CEREBRAL DOMINANCE—EVALUATION OF THE METHODS OF ITS DETERMINATION AND ITS CLINICAL USES

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In this paper the concept of cerebral dominance for various functions with emphasis on speech, is examined in the light of the recent literature available to us. A few ways in which this knowledge of cerebral dominance can be used in the differential diagnosis of speech disorders due to cortical lesions have been discussed. And, finally, some of the methods which help in determining the "dominant hemisphere" are pointed out.

The term "dominance" expresses the idea of unequal capacities of the two hemispheres in a quantitative sense : the dominant hemisphere is that which governs, which controls; the other hemisphere is the non-dominant one (Rossi and Rosadini, 1967, p. 175)/ In other words for any particular function the dominant hemisphere or the major hemisphere 'does the work' while the non-dominant hemisphere or the minor hemisphere is sileni or capable of only rudimental activity. This is especially true for speech in the great majority of healthy adults and is supported by the results of intracarotid amobarbital test and the Tsunoda test. Whether a similar type of inter hemisphere relationship exists for some gnosic (recognition of forms) and praxic (formulation and/or execution of a motor plan) function is not yet clear. However, a dominant role of the right hemisphere is generally admitted. [Brain (1969), Hecaen (1962), and Zangwill (1960) as quoted by Rozsi and Rosadini (967) p. 175]. "The tendency is to ascribe to each hemisphere in the great majority of adult subjects a specialization in a particular field in which the other hemisphere has nothing to do or performs only an auxiliary or supplementary activity" [Rossi and Rosadini (1967), p. 175].

Lord Brain [(1965), p. 24-25] used the term 'hemisphere dominance' ". . . . when the anatomical basis of a certain function is located mainly or exclusively in one cerebral hemisphere", Bay and Zangwill, et al (Discussion in Disorders of Language, 1964, p. 216-217) pointed out "It is simply not correct to speak of dominant Versus non-dominant hemispheres". They indicate (p. 217) "Dominant might mean that it controls the other hemisphere or it might merely mean predominant," and point out (p. 217) "there is no good evidence that the dominant hemisphere exercise any direct control over the subordinate hemisphere". They suggest also that (p. 216)

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the problem is very complex and it might be better to speak of a percentage of dominance on either side.)

Asimov (1965) while dealing with Cerebral dominance in his book "The Human Brain" says "Naturally, in any such two-in-change situation, there is always the danger of conflict and confusion. To avoid that, one cerebral hemisphere (almost always the left one in human beings) is dominant".

We propose to use the term dominance as denned by Rossi, et al and Brain. It is to be remembered that the hemisphere dominant for one set of functions may not be dominant for all functions. For example, in the majority of people for functions such as speech and hearing the left hemisphere is found to be dominant and for functions such as body image and spatial awareness the right hemisphere is found to be dominant.

Hand Preference and Cerebral Dominance

A great majority of the people are right handed that is to say, they prefer their right hand for carrying out the more skilled movements and are more skillful — literally dextrous —with the right hand than with the left.

What determines handedness? Brain (1965, p. 23) states, "Such preference is largely determined by heredity. (jThe inheritance of right handedness, as a dominant and left handedness as a recessive will explain most, although not all of the facts" Weakness of one upper extremity from other causes than cerebral disease may determine left handedness in some individuals. Another factor is [(Lord Brain (1965) p. 24)] "cerebral injury may produce hemiplegia and necessitate the use of the opposite hand", However, "All people with weakness of one hand from cerebral disease do not use the other hand predominantly, but certainly most do and some that do not have bilateral brain disease" [(Penfleld and Roberts (1959) p. 98)].

Estimates of the incidence of left handedness in the general population vary considerably. After a survey of various investigations Brain (1965), p. 23) estimates that between 5 to 10 per cent of the population of USA and UK are left handed, left handedness being about twice as commom in males as in females. According to Gordan (1920-21) [As quoted by Brain (1965, p. 24)] there is twice the normal incidence of left handedness among mental defectives and in this group left handedness is more common in females than in males.

Conrad (1949) [as quoted bv Critchley (1969) p. 399] studied a series of 808 patients with unilateral disease of the brain, of which 47 (5.8%) were regarded as being left handed. He observed that, though right handedness implies left cerebral dominance, the contrary does not follow, and left handedness does not necessarily indicate right Cerebral dominance. Rather it does imply the expression of a less specialized transition stage between a bilateral controlling mechanism and a

unilateral dominance. In other words, the left handed subject possesses a sort of bi-cerebrality'.

Subiraria (1952), [as quoted by Critchley (1969) p. 399)] in his thoughtful studies of right handedness in relation to unilateral cerebral disease, was inclined to support Conrad, and his electro-encephalographic researches suggested a certain cerebral immaturity in sinistrals. He pointed out that the right handedness and left handedness are not mirror-opposite phenomena. Further, he noticed "more abnormal brain waves in the left handed than in the right handed among 316 normal children". [(as quoted by Penfield and Roberts (1959) p. 99)].

Humphrey and Zangwill (1952) also, in the main, support Conrad's views.

It is accepted that most people develop in early childhood a preference for the use of one hand for all single handed skills as for writing, cutting etc The majority develop a preference for the right hand, but a small proportion have decided preference for the left hand which persists often in spite of attempts to establish the use of the rigtvt hand.

(To some extent, however, such preference is one of degree, as we all use both hands for certain acts such as typing and playing the piano. A proportion of the naturally left handed people are brought upto use their right hand and these are so called 'shifted sinistrals'.

In some individuals decided preference never develops. Most of these ambidextrous persons are shifted sinistrals. A few use either hand indifferently because they possess no additional skill with the right hand and are equally clumsy with both. Such people are well named 'ambilevons' by Galon.

According to Penfield and Roberts (1959), p. 102) "Handedness is determined by multiple factors including Pathological, Psychological (normal and abnormal), heredity and perhaps unknown factors. Man seems to have acquired language and to have become right handed at about the same time in evolution .. . brain functions and handedness may be unrelated except by disease".

Critchley (1969), p. 397) is of the opinion that the relationship of handedness to cerebral dominance is still not fully understood; which phenomenon is causal, and how the one entails the other. Nor is the relation of handedness to sidedness (eyedness, footedness, etc.) as yet established.

Observations of Bauer and Wepman (1955) confirm the findings that right sidedness is associated with left cerebral dominance but suggest that left handedness may not necessarily be associated with dominance of the hemisphere of the opposite side. It is probable that in left handed patients and in those where there is ambidexterity or cross laterality there may be lack of, or inadequate cerebral dominance. They conclude "cerebral dominance seems unique to the left hemisphere. Those in the population who lack consistent right hemisphere dominance except in rare instances. (This would imply that individuals commonly regarded as left handed

are more likely to be ambidextrous and probably should be said to be people in whom lateralization has not yet fully developed"./

We are of the opinion that available evidence points to the existence of a relationship between hand preference and cerebral dominance.

Speech and Cerebral Dominance

Broca reported the case of a 47 year old woman who had epilepsy and right hemiparesis since infancy. She was left handed. At no time had there been any speech disturbance. The autopsy showed there was a large lesion in the distribution of the left middle cerebral artery. Broca assumed that speech had been subserved by the right hemisphere in this patient. He then went on to generalize that the right hemisphere is dominant for speech in all of the left handed. Thus was created the dogma that the right cerebral hemisphere is dominant for speech in the left handed in the same way that the left cerebral hemisphere is for the right handed.

According to Brain (1965, p. 25 the most obvious example of cerebral dominance is speech, the higher nervous pathways for which are usually situated in the left cerebral hemisphere in the right handed persons/ The left cerebral hemisphere is dominant for speech which does not exclude the attribution of a subordinate function to the right hemisphere. It was Jackson (1932) (as quoted by Brain, 1965, p. 25) who introduced the idea of a leading hemisphere. The "two brains" he wrote "cannot be mere duplicates if damage to one alone can make a man speechless. For these processes (of speech), of which there are none higher, there must surely be one side which is leading". He believed, however, that ". . . . both sides of the brain are educated in speech and yet that the left is the leading side, and the right the involuntary or automatic".

The following explanation was given by Lord Brain (1965, p. 25) for the evolution of Cerebral dominance. "It seems more probable that the establishment of the left hemisphere for speech resulted in the development of the right hand as the dominant hand. Speech calls for articulation—the precise integration of the small muscles of the lips, tongue, palate, and larynx besides the respiratory muscles, so that these contract synchronously on the two sides in such delicacy that a variety of sounds can be differentiated through a range of fine graduations. This motor integration seems to require that the motor cortex of both hemispheres should be under the control of a single co-ordinating area 'the motor speech center', speech in other words necessitates localization."

'Speech is not the only function which is predominantly represented in one hemisphere. This is also the case with calculation, with the recognition of objects and sounds—eugnosia, with the capacity to carry out purposive movements—eupraxia, and with topographical memory. Moreover, the two hemispheres possess different

functions in relation to awareness of space and awareness of the body. All these functions appear to behave independently of one another in relation to hemisphere dominance, that is to say, though as a rule the same hemisphere is the major hemisphere for all of them, this is not always the case, and the left may be the major hemisphere for some functions and the right for others. Indeed, in respect of body image and spatial awareness the same hemisphere (usually the right) may function as both major and minor at the same time.

In general, the left cerebral hemisphere is the major one for speech, in right handed persons. During recent years, many observations on the relationship between left handedness and cerebral dominance have been reported, as well as exceptional cases in which the right hemisphere appears to have been the dominant one in aright handed person. Ettlinger, Jackson, C. V. and Zangwill (1955) (as quoted by Brain, 1965, p. 27) showed that sinistrals show some degree of ambilaterality in respect of cerebral dominance but unilateral representation of speech is the rule, generally on the left side, but occasionally on the right. Hecaen and Piercy (1956) (as quoted by Brain, p. 27) suggested that left handers have a greater equipotentialuy for language than right handers in respect of two hemispheres and so are more vulnerable to acute disturbances. On the other hand, there is evidence that the prognosis of aphasia is in general better in left handers than in right handers (Subirana, 1958).

It has long been known that aphasia may sometimes follow a lesion of the right cerebral hemisphere in a right handed individual. Examples of this have been recorded by Ettlinger, Jackson, C. V, and Zangwill (1955) (as quoted by Brain, 1965, p. 12).

Penfield and Roberts (1959) reviewed the records of 569 patients who were operated upon for treatment of focal cerebral seizures for handedness and evidence of aphasia before and after operation. It has been noted by them (1959, p. 94) that a person may be left or right handed despite injury to the hemisphere opposite the preferred hand and the preferred hand may be weak or clumsy.

"Despite the fact that a patient is left handed with weakness of the right hand from early in life, dysphasia may follow operation on the left hemisphere The right hemisphere is not necessarily dominant for speech, even though the right hemiparesis occurred early in life as a result of damage to the left hemisphere". (Penfield and Roberts, 1959, p. 94).

Rossi and Rosadini (I960, p. 169) studied 126 hospitalized subjects for the reactions to the intracarotid amobarbital injections. Aphasia occurred in 91.6 per cent of cases following left side amobarbital injection (left dominance) and in 5.9 per cent following a right side injection (right dominance). In two cases (2.5 per cent) amobarbital produced the typic.il Contralateral rieniparesis upon injection into the right as well as the left Carotid artery, however, in one subject both injections failed to produce aphasic disturbances.

The relation between lateralizations of hand dominance and speech dominance were found to be as follows :

Table 1. *Shows relation between lateralization of hand dominance and speech dominance in 84 subjects given intracarotid sodium amobarbital injections {Rossi and Rosadini, 1967)*

Speech dominance	Hand dominance			
	Right	Left	Bilateral	Total
Left	73 (98.6%)	2 (28.6%)	2 (66.7%)	77
Right	—	5 (71.4%)	—	5
Bilateral	1 (1.4%)	—	1 (33.3%)	2
Totals	74 (100%)	7 (100%)	3 (100%)	84

(a) Right handers: left speech dominance in 98.6 per cent of the subjects; right speech dominance in no cases; and bilateral representation of speech in 1.4 per cent of the cases.

(b) Left handers: right speech dominance in 71.4 per cent and left speech dominance in 28.6 per cent. In the three patients considered to be ambidextrous the major hemisphere for speech was the left one in two case, bilateral representation of speech was found in the other one.

"The low number of left handed and ambidextrous subjects makes the value of their contribution to the study of the relationship between handedness and speech dominance very poor. Nonetheless, the following remarks can be made. Rossi and Rosadini, (1967, p. 170).

1. Our findings add further support to the widely accepted view of the possible independence of handedness and speech dominance.

2. Quite independently of their questionable statistical value, our findings appear atleast sufficient to confirm that speech can be represented on the right hemisphere in left handed persons. The percentage of right speech dominance in our left handed patients appears to be considerably higher than that reported by authors on the basis of the analysis of pathological material.

3. Right dominance was never found in the 74 right handers utilized for this analysis. This seems to confirm the diffused opinion of speech in right handed people.

4. The occurrence, as well as the absence, of aphasic disturbances in the same subject upon left and right amobarbital injection indicates that there may be bilateral representation of speech in some adults.

In recent years there has been much speculation concerning the relationship between handedness and the cerebral organization of language. Critchley (1954) (as quoted in Disorders of Lang, 1964, p. 200) observed that the overwhelming predominance of left sided speech representation in the left handed and ambidextrous persons is rarely the mirror image of that seen in dextrals. The evidence of this comes from tabulating the incidence and cause of dysphasia after unilateral brain lesions of either hemispheres in left handed subjects. Such studies have led to widely divergent interpretations. Penfield and Roberts (1959) found that the left hemisphere is dominant for speech in most people with handedness of questionable relevance. And similarly Russel Brain and Espire (1961) (as quoted in Disorders of Lang) are impressed by how rarely dysphasia follows penetrating missile wounds of the right hemisphere, infering from this that speech is almost always represented in the left hemisphere even in left handed subjects. Other workers though taking a less extreme view, still hold that speech representation is more likely to be on the left, even in left handers, but that this is a less frequent occurrence than in strongly right handed persons (Ettlinger, Jackson and Zangwill, et al, 1956, as quoted in Disorders of Lang. 1964, p. 200).

The results of 123 patients studied consecutively by Milner, et al, (1965, p. 202) using the 'WADA' technique of intracarotid injection of sodium amytal confirm the hypothesis drawn from the clinical literature that the cerebral organization of language is less predictable in left handed and ambidextrous persons than in right handers.

Table 2. *Shows relation between handedness and carotid amytal speech lateralization (Milner, 1954)*

Handedness	Speech Representation			
	Left	Bilateral	**Right**	**Total**
Right	**43**	0	**5**	**48**
	(90%)	(0%)	**(10%)**	**(100%)**
Left or ambidextrous without early left brain damage	**28**	7	**9**	**44**
	(64%)	(16%)	**(20%)**	**(100%)**
Left or ambidextrous with early left brain damage	**6**	**3**	**18**	**27**
	(22%)	(11%)	**(67%)**	**(100%)**

In those left handers without evidence of early damage to the left hemisphere, speech was found to be represented more often on the left than on the right, but the

proportion of left hemisphere dominance was still significantly lower than in right handers. When the left handedness was secondary to early damage to the left hemisphere, right sided speech representation was more common, but in about one-fifths of the cases the left hemisphere proved to be dominant. In ten instances in the total series of patients some evidence of bilateral speech representation was found. This lends some support to the notion that individuals with left handed tendencies may show less clear cut unilateral hemispheric specialization for language than strongly right handed persons.

Bauer and Wepman (1955) suggested that damage to the left hemisphere at birth or before the development of the speech patterns, may be a possible explanation of asphasic symptoms occurring in association with a lesion of the right cerebral hemisphere,

To the question, "Is it possible for an adult voluntarily to change his handedness, and does it lead to any measure of speech disturbance?" Eisenson (as quoted in Disorders of Lang, 1964, p. 220) answered, "yes, this ability to the best of my knowledge does not affect speech of the person".

Ear Preference : To the question 'Is there a dominant ear ?' Milner (1965, p. 220) answers with a definite yes. Kimura, et al, (as quoted in Disorders of Lang, 1961, p. 220) have shown that right handed subjects who have their speech on the left are better on the right ear and so are left handed subjects who have their speech on the left. But if the speech is primarily represented in the right hemisphere, then this is reversed. Their studies also revealed that for verbal material for ear contralateral to the dominant temporal lobe is favored. The same normal subjects did better on the left ear for melodies and on the right ear for digits.

These results have since been verified by Tsunoda (1967) using an audiological approach. He found that in a great majority of the subjects for verbal material the left cerebral hemisphere (dominant) is favored while for pure-tones and white noise right, (non-dominant) cerebral hemisphere is favored.

Spreen and Boucher (1970) reviewed the literature on cerebral dominance for ear preference and they conducted a study which threw greater light on ear preference. They reter to this dominance of one ear over the other as the 'asymmetry effect'.

Broadbent's initial experiments and Kimura's findings of a 'right' ear superiority of recall for verbal material and of left superiority for music (Kimura as quoted in Disorders of Lang, p. 220) have stimulated a large number of replication studies including variations of type of material, instruction, method of presentation, presen tation rate and subject variables. The right ear superiority of recall for verbal material has been firmly established in many studies and is considered evidence for a perceptual asymmetry, based on physiological mechanisms and related to a left hemisphere cerebral dominance for speech (Kimura, 1968). Confirmation of a left ear superiority for musical stimuli based on a reversal of perceptual asymmetry and

relating to a right hemisphere involvement in the perception of music has come from relatively few studies so far; imong others (as quoted by Spreen and Boucher, 1970) by Chaney and Webster (1966) using sonar sounds, Bakker (1967, 1970) for Morse type signals; Curry 1967) for environmental sounds; Spellacy (1970) for music; Spreen and Boucher (1970) for music and tonal patterns and Shankweiler (1966) for the naming and singing of popular tones. Spreen and Boucher indicate that several studies have also failed to demonstrate such an asymmetry. The inconsistency in outcome of studies with non-verbal stimuli is perhaps traceable to increased subject variability, the inherently verbal nature of some musical stimuli (example: sounds and tunes are immediately verbally labelled by the listener) the effect of the length of the interstimulus interval [Spreen, et al, (1970)] and varying definitions of the response mode (recall, recognition, singing, humming and naming).

Shankweiler and Studdert-Kennedy (as quoted by Spreen and Boucher, 1970) presented synthetic CV syllables and steady-state vowels dichotically. They found that both types of stimuli showed a right ear superiority of identification similar to the one found for meaningful words. However, the right ear superiority was larger for CV syllables and relatively small for vowels. It could be argued that right ear superiority decreases when some of the normal characteristics of speech are removed, example : by the use of nonsense syllables, bigrams and vowel sounds. Liberman, et al, (as quoted by Spreen and Boucher, 1970) use a similar interpretation is that hemispheric dominance obtains only for highly encoded speech sounds, but not for minimally encoded ones.

It is well known that recognition of speech is directly dependent on the frequency characteristics of the speech signal (Millar, 1951). If the high frequency part of the signal is removed, primarily the consonant part of speech signal is affected. With large amounts of filtering, speech is eventually reduced to vowel components only.

Meaningful one syllable words matched for initial phoneme were presented dichotically by Spreen and Boucher (1970) to 32 subjects under four low pass filter conditions ranging from 2.5 to 1KHZ. A right ear superiority of recall obtained at the 2.5KHZ condition disappeared gradually with increasing amount of filtering. Results were interpreted as support for the notion that right ear superiority is dependent on the degree of similarity of the stimulus material to highly encoded speech sounds.

Eye preference

Most people who possess equal visual acuity in the two eyes nevertheless prefer to use one eye rather than the other sighting—such as sighting a gun for looking through a telescope or a microscope. Jasper and Raney (1931) (as quoted by Brain, 1965) using a Psycho-physiological procedure known as the 'Phi test' (a test which determines as to which Cerebral hemisphere is dominant in vision and also which is

the dominant eye) found a close correspondence between hemisphere dominance determined in this way and handedness on the opposite side. It is reported that approximately 70 per cent of all individuals prefer the right eye and 29 per cent the left eye, whilst less than 1 per cent show absence of definite preference.

The relationship between a dominant eye for monocular sighting and cerebral dominance has never been established. Brain (1965, p. 24) states that the eye is not represented in the Cerebral Cortex as a unit for purposes of visual perception, space perception or ocular movement. The two halves of each retina are represented in different cerebral hemispheres, impulses from each being intermingled with those from the corresponding half of the other retina, so that normally we cannot distinguish what we see with one eye from what we see with the other. The eyes are equally closely linked for purposes of movement and each cerebral hemisphere can only move the two eyes together.

However, later studies by Geschwind (1967) and Sperry and Gazzaniga (1967) have pointed out the reasons for failing to establish the relationship between eyedness and cerebral dominance. Dominance could not be established because the visual stimuli incidenting on the left half and right half of the eye could not be separated. They went on to show that by use of a tachistoscope and controlling the angle of incidence of visual stimuli the dominant eye can be determined.

Foot preference

Most people show a definite preference for the use of one foot rather than the other in such actions as kicking a ball, stepping upon a chair, etc. Because we use both feet for walking and do not normally develop the use of the feet for fine skills, preference for one or the other is often less definite. In many, however, there is more uncertainty and less definite preference between the two feet than between the hands". (Morley, 1965).

Many children with ambidexterity of hand, foot or eye or cross laterality, encounter special difficulties in learning to speak and to read, and the incidence of lack of definite preference for the right side (hand, foot and eye) is higher in children than in the normal population.

Hemispheric specialization for mood and emotion

In 1959 Terzian and Cecotto (as quoted by Rossi and Rosadini, p. 170) noticed the occurrence of emotional reactions in patients undergoing intracarotid amobarbital injection. The most interesting aspect of their observations was that the emotional reaction had different characters according to the side of the injection, a 'depressive catastrophic' reaction followed the barbiturization of the dominant hemisphere and a 'euphoric manical' reaction followed the barbiturization of the non-dominant side. These observations were confirmed to a large extent by the results of Rossi and Rosadini (1967, p. 171).

Table 3. *Shows relation between lateralization of speech dominance and type of emotional reaction following intracarotid amobarbital sodium injection in 63 subjects (Rossi and Rosadini, 1967)*

Emotional Reaction	Speech dominance			
	Dominant	Non-dominant	Bilateral representation	Total
Depression	15 (60%)	5 (15%)	—	20
Euphoria	10 (40%)	26 (76%)	4 (100%)	40
Depression and Euphoria	—	3 (9%)	—	3
Total	25 (100%)	34 (100%)	4 (100%)	63

"According to the results of the analysis, the type of emotional specialization of the right and left hemisphere may be different in different subjects, nonetheless there is a definite prevalence of depressive reactions following left side and of euphoric reactions following right side barbiturization. It should be remembered that such a relation is valid in the majority but no means in all cases".

Milner, et al, (1960) (In Brain Mechanisms underlying Speech and Language, p. 182) analyzed the results for 104 consecutively tested patients on whom mood ratings had been systematically made. They did not find any evidence linking depressive reactions to left sided injections and euphoria, or elation, to the right sided ones. However, Hecaen (1965) (In Brain Mechanisms underlying Speech and Language 1965, p. 182) confirmed the results of Dr. Rossi.

The question of a hemisphere dominance for consciousness

Quite recently Serafetinides, Hoare and Driver (as quoted by Rossi and Rosadini, 1967, p. 173) having used the intracarotid amobarbital test in 22 patients, stated that loss of consciousness is in general linked with the function of the hemisphere dominant for speech. However, the results of Rossi and Rosadini (1967, p. 173-174) do not confirm the hypothesis of a prevalent participation of the dominant hemisphere in the mechanism of consciousness.

Cerebral dominance and Memory and Attention

The idea that the dominant hemisphere (both the parietal and the frontal lobes) plays a special role in the genesis of defects of memory and attention, derives chiefly from Pfeifer (1928) (as quoted by Critchley, 1969, p. 385). Confirmation of this

idea is, however, still awaited. In many ways, it is the opposite contention to that made by Hughlings Jackson, Bestian, and Rosenthal. Each of these writers believed that the posterior parts of the brain are more concerned with intellectual functions than the anterior, and that lesions there produced physical disturbances. Jackson (as quoted by Critchley, 1969, p. 395-96) specified the right side in particular ".... I am convinced that disease of the right cerebral hemisphere is more likely to cause mental deficit (other than affection of speech) than is disease of the left, and again that mental defect is more likely to result the further back in the hemisphere the damage is."

Lloyd Anderson (1951) (as quoted by Critchley, 1969, p. 386) observed changes which were more qualitative when lesions of the two sides of the brain were compared. The patient with damage to the dominant half of the brain forgets what to do, while the patient with a lesion of the non-dominant hemisphere forgets how to do it.

Also using the Wechsler-Bellevue indices of deterioration, he found that the functions of the non-dominant and the dominant hemispheres were comparable with disorders of a front office (executive) and a warehouse (storage) respectively.

The evidence clearly points that memory and attention and cerebral dominance are related.

Cerebral dominance and body image

"The parietal lobe is of added interest when cerebral dominance is concerned, in that disease of the minor or subordinate hemisphere seems .... to be associated with a great measure of upset in the integrity of the body image" (Critchley, 1969, p. 89). It was suggested by many investigators that damage to the left posterior parietal region may produce a disturbance in the concept of one's body image. The presence of the Gerstmann syndrome (agraphia, acalculia, right-left disorientation and finger agnosia) is often attributed to a depressed awareness of the patient's image of his own physical make up, and most authorities agree that the Gerstmann syndrome is almost exclusively caused by left parietal damage. However, this opinion was criticized by some (Poeck and Orgass, 1966) in recent years and whether body image conception is purely a lateralized function is in question (Benson and Geschwind, 1968).

Studies of cerebral dominance and temporal lobes and corpus callosum syndrome

Comparison of both left and right temporal lobes have thrown much light on cerebral dominance. "The left temporal lobe appears to be remarkably specialized in its essential functions, and on a variety of non-verbal tasks the performance of patients after left temporal lobectomy has been found to be indistinguishable from that of normal control subjects. Right temporal lobe lesions, on the other hand, are associated with low scores on a number of perceptual and memory tasks" Brenda

Milner (1969, p. 123). After a study of the brain mechanisms underlying speech and language, Hecean (1967, p. 158) concluded "the temporal lobe, which, when injured on the left, produces alterations of the reception of language, seems to play a very minor part, and perhaps no part at all, in the function of language when there is corresponding injury on the right".

These studies clearly indicate the existence of dominant and non-dominant temporal lobes.

Hughlings Jackson [as quoted by Falconer (1967), p. 185] felt that both hemispheres were employed in speech, and in his classic paper "on the Nature of the Duality of the brain" he stated his view that "the right cerebral hemisphere is the one for the most automatic use of words, and the left the one in which the automatic use of words merges into the voluntary use of words into speech". Neurophysiologic studies of Brain mechanisms made by Falconer (1967, p. 185) lend support to Jackson's views on cerebral dominance.

Recent studies made by Geschwind (1967) on 'corpus callosum syndrome' and by Sperry and Gazzaniga (1967) on 'surgical disconnection of the hemispheres' have resulted in conflicting opinions about cerebral dominance for various functions.

Cerebral dominance and stuttering

No discussion on cerebral dominance will be complete without referring to the Orton-Travis (1936) theory of stuttering on the basis of cerebral dominance. The basic concept of this theory was developed by Orton in connection with reading, writing and speech problems in general. It was applied to stuttering during the late 1920s and popularized. The essential element of this concept of cerebral dominance in connection with stuttering is related to the precise co-ordinations of many paired muscle groups which are innervated in different sides of the brain during the act of talking. Thus, to move the tongue for speech purposes, impulses must be initiated from both cortical hemispheres and then arrive simultaneously at nerve endings in muscles on both sides of that important oral structure. This demands an integration of activities between the two hemispheres which was hypothesized as possible only if one of them was functionally dominant serving as a master control unit, so to speak. It was thought that the majority of stutterers were people who lacked sufficient margins of unilateral dominance for proper co-ordination under all circumstances. If the margin was small (equilateral), stuttering would be triggered by relatively small amount of stress, such as physical fatigue or emotional upset. As the margin approximated unilateral dominance, the individual was presumed to be less and less vulnerable to the triggering or precipitating conditions. In some cases, the confused laterality was believed due to an inherited system incapable of providing satisfactory unilateral motor leads for speech. Others acquired stuttering when the normal

development of unilateral dominance was disrupted by certain environmental influences, such as the forced changing of handedness.

Travis-Orton .theory lost the status it once enjoyed because it could not explain several phenomena including the one in which stuttering is found in persons who have definite unilateral cerebral dominance, for various functions including speech.

Table 4. *Showing relationship of Cerebral dominance for various functions*

Sl. No.	Function	Studied by	Findings made
1	Handedness	Conrad (1949) Subirana (1952) Humphrey and Zangwill (1952)	Right handers—Left cerebral dominance Left handers—'bi-cerebrality'
		Bauer and Wepman (1955)	Right handers—Left cerebral dominance Left handedness is not necessarily associated with dominance of opposite hemisphere
		Pen field and Roberts (1959)	Handedness is determined by multiple factors
		Brain (1965)	Hand preference is largely determined by heredity
		Critchley (1969)	Relationship of cerebral dominance and hand preference is still not fully understood
2	Speech	Jackson, H. (1969)	Both sides of the brain are educated in speech. Left is the leading side. Right is the involuntary or automatic.
		Penfield and Roberts (1953)	Left Cerebral hemiphere is dominant for speech in majority. Right hemisphere is not necessarily dominant in left handers.
		Brain (1965)	Most obvious example of cerebral dominance. Left hemisphere is dominant for speech. Does not exclude the attribution of a subordinate function to the right hemisphere
		Milner (1965)	Speech is more often represented on the left in the left handers than on the right

		Rossi and Rosadini (1967)	Left hemisphere is dominant in majority. Speech can be represented on the right hemisphere in left handers
3	Ear preference	Milner (1965)	There is a dominant ear. Right handers with speech on the left are better on Right ear and vice versa
		Tsunoda (1968)	Left hemisphere is dominant for verbal material. Right hemisphere is dominant for pure tones and white noise
4	Eye preference	Jasper and Raney (1931)	70% prefer right eye; 29% the left eye: 1% absence of definite preference
		Brain (1965)	Relationship is not yet established
		Geschwind (1967) Milner (1967) Sperry (1967)	Eye preference and cerebral dominance are related
5	Foot preference	Morley (1965)	Relationship is not definite
6	Mood and Emotion	Terzian (1959) Rossi (1967) Hecean (1965)	Right hemisphere is dominant for euphoric-manical reaction and left hemisphere is dominant for depressive-catastrophic reactions
		Milner (I960)	Did not find any evidence
7	Consciousness	Serafetinides (1967)	Consciousness and hemisphere dominant for speech are generally related
		Rossi and Rosadini (1967)	Did not find any relationship
8	Memory and attention	Pfeifer (1928)	Dominant hemisphere for speech is also dominant for this
		Jackson, H. (et al)	Non-dominant, or the right, hemisphere for speech is related to memory and attention
9	Body Image	Poeck and Orgass (1966) Benson (1968)	Questioned the relationship
		Critchley (1969)	Body image and minor or non-dominant hemisphere are related

Till now a review of the literature on cerebral dominance for various functions has been made. For functions such as speech, handedness, vision, and hearing there seems to be positive evidence that they are predominantly represented in one hemisphere. All these functions appear to behave independently of one another in relation to hemisphere dominance, that is to say, though as a rule the same hemisphere is the major hemisphere for all of them, this is not always the case, and the left may be the major hemisphere for some functions and the right for others. For functions such as footedness; emotions and mood, and consciousness the dominance does not seem to be well defined in a majority of the cases. Before going into the details of how the dominance for these functions can be determined we would like to point out the significance of finding the cerebral dominance.

Clinical Uses

1. Orientation of the dominant hemisphere helps in the differential diagnosis of speech disorders as a result of brain damage (As shown by the results of Tsunoda's study).
2. Neuro speech therapy for the speech disorders in cerebral palsy children makes use of the knowledge of the orientation of dominant hemisphere for speech (Mysak, 1968).
3. An abnormally functioning brain may prevent regression of the aphasia. Surgery results in the control of seizures with no evidence of remaining abnormally functioning brain. Orientation of dominant hemisphere is helpful in treating these cases.
4. In cases of focal cerebral lesions resulting in seizures the patient can be helped by operation. Before the operation is performed it is essential for the neurosurgeon to know which is the site of the lesion. This knowledge could be obtained by EEG, Pneumography, bilateral angiograms etc However, if the area that is affected is in the dominant cefebral hemisphere for speech—the removal of portions of it may result in dysphasia. So a knowledge of the orientation of the dominant hemisphere helps in determining the portions that can be sectioned without disturbing speech.
5. Studies of cerebral dominance help in increasing our knowledge about localization of brain functions which in turn helps in differential diagnosis and treatment of various disorders due to cortical lesions.

Tests of cerebral dominance for various functions

What are the methods of determination of the dominant side? Here we will deal with the determination of handedness, ear preference and speech preference only.

Hand preference : The infant shows little evidence of a preferred hand and will use either for grasping or shaking a rattle. Burt (1964) states that soon after the 9th

month some preference for right or left may be noticed if effort is required for reaching or grasping. However, the mother usually notices any tendency towards use of the left hand when the child begins to use a spoon around the age of 18 months, and at the time when normally the child is also beginning to use words and develop the use of speech.

Weisenberg and McBride (1935) observed that the dominance indicated by handedness is a criterion of the crucial hemisphere for speech in about 95 per cent of the cases.

Lord Brain (as quoted by Rossi and Rosadini 1965) states that a whole battery of tests of handedness has been deviced, but it is doubtful if the more elaborate are of much more value than simple ones.

Gordan (1921) working with young children found that the hand used to rub a 'desk' with a duster and to throw the duster rolled into a ball was a reliable test of handedness. Adults may also be asked which hand is used for throwing. "Cutting bread and dealing cards are activities often still carried out with the left hand by naturally left handed people who have been brought up to be right handed" (Brain, 1965).

Rossiand Rosadini (1967, p. 169) suggested the following procedure: "Handedness was established by direct examination and by asking the patient and his relatives which was the hand preferred for carrying out familiar (as for instance, the use of spoon and scissors, throwing a ball, singing etc.) as well as less common skilled movements". The judgement may be based on a number of criteria such as the hand used in writing, eating, throwing a ball, holding scissors, pushing the thread through a needle, dealing cards or reaching for a knob or handle and on the position of two hands in bimanual activities like holding a cricket bat, shovel, rake etc. Tests of handedness are not practical for the pathological cases, the large majority of the patients have some weakness or loss of motor function which prevents any determination as to the dominant hand or foot. As many facts as possible are to be obtained from the patient or his relatives.

Ear preference

1. We have a test for this that we owe entirely to Dr. Broadbent. different digits are fed simultaneously into the two ears, so that for example you hear '6' in the left ear at the same time that you hear '9' in the right ear. This is done in groups of six digits, a pair at a time and after the third pair the subject reports all the digits that he had heard, in any order. Dr. Doren Kimura (Disorders of Lang., 1964, p. 220) observed epileptic patients in this test before they had any excisions. She was struck by the greater efficiency of the right ear and she has, since confirmed this in normal adult subjects and in children down to age five. Correlations were obtained between ear preference, handedness and side of the major hemisphere, for language. Right handed subjects who have their speech on the left are better on the

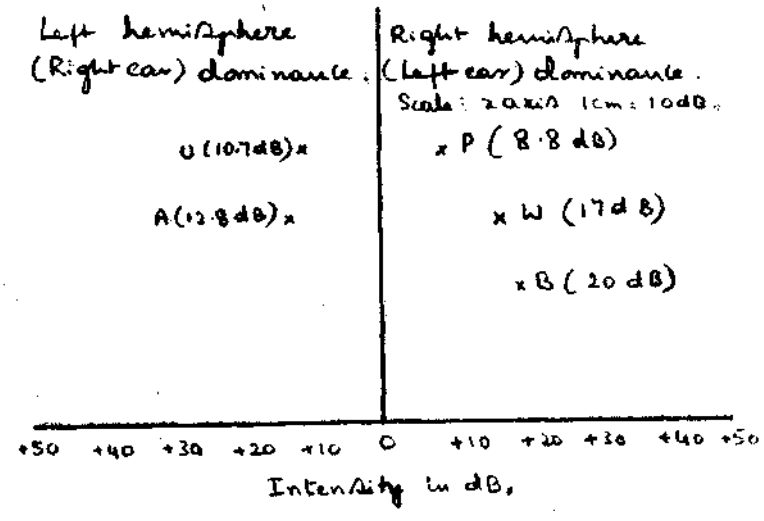
right ear and so are left handed subjects who have speech on the left. But if the speech is represented in the right hemisphere, then t h i s reversed.

2. Tadanobu and Tsunoda devised an objective method for detecting dominant hemisphere towards verbal and non-verbal sounds. Application of his method to normal subjects and subjects with speech disorders primarily due to cortical lesions, the following results were obtained.

(a) *Normgl subjects*: In the majority of normals left cerebral hemisphere is dominant fo/human vowels 'ah', 'uh' and right cerebralTiemisphere is dominant for turn-verbal sounds such as IKHZ pure-tone, white noise and buzzer sound. The pattern of the cerebral dominancy for several sounds obtained in normal subjects is as follows:

Table 5. *Shows cerebral predominancy for various sounds in normal subjects (Tsunoda, 1969)*

S.No.	Sound used	Symbol used	Dominant hemisphere	No. of cases	Range in dB between which dominancy effect is noticed	Average value in dB at which the dominancy effect is noticed
1	Vowel 'ah'	A	left	57	0-35 dB	12.8 dB
2	Vowel 'u'	U	left	25	2-30 dB	10.7 dB
3	IKHZ puretone	P	Right	57	0-34 dB	8.8 dB
4	White noise	W	Right	5	10-25 dB	17 dB
5	Buzzer sound	B	Right	5	15-30 dB	20 dB



Graph 1. Shows cerebral dominance for various sounds in normal subjects (Tsunoda 1969)

IN vowel 'ah' left cerebral hemisphere (right ear) is dominant by an average of 12.8 dB.

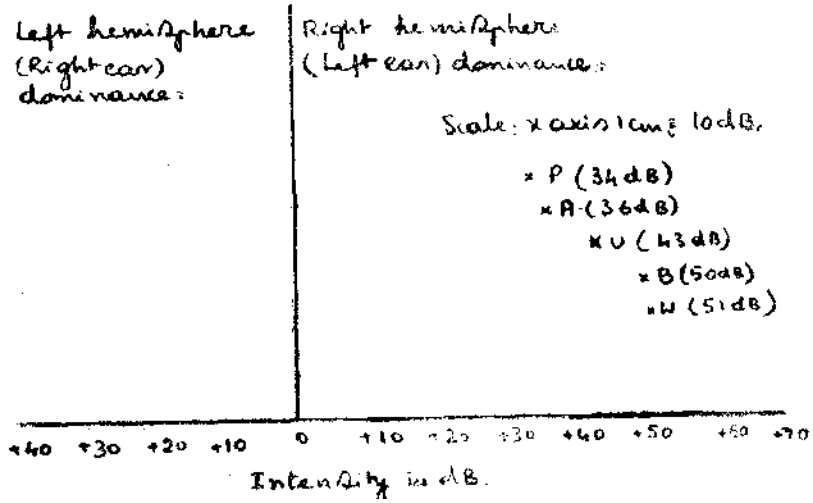
on 1 K H Z pure-tone, right cerebral hemisphere (left ear) is dominant by an average of 8.8 dB.

The difference of the dominancy effect shown in dB between the tests on vowel sounds and puretone IKHZ is statistically significant.

(b) *Cases of Aphasia with right hemiplegia :* Most strikingly different findings from normal groups are that vowel 'ah' (indicated by 'A') is shifted from the left to the right hemisphere which originally was not the dominant side for speech.

Table 6. *Shows cerebral dominance for various sounds in cases affected by aphasia with right hemiplegia (Tsunoda, 1969)*

S. No.	Sound used	Symbol	Dominant hemisphere	No. of cases	Range in dB between which dominancy effect is noticed	Average value in dB at which the dominancy effect is noticed
1	Pure tone 1KHZ	P	Right	28	8-74 dB	34 dB
2	Vowel 'ah'	A	Right	22	12-72 dB	36 dB
3	Vowel 'Uh'	U	Right	10	12-88 dB	43 dB
4	Buzzer sound	B	Right	3	38-64 dB	50 dB
5	White noise	W	Right	10	40-90 dB	51 dB



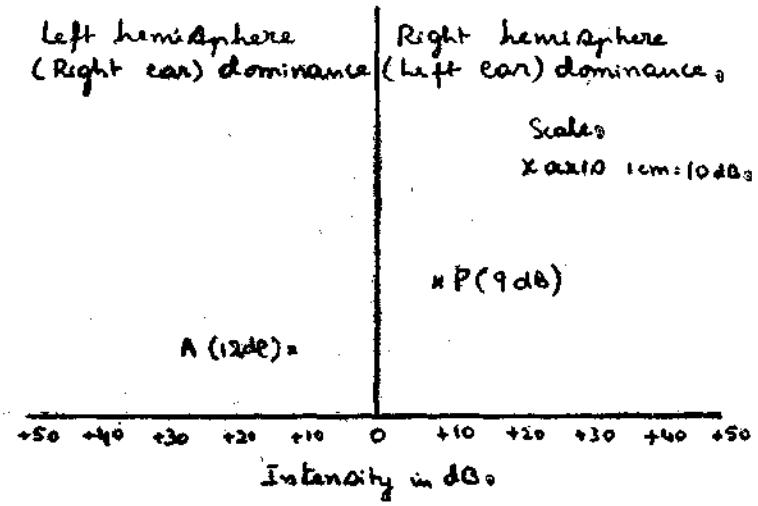
Graph 2. Shows cerebral dominance for various sounds in cases effected by aphasia with right hemiplegia (Tsunoda, 1969)

1KHZ pure-tone (p), white-noise (w) and buzzer sound (B) are located in their original right hemisphere of the brain, although their predominancy shown in dB are extremely increased beyond normal rejection limit.

The maximum shift is 95 dB for white noise. These pathological shifts of the dominancy effect on both vowel and non-verbal sounds means the possible existence of the severe pathological process in the left cerebral (dominant) hemisphere.

(c) *Cases of dysarthria with right hemiplegia* : On the contrary to the aphasic cases, their patterns of the dominancy for the vowel 'ah' and 1KHZ pure-tone are considered to be normal.

Table 7. *Shows cerebral dominancy for various sounds in cases affected by dysarthria with right hemiplegia (Tsunoda, 1969)*



Graph 3. Shows cerebral dominance for various sounds in cases affected by dysarthria with right hemiplegia (Tsunoda, 1969)

(d) *Cases of Aphasia with left hemiplegia:*On both vowels and non-verbal sounds, the extreme shift of the dominancy was seen to the left hemisphere.

S.No.	Sounds used	Symbol	Domi-nant hemi-sphere	No. of cases	Range in dB between which dominancy effect is noticed	Average value in dB at which the dominancy effect is noticed
1 2	Vowel 'ah' 1KHZ Pure-tone	A P	left right	14 13	4-34 dB 2-30 dB	12 dB 9dB

(e) *Cases of left hemiplegia without speech disorders*: A case with left hemiplegia showed normal pattern, but other 8 cases showed abnormal patterns of the cerebral dominancy. Regardless of the extreme shift of both vowels and non-verbal sounds to the left hemisphere, speech disorders were not observed because the damaged side had not been the dominant cerebral hemisphere for speech.

Tsunoda's test is readily available for the orientation of the dominant cerebral hemisphere towards various sounds in normals and for detection and evaluation of pathological cerebral hemisphere.

Tsunoda's technique : /The principle of the new objective testing method lies it applying, to the binaural competing technique, a DAF technique using key tapping.

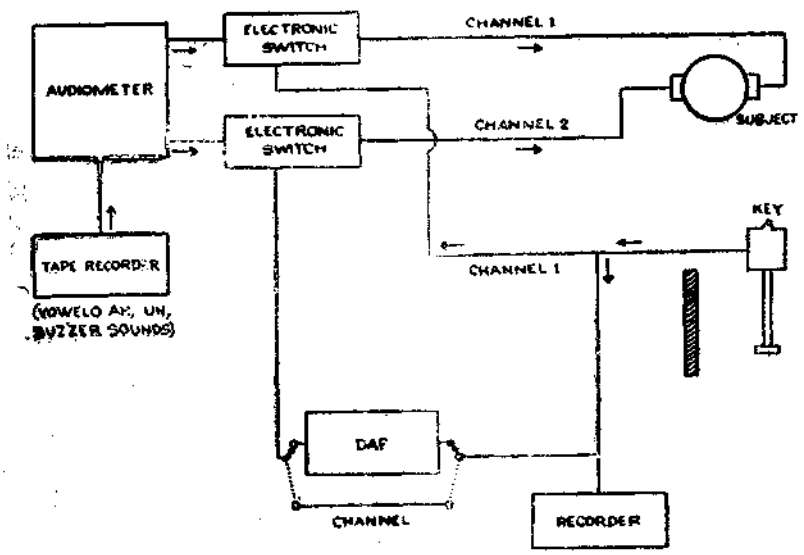


Fig. 1. The block diagram of Tsunoda's method of determination of cerebral dominance (Tsunoda, 1969)

The apparatus as stated by Tsunoda consists of a 2 channel auditory feedback recorder, including an electronic key, a pen recorder, and a delay circuit, and a 2 channel electronic switch. Delay time was 200 millisec and stimulus duration 75 millisec (rise-fall time was 25 millisec). Prior to the experiment proper, subjects' thresholds for the stimuli were measured in a sound treated room.

Subjects were trained in tapping a certain pattern, such as 4-2, 3-3 and 4-4, as quickly as possible so that they could tap the correct pattern automatically. The pattern signals triggered by the tapping of the forefinger were recorded on the paper of the pen-recorder and were also fed to channels 1 and 2.

In channel 1, short 75 millisec tones synchronous to the tapping were presented to the right ear through electronic switch 1. In channel *2,* short synchronous 75 millisec

tones were presented to the left ear through electronic switch 2, but delayed by as much as 200 millisec right through the circuit described.

When channel 2 was switched to the delayed circuit, the synchronous tones favorable to rhythmical patterns tapping, were presented to one ear and the delayed tones that disturbed rhythmical pattern tapping were presented to the other ear. In this manner, dichotic competing conditions could be established between the ears.

At first, the synchronous tones to one ear were kept at 40 dB above threshold and the delayed tones to the other ear were progressively raised in intensity unto such a level that a DAF effect could be found on the subjects tapping pattern. Then the delayed channel is switched to the opposite ear and the same procedure is followed. When for example, threshold for appearance of the DAF effect was reached i.e. 60dB in the left ear and 30 dB more in the right ear, the right ear was considered to be 30 dB more prominent than the left ear for this type of stimuli. Thus by reversing stimuli to the 2 ears, the cerebral hemisphere dominant for any stimulus can be objectively determined in dB. These differences between the ears are here interpreted as reflecting functional differences between the cerebral hemispheres.

Sodium amobarbital test or WADA technique of detemination of the cerebral hemisphere dominant for speech

A more direct approach to the problem of dominance for speech is provided by the WADA (1949) technique of intracarotid injection of sodium amytal, the right and left sides being injected on different days. By thus temporarily interfering with the functioning of each hemisphere in turn, it is possible to compare the two cerebral hemispheres of the same patient with respect to their participation in speech. Th ere is ample neurosurgical confirmation that the test is a valid indicator of cerebral dominance for speech. Milner (1964, p. 202 to 203) gave the following standardized procedure. The patient is first given some practice in naming a number of common objects rapidly on request, repeating the days of the week forwards and backwards, counting and reading. A 3-second injection of 200 mg of 10% per cent sodium amytal solution is then made into the common carotid artery of one side, while the patient is counting aloud slowly, with legs flexed, arms raised and fingers moving. The injection normally produces an immediate contralateral hemiplegia, the arm and leg falling to the bed and becoming flaccid, but the limbs on the injected side remain raised and voluntary movements of the ipsilateral arm and leg can be made to command as soon as the. initial few seconds of confusion are over. The patient will usually hesitate, or stop counting, at the end of the injection, but if the injection is into the non-dominant hemisphere, he will resume counting within a few seconds and will then name objects accurately and repeat the days of the week correctly while the contralateral hemiplegia is still complete. When the injection is made on the side of the dominant hemisphere for speech, motor and sensory changes are seen, but, in

addition, there are signs of dysphasia which usually outlast the hemiparesis by a few minutes. In this case, the patient will sometimes appear mute for the first few minutes, after the injection but will still obey commands involving the ipsilateral arm and leg, thus showing that he is in contact with his environment. As speech returns, he may make mistakes in naming objects, with perseveration, substitution, and occasional jargon; but will normally be able to demonstrate how the objects should be used; he will be apt to mix up the sequences when counting backwards, or saying the days of the week backwards, and he may or may not make mistakes in simple reading. After about 10 minutes, speech will have returned to normalcy.

Walter (in Brain Mechanisms underlying speech and language, 1967, p. 179) and Rossi and Rosadini (1967) have pointed out that counting or failure to count is not a very good test of speech dominance.

Conclusion

In the light of the recent available literature the concept of cerebral dominance for various functions with emphasis on speech is examined. Few ways in which this knowledge of cerebral dominance can be used in the differential diagnosis of speech disorders due to cortical lesions have been discussed. And, finally, some of the methods which may help in determining the 'dominant' hemisphere are pointed out.

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