, 1949; Fendrick, 1935), another correlation in Table 1 seemed important. The correlation of .54 for normals and .51 for the group as a whole between hand-eye coordination and intelligence, were significant ones and contributed a good deal to the overall ICD score. Here again, though, as with hand and foot dominance, it has been found that even though these are significant correlations, none of the correlations are as high or as reliable as that obtained when a total, comprehensive battery was used. The same statement would apply to findings associated with any of the other partial measures of dominance as, for example, those by Kimura (1961a, 1961b, 1959).

Data from Table 1 lend support to Luria's (1966) contention that dominance varied not only from person to person but also from function to function within the same person. Many subjects had differences in laterality among hand, foot, eye and ear; however, the most consistent finding of this nature had to do with ear dominance. It was not uncommon to inspect the data and find individuals with quite definite, unilateral dominance for hand, foot and eye, but who scored almost directly opposite on ear laterality. Such cases were more frequent among the lower intelligence groups than among normals or superior groups. A conclusion from this might be that, of all aspects of dominance, ear dominance is the least stable in most of the population and that any disorder of dominance reflects itself first in ear laterality discrepancies.
Another important statistic in Table 1 is the correlation of total Right-Left (r-L) score with intelligence. This score was a simple arithmetic total of right responses minus left responses, regardless of which part of the body was involved, and without any weighting of scores. This simple method of scoring appears to have provided a correlation not significantly different from that obtained by the complicated scoring method used in this research. However, the more circuitous procedure did provide helpful subscores for analyzing components of the total score. Therefore, as long as the two scoring procedures appeared to provide substantially the same correlations, the present system remained desirable.

A very important finding was the support gained in this research for hypothesis #4. This hypothesis was based on the neuroanatomical theory outlined in the first part of the introduction. The theory asserted in part that cerebral dominance is just one of a variety of neuroanatomical factors that enter into determining intelligence. Gross brain damage causes the consequences of dominance problems to become less predictable. Because of the difficulty in most cases of determining laterality of brain damage with acceptable reliability, the predictability of intellectual effects is reduced, although it would be expected that such damage on the dominant side would have more serious consequences. In this research an attempt was made to study whether, within the brain-damaged groups, laterality of brain damage was related to the degree of intellectual impairment. No consistent relationship could be found. It is believed that this problem should be investigated further, particularly when neurological or
psychological location of brain damage becomes more precise.

One of the more provocative findings is related to hypothesis #5. The fact that retarded individuals with no evidence of brain damage scored significantly lower on the ICD than retarded individuals who had suffered brain injury raised the question of the role played by cerebral dominance in the etiology of mental retardation. The fact that individuals in Group 3 (retarded without brain damage) scored lowest of all groups on the ICD may be explained in three ways. One possible explanation would be to hypothesize that individuals in Group 3 really were brain damaged, but that such brain damage had not been discovered. This explanation seems unlikely for several reasons. Individuals in Group 3 were perhaps the most thoroughly screened. Individuals without extensive neurological and psychological examination data were not included. All members of this group, in addition to psychological and neurological data, had also undergone chemical tests which would have uncovered any known metabolic cause of brain damage. It seems probable that no individual in Group 3 had brain damage detectable by current diagnostic techniques.

There remains the argument that perhaps Group 3 subjects were brain damaged in a way that is unknown and unsuspected at present. Simple logic would lead to doubt that all members of this group were afflicted by some unusual types of brain damage which, although unknown, were nevertheless severe enough to cause such serious dominance confusion that the individuals scored more poorly than subjects with known brain disfunction. The probability of such an occurrence would seem to be remote.
The third possible conclusion from the data of Group 3 would be that cerebral dominance, in itself, might be an important determinant of intelligence. We have already demonstrated the relationship between dominance and intelligence. While not inferring a causative relationship from correlations, it is believed that such a relationship may be inferred from differences evidenced between Group 3 and Group 5. Brain damage makes the relationship between dominance and intelligence less predictable because brain damage itself is another variable involved in determining intelligence. Therefore, if indeed cerebral dominance had any causative relationship to intelligence, it would be expected that of the two retarded groups (Groups 3 and 5) the group without the brain damage would show lower dominance scores.

Cerebral dominance is an indicator of neurological organization. The theory developed earlier in this paper explained a conception illustrating the operation of this organization. Results obtained here would lend support to such a theory, since the theory is based upon the necessity for proper neural connections on the dominant side. The question now arises as to whether improper neurological organization is, in itself, brain damage. This issue appears really one of semantics. It cannot be determined whether or not it is actual tissue damage which causes improper organization, whether the disturbance is electrical, or whether lack of organization is due to faulty development of the dominant hemisphere. This is a question for future research. From this research it has been concluded that cerebral dominance, as an entity in itself, can fail to develop properly, leading to a disruption of neurological "flow" on the dominant side. It has been shown that such faulty
dominance development does not necessarily have to be associated with any other types of brain disfunctions more commonly thought of as brain damage. It may occur in isolation, in all degrees of severity, with no other discernible evidence of cerebral disorder.

A. Implications for Future Research

Such considerations inevitably lead to a wealth of implications not tested by this investigation, but which would provide considerable fruit for future research. The first implication is evolved out of the neuroanatomical theory proposed earlier. While this research did not involve a direct test of the theory, the theory has heuristic value for future research. It was pointed out that there was not enough evidence at present to determine whether emotional associations, in addition to verbal and symbolic, depended upon the dominant side. This suggestion is especially provocative since it has been suggested (Delacato, 1963; Walters, 1967) that not only intellectual disorders, but also emotional disorders, might be traced to a dominance disfunction. In terms of the present theory, just as there is the possibility that cerebral dominance problems may effect the sensory portion of verbal associations, there is also the possibility that the emotional component can be disturbed.

The suggestions put forth by Delacato and Walters were derived from reports of isolated improvements of a few autistic children when exposed to a regimen of exercises designed to improve cerebral dominance. Nevertheless, such anecdotal evidence is often not so labelled and is stated as experimental evidence where none really exists. The present
research was not designed to examine the problem of whether emotional sequelae might also be involved. Nevertheless, some inferences might be made from the fact that, of all subjects in Group 3, which had the lowest dominance scores of any group, not one was considered to have a serious emotional or personality disorder. If the emotional component of verbal associations is as lateralized as the sensory component, then it could be expected that dominance disorders would cause emotional disturbances as well as intellectual deficits. None of this was found in the present sample; however, it must be clear that this is only inferential, since sample groups were not selected with this question in mind. Actually, it may be that the very individuals who would have been selected for this research are biased with regard to the problem of emotional disturbances. Thus, no definitive statement may be made, from the sample population used. There is also the possibility that since the verbal and emotional pathways are somewhat different, the same dominance disorder might not effect both components.

The foregoing considerations would seem to be very worthwhile material for future research, especially since so many types of serious personality disorders are characterized by inappropriate affect and an apparent lack of congruence between what the individual says and the emotional reaction he exhibits. Somehow, it appears as though the sensory and emotional associations fail to become integrated, resulting in the pathological signs of inappropriate or flattened affect.

The idea of dual, interacting memory traces is not a new one. E. R. John (1964) has proposed a theory to explain discrimination
learning, which he developed from using electrodes recording in various brain structures of cats, while the animals were undergoing discrimination learning. As Penfield and Roberts (1959) have pointed out, verbal learning is, essentially, discrimination learning, and therefore John's theory assumes relevance here.

John hypothesized that, with repeated trials or experience, a "general representational system" is built up, residing in nonspecific brain structures in subcortical areas. At the same time, with repeated trials, a "specific representational system" is established within the specific sensory system. If sufficient correspondence exists between the activity of the general and specific representational systems there occurs a "resonance effect" which gives a clue to the discriminatory response. If there is correspondence between the output of the thalamus and the limbic system (nonspecific system) and the association areas (specific system), memory results.

John also suspected that the sensory (specific) component of learning is not enough to account for response variations and electrode patterns he observed. He too hypothesized that the limbic system and thalamus must also be involved in learning and memory, and he termed this the general representational system. He too believed that discrimination learning involves two memory traces, both a specific (which has been here termed sensory) and a general (which has been called emotional). While John was dealing with cats and not with humans, the experimental proof he has obtained that two such systems might exist in lower animals lends support to the notion that
such a system also operates in humans and attains its greatest significance in verbal and symbolic learning and memory.

Another important implication from the present investigation is that verification of hypothesis #2 would seem explicitly to confirm that the important factor in dominance is not which side is dominant, but what degree of dominance is maintained. Pertinent to this issue are some interesting results obtained from scanning the data. Such scanning indicated that many individuals who were left-handed still scored a total ICDC favoring the right side. Relatively few individuals scored left dominance for all four aspects of laterality studied. It would seem, as Penfield and Roberts (1959) have speculated, that most (at least 90%, according to Penfield and Roberts) individuals possess brains with the left hemisphere dominant, leading to right-handed laterality. Of the left-handers in our culture, very few actually have a dominant right hemisphere. Most left-handed individuals have dominant left hemispheres, but in spite of this have learned to use their left hand.

The ICDC appears to be able to discriminate among those individuals who were left-handed by a quirk, so to speak, and those who truly had dominant right hemispheres. There were two ways in which such a discrimination could be made. First was by means of the overall dominance pattern. An individual who scored left dominance for handedness, but right dominance for foot, eye, and ear, was apparently an individual with left hemisphere dominance. However, there was another way of determining these cases. Individuals who scored
left-hand dominance but scored right-side laterality otherwise showed a very different pattern within the hand dominance tasks than individuals who scored complete left laterality. The former group seemed to be somewhat ambidextrous, using the left hand for such things as writing, cutting with a scissors, and other maneuvers requiring fine movements. They used the right hand for such movements as hammering a nail, batting a ball, and other tasks requiring strength. Individuals who scored complete left laterality did not show such a scatter of scores.

There is also the question of the relationship of the above considerations to some early research (Burt, 1937, e.g.) correlating left-handedness with a higher incidence of mental retardation. In an earlier section the shortcomings of much of this early research were discussed, shortcomings shared by the article cited here. The present investigation would seem to bear out the point: left-handedness, in itself, does not indicate greater probability of retardation. Further, well-designed research, specifically aimed at this question, would be desirable.

A natural question to arise here relates to the heredity-environment controversy. At present there is no research indicating why the majority of people have left hemisphere dominance, and a few have right hemisphere dominance. Countless heredity studies have been performed with either insignificant or inconclusive results. It does not appear that parental dominance plays a crucial role. Penfield and Roberts (1959) believed that it is almost a matter of chance; i.e., one hemisphere just starts developing faster and becomes dominant. There have been many speculations, ranging from which ear the first
verbal stimulation approached, to which side the fetus favored in utero. As yet, however, there are no conclusive facts.

What is known is that dominance is rather unstable for the first few years of life, varying from one side to the other, and then as speech begins to develop, one side becomes preferred more and more over the other (Byers and McLean, 1962; Carmichael, 1954). The same studies have shown that, when an individual is brain damaged prior to the time dominance has been established, some transfer of function takes place to the other side of the brain. However, it is still not known exactly what the best method is for facilitating such transfer, or whether transfer is possible after the establishment of dominance has taken place.

With such implications, a crucial issue becomes whether the method used for ascertaining cerebral dominance in this research was in actuality the most efficient yet very reliable technique. There have traditionally been two ways of determining dominance, physiologically or behaviorally. The physiological approach has naturally been the more direct method and has left less room for inference. The technique of this type most widely used was developed by Wada (1949) and confirmed by Rasmussen and Wada (1959). To ascertain whether the left hemisphere was dominant, sodium amytal was injected into the left carotid artery. If the left hemisphere was dominant its temporary inactivation resulted in transient paresis accompanied by aphasia; when the same solution was injected into the right carotid artery no such effect was obtained. Opposite results were found if the right
hemisphere was dominant. Short of actually exposing and stimulating brain hemispheres as did Penfield and Roberts (1959), this technique, now referred to as the Wada Test, has remained the most direct measurement of cerebral dominance. There are, however, two major shortcomings of the Wada Test. First, as Luria (1966) pointed out in his discussion, use of the Wada Test must necessarily be restricted to experienced neurosurgeons, and then only under well-controlled conditions. This apparently is feasible for diagnostic cases in case of injury, but would be difficult if not impossible to carry out in large numbers solely for the purposes of research.

Even if the above practical limitations did not exist, there is a second reason why the Wada Test has not been more widely accepted. It appears that even this very direct procedure has not been highly reliable. Anan'ev (1960) has indicated that reliability coefficients of from .65 to .82 exist, depending upon such factors as the particular neurosurgeon operating, and the precise position of the patient during the injection.

Behaviorally there have been many techniques, which were discussed in previous sections. Behavioral techniques have had practical advantages since they were fairly easy to use, could be scored objectively, and could be administered in many cases by relatively untrained personnel in large numbers to make research more expedient. A problem has been, however, that most behavioral measures used have lacked any theoretical premise and have not proven to be very reliable. In most cases reliability data has not been presented at all. The ICD was
found to have a reliability coefficient of .86. While definitive statements cannot be made on the basis of one study, it appears as though the ICD is at least as reliable as the Wada Test for determining cerebral dominance, and is the only behavioral measure which has been found that has such confirmatory data. A future area of research, however, if it were experimentally feasible, might be to run comparative studies of the ICD and the Wada Test.

B. Critique of the Present Study

There are many limitations to the present research, and several points which should be reconsidered for future investigations.

First there is the matter of age of subjects. Present results are applicable only to the age group studied. Use of the ICD for individuals under age 8 or over age 13 has not been studied and may not be reliable. There is reason to believe that, for individuals under 8 years of age, a battery such as the ICD would not be practical. Aside from the issue of stabilization of the dominance pattern, there is the problem of the subjects' understanding the instructions. One of the reasons that an IQ of 45 was set as the lower limit of the retarded groups was that it was discovered that individuals below this level could not understand the directions for a few of the more complicated tasks. Thus it is believed that children under 8, as well as individuals with very low IQ, would require a more simplified version of the test, if one with high reliability could be devised.

A different limitation manifested itself when dealing with subjects older than 13. This was the problem of the subjects' being able
to determine correctly the purpose of the ICD tasks, and who thus
biased their scores by deliberate or unconscious falsification. A few
very bright children under 13 were tested who had to be excluded from
the sample because it was apparent that they had decided what they were
"supposed" to do. During the present research, attempts were made to
determine and exclude these individuals by post-test questioning. A
possible way of eliminating this problem would be the establishment of
a battery that would, while measuring the same things, use tasks that
always required the use of both hands or feet, and from which scores
were derived by means of comparison. Some items such as these were in­
cluded in the present battery.

Another necessary step before future research is a complete,
detailed item analysis of the present ICD tasks to determine if any
items should be eliminated or changed. In addition, the setting of
the test administration should be standardized as much as possible.
Since it was necessary to travel to several widely separated cities to
obtain subjects, such standardization was not possible for the present
investigation, although every effort was made to adjust for differences.

The Columbia Mental Maturity Scale was found to be highly ex­
pedient and appropriate for this study. It was quick and easy to
administer and required no verbal responses. It would be interesting,
however, to note what comparisons would exist if one of the more tradi­
tional intelligence tests were used. This, too, should be done before
results may be generalized.

It should also be remembered that sample groups consisted of 20
subjects each. While this was an acceptable amount for the exploratory nature of this research, additional subjects should be included before results may be considered definitive. The extremely high levels of significance obtained in this investigation should be emphasized, though, especially considering the small sample groups.

Some discussion must be devoted to consideration of the one hypothesis which was rejected by the data. It was expected that directional differences in laterality would not be significant, and that only degree of laterality would be important. The .20 biserial correlation between sidedness and dominance scores was just barely significant and did indicate a relationship between sidedness and dominance. However, from examination of the data, it is believed that this correlation would not be significant if larger groups had been used. This assumption must be tested before future research is carried out; for if the correlation should be found to hold there would be serious implications which, while not impugning the present results, would change the interpretation somewhat. Such a finding would have its greatest impact on the above discussion of left-handedness. It would suggest that left-handers do actually have poorer dominance than individuals who are right-handed. This would somewhat cloud the relationship between the cerebral dominance of left-handers and their intelligence.

Finally, there is the issue of localization of brain damage. It would have been most desirable experimentally to break down the brain-damaged groups according to whether brain damage was on the right or left side, and then measure differences among various brain-damaged
groups. We would hypothesize that individuals with brain damage on the dominant side would score lowest on the ICD and would suffer the greatest intellectual deficits. There are several problems to this approach. First there is the obvious necessity of knowing what an individual's intelligence had been (or would have been) before brain injury. It would be necessary to find large numbers of individuals who suffered traumatic brain damage after birth, and who had psychometric evaluations prior to the damage. Aside from methodological difficulties involved in using groups which had been tested at different ages by different people with different tests, the location of such a group of individuals would be difficult.

Even aside from the above practical difficulties, there is the problem of the reliability of localization of brain damage. This problem has been discussed at length with neurologists (Larsen, 1967; Hackett, 1967) who maintained that, even at best, localization is rudimentary and highly unreliable. For these reasons, a breakdown of right- and left-sided brain-damaged individuals was not undertaken in this research, although it should be attempted for future research. Even though the reliability of localization is less than desirable, such research would provide important additional information to some of the hypotheses and inferences derived from this investigation.
CHAPTER VI

SUMMARY

Five groups of 20 subjects each were studied to investigate the relationships between cerebral dominance and intelligence test scores. The groups were broken down as follows: (1) superior intelligence, no brain damage; (2) normal intelligence, no brain damage; (3) retarded intelligence, no brain damage; (4) normal intelligence, with brain damage; (5) retarded intelligence, with brain damage. An Index of Cerebral Dominance was developed which was found to have high reliability, and this was administered to all subjects along with the Columbia Mental Maturity Scale.

Results confirmed a correlation of .81 between cerebral dominance and intelligence for individuals with no brain damage. For individuals with brain damage the correlation was lower, but still highly significant. It was also found that hand and foot dominance contributed most to the correlations, and that hand-eye coordination was also related to intelligence level.

Results were discussed in terms of a comprehensive theory of neuroanatomical correlates of verbal and symbolic activity in man. It was suggested that previous conflicting and indecisive research had failed both to provide reliable dominance measures, as well as to take account of several important methodological variables. In addition, implications for future research were discussed, both in terms of future testing of the neuroanatomical theory suggested, as well as
for other research not connected with the theory. It was suggested that research relating emotional disorders to dominance might be an interesting next area for study.

Several limitations to the present investigation were considered, as well as suggestions for alteration of the procedure, and design for future research. Necessary replications were also outlined.
APPENDICES
APPENDIX A

COMPUTATION OF POINT BISERIAL CORRELATION BETWEEN LATERALITY (LEFT OR RIGHT) AND TOTAL DOMINANCESCORES

\[ r = \frac{X_L - X_P}{\sqrt{p} \sqrt{q}} \]

\[ r = \frac{75.08 - 56.40}{50.63} \sqrt{.23} \]

\[ r = \frac{18.68}{50.63} \sqrt{.23} \]

\[ r = .3689 \sqrt{.300} \]

\[ r = .3689 (.5477) \]

\[ r = .2020, \text{ Significant at .05 level} \]
APPENDIX B

COMPUTATION OF TEST-RETEST CORRELATION OF RELIABILITY

\[ r = \frac{\sigma_{xy}}{\sqrt{\sigma_x \sigma_y}} \]

\[ r = \frac{75988.26}{100 \times (29.10) \times (30.30)} \]

\[ r = \frac{75988.26}{88173.00} \]

\[ r = 0.86, \text{ Significant beyond .001 level.} \]
APPENDIX C

SCATTER DIAGRAM OF CORRELATION BETWEEN ICD AND CMMS FOR SUBJECTS WITH NO BRAIN DAMAGE (N = 60)
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VITA

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EXAMINATION AND THESIS REPORT

Candidate: Allan Berman

Major Field: Psychology

Title of Thesis: An Investigation of the Relationship between Cerebral Dominance and Intelligence

Approved:

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Major Professor and Chairman

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Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:

May 13, 1968