STABILITY OF AUDITORY ASYMMETRY IN THE CONTROL OF PHONATION

by Maurice Dionne

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CURRICULUM STUDIORUM

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INTRODUCTION

Though Tomatis formulated the concept of a "leading ear" in the early fifties, only recently has it been subjected to controlled experimental verification. The notion of a leading ear embodies two separate ideas: auditory asymmetry and control. Taken separately, these ideas have been extensively researched.

Since the early sixties, asymmetries in auditory perception have been studied by several experimenters, usually within the context of a massive research effort directed to the investigation of hemispheric differentiation of function. More specifically, research using these asymmetries has been applied to a better understanding of cortical lateralization of linguistic mechanisms and the process of speech perception.

The control dimension is represented in an important body of research devoted to the application of the principles of cybernetics to the speech process. In this context, language is studied as a servosystem whose ongoing function is controlled by its various feedback relationships, auditory feedback being given a crucial role.

Inspection of present research indicates that the combination of these two trends, present in Tomatis' early but largely unknown work, will soon be given considerable attention. It is the purpose of this study to provide a contribution to this effort, by dealing with temporal and articulatory aspects of the lateralized control of audition on phonation.

The thesis is divided into four chapters. The review of the literature begins with a selective discussion of cerebral dominance, which provides the necessary theoretical background for interpreting laterality differences in auditory perception. The third section deals with the auditory control of phonation and is followed by the importance of laterality in this control. The second chapter presents a description of the sample, instrumentation, testing procedures, analysis of the dependent variables, and the statistical design. Chapter III presents the results and an interpretation of the latter is offered in Chapter IV. In the last section, a summary and conclusion is offered and possible implications for future research are suggested.

CHAPTER I

REVIEW OF THE LITERATURE

Since ancient times, man has been intrigued by the fact that, without any apparent reason, men choose one hand, usually the right, for the performance of skilled activities. Psychology shared this interest in the body's functional preferences, and, quite early in its development, beyond the mid-nineteenth century, began to relate it to neurological organization. An adequate understanding of the specific topic discussed in this study requires at least a cursory investigation of cerebral dominance theory and its origins.

1. Cerebral Dominance.

The theoretical foundation for the obtained laterality differences in auditory perception rests upon cerebral dominance theory, which has proven the existence of several functional asymmetries between the two cerebral hemispheres. Only recently have Geschwind and Levitsky[1] reported the discovery of an anatomical difference between the temporal lobes, providing an indication of an innate

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1 N. Geschwind and W. Levitsky, "Human Brain: Right-Left Asymmetries in the Temporal Speech Region," Science, Vol. 161, 1968, p. 186.

structural basis with which the left hemisphere superiority for the organization of language can be correlated.

Historically, cerebral dominance was synonymous with the demonstrated relationship between language disturbance and unilateral cortical deficit. The idea of left hemisphere localization of speech was first published by Broca in 1865 (Goodglass and Quadfasel[2]). However, as Benton[3] has pointed out, functional differentiation between the two cerebral cortexes were discovered in other areas of human behavior and mentation, a field which is presently being extensively researched (Benton[4]).

The specific concern of this section is to provide a broad overview of the concept of cerebral dominance regarding language functions and the latter's relationship to manual laterality. Though the latter relationship is not of direct bearing on this study, since its design does not deal with handedness, it is reviewed because it is a major variable in studies directly related to the hypothesis

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2 H. Goodglass and F.A. Quadfasel, "Language Laterality in Left Handed Aphasics," Brain, Vol. 77, 1954, p. 521-548.

3 A.L. Benton, "Hemispheric Cerebral Dominance," Israel Journal of Medical Sciences, Vol. 6, No. 2, 1970, p. 294-303.

4 A.L. Benton, "The Problem of Cerebral Dominance," Canadian Psychologist, Vol. 6A, No. 4, 1965, p. 332-348.

under scrutiny here. Historically also, handedness has been intimately tied to the study of cerebral dominance. The functional asymmetries of the temporal lobes with reference to auditory perception will also be reviewed.

a) Handedness and Cerebral Dominance for Speech.

The historical origins of the notion of the localization of speech within the left hemisphere have been well documented by Penfield and Roberts.[5] The association of the linguistic function with the left hemisphere was inferred because of the repeated observation that speech disorders accompanied paralysis (resulting from brain damage) of the right side of the body, but were rarely found in patients with paralysis of the left side. Further corroboration of locus of lesion could be obtained with autopsies.

The ensuing century of clinical investigation and research has sustained the validity of these observations, at least in right handers. This issue is reviewed by Zangwill who states:

> For practical purposes, the probability of right cerebral dominance in a fully right handed individual is so low that it may be disregarded.[6]

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

6 O. L. Zangwill, "Handedness and Dominance," Reading Disabilities, J. Money, Baltimore, John Hopkins Press, 1962, p. 106.

However, the relationship of the cortical lateralization of language functions and handedness in sinistrals has been fraught with much confusion. The origins of the controversy are related by Penfield and Roberts:

> ...in 1865, Bouillaud correlated the fact that aphasia occurs with lesions of the left cerebral hemisphere with the fact that most people are right handed.[7]

Weeks later, Broca summarized the case of a woman with right sided hemiparesis (due to a lesion suffered during infancy) who showed no evidence of speech disturbance.

> He then went on to generalize unjustifiably 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 supposed to be for the right handed.[8]

This "mirror image theory" of the relation between handedness and cortical speech representation prevailed for several decades (Weisenburg and McBride[9]) and was hardly challenged until the early fifties. Ettlinger, Jackson and Zangwill summarize the new point of view:

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7 Penfield and Roberts, Op. cit., p. 89.

8 Ibid.

9 T.H. Weisenberg and K.E. McBride, Aphasia, A Clinical and Psychological Study, New York, Commonwealth Fund, 1935.

It has become abundantly clear in recent years that the relationship between handedness and cerebral dominance is far less clear cut than was formerly supposed. Although the classical rule relating right handedness and left hemisphere dominance has not been seriously challenged the position with regard to left handedness has undergone a complete transformation. No longer can it be accepted that right cerebral dominance is the rule in left handed individuals or that aphasia resulting from a left sided lesion in a left handed patient is in any way exceptional.[10]

Though the mirror image theory for sinistrals was dropped, interpretations of research tabulating the incidence and course of dysphasia after unilateral lesions of either hemisphere in left handers remained controversial.

Penfield and Roberts state:

In almost one hundred years, only about 140 cases have been reported with aphasia and 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 for speech remains unclear, but it is not related solely to handedness.[11]

Similarly Russell and Espir[12] reported how rarely dysphasia followed penetrating wounds to the right

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10 Ettlinger, C.O. Jackson and O.L. Zangwill, "Cerebral Dominance in Sinistrals," Brain, Vol. 79, 1956, p. 569.

11 Penfield and Roberts, Op. cit., p. 102.

12 W.R. Russell and M.L. Espir, Traumatic Aphasia, "A Study of Aphasia in War Wounds of the Brain," London, Oxford University Press, 1961.

hemisphere, inferring from this that speech is almost always represented in the left hemisphere regardless of handedness.

Others took a less extreme view (Humphrey and Zangwill,[13] Ettlinger, Jackson and Zangwill,[14] Goodglass and Quadfasel,[15] Zangwill[16]), stating that though speech representation is more likely to be on the left even in left handers, it is a less frequent occurrence than in strongly right handed persons. As Ettlinger and co-workers state,

> Taken together, these findings provide strong evidence for right hemisphere language laterality - in some sinistrals at least. We may, however, agree with Goodglass and Quadfasel (1954) that right hemisphere dominance is very much less common than left handedness.[17]

The possibility of bilateral representation in sinistrals has also received a good deal of research support and is reviewed in Zangwill.[18] In support of this view is the evidence of frequency of aphasia in sinistrals with

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13 M.E. Humphrey and O.L. Zangwill, Journal of Neurosurgery and Psychiatry, Vol. 15, 1952, p. 184.

14 Ettlinger, Jackson and Zangwill, Op. cit.

15 H. Goodglass and F.A. Quadfasel, Op. cit.

16 O.L. Zangwill, Cerebral Dominance and Its Relation to Psychological Function, Springfield, Ill., Charles C. Thomas, 1960.

17 Ettlinger, Jackson and Zangwill, Op. cit., p. 570.

18 Zangwill, Op. cit., 1962.

lesions in either hemisphere and the frequency of mild but transitory aphasic syndromes in left handed patients (Zangwill[19]), the finding that paroxysmal dysphasia in sinistrals is likely to occur with a focus in either hemisphere (Hecaen and Piercy[20]), and finally, that in cases of hemiplegia and aphasia due to vascular accidents, prognosis for recovery of speech is significantly better for patients with left handed tendencies, or with familial left handedness than it is in strongly right handed persons of right handed stock (Subirana[21]).

The introduction of the sodium amytal technique (Wada and Rasmussen[22]) was a factor in settling some of the controversy, since it permitted a comparison of the two cerebral hemispheres in a single patient regarding their participation in the speech function. Like the previous studies, however, it was limited to the brain damaged

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19 Zangwill, Op. cit., 1960.

20 H. Hecaen and M. Piercy, "Paroxysmal Dysphasia and the Problems of Cerebral Dominance," Journal of Neurology, Neurosurgery and Psychiatry, Vol. 19, 1956, p. 194-201.

21 A. Subirana, "The Prognosis in Aphasia in Relation to Cerebral Dominance and Handedness," Brain, Vol. 81, 1958, p. 415-425.

22 J. Wada and T. Rasmussen, "Intracarotid Injection of Sodium Amytal for the Lateralization of Cerebral Speech Dominance," Journal of Neurosurgery, Vol. 17, 1960, p. 266-282.

population because of the risks inherent to the technique which is used only when information regarding localization of language functions is required prior to surgical intervention.

Branch, Milner and Rasmussen[23] executed a major investigation using this technique with 119 patients. They found that out of 48 right handed patients, ninety percent showed left hemisphere speech representation and ten percent right hemisphere representation. As the authors note, the ten percent incidence of right hemisphere speech representation in right handers very probably does not represent an accurate estimate of the proportion of right handers with such language localization in the normal population; this was a highly select group which contained a number of patients for whom the question of right hemisphere dominance had already been raised on the basis of psychological test results and clinical history.

Left handers and ambidextrous subjects were grouped together and differentiated into those who had not suffered early left brain damage and those who had. Of the former group, out of forty-four patients, 64 percent had left hemisphere representation, 20 percent had right

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23 C. Branch, B. Milner and T. Rasmussen, "Intracarotid Sodium Amytal for the Lateralization of Cerebral Speech Dominance," Journal of Neurosurgery, Vol. 21, 1964, p. 399-405.

hemisphere representation and 16 percent were bilateral. In the group who had a clinical history of early left hemisphere damage, speech representation was left: 22%, right: 67%, and bilateral: 11%.

These results tend to support the more moderate of the previously mentioned points of view, in that they testify to the very high probability of left hemisphere representation in right handers and also to the fact that speech representation in the left hemisphere is the more common occurrence even in sinistrals, though not to the same extent as in dextrals.

Finally, the fact that all ten subjects who gave evidence of bilateral speech representation were in the left handed or ambidextrous group, seems to support the previously mentioned viewpoint that people with left handed tendencies have less clear-cut unilateral hemisphere specialization than right handers. Furthermore, the authors state that even in those left handers not classed as bilateral in speech representation, injection into the dominant hemisphere of right handers caused a more pronounced speech difficulty than similar injections for sinistrals. In a further study, the authors state:

> This suggestion of a considerable margin of safety in the cerebral organization of left handed and ambidextrous patients again accords well with the notion of a more bilateral representation, and there may well be considerable individual differences in this respect which find no place in our all or none scoring system.[24]

In another study using the sodium amytal technique with 217 patients, of whom eighteen in the left handed and ambidextrous group gave evidence of bilateral speech representation, Milner reports a curious and unexpected result:

> Furthermore, in nine of the eighteen cases, an interesting and totally unexpected dissociation between defective naming and defective serial order was obtained, seven patients making mistakes in saying the days of the week and in counting, forward and backward, after right sided injection, and mistakes in naming common objects and no mistakes in series after left sided injection, and two showing the reverse pattern.[25]

These results indicate that much further research is required before an adequate understanding or even an adequate description of bilateral speech representation is to be obtained.

Before concluding, it is necessary to mention the further contribution of the split brain studies regarding

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24 B. Milner, C. Branch and T. Rasmussen, Observations on Cerebral Dominance, in A.V.S. de Reuck and M.O' Connor (Eds.), CIBA Founfation, Symposium on Disorders of Language, London, Churchill, 1964, p. 200-214.

25 B. Milner, C. Branch and T. Rasmussen, "Evidence for Bilateral Speech Representation in Some Non-Right Handers," Transactions of American Neurological Association, Vol. 91, 1966, p. 307.

the understanding of the role of both hemispheres in the mediation of language. Sperry and Gazzanniga,[26] conclude from their study that even in a right handed subject presumably left brained for speech, the right hemisphere can mediate the comprehension of simple written and spoken speech, and can even spell simple words with large cut-out letters manipulated out of sight by the left hand. However, it does not control an expressive mechanism.

In a more recent article, Gazzaniga and Hillyard have explored "the upper limits of semantic and syntactic structure within the right hemisphere."[27] This study involved asking more complex linguistic questions to the right hemisphere than had been asked before. In their discussion, the authors state:

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26 R.W. Sperry and M.S. Gazzaniga, "Language Following Surgical Disconnection of the Hemispheres," Brain Mechanisms Underlying Speech and Language, New York, Grune and Stratton, 1967, p. 108-121.

27 M.S. Gazzaniga and S.A. Hillyard, "Language and Speech Capacity of the Right Hemisphere," Neuropsychologia, Vol. 9, 1971, p. 273-280.

> The foregoing studies clearly suggest that there are limits on the language capacity of the right hemisphere of adult man. The right hemisphere is unable to relate subject to object via a verb, to respond to verb commands or to comprehend the semantic aspects of verbs. It is skilled mainly at attaching noun labels to pictures and objects. Yet, the ability to tell the negative from the positive would seemingly imply an understanding of "doing" versus "not doing" something, and hence some comprehension of verbs. ...The extent and nature of verbal structure processing in the right hemisphere remains unknown, but it conceivably has become locked in an infantile mode, wherein only simple naming is possible and "no" is the most deeply entrenched concept.[28]

In conclusion, it is important to emphasize that the literature reviewed here deals with brain damaged subjects and conclusions extending to the normal population must remain qualified. Moreover, much of the confusion regarding the relationship of manual and cortical asymmetries has been due to an inattention to the complexities involved in the classification of handedness. Most reports fail to state explicitly what laterality tests have been used in determining handedness. They usually rely on a questionnaire requiring the subject to indicate which hand he prefers for a series of activities and measures of proficiency are rarely if ever used. Benton, Meyers and Polder have pointed out that this might have led to serious confusion regarding the classification of left handers.

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28 _Ibid_., p. 277.

They state:

> ...self-classified left handed individuals form such a heterogeneous group with respect to actual hand preference and relative manual dexterity that this typological designation is virtually meaningless from a practical standpoint.[29]

This matter has been given more adequate consideration in further research dealing with handedness and cortical representation of speech as estimated by the dichotic technique. Consequently, a discussion of this matter will be undertaken in the second section of this review.

b) Functional asymmetry of the temporal lobes in auditory perception.

The studies to be reviewed here deal with patients with unilateral damage to either the right or the left temporal lobe, and the differential effect of sidedness of cortical deficit on auditory perception. These studies provide an interpretative background for the literature to be discussed in a later section.

Milner[30] summarized research showing the selective effects of left temporal lobectomy on assimilation and

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29 A.L. Benton, R. Meyers and G.J. Polder, "Some Aspects of Handedness," Psychiatric Neurology, Vol. 144, 1962, p. 335.

30 B. Milner, "Laterality Effects in Audition," Interhemispheric Relations and Cerebral Dominance, Baltimore, John Hopkins Press, 1962, p. 177-195.

recall of verbal materials. At the time, the verbal defect had been mostly obtained using auditorially presented material and therefore might have been thought to contain a strong auditory component. However, Milner did not believe it to be a modality specific defect and predicted that impairment in the learning and rentention of visually presented material would be present in patients with left temporal lobe lesions. This prediction was supported by further research which she conducted in 1967.[31]

In the earlier study, she investigated the effects of right and left temporal lobe lesions on non-verbal auditory tasks:

> ...in order to determine whether the left temporal lobe lesions produced a general impairment of auditory discrimination, or whether the verbal or non-verbal nature of the task was the critical factor.[32]

The test used was the Seashore Test of Musical Talents and the variables measured were pitch, loudness, rhythm, time, timbre and tonal memory. The results clearly showed that right temporal lobectomy made auditory discrimination more difficult, especially on the timbre and tonal memory tasks, though the difference also reached

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31 B. Milner, "Brain Mechanisms Suggested by Studies to Temporal Lobes," Brain Mechanisms Underlying Speech and Language, New York, Grune and Stratton, 1967, p. 108-121.

32 Milner, Op. cit., 1962, p. 181.

significance for loudness and was in the expected direction for the other three tasks but not approaching significance. There were no indications whatever that left temporal lobectomy affected auditory discrimination. Combined with the results in the visual modality, there appeared to be a strong case for differentiation of function of the temporal lobes along the verbal-non-verbal dimension.

Further support for this functional asymmetry was provided by Spreen, Benton and Fincham[33] who reported a case study of a patient with right hemisphere damage who showed a marked difficulty in identifying common sounds such as a cat, meowing, coughing, whistling, etc.

More recently, Vignolo[34] has reported an impressive study using ninety-five patients with unilateral hemispheric damage (51 aphasics and 16 non aphasic left brain damaged subjects, and 28 right brain damaged subjects). They devised essentially two tests of sound recognition. One involved the identification of meaningful sounds such as a canary song. A multiple choice procedure was used which permitted the patient to pictorially identify either the

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33 A. Spreen, A.L. Benton and R.W. Fincham, "Auditory Agnosia Without Aphasia," Archives of Neurology, Vol. 13, 1965, p. 84-92.

34 L.A. Vignolo, "Auditory Agnosia: A Review and Report of Recent Evidence," Contributions to Clinical Neuropsychology, Chicago, Aldine, 1969, p. 172-208.

correct source of the sound (canary singing), an acoustically related alternative (a man whistling), a sound producing event belonging to the same semantic category as the source sound but acoustically unrelated (cock crowing), and a sound having no acoustic or semantic relationship to the source sound (train in motion). The second test involved a judgement of similarity or difference between sequentially presented meaningless sounds (noises such as a crackling sound or a buzzing background).

The results indicated that the patients with disease of the right hemisphere showed a defect in acoustic discrimination (meaningless sound test) but not in the identification of meaningful sounds. The left hemisphere patients showed the reverse pattern: i.e., normal acoustic discrimination but a clear impairment in the identification of meaningful sounds. In support of Milner, Vignolo concluded:

> In agreement with other experimental evidence in normal and brain damaged subjects, this finding supports the notion of a cerebral asymmetry in auditory recognition: it appears that subtle perceptual discrimination of sounds is subserved mostly by the right hemisphere, while semantic decoding takes place chiefly in the left hemisphere.[35]

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35 *Ibid.*, p. 208.

Finally, using a dichotic presentation of melodies and digits (see next section), Shankweiler[36] showed that the perception of dichotically presented melodies was selectively impaired by right temporal lobectomy whereas perception of dichotic digits was selectively impaired by left temporal lobectomy, again a differentiation along the verbal-non-verbal dimension.

In this section, functional asymmetries between the left and right cerebral cortex have been considered where asymmetries usually were inferred from compared performances of different subjects suffering from unilateral cortical deficits. What is to follow, however, will be concerned with within subject comparisons of the performances of the left and right ears, and in the majority of cases, with normal subjects; especially of interest will be the relationship between those obtained laterality differences (LD's) in perception and hemispheric asymmetries of function.

2. Laterality Differences in Auditory Perception.

Unlike cerebral dominance, laterality differences (LD's) have a shorter history, their investigation having

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36 D.P. Shankweiler, "Effects of Temporal Lobe Damage on the Perception of Dichotically Presented Melodies," Journal of Comparative Physiological Psychology, Vol. 62, 1966, p. 115-119.

been intensive only since the early sixties. Our concern is specifically with audition, though research in the visual modality (White[37]) has also been extensive.

Since the appearance of Kimura's first two articles[38,39] on the subject, LD's in auditory perception have been and continue to be intensively investigated. We will first sketch the immediate background of these studies which were part of a long term investigation of the McGill group on learning and perception in human subjects undergoing unilateral temporal lobectomy for the relief of focal epilepsy.

Despite extensive connections of each cerebral hemisphere with both ears, evidence shows that audition, like other perceptual and motor systems, was functionally at least, a crossed system. Tunturi[40] in the dog and

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37 M.J. White, "Laterality Differences in Perception," Psychological Bulletin, Vol. 72, 1969, p. 387-405.

38 D. Kimura, "Some Effects of Temporal Lobe Damage on Auditory Perception," Canadian Journal of Psychology, Vol. 15, 1961a, p. 156-165.

39 D. Kimura, "Cerebral Dominance and the Perception of Verbal Stimuli," Canadian Journal of Psychology, Vol. 15, 1961b, p. 166-171.

40 A.R. Tunturi, "A Study on the Pathway from the Medial Geniculate Body to the Acoustic Cortex in the Dog," American Journal of Physiology, Vol. 147, 1964, p. 311-319.

Rosensweig[41] in the cat had provided electrophysiological evidence that the evoked cortical responses triggered by input to the contralateral ear were stronger in amplitude than those triggered by input to the ipsilateral ear; no differences in latency had been obtained.

In humans, it had been found that unilateral temporal lobectomy produced at most a slight hearing loss in the high frequencies (Sinha[42]) and at times, no loss at all (Jerger[43]). However, Bocca, Calearo, Cassinari and Migliavacca[44] showed that recognition of words distorted by a low pass filter was impaired in the side contralateral to a temporal lobe tumour. Extending these findings, Sinha[45] showed that recognition of speech arriving at the ear contralateral to unilateral temporal

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41 M.R. Rosensweig, "Representations of the Two Ears at the Auditory Cortex," American Journal of Physiology, Vol. 167, 1951, p. 147-158.

42 S.P. Sinha, The Role of the Temporal Lobe Hearing, Unpublished Master's Thesis, McGill University, 1959.

43 J.F. Jerger, "Observations on Auditory Behavior in Lesions of the Central Auditory Pathway," Archives of Oto-Laryngology, Vol. 71, 1960, p. 797-806.

44 E. Bocca, C. Calearo, O. Cassinari and F. Migliavacca, "Testing Cortical Hearings in Temporal Lobe Tumours," Acta Oto Laryngologica, Vol. 45, 1955, p. 289-304.

Sinha, Op. cit.

lobectomy was impaired when the words were presented together with white noise but that no difference between the contralateral and ipsilateral ear was present in the absence of the masking sound. Related deficits in speech perception for the ear contralateral to a temporal lobectomy including Heschel's gyrus was also reported by Jerger and Mier[46] when irrelevant conversation was being channelled to the ipsilateral ear. In all these studies, it is evident that the difference between ears is subtle; difficult listening conditions are required to elicit the deficit.

The other background information relevant to Kimura's studies involves the effects of unilateral temporal lobe damage on the verbal-non-verbal dimension of auditory perception discussed in the previous section.

As Kimura states, her study dealt with two separate aspects of the problem of the effect of unilateral temporal lobe damage on auditory perception:

> One is the impairment in recognizing stimuli arriving at the contralateral ear. The other is an impairment specific to certain kinds of stimuli, an effect which in man appears to vary with the laterality of the lesion.[47]

Kimura's subjects for this study included seventy-one patients suffering from seizures mostly due to static

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46 J.F. Jerger and M. Mier, The Effect of Brain Stem Lesions in Auditory Responses of Humans, Paper read at first annual meeting of Psychonomic Society, Chicago, September 1960.

47 Kimura, Op. cit., p. 157, 1961a.

atrophic lesions dating from birth to infancy. Groups were classified according to locus of abnormality, which was either left or right temporal, frontal or subcortical.

One of the stimulus conditions used involved a dichotic listening task (DL) first introduced by Broadbent[48] and used extensively in the context of his theory of attention and memory span. The essential component of the DL technique requires simultaneous stimulus presentation to both ears. In Kimura's study, groups of six different digits were used, forming three pairs separated by half-second intervals. After listening to each six digit-three pair sequence, the subject reported as many of the digits he had heard as he could. Kimura's decision to use such a task was no doubt prompted by the previously demonstrated need to use difficult listening conditions, in this case temporal competition between stimuli.

A comparison of the left and right temporal groups supported both the hypothesis of a left temporal superiority in the processing of verbal information (digits) and of stronger contralateral connections between ear and brain. Regarding the latter, a significant contralateral loss was shown irrespective of sidedness of cortical deficit.

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48 D.E. Broadbent, "The Role of Auditory Localization in Attention and Memory Span," Journal of Experimental Psychology, Vol. 47, 1954, p. 191-196.

However, the finding which was to have the most importance for future work, an unexpected one, involved a curious asymmetry in the preoperative scores for the left and right ears. Kimura observed that her subjects tended to report higher scores for their right ear rather than the left, irrespective of the locus of the lesion ($p < .001$).[49]

In view of the previous evidence, an acceptable rationale for this effect was that the right ear, due to stronger contralateral connections in the auditory system, has more efficient connections with the left hemisphere, which is usually dominant for speech, and that in a competitive listening situation, the right ear thus has a perceptual priority over the left ear.

This theory generated three basic predictions, the first two being that using a DL digit task, a right ear superiority should be demonstrable using normal subjects and that subjects with speech represented in the right hemisphere would demonstrate a left ear superiority. The third prediction appealed to the previously cited evidence for right hemisphere superiority in the processing of non-verbal stimuli (Milner),[50] maintaining that the LD should be reversed using dichotically presented non-verbal

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49 Milner, *Op. cit.*, 1962.

50 *Ibid.*

stimuli.

The first two predictions were tested and borne out by Kimura in 1961.[51] In this study, three groups were used: one consisted of thirteen right handed normal controls. Another consisted of thirteen subjects having speech represented in the right hemisphere as ascertained by the sodium amytal technique while the remaining group consisted of 107 subjects with speech located in the left hemisphere. All left handers in this latter group were tested with the Wada technique whereas some of the right handers were not.

A right ear superiority was obtained in the normal controls and the left hemisphere dominant (for speech) brain damaged group. In the group which was right hemisphere dominant for speech, a significant left ear superiority was obtained.

Regarding the third prediction, a study using dichotic presentation of clicks as well as digits was performed with fourteen normal subjects (Milner[52]). The right ear superiority for digits again emerged. A non-significant trend towards left ear superiority was obtained using clicks. However, in 1964, Kimura[53] further tested the third prediction.

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51 Kimura, Op. cit., 1961b.

52 Milner, Op. cit., 1962.

53 D. Kimura, "Left Right Differences in the Perception of Melodies," Quarterly Journal of Experimental Psychology, Vol. 16, 1964, p. 355-358.

Besides the digits task, a dichotic melodies test using solo passages from popular concertos was constructed and administered to twenty right handed student nurses. In the melodies task, the subject heard a dichotic pair of melodies of four seconds duration and was required to identify them from a set of four binaurally presented melodies following the dichotic presentation. The right ear superiority was again confirmed for digits and a significant left ear superiority for the recognition of melodies was obtained.

The body of research just described indicates why the dichotic paradigm has continued to receive such thorough attention. The method has demonstrated dual functional asymmetries of the brain along the verbal-non-verbal stimulus dimension and convincingly related it to cerebral dominance theory and the crossed nature of the auditory system. It has demonstrated this asymmetry within subjects and related it to laterality differences in auditory perception. Finally, and probably most important, it has paved the way to the study of the division of labor between hemispheres in normal subjects, obviating the need to wait for "accidents of nature" and circumventing the perplexing problem of the effect of cortical deficit on the interaction of various functional systems within the brain.

Kimura further used the dichotic technique to investigate a series of problems, among which the development of cerebral dominance for speech or the age of onset at which the left hemisphere becomes specialized for speech perception, arguing that the presence of a right ear superiority for verbal material could be used as an index of this phenomenon. In 1963,[54] she found that the right ear effect was obtained as early as age four. Regarding the LD, no age by sex interactions occurred, though girls had a higher total score at the earlier ages, a fact which Kimura interpreted as congruent with the demonstrated superiority of girls in speaking skills at an early age. However, a further study,[55] this time in a low to middle class socioeconomic area, gave evidence of an age by sex interaction, five year old boys not obtaining the right ear effect, thus suggesting a sex difference in the development of left hemisphere dominance for speech perception.

Knox and Kimura also reported[56] a sex effect for non-verbal materials. In this study, though the LD favoring the left ear was obtained in both sex groups, the total

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54 D. Kimura, "Speech Lateralization in Young Children as Determined by an Auditory Test," Journal of Comparative and Physiological Psychology, Vol. 56, 1963, p. 899-902.

55 D. Kimura, "Functional Asymmetry of the Brain in Dichotic Listening," Cortex, Vol. 3, 1967, p. 163-178.

56 C. Knox, and D. Kimura, "Cerebral Processing of Non-Verbal Sounds in Boys and Girls," Neuropsychologia, Vol. 8, 1970, p. 227-237.

scores of boys were superior to girls on non-verbal tasks, thus suggesting a possible difference in right hemisphere function in males and females.

Kimura has further studied the relationships between cortical speech representation and handedness,[57,58] the interaction of the dominance and the lesion effect in dichotic listening,[59] and the critical characteristics of stimuli accounting for the LD. These aspects will be discussed separately as several independent investigators have dealt with these questions.

In an elaborate series of experiments, Knox and Kimura[60] systematically dealt with several relevant variables. The results showed that the various manipulations used did not affect the dual functional asymmetries established in the original studies.

Empirical support from independent investigators of a right ear laterality effect in dichotic listening to verbal stimuli has been overwhelming and leaves little doubt regarding the reliability of the phenomenon. In normal

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57 Kimura, Op. cit., 1961b.

58 Kimura, Op. cit., 1967.

59 Ibid.

60 Knox and Kimura, Op. cit.

right handed subjects, the effect for digits has been reported by the following: Bartz, Satz and Fennell;[61] Broadbent and Gregory;[62] Bryden;[63,64,65] Carr;[66] Cooper, Achenbach, Satz and Levy;[67] Dirks;[68] Satz, Achenbach, Pattishall and Fennell;[69]

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61 W.H. Bartz, P. Satz and E. Fennell, "Grouping Strategies in Dichotic Listening: The Effects of Instructions, Rate and Ear Asymmetry," Journal of Experimental Psychology, Vol. 74, 1967, p. 132-136.

62 D.E. Broadbent and M. Gregory, "Accuracy of Recognition for Speech Presented to the Left and Right Ears," Quarterly Journal of Experimental Psychology, Vol. 16, 1964, p. 359-360.

63 M.P. Bryden, "Ear Preference in Auditory Perception," Journal of Experimental Psychology, Vol. 65, 1963, p. 103-105.

64 M.P. Bryden, "Short Term Memory for Unbalanced Dichotics Lists," Psychonomic Sciences, Vol. 6, 1966, p. 379-380.

65 M.P. Bryden, "An Evaluation of Some Models of Laterality Effects in Dichotic Listening," Acta Otolaryngologica, Vol. 63, 1967, p. 595-604.

66 B.M. Carr, "Ear Effect Variables and Order of Report in Dichotic Listening," Cortex, Vol. 5, 1969, p. 63-68.

67 A. Cooper, K. Achenbach, P. Satz and C.M. Levy, "Order of Report and Ear Asymmetry in Dichotic Listening," Psychonomic Sciences, Vol. 9, 1967, p. 97-98.

68 D. Dirks, "Perception of Dichotic and Monaural Verbal Material and Cerebral Dominance in Speech," Acta Otolaryngologica, Vol. 58, 1964, p. 73-80.

69 P. Satz, K. Achenbach, E. Pattishall and E. Fennell, "Order of Report, Ear Asymmetry, and Handedness in Dichotic Listening," Cortex, Vol. 1, 1965, p. 377-396.

Zurif and Bryden.[70] Besides Kimura, Ling[71] has reported the effect for digits in normal children. Also, Geffner and Hochberg[72] have confirmed Kimura's findings regarding the emergence of a right ear effect as early as age four, for children of middle socioeconomic level, as well as the later emergence of significant laterality differences in children from lower socioeconomic areas.

The effect has also been reported using meaningful words by Bartz, Satz, Fennell and Lally;[73] Borkowski, Spreen

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70 E. Zurif and M.P. Bryden, "Familial Handedness and Left Right Differences in Auditory and Visual Perception," Neuropsychologia, Vol. 7, 1969, p. 179-187.

71 A.H. Ling, "Dichotic Listening in Hearing Impaired Children," Journal of Speech and Hearing Research, Vol. 14, 1971, p. 793-803.

72 D.S. Geffner and I. Hochberg, "Ear Laterality Performance of Children from Low and Middle Socioeconomic Levels on a Verbal Dichotic Listening Task," Cortex, Vol. 7, 1971, p. 193-203.

73 W.H. Bartz, P. Satz, E. Fennell and J.R. Lally, "Meaningfulness and Laterality in Dichotic Listening," Journal of Experimental Psychology, Vol. 73, 1967, p. 204-210.

and Stutz;[74] Curry and Rutherford;[75] Curry;[76,77] Dirks,[78] and Spellacy.[79] Bartz, Satz, Fennell and Lally[80] have also reported the effect using word-digit pairs. Also, using meaningful words, the effect has been reported using retarded children by Jones and Spreen.[81]

The use of nonsense speech has not altered the appearance of the LD as the following studies testify:

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74 J.G. Borkowski, O. Spreen and J.Z. Stutz, "Ear Preference and Abstractness in Dichotic Listening," Psychonomic Sciences, Vol. 3, 1965, p. 547-548.

75 F.K. Curry and D.R. Rutherford, "Recognition and Recall of Dichotically Presented Verbal Stimuli by Right and Left Handed Persons," Neuropsychologia, Vol. 5, 1967, p. 119-126.

76 F.K. Curry, "A Comparison of Left-Handed and Right-Handed Subjects in Verbal and Non-Verbal Dichotic Listening Tasks," Cortex, Vol. 3, 1967, p. 343-352.

77 F.K. Curry, "A Comparison of the Performances of a Right Hemispherictomized Subject and Twenty-Five Normals on Four Dichotic Listening Tasks," Cortex, Vol. 4, 1968, p. 144-153.

78 Dirks, Op. cit.

79 F.J. Spellacy, "Lateral Preferences in the Identification of Patterned Stimuli," Journal of the Acoustic Society of America, Vol. 47, 1970, p. 574-578.

80 Bartz, Satz, Fennell and Lally, Op. cit.

81 D. Jones and O. Spreen, "Dichotic Listening by Retarded Children: The Effects of Ear Order and Abstractness," Child Development, Vol. 38, 1967, p. 101-105.

Curry and Rutherford;[82] Curry;[83,84] Studdert Kennedy and Shankweiler.[85] Zurif and Sait[86] obtained the effect using meaningless nonsense sequences. Kimura has reported the effect using nonsense syllables[87] and words played backwards.[88] Synthetic nonsense speech has also been used as a stimulus dimension and the right ear effect has been frequently reported when consonantal discriminations are required: Berlin, Lowe and Thompson,[89] Darwin,[90] Gerber

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82 Curry and Rutherford, Op. cit.

83 Curry, Op. cit., 1967.

84 Curry, Op. cit., 1968.

85 M. Studdert Kennedy and D. Shankweiler, "Hemispheric Specialization for Speech Perception," Journal of the Acoustic Society of America, Vol. 48, 1970, p. 579-594.

86 E.B. Zurif and P.E. Sait, "Role of Syntax in Dichotic Listening," Neuropsychologia, Vol. 8, 1970, p. 239-244.

87 Kimura, Op. cit., 1967.

88 D. Kimura, "Neural Processing of Backwards Speech Sounds," Science, Vol. 161, 1968, p. 395-396.

89 C.I. Berlin, S.S. Lowe and C.L. Thompson, "Simultaneous and Time-Staggered Speech Signals in Monaural and Dichotic Listening," Journal of the Acoustic Society of America, Vol. 45, 1969, p. 337 (Abstract).

90 C.J. Darwin, "Laterality Effects in the Recall of Steady State and Transient Speech Sounds," Journal of the Acoustic Society of America, Vol. 46, 1969, p. 114 (Abstract).

and Goldman,[91] Shankweiler and Studdert Kennedy.[92]

Regarding research on LD's in DL to non-verbal stimuli, a significant left ear superiority in normal right handers has been reported by Chaney and Webster[93] for sonar signals, by Curry[94,95] for environmental sounds, by Spellacy for musical stimuli[96] and Spreen, Spellacy and Reid[97] for musical stimuli and sequences of pure tone patterns. Besides her study using melodies, Knox and Kimura have obtained the left ear effect in children using environ-

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91 S.E. Gerber and P. Goldman, "Ear Preference for Dichotically Presented Verbal Stimuli as a Function of Report Strategies," Journal of Acoustic Society of America, Vol. 49, 1970, p. 1163-1171.

92 D.P. Shankweiler and M. Studdert Kennedy, "Identification of Consonants and Vowels Presented to Left and Right Ears," Quarterly Journal of Experimental Psychology, Vol. 19, 1967, p. 59-63.

93 R.B. Chaney, Jr. and J.C. Webster, "Information in Certain Multidimensional Sounds," Journal of the Acoustic Society of America, Vol. 40, 1966, p. 447.

94 Curry, Op. cit., 1967.

95 Curry, Op. cit., 1968.

96 Spellacy, Op. cit., 1970.

97 O. Spreen, F.J. Spellacy and J.R. Reid, "Effect of Inter-Stimulus Interval and Intensity of Ear Asymmetry for Non-Verbal Stimuli in Dichotic Listening," Neuropsychologia, Vol. 8, 1970, p. 245-250.

mental sounds,[98] and Kimura recently reported[99] a significant left ear effect for vocal non-speech sounds such as laughing, crying and coughing.

In view of the evidence, the fact that consistent LD's in auditory perception emerge under dichotic listening cannot be doubted. Controversies relate to the interpretation of LD's, two of which are relevant to this study, 1) that the effect is not due to cerebral dominance and the stronger contralateral pathway but to an interaction of report strategies and short term memory effects, and 2) the neurophysiological mechanisms that would account for LD's.

Also remaining to be discussed under LD's in auditory perception, is the contribution of the DL technique to the study of lateralized factors in speech perception and to the problem of the relationship between handedness and cortical representation of speech discussed in the first section of this chapter.

a) LD's in auditory perception - cerebral dominance or artifact of order of report.

This controversy must be reviewed briefly as it directly challenges the cerebral dominance interpretation

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98 Knox and Kimura, <u>Op. cit</u>.

99 D. Kimura, "The Asymmetry of the Human Brain," <u>Scientific American</u>, Vol. 228, No. 3, 1973, p. 70-78.

of the LD. Broadbent[100] has shown that under DL, at a fast rate of presentation, individuals tend to report all the digits from one ear before the other (ear order of report or EOR). The half span reported first was called the immediate channel (IC) and the one reported second the delayed channel (DC). Broadbent found that report from the DC was consistently inferior to report from IC. He termed this the "serial order effect" and suggested a model to account for the phenomena based on a "p" (perceptual) and "S" (storage) mechanism.

Inglis[101] used this model and research on DL in memory disorders and the age variable to criticize Kimura's interpretation of the LD's. He argued that the right ear effect was an artifact of order of report, being due to the subject's tendency to use the right ear first in reporting dichotic materials, the right ear thus benefitting from the mnemonic advantage of the IC over the DC. (The issue does not arise regarding the left ear effect, since due to the non-verbal nature of the stimuli, multiple choice recognition techniques are used rather than verbal recall.)

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100 Broadbent, Op. cit., 1954.

101 J. Inglis, "Dichotic Listening and Cerebral Dominance," Acta Otolaryngologica, Vol. 60, 1965, p. 231-238.

As Bryden mentions,[102] Inglis' model would predict that the right ear effect would disappear if order of report is controlled, i.e., if subjects are told to report the right ear first on half the trials and the left ear first on the other half. However, in several studies where order of report has been controlled, the right ear asymmetry for verbal materials has been maintained (reviewed by Satz[103]).

Furthermore, Inglis' criticism does not explain why subjects tend to report the right ear first. Besides, though it is true that under free recall, subjects do tend to report the right ear first, this finding has not been universal (Satz, Achenbach, Pattishall and Fennell,[104] Carr[105]). In these studies, no consistent tendency to report the right ear first was found but the right ear asymmetry still emerged.

Finally, Kimura,[106] rather unequivocally settled the issue as subjects under DL were told to report from

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102 Bryden, Op. cit., 1967.

103 P. Satz, "Laterality Effects in Dichotic Listening," Nature, Vol. 218, 1968, p. 277-278.

104 Satz, Achenbach, Pattishall and Fennell, Op. cit.

105 Carr, Op. cit.

106 Kimura, Op. cit., 1967.

one ear only (each ear on half the trials), and still a right ear asymmetry was obtained.

In conclusion, in free recall situations, some of the variance in the LD may be accountable on the basis of EOR if the right ear does tend to be reported first more often since the superiority of IC over DC has been repeatedly demonstrated. However, the evidence quoted above shows that attempts to account for it solely on this basis have failed.

b) Mechanisms in dichotic listening.

As has been mentioned above, the ear asymmetry obtained in DL situations was accounted for on the basis of stronger contralateral connections of the right ear with the left hemisphere which is dominant for speech. As to why dichotic listening should be necessary for such an asymmetry to be demonstrated, Kimura has this to say:

> Part of the answer probably lies in the way in which the auditory pathways are arranged. This arrangement is shown schematically in Fig. 1. It suggests that the auditory receiving area receives only a slightly greater number of fibers from the contralateral ear than from the ipsilateral ear. Rosensweig (1951), however, has proposed that there is in addition a point of overlap between the two pathways and that at this point of overlap the contralateral pathways are capable of occluding impulses arriving along the ipsilateral pathways. The occlusion is represented in Figure 1 by arrows. When different stimuli are presented to the two ears, as is the case in the dichotic condition, the impulses arriving along the ipsilateral pathway would be partially occluded, and thus the advantage of the contralateral over the ipsilateral pathway would be enhanced (Kimura).[107]

Kimura goes on to say that the advantage issuing to the contralateral ear could be further enhanced by central competition.

From the above, it can be gathered that in accounting for LD's in auditory perception, Kimura was mainly considering the interaction of the contralateral connections of the right ear and ipsilateral connections of the left ear with the left hemisphere. (It would be the reverse for non-verbal stimuli.) However, recent studies by Sparks and Geschwind,[108] Milner, Taylor and Sperry,[109] and Bryden and Zurif,[110] using DL in

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107 Kimura, Op. cit., 1967, p. 170-171.

108 R. Sparks and N. Geschwind, "Dichotic Listening in Man after Section of Neocortical Commissures," Cortex, Vol. 4, 1968, p. 3-16.

109 B. Milner, L. Taylor and R.W. Sperry, "Lateralized Suppression of Dichotically Presented Digits after Commissural Section in Man," Science, Vol. 161, 1968, p. 184-186.

110 M.P. Bryden and E.B. Zurif, "Dichotic Listening Performance in a Case of Agenesis of the Corpus Callosum," Neuropsychologia, Vol. 8, 1970, p. 371-377.

patients having undergone section of the corpus callosum for seizure control have shed further light on this question.

The most significant finding emerging from two of these studies is that in right handed commisurectomized patients, a complete or near complete suppression of left ear input occurs in DL task using verbal material while monaural testing indicates no between-ears difference. Milner and co-workers have shown that the size of this suppression effect is by far greater than that caused by temporal lobectomy to the right hemisphere. In their study,

> Five of the seven subjects with callosal section obtained near zero scores for the left ear and complained that they could hear nothing in the left ear, although they had been expecting to hear numbers at both ears. The remaining two Ss reported about a third as many digits for the left as for the right.[111]

These latter two subjects were both very experienced examinees with respect to other modalities.

Analogously, the patient in the Sparks and Geschwind[112] study obtained total suppression of the left ear in both a dichotic digits and words task. However, with repeated practice and strong instructions to attend to the left ear, he obtained 35 percent recall on the latter. This study further showed that a valid report could be obtained for the left ear

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111 Milner, Taylor and Sperry, Op. cit., 1968, p. 185.

112 Sparks and Geschwind, Op. cit.

when competing material was not highly similar in nature, e.g., masking noise or irrelevant conversation.

This evidence appears to have the following implications for DL results in normals, left brained for speech: that the verbal signal from the left ear is suppressed ipsilaterally, travels the contralateral path to the right hemisphere for processing. If, as Kimura had suggested, the ipsilateral connection of the left ear to the left hemisphere were involved in the processing of verbal input, no drastic suppression effects should occur in commisurectomized patients.

Shankweiler and Studdert Kennedy summarize the probable neurophysiological basis for LD's thusly:

> Inputs to both ears therefore converge on the dominant hemisphere, that from the right ear by the direct contralateral path and that from the left ear by an indirect path... The right ear advantage in dichotic studies of speech must then arise because the left ear input, travelling an indirect path to the left hemisphere, suffers, on certain trials, a disadvantage or "loss" to which the right ear input, travelling a direct route, is less susceptible.[113]

The opposite would presumably be true with non-verbal materials and their relation to right hemisphere superiority.

However, the fact that practice helps to overcome at least some of the ipsilateral suppression, indicates that

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113 Studdert Kennedy and Shankweiler, Op. cit., 1970, p. 588.

the ipsilateral pathway can be used in DL. That the brain is functionally flexible in dealing with dichotic input was further attested to in the Bryden and Zurif[114] study of a case of agenesis of the corpus callosum: the latter case showed no suppression effect at all. Contaminating factors such as possible bilateral speech representation or only partial hemispheric separation could be operative in this case. However, the authors quote Netley[115] as having administered a dichotic test to twelve hemispherectomized patients and in none of the cases was extreme unilateral suppression obtained. Furthermore, in two cases, the dominant ear was on the same side as the remaining hemisphere.

This data indicates that, given the anatomical necessity and the time, the brain can use alternative routes. Nevertheless, evidence for the left ear - right hemisphere - left hemisphere route for input arriving at the left ear in DL in normals is quite convincing.

We now turn to the studies which have attempted to dissect the speech signal in order to determine which of its components engage lateralizing mechanisms.

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114 Bryden and Zurif, Op. cit., 1970.

115 C. Netley, Dichotic Stimulation in Hemispherectomized Patients, Unpublished manuscript, Toronto, Hospital for Sick Children, 1969.

c) Crucial stimulus characteristics generating the laterality effect in DL.

The studies using DL to nonsense speech (see above) clearly demonstrated that the right ear effect in listening to verbal material was not contingent upon the stimuli being meaningful. The studies to be quoted here spoke to the further question, namely, whether all phonetic elements or features of phonetic elements are processed in the same way.

In a study comparing DL to synthetic CV (consonant-vowel) syllables and steady state vowels, Shankweiler and Studdert Kennedy[116] obtained a significant right ear effect only for the CV syllables. Also, there was evidence for lateralization by feature: when the consonantal elements in a CV pair differed with respect to both voicing (unvoiced stop consonants p,t,k, and voiced stop consonants b,f,g) and place of articulation (labial: p,b, - alveolar: t,d, - velar: k,g) the LD was greater than when they differed only along one dimension.

They further extended their research[117] using natural CVC speech syllables. Three DL tasks were used, which contrasted only in one phone: initial consonant varying (ICV), final consonant varying (FCV) and middle vowel varying.

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116 Studdert Kennedy and Shankweiler, Op. cit., 1967.

117 Studdert Kennedy and Shankweiler, Op. cit., 1970.

Confirming prior studies, a significant right ear effect was obtained for the ICV and FCV conditions, and only a non-significant trend for vowels. Evidence for analysis by feature was again obtained.

Interestingly, the right ear effect for the FCV condition was significantly smaller than for the ICV condition. A possible interpretation was offered in that the reduced laterality effect for FVC could be due to an absence of formant transitions involved between the middle vowel and plosive burst of the final consonant, and that there was thus less opportunity for signal loss from input following the left ear route (see above). Accordingly, the LD would be greater in the ICV condition since formant transitions are delicately implicated with the middle vowel and such complex and subtle cues are more subject to information loss via the left ear route. This interpretation was derived from Darwin's[118] work which had shown that formant transitions were a necessary condition for a right ear advantage using synthetic fricatives and vowels.

The same line of reasoning was applied to the understanding of the results for vowels. Though a right ear advantage in this study was not significant ($p = .06$), a trend was evident. Studdert Kennedy and Shankweiler conclude,

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118 Darwin, Op. cit.

> In short, vowels display a weak variable right ear advantage, and by this are distinguished from consonants for which a strong right ear advantage is the rule and also from musical and other nonspeech sounds for which a left ear advantage is the rule.[119]

The authors go on to speculate that vowels embedded in CVC's but limited in duration by rapid articulation, would show a significant right ear advantage. Besides Darwin's study, further support for this hypothesis is provided by Haggard[120] who has shown that synthetic semi-vowels and laterals (w,l,r,j) for which important cues are carried by relatively slow formant transitions, may give a right ear effect of the same order as consonants.

In conclusion, Studdert Kennedy and Shankweiler[121] state that the lack of a consistent laterality effect for vowels does not necessarily imply absence of cerebral dominance for the processing of such stimuli but possibly only the lesser opportunity accruing for loss of signal from the left ear.

We now turn to the final issue to be discussed in this section.

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119 Studdert Kennedy and Shankweiler, Op. cit., 1970, p. 591

120 M.P. Haggard, "Perception of Semi-Vowels and Laterals," Journal of the Acoustic Society of America, Vol. 46, 1969, p. 115 (Abstract).

d) Contribution of the dichotic technique to the problem of the relationship between handedness and cerebral dominance for speech.

In our discussion above, we found that research with brain damaged subjects had led to an approximate estimate of the relationship between handedness and cortical representation of speech which Satz and co-workers express as follows:

> The probability of left brained speech representation in the right hander is high and reliable ($p = .97$), whereas right brainedness in the left hander is less reliable ($p = .35$).[122]

However, we also reported Benton's[123] position referring to the self report of left handers as being markedly unreliable and only poorly related to actual performance measures, as left handers, so classified, are a heterogeneous group of individuals. On the other hand, self reports are usually accurate for right handers.

In this section we will speak to two new factors in the approach to the problem: investigation of this relationship with normal subjects via the dichotic technique and its demonstrated validity as a measure of localization of speech; and secondly, at least in some of the

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121 Studdert Kennedy and Shankweiler, Op. cit., 1970.

122 Satz, Achenbach, Pattishall and Fennell, Op. cit., 1965, p. 379.

123 Benton, Op. cit., 1962.

studies to be mentioned, a more discriminative approach to the classification of handedness.

We will begin by giving detailed consideration to a study by Satz, Achenbach and Fennel[124] since it is the most instructive in sorting out the main issues involved. We will then compare the contribution of the other studies, especially with regard to the classification of handedness, in an attempt to relate convergencies and divergencies.

The Satz study used multivariate analysis in order to determine the relationship between the self classification of the subject as either right or left handed, a ten item questionnaire, and three tests of manual dexterity (grip strength, finger tapping speed and a test of manual dexterity). It also studied the relationship between a composite performance measure of handedness (derived from all the criteria above save self classification), and scores on a dichotic listening task with a high level of difficulty, i.e., six pairs of digits per trial at a rate of two pairs per second.

The results supported Benton's position in showing the homogeneity of performance of right handers across the various criteria, including self classification, while self

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124 P. Satz, K. Achenbach and E. Fennell, "Correlations Between Assessed Manual Laterality and Predicted Speech Laterality in a Normal Population," Neuropsychologia, Vol. 5, 1967, p. 295-310.

reports of left handedness were shown to be unreliable estimates of manual dexterity and even of questionnaire scores. Actually, 14 percent of self classified sinistrals endorsed more activities for the right hand in the questionnaire data and only 50 percent stated their left hand as the primary one on at least seven of 10 activities.

Using the composite score mentioned above, the authors divided the self classified sinistrals into three groups: (a) 17 percent who were actually strongly right handed, (b) 22 percent ambidextrous (defined as a deviation of $\pm$ .20 standard scores on either side of a mean reflecting no differences in dexterity), and (c) 61 percent who were strongly left handed.

This breakdown predicted significant variations in performance on the dichotic listening task. Whereas right handers were in the great majority consistent with regard to both manual and speech laterality (as inferred from better right ear performance on the dichotic task), self classified left handers in groups (a) and (b) behaved mostly like right handed subjects (had better right ear scores). In the strongly left handed group (c), LD's were distributed in almost 50-50 fashion; approximately half the subjects had a better right ear performance and the other half the converse. In view of these findings, the authors could state that the smaller functional asymmetries of the self classified left handers in both the manual and auditory areas, was an artifact of variable lateral preferences, this group not being homogeneous like the right handers.

Finally, in an attempt to gain further understanding of the results of subjects who did not show a contralateral relationship between manual and speech laterality (a small number of right handed subjects and slightly over half of the strongly left handed group), the subjects were examined for familial incidence of left handedness. The authors found that the occurrence of familial sinistrality was nearly twice as high in test classified left and right handers who showed speech representation ipsilateral to the dominant hand, i.e., twice as many right handers with right hemisphere dominance and twice as many left handers with left hemisphere dominance had other family members who were left handed. The authors advanced several hypotheses to account for the variation of left handedness, the most important for our present purpose being the following:

> Superior left handed dexterity may be associated with either left sided or right sided representation of speech. If the influence of familial sinistrality is strong, the probability of ipsilateral left sided speech representation is increased.[125]

Regarding the other studies examining the relationship between handedness and LD's, the first three to be

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125 Satz, Achenbach and Fennell, Op. cit., p. 306.

described here did not use a differentiated breakdown of left handedness. Curry and Rutherford[126] give no information on the matter of handedness classification. In Satz, Achenbach, Pattishall and Fennell[127] criteria of inclusion into the sinistral group appear to be too lenient (self classification plus a demonstration of left handed preference on at least three of 10 activities). A further study by Curry[128] classified subjects on the basis of coincidence of reported handedness with hand usage on writing and throwing tasks. No further information is given. Presumably, the sinistrals so classified could belong to any of the three categories described by Satz and co-workers.

Of interest, however, is that all these studies, using varying designs, report essentially the same results. Though the sinistrals obtained superior right ear scores on verbal dichotic tasks, the differences between their ear scores were consistently smaller than the right handers, usually due to the fact that more left handers had superior left ear scores, and also because they tended to show lesser

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126 F.K. Curry and D.R. Rutherford, "Recognition and Recall of Dichotically Presented Verbal Stimuli by Right and Left Handed Persons, Op. cit., 1967.

127 Satz, Achenbach, Pattishall and Fennell, Op. cit., 1965.

128 F.K. Curry, "A Comparison of Left-Handed and Right-Handed Subjects in Verbal and Non-Verbal Dichotic Listening Tasks," Op. cit., 1967.

auditory asymmetries, regardless of ear preference. The hypotheses advanced to account for these results centered around the theory of greater hemispheric equipotentiality in sinistrals.

A more recent study by Knox and Boone was a significant addition since its classification of handedness was based on a tested criterion differentiating strongly left handed and right handed subjects.

> The criterion established for strongly "left-sided" was for each subject to perform at least 80% of all hand-foot motor items on the Lateral Dominance Test with only the left hand or the left foot. Only 11 of 80 left handed subjects tested on the Harris Test of Lateral Dominance met this over-80% criterion. All self-rated right handed matched subjects were found to be strongly right handed by Harris testing demonstrating relative exclusivity of right hand-foot usage.[129]

It is worth noting that these criteria are not necessarily applicable to the strongly left handed dimension described by Satz and co-workers[130] since demonstration of preference is not operationally identical with superior dexterity. Even if these different measures did correlate highly, the high cut-off score of 80 percent could presumably still further differentiate this category, since "strong left handedness" (under Satz, Achenbach and Fennell) was

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129 A. Knox and D.R. Boone, "Auditory Laterality and Tested Handedness," <u>Cortex</u>, Vol. 6, 1970, p. 166.

130 Satz, Achenbach and Fennell, <u>Op. cit</u>., 1967.

defined as any standard score above only +.20 standard score units above a mean reflecting no tested functional asymmetries.

These qualifications should be kept in mind in view of the significant variation obtained in the Knox and Boone study. It was found that on some verbal dichotic tests, increased in difficulty by the use of masking noise and random signal interruption, that the left sided group had significantly higher left ear scores, a finding never before obtained under the other definitions of left handedness. The authors concluded:

> This finding of listening asymmetry related to test confirmed sidedness suggests a strong relationship (our underlining) between sidedness and cerebral dominance for speech and language.[131]

A study by Zurif and Bryden[132] spoke to the variable of incidence of familial sinistrality and its effect on LD's in left handers. This study classified left handedness firstly according to extreme scores on a questionnaire. The selected sinistrals were further broken down into two groups: those having left handed family members and those who did not. It was found that on verbal dichotic listening tasks, non-familials showed a right ear effect of equal

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131 Knox and Boone, *Op. cit.*, p. 172.

132 E.B. Zurif and M.P. Bryden, "Familial Handedness and Left-Right Differences in Auditory and Visual Perception," *Neuropsychologia*, Vol. 7, 1969, p. 179-187.

magnitude to the right handers, while familials were of undetermined asymmetry, with a non-significant trend towards left ear dominance. They showed not only variability in ear preference but weaker auditory asymmetries as well.

These results are at variance with the hypotheses proposed by Satz and co-workers,[133] since the latter predicted a higher probability of left sided speech representation in left handers with familial sinistrality. However, since classification procedures were different, meaningful comparisons are difficult to formulate.

In fact, inter-comparisons of any of the studies mentioned is problematic since all their methodologies vary in some respect regarding the classification of handedness. However, some common trends do emerge, and the probable picture of the relationship between left handedness and speech brainedness appears to have been modified, or at least more clearly articulated. If performance criteria are used, measured left handedness may be related to right speech brainedness in as much as 50 percent of the population, and even more so, when high cut-off scores are used.

In order to disentangle the problems of varying methodologies, it seems that further research in this area

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133 Satz, Achenbach and Fennell, Op. cit., 1967.

should systematically manipulate and possibly attempt to dimensionalize some of the following measures of handedness: performance measures, demonstrated preference measure, criteria for strength of handedness (applied to the previous two variables), sidedness measures (compared to handedness testing alone), and the heredity issue. It seems that only once these factors have been systematically researched and their relationships understood, will a more adequate understanding of causal or genetic factors (if any) involved in the problem of handedness and speech representation be achieved.

Finally, a study by Dee[134] has further complicated the empirical picture and leads to different implications regarding future investigations. This particular study demonstrated that strongly left-handed subjects, classified on the basis of performance measures and a questionnaire, behaved, on both a verbal and non-verbal dichotic task, indistinguishably from strongly right handed subjects. It was the moderately left handed subjects who showed a left ear superiority for verbal materials. In view of the apparent unpredictability of ear asymmetries in left handers, it appears that future research should not only concern itself with the factors mentioned above, but with

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134 H.L. Dee, "Auditory Asymmetry and Strength of Manual Preference," Cortex, Vol. 7, 1971, p. 236-245.

an even more basic question:

> ...it should be noted that the reliability of performance (in terms of test-retest reliability) on dichotic listening tasks in either right or left-handed people is not well established. It is conceivable that left-handers are less reliable with respect to performance on such tasks. All of these problems would appear to be fertile ground for future investigation.[135]

3. Auditory Monitoring of Speech.

In the previous section, we discussed perceptual auditory asymmetries and their relationship to hemispheric differentiation of function. This section will speak to the importance of audition as a regulator of vocal output, preparing for future discussion on the relevance of auditory asymmetry to the speech monitoring role of the ear.

Since the publication of Wiener's Cybernetics,[136] servosystem models have been applied to a wide variety of problems concerning control and communication, from the engineering of anti-aircraft guns to the understanding of biological organizations such as the central nervous system. We will discuss here only a few basic concepts, essential for an understanding of what is to follow.

Cybernetics considers mainly two kinds of systems, the open and closed loop types. In the former, a number of

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135 Ibid., p. 243.

136 N. Wiener, Cybernetics, New York, Wiley, 1948.

steps is carried out regardless of the performance of the system at any stage; for example, a musical box. In the closed loop system, or servosystem, information regarding the ongoing performance of the unit is continuously fed back to it such that it can be informed of any errors in its performance and correct them. The thermostat would be an example of the latter type.

The closed loop or servosystem has obvious application to any form of neurological organization where the brain's efficient regulation of the various bodily systems is contingent upon feedback from these systems. In 1954, Fairbanks[137] proposed a servosystem model of the speech mechanism, where auditory feedback especially, but also tactile and proprioceptive feedback, served as ongoing regulators of vocal output. The reader is referred to Fairbanks for a more detailed description. For our purposes, we need only mention that in this model, both ears performed identical roles.

The impetus of Fairbanks' servosystem model came from an attempt to explain the disruptive effect on speech of delayed auditory feedback (DAF). The phenomenon was

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137 G. Fairbanks, "Systematic Research in Experimental Phonetics: I. A Theory of the Speech Mechanism as a Servo Mechanism," Journal of Speech and Hearing Disorders, Vol. 19, 1954, p. 133-139.

first reported by Lee[138] and since then has been extensively researched. It involves essentially a situation where the subject hears his own voice through headphones with a delay (usually about one-fifth of a second) while reading aloud. The area has been reviewed by Smith,[139] Yates[140] and more recently by Van Riper.[141]

We will summarize here only the more unequivocal findings essential to a proper understanding of the phenomenon. Generally, under DAF, rate and intensity of speech increase, and the fundamental frequency of the voice rises. Several types of articulatory errors tend to occur: mispronunciations, omissions, substitutions as well as marked changes in fluency. However, the authors report that the bulk of errors involve repetitive duplications of sounds and syllables resembling stuttering.

Individuals differ in terms of the delay interval which produces maximal disruption, but in most young adults

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138 B.S. Lee, "Effect of Delayed Feedback on Speech," Journal of Acoustic Society of America, Vol. 22, 1950, p. 824-826.

139 K.U. Smith, "Delayed Auditory Feedback," Sensory Feedback and Behavior, Philadelphia, W.B. Saunders, 1962.

140 A.J. Yates, "Delayed Auditory Feedback," Psychological Bulletin, Vol. 60, 1963, p. 213-232.

141 C. Van Riper, "Stuttering as the Result of Disturbed Feedback," The Nature of Stuttering, New Jersey, Englewood Cliffs, 1971.

it tends to range from .16 to .22 seconds. McKay[142] has recently shown that young children's speech is more disturbed by DAF than that of adults, but the delay times necessary to produce maximal speech disruptions are much longer. Buxton[143] reports that for the aged, the critical delay time is also longer than for young adults.

Degree of disturbance is also highly related to intensity of DAF, the more important factor being that sound pressure level of the DAF signal must be greater than that of the subject's own speech. Binaural delay causes more disturbance than monaural delay. Regarding all the above, most investigators report marked individual differences, even within an age range, in a subject's reaction to DAF, much of this variance remaining unexplained. Some relationships have been found between degree of disturbance and verbal facility (Arends and Popplestone[144]) as well as degree of rapidity of speaking (McKay[145]); also, some

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142 D.G. McKay, "Metamorphosis of a Critical Interval: Age-Linked Changes in the Delay in Auditory Feedback that Produces Maximal Disruption of Speech," Journal of the Acoustic Society of America, Vol. 43, 1968, p. 811-821.

143 J.F. Buxton, "An Investigation of Sex and Age Differences," Speech Behavior Under Delayed Auditory Feedback, Unpublished Doctoral Dissertation, Ohio State University, 1969.

144 C.J. Arends and J.A. Popplestone, "Verbal Facility and Delayed Speech Feedback," Perceptual and Motor Skills, Vol. 9, 1959, p. 270.

145 McKay, Op. cit.

variability has been found with respect to personality.

Though the issue is somewhat controversial, investigators report little adaptation to binaural DAF. By the use of certain strategies, some subjects manage to avoid articulation errors but the alteration of their normal rate of speech remains. If adaptation is taken to mean a return to the normal flow and rhythm of the speaker, then it can be said not to occur to any significant degree.

As the above demonstrates, research using DAF has demonstrated the importance of auditory feedback in the control of the speech process and helped to promote the conceptualization of linguistic organization along cybernetic lines. More specifically, though controversy presently exists as to the kinship of speech disturbance under DAF and genuine stuttering behavior (Wingate[146]), DAF has greatly affected thinking and research regarding the problem of stuttering.

Recently, Van Riper has addressed his book to the hypothesis that stuttering is basically a disorder in timing.

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146 M.E. Wingate, "Effect on Stuttering of Changes in Audition," Journal of Speech and Hearing Research, Vol. 13, 1970, p. 861-873.

> ...a temporal disruption of the simultaneous and successive programming of muscular movements required to produce one of the word's integrated sounds, or to emit one of its syllables appropriately or to accomplish the precise linking of sounds and syllables that constitutes its motor pattern.[147]

Viewed in the perspective of a timing disorder, feedback considerations become paramount in importance.

> Information about the speech output is returned to the central integrating mechanism through six auditory channels, via the right and left feedback routes from (1) airborne side-tone, (2) bone-conducted side-tone, and (3) tissue conducted side-tone. Other feedback signals come from the kinesthetic tactile proprioceptive sensors on both sides of the body. Stromsta (1962) showed that the auditory feedback signals in these different channels arrive at markedly different times and that the temporal information-processing of speech output by the brain is very complex. Some central mechanisms for integrating all these feedback signals must be present, although their nature is not yet known... All we are saying is that there is ample opportunity built into the system that we use in monitoring our speech for the kinds of signal distortion, interference, or overload which could lead to stuttering.[148]

The relevance of stuttering to this paper lies not only in its plausible exemplification of the importance of auditory control of phonation as indicated above, but especially, within its conceptualization as a disorder of timing, to its possible relationship with cerebral dominance and auditory asymmetries. Consideration of this latter aspect

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147 Van Riper, Op. cit., p. 404.

148 Ibid., p. 383-384.

has early historical roots.

As Van Riper states:

> The theory that a lack of cerebral dominance creates mistiming of the motor impulses to the bilateral speech muscles and thus produces stuttering was first formulatedby Stier (1911) and by Sachs (1924), but it received its early acceptance through the writings of Orton (1927) and Travis (1931). More recently it lost former popularity largely because of research which cast doubt on the scanty evidence that stutterers showed mixed sidedness or had been shifted in their handedness.[149]

In view of the previously discussed complexities of the relationship between sidedness and cerebral dominance as well as of the methodological inadequacies involved in the classification of handedness, it is no wonder that the issue became shrouded in confusion and disrepute. However, since the new methods for assessing cerebral dominance bypass the need to consider sidedness, their beginning application to the problem of assessment of cerebral laterality of stutterers deserves some detailed consideration.

Jones[150] administered the sodium amytal technique, both pre and post-operatively, to four patients who had been severe stutterers since childhood and who had recently developed brain pathology. He found on pre-operative

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149 *Ibid*., p. 351.

150 R.K. Jones, "Observations on Stammering After Localized Cerebral Injury," *Journal of Neurology, Neurosurgery and Psychiatry*, Vol. 29, 1966, p. 192-195.

testing that all four stutterers gave clear evidence of bilateral speech representation. Following unilateral surgical intervention, complete remission of the stuttering problem occurred in all four patients. Results on the post-operative amytal test indicated unilateral representation of speech. The author also reports that the clearing of the stuttering problem has maintained itself post-operatively in all cases, the longest period at the time of the article being twenty-seven months.

Van Riper[151] quotes similar cases where unilateral surgical intervention was associated with the disappearance of stuttering.

Obviously, no causal or exclusive relationship between cerebral ambilaterality and stuttering can be inferred from so few cases. There also remains to be explained the fact that many patients showing ambilateral speech representation (as tested by the amytal technique) do not stutter. In this regard, Jones' explanation appears too hasty:

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151 Van Riper, Op. cit., p. 352.

> Though bilateral speech representation occurs in persons who do not stammer, stammerers are unfortunate in having this bilateral representation for speech so evenly balanced that incoordination in the speech effort, in the form of stammering, results.[152]

If the technique could be administered to a great number of stutterers, the relevance of speech ambilaterality to stuttering could be appropriately weighted. However, the dangers involved render this methodological approach untenable.

Using the dichotic technique, however, a study by Curry and Gregory[153] has provided further support for the hypothesis. This study showed that the size of LD's obtained on a dichotic listening task was significantly smaller in a group of twenty right handed adult stutterers as compared to a control group of normal subjects ($p<.005$). Furthermore, eleven out of these subjects had higher left ear scores.

A more recent study by Slorach and Noehr,[154] however, found that a group of right handed stuttering

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152 R.K. Jones, "Dyspraxic Ambyphasia: A Neurophysiologic Theory of Stuttering," Transactions of the American Neurological Association, Vol. 92, 1967, p. 199.

153 F.K. Curry and H.H. Gregory, "The Performance of Stutterers on Dichotic Listening Tasks Thought to Reflect Cerebral Dominance," Journal of Speech and Hearing Research, Vol. 12, 1969, p. 73-82.

154 N. Slorach and B. Noehr, "Dichotic Listening in Stuttering and Dyslalic Children," Cortex, Vol. 9, 1973, p. 295-300.

children did demonstrate a statistically significant right ear effect and did not behave differently from a control group.

Overall, the studies reported here do provide new signs of life to the cerebral dominance theory of stuttering, inferring that without a single dominant centre to organize the timing of the bilateral impulses to the peripheral paired speech muscles, the motor sequences tend to be disorganized or disrupted. In view of the availability of the dichotic technique, it can be expected that future research will help to articulate and provide further statistical support for this relationship.

Stuttering will again be alluded to in the next section in the context of Tomatis' conception of the "oreille directrice."[155]

4. Auditory Asymmetry in the Control of Phonation.

The previous section, dealing essentially with DAF, demonstrated the importance of audition in the control of phonation and its impact upon the theory of stuttering. Within the domain of stuttering theory, the importance of cerebral asymmetry was also considered. We will now address ourselves specifically to the relevance of auditory asymmetry

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155 A. Tomatis, L'oreille et le Langage, Paris Edition du Seuil, 1963.

in the regulation of phonation. We will deal first with studies reflecting on the effect of asymmetry on the control of parameters of motricity other than phonation. Secondly, we will describe the context of the derivation of Tomatis' notion of the "oreille directrice." Finally, three studies dealing quite specifically with the topic considered in this experiment will be examined in detail.

In two recent studies,[156,157] Kimura has demonstrated a relationship between asymmetries in free movements of the hands to hemispheric dominance for language, as inferred from laterality differences obtained on a dichotic listening task. That is, right ear dominance was related to a significantly greater number of free movements with the right hand while subjects were engaged in speaking behavior. Furthermore, only seven of the 65 right handers in the first study showed a greater number of free movements with the left hand. Of the six who were tested on the dichotic task, four had higher left ear scores.

The results for left handed and ambidextrous subjects tested in the second study were less clear-cut. These subjects were classified into two groups: those

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156 D. Kimura, "Manual Activity During Speaking- I. Right Handers," Neuropsychologia, Vol. 11, 1973, p. 45-50.

157 D. Kimura, "Manual Activity During Speaking- II. Left Handers," Neuropsychologia, Vol. 11, 1973, p. 51-55.

showing right and left superiorities on the dichotic task. For both groups, a greater absolute number of free movements were produced by the left hand. However, the movement asymmetries favoring the left hand were larger for the left ear dominant - left handed group. For the right ear dominant - left handed group, the differences were minimal. Kimura suggests that the most plausible explanation of these results would involve a reference to the more frequent bilateral cortical representation of language functions in left handers.

> Given a connection between speaking and gesturing, it is reasonable to suppose that where speech is not unilaterally organized, gesturing should also be manifested less unilaterally.[158]

Simon[159] performed an auditory reaction time experiment requiring his subject to depress a key on hearing a 1000 cps stimulus tone presented to either the right or left ear, or both ears simultaneously. In his series of three experiments, he manipulated age, sex, responding member and handedness. In the first two experiments,

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158 Ibid., p. 54.

159 J.R. Simon, "Ear Preference in a Simple Reaction Time Task," Journal of Experimental Psychology, Vol. 75, 1967, p. 49-55.

where subjects did not know prior to a trial which ear would be stimulated, response to right ear stimulation was quicker than to the left ear, regardless of body member used. However, when subjects were informed in advance as to which ear would be stimulated, the differences previously noted were no longer apparent. The author explains his results using an expectancy theory under conditions of uncertainty, the latter condition being omitted when subjects were pre-advised.

A more recent study by Haydon and Spellacy[160] fully supports Simon's results. This experiment also checked for reaction times to speech sounds (CVC syllables) as well as pure tones. As in Simon's study, reaction times to right ear stimulation were faster for both stimulus conditions when subjects were uncertain as to the site of the stimulation. The asymmetry disappeared when subjects were pre-advised as to which ear would be stimulated.

In an attempt to control for attentional factors, and to further verify if competitive input was a prerequisite for eliciting a laterality effect, Sussman[161] performed an experiment using pursuit auditory tracking.

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160 S.P. Haydon and F.J. Spellacy, "Monaural Reaction Time Asymmetries for Speech and Non-Speech Sounds," _Cortex_, Vol. 9, 1973, p. 288-294.

161 H.M. Sussman, "Laterality Effects in Lingual Auditory Tracking," _Journal of the Acoustic Society of America_, Vol. 49, 1971, p. 1874-1880.

The objective in such a task is to match a cursor stimulus with a variable target stimulus, the auditory stimuli in this case being tones varying from 100 to 1300 Hz. In this experiment, the target tone was externally controlled by a computer, and the subject's task was to match this target tone (presented to one ear) with a cursor tone (presented to the other ear). The subject controlled the cursor tone with his tongue movements, lateral displacements of the tongue being translated into frequency variation and fed back as such to the subject. Stated differently, the difference between the two auditory signals is that the cursor tone is under the active closed loop motor control of the major speech articulator, the tongue, whereas the subject has no control over the target signal, randomly generated by the computer. The author further checked on the effect of tongue anesthesia on the subject's tracking ability in order to assess the relevance of somesthetic feedback on the laterality issue.

The study showed that tracking performance was significantly superior, when the tongue cursor tone (controlled by the subject) was presented to the right ear and the target tone to the left ear, as opposed to the reverse condition. Secondly, this laterality effect was significantly accentuated under the anesthetic condition.

In his discussion, Sussman states:

> Since the task required the subject to monitor both tones simultaneously and respond accordingly, there was no direct competition between the inputs to the left and right ears, and, furthermore, the subject could not selectively attend to one input while neglecting the other. Both signals had to be jointly processed so that tracking could be performed at a satisfactory level.[162]

In view of these conditions, the author feels that the appearance of a right ear superiority in the processing of non-speech acoustic input, has put the laterality question in a different focus. Since the stimuli were continuously varying pure tones, the left hemisphere superiority indicated here cannot refer to the processing of speech sounds. Sussman speculates that the results could be due to the following type of process:

> The left hemisphere is especially adept at integrating the afferent discharges from the speech musculature with the resultant self-generated auditory input. The functional prepotency of the contralateral pathway for speech processing, as first proposed by Kimura (1964), can now be extended to include a functional prepotency of the sensorimotor feedback channels from the tongue to the left hemisphere.[163]

This position seems to obtain further corroboration in view of the heightened laterality effect obtained under the anesthetic condition.

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162 Ibid., p. 1877.

163 Ibid., p. 1878.

> It is to be expected that the speech dominant left hemisphere, which has built up a sophisticated monitoring system for detecting tongue position during speech, is more capable of operating under conditions of reduced redundancy as compared to the right hemisphere. Therefore, when the tactual feedback modality is grossly diminished, the right hemisphere "suffers" relatively more than the left and the over-all processing differences between the two hemispheres are accentuated.[164]

Sussman's experiment speaks to the importance of the integration of various feedback relationships in the control of movements of the speech articulators, but also, to the relevance of laterality effects (the right ear-left brain system) in this control relationship. As the authors note, their results with the laterality effect point in another direction from speech perception, i.e., speech production.

With Tomatis' theory, we turn specifically to this aspect. His theory of the "leading ear,"[165] emerging in the early fifties, was also embedded in a cybernetic framework. Tomatis' work with voice professionals between 1946 and 1951, led him to conclude as to the regulatory function of audition in the control of phonation. He had been impressed by the fact that there was little correspondence between classical anatomical description (in terms of the

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164 Ibid.

165 A. Tomatis, "Le Bégaiement: Essais de Recherche sur sa Pathogénie," Bulletin du Centre d'Etudes et de Recherches Médicales de la S.F.E.C.M.A.S., Juin 1953, 21 p.

size of the larynx) and the voice qualities expected from exceptional voice professionals. He relates that direct intervention on the larynx (for example using strychnine) did not help them regain their loss of tonal control. He had also been impressed by the fact that structural damage to the phonatory organs could be compensated for.

He began administering audiograms to his clients and found in several cases a systematic evolution of a hearing deficit paralleling phenomena obtained in cases of industrial deafness. After measuring the intensity of these individuals' vocal output while singing, Tomatis concluded that they emitted enough intensity to gradually deafen themselves. As he charted the course of hearing loss, he found that specific audiometric patterns were reliably correlated to specific problems of voice control. He further verified the relevance of the effect of audition on phonation, by using masking noise and band pass filters introduced into the subject's airborne feedback. Within this background of experience with the audiometric patterns of renowned musicians and voice professionals, he[166] went on to specify the general audiometric patterns of a musical ear, i.e., an ear capable of appreciating and controlling the accuracy of musical reproduction.

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166 A. Tomatis, "L'oreille Musicale," Journal Français d'Oto-Rhino-Laryngologie, Février 1953, No. 2.

Besides the regulatory function of the auditory system in general, Tomatis further claimed that the proper cybernetic control of vocal output requires the functional dominance of one ear (oreille directrice) as the control monitor. This conclusion was derived from his work both with voice professionals and stutterers.

Regarding the former, Tomatis[167] relates that in his experiments using masking noise and band pass filtering inserted in the auditory feedback of his subjects, phonatory reactions to interference with the right and left ears were not identical. Using a highly trained professional, he found that masking or suppression of inputs to the subject's left ear did not significantly modify his singing performance while the same interference with the right ear altered the quality of timbre and tonal accuracy, the most marked effect being a considerable slowing down of rhythm.

He later repeated this experiment with a well known actor who was merely requested to speak normally. In this case, when the right ear was interfered with, tempo did not only slow down, but there were even syllable reduplications and indices of blocking similar to stuttering phenomena. This not only led Tomatis to hypothesize that the notion of

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167 Tomatis, Op. cit., 1963.

the "oreille directrice" applied to the control of normal speech as well as singing, but also to investigate the problem of stuttering in terms of auditory dominance.[168]

Tomatis states that the former hypothesis was frequently reverified and supported, though the rhythmic disturbances infrequently involved stutter-like behavior. He summarizes the results as follows:

> Sur une voix assurée, solidement placée, bien affirmée dans son timbre, dans son rythme, le jeu de suppression de l'une ou l'autre oreille entraîne en règle les constatations suivantes: la voix écoutée des deux oreilles libres se trouve perturbée dès que l'on atteint l'oreille de visée auditive, l'oreille de contrôle. Cette perturbation se remarque sur le timbre. La voix s'aggrave et se détimbre tout à coup. Il n'y a que peu de possibilités de dérogations à cette épreuve.
>
> Les troubles du rythme sont plus variables et pratiquement spécifiques de chaque individu. Ce n'est pas toujours un bégaiement que l'on trouvera comme il nous a été donné de la contrôler d'emblée, mais le rythme subit toujours une modification qui se caractérise par un allongement de la durée de la coulée verbale, associée à des irrégularités plus ou moins marquées, à des freinages.
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> Il s'agit bien là, comme nous l'avons précisé dans le cas présent, de la recherche de la détermination de l'oreille directrice chez des sujets dotés d'une bonne voix. Il nous est apparu rapidement que les voix mal assurées, peu riches, difficiles à extérioriser, répondaient souvent à des contrôles auditifs encore mal conditionnés ou non élaborés.[169]

In the last paragraph of this quotation Tomatis suggests that the demonstration of the leading ear, in terms

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168 Tomatis, "Le Bégaiement," Op. cit., 1953.

169 Tomatis, Op. cit., 1963, p. 136-137.

of its effects on phonation, is not always apparent, because auditory dominance, in the strict cybernetic sense in which Tomatis considers this term, is a developmental acquisition subject to pitfalls, and may in some subjects be poorly elaborated.

This reflects upon his earlier and later views regarding stuttering behavior. In his earlier writings,[170,171] he suggested that stuttering was due to perceptual distortions analogous to those caused by DAF. He stated that stutterers monitor their speech with the ear opposite that which should be dominant (the dominant ear at this stage in his theory being equated with sidedness measures and thus presumably opposite the hemisphere invested with language functions). Consequently, feedback from their vocal output would presumably have longer transit times, going from the non-dominant ear, to the opposite hemisphere, and via the corpus callosum to the dominant hemisphere. This lag in transit times would produce disruptions in the temporal monitoring of speech similar to those obtained under DAF.

His later formulations considered that stuttering behavior was caused by a lack of development of dominance

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170 Tomatis, "Le Bégaiement," Op. cit., 1953.

171 Tomatis, "Relations entre l'Audition et la Phonation," Annales des Télécommunications, Tome II, Juillet-Août 1956, p. 3-8.

in auditory controls, emphasizing that such a situation renders the coordination of vocal output with auditory feedback cybernetically troublesome. In the context of his later formulations, he became interested in the ontogenesis of auditory dominance and its relationship to somesthetic laterality and language development. Within the clinical orientation of his work, he invented an apparatus, the Electronic Ear, which, among other aspects, promotes unilateral auditory control of speech.

Using Tomatis' theory and Kimura's first studies with the dichotic technique as background, an unpublished doctoral dissertation by Roode[172] attempted to experimentally verify the notion of auditory dominance on the level of speech monitoring and its relationship to hemispheric language laterality. Dichotic tapes being unavailable at the time, he assumed speech lateralization on the basis of exacting criteria of sidedness, including handedness, footedness, eyedness and earedness. The latter criterion required that the dominant ear have a mean acuity score superior to the non-dominant ear.

Two groups were formed, twenty completely right-sided and ten completely left-sided subjects according to

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172 C.D. Roode, An Experimental Study of Auditory Asymmetry and Cerebral Language Laterality, Unpublished Doctoral Dissertation, University of Ottawa, 1963.

the above criteria. The subjects were exposed to four conditions: binaural direct feedback, binaural delayed feedback, monaural delayed feedback to the dominant ear with direct feedback to the non-dominant ear and the reverse of the above. The main interest of the study involved a comparison of the latter two conditions. Roode decided to use DAF because of its known disruptive effect on speech, hypothesing that monaural delayed auditory feedback to the dominant ear would cause more speech disturbance than similar interference to the non-dominant ear. He used a combination of direct and delayed feedback in the latter two conditions because of the evidence that perceptual laterality differences only emerged under competitive listening conditions.

His dependent variables included percent phonation time (a ratio of phonation time to total speaking time), mean syllable duration (phonation time divided by the number of syllables in the text to be read), and mean intensity.

On the mean syllable duration variable, the predicted dominance effect was obtained at statistically significant levels in both the right sided and left sided groups, i.e., right siders had longer mean syllable durations with DAF to the right ear than the left ear, and left siders showed the reverse. Roode concluded that auditory dominance on the level of speech monitoring, as well as its crossed relationship to speech brainedness, was supported by his study, and that servosystem models should incorporate such asymmetries.

Presumably unaware of either Tomatis' or Roode's work, Abbs and Smith related the research on DAF to the by then established results with the dichotic paradigm and formulated the following hypothesis:

> If externally produced speech is perceived by the same system that a listener uses to monitor and perceive self-produced speech, it could be assumed from the above-cited findings that auditory feedback to the right ear would be more critical in influencing speech production than auditory feedback to the left ear.[173]

The sample included eight females, and no details on handedness or tested auditory dominance were given. In this design, masking noise was presented to the ear not receiving DAF and four intervals of delay were used (0.0, 0.1, 0.2, 0.3 sec.). The dependent variables included a measure of total speaking time as well as number of articulation errors.

The authors report that, at delay intervals of 0.2 and 0.3 seconds, delayed feedback to the right ear with masking noise on the left resulted in significantly greater number of articulation errors in speech than did the reverse

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173 J. Abbs and K.U. Smith, "Laterality Differences in Auditory Feedback Control of Speech," Journal of Speech and Hearing Research, Vol. 13, 1970, p. 298.

condition. No significant differences were found in the total speaking time variable. The authors conclude:

> Overall, the experimental findings confirm the assumption that guided the design of the study: that auditory input during speech encompasses the differential function of the two ears in controlling speech production.[174]

Regarding the absence of a dominance effect for the total time variable, the authors state the following:

> These differences in reaction of the two ears to different feedback parameters of speech may mean that vowels, where most elongation under delay occurs (Abbs, 1968), are monitored equally for feedback control by both ears, while consonants (where most articulatory errors occurred, 20 consonant errors : 1 vowel error) are monitored primarily by the right ear. Vowels, however, may be controlled adjunctly by feedback channels other than the auditory, i.e., proprioceptive or tactile.[175]

While these two studies do support the existence of auditory asymmetry in the control of phonation, they do not appear to agree on the parameters affected. However, this could be due to differences in the measuring operations. Regarding time measurements, Roode's mean syllable duration variable is based on phonation time only, while the total speaking time measurement in the Abbs and Smith study includes both phonation time and pause time. Secondly, Roode did not provide for a separate measure of articulation

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174 <u>Ibid</u>., p. 302.

175 <u>Ibid</u>.

errors, hence no direct comparison is possible. Thirdly, Roode's mean syllable duration variable might possibly reflect variance due to articulation errors, since repetition errors especially would tend to relate directly to increments on this variable.

In an attempt to clarify these issues and to relate asymmetries in the control of phonation to asymmetries on a verbal dichotic task, Dionne[176] performed a study similar to Roode's regarding the various conditions except that the binaural delayed auditory feedback condition was omitted. The sample consisted of thirty-one university student volunteers, classified into three groups according to their right ear percentage of total correct recall on a dichotic word test. This dimension was called Degree of Auditory Asymmetry and the groupings were composed of five left ear dominant subjects (37.1-45%), eleven who demonstrated no marked asymmetries (48.4-55.8%), and fifteen who showed definite right ear dominance (60.0-79.2%). The purpose of this classification was to ascertain if the degree of perceptual auditory dominance (as defined by the direction and size of between ears differences on the dichotic task) was related, if at all, to the comparative amount of speech

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176 M. Dionne, Degree of Auditory Asymmetry in the Control of Phonation, Upgrading Paper, University of Ottawa, April, 1974.

impairment obtained between the conditions of delayed feedback to the right and left ear. The speech measures included not only total speaking time but also its components, phonation and pause time, as well as a measure of articulation errors.

It was found that disturbance to the right ear caused subjects to produce significantly more phonation time and errors than disturbance to the left ear, regardless of degree of auditory asymmetry. Results on the total time variable showed only a non-significant trend because of the effect of pause time, where no indication of speech monitoring asymmetries was present. Regarding the relationship of perceptual and speech asymmetries, however, inspection of the means indicated that the magnitude of the speech monitoring laterality effect increased directly in relation to degree of auditory asymmetry for temporal measurements only. Analysis of variance using difference scores did not report this trend as significant but the relationship between these two dimensions as assessed by correlation was the following: for Total Speaking Time, $r = .30$ ($p < .05$), and for Phonation Time, $r = .21$ ($p > .05$).

Dionne concluded that the presence of auditory asymmetry on the level of speech monitoring appeared to be a reliable phenomenon, and that both temporal and articulatory aspects of speech output were susceptible to the effect. He suggested that a measure of time, uncontaminated by the unpredictable loadings of error variance, would be far more conclusive in this respect.

The author further concluded that the study had not clarified the relationship, if any, between perceptual and speech monitoring asymmetries but had at least suggested some trends with regard to time variables. He proposed that more adequate verification of this relationship would obtain if extreme groups, especially of the left ear dominant type, could be manipulated.

5. Summary and General Hypothesis.

In view of the evidence reviewed here, it appears that the notion of auditory dominance on the level of perception can be considered a proven fact. An asymmetry of the speech monitoring function of the ear also seems quite plausible.

In this latter respect, we have reviewed four studies dealing with the relationship between laterality differences in auditory perception and asymmetries in body movement, measured by differentials in the free movement of the hands and speed of reaction time to right and left ear input. Another study was described where an asymmetry favoring the right ear was related to the accuracy of performance in a pursuit auditory tracking task. This latter study was embedded in a servosystem framework and pointed to the relevance of a right ear effect in speech production. Tomatis had stated this relationship much earlier, but remained relatively unknown and his findings were not statistically confirmed. We saw that Roode, aware of Tomatis' work, presented an unpublished dissertation bearing directly on this topic in 1963, and Abbs and Smith, presumably unknowing of either Tomatis or Roode, published their study in 1970. We further noted that the results of these latter two studies supported the reality of auditory asymmetry in the control of phonation but appeared contradictory with regard to the speech parameters affected.

Dionne's study indicated that speech asymmetries could be demonstrated for both time and errors but that such asymmetries were not predictably related to dichotically defined left ear dominance, except, possibly, when time measures were considered.

The present study will deal with the same general hypothesis and be of the same basic design as the author's former experiment, where the rationale for that design is described. It will investigate two suggestions proposed in the former experiment, namely, the inclusion of a speech measure which is free of contamination by error variance and the manipulation of a more extreme left ear dominant group in the sample.

Furthermore, the design will incorporate a unique addition to research in dichotic listening: longitudinal assessment of auditory dominance. Within the sample used, to be described in the following chapter, periodic assessment of dichotic listening performance has revealed that most subjects maintain the direction of their ear superiority over time, but that others fluctuate from right to left ear dominance and vice versa, occasionally within brief time spans. Such findings may have considerable bearing on the meaning of laterality differences in auditory perception and will be discussed later on. The decision to include stability of auditory dominance in the design was taken in order to verify if stability was a significant dimension in the relationship between perceptual and speech monitoring asymmetries.

The following chapter will specify and elaborate on the general hypothesis and describe the experimental design.

CHAPTER II

EXPERIMENTAL DESIGN

The present chapter will attempt to give a precise description of the sample and criteria used for the formation of groups, the instrumentation and its functions, of testing procedures, the dependent variables, and finally, of the statistical design and hypotheses.

1. The Sample.

The sample consisted of thirty-six children, 21 boys and 15 girls, from the Child Study Centre of the University of Ottawa. Ages ranged from 7 years and 6 months to 13 years and 7 months with a mean of 10 years and 5 months and a standard deviation of 21 months. This sample was selected because the children involved have been repeatedly tested with a dichotic listening task, thus providing a longitudinal appraisal of their auditory asymmetry. This data had been gathered as part of a diagnostic psychological battery used at this Centre. Therefore, a detailed description of the concerned records follows. This description refers to dichotic testing done since January, 1967.

a) Description of the records. - This description will be organized from the point of view of constancies and inconstancies of the testing procedure.

The factors that remained constant are the following: type of material, rate of presentation, test construction, instructions, scoring, acoustically controlled facilities and control of hearing loss.

The digits from 1 to 9 were used on all Dichotic Digits Tests (DDT). The same digit never occurred twice on a trial and the same voice was used on both channels. Rate of presentation of each dichotic pair was one pair per second.

Regarding test construction, with the tape recorder used, it was possible to record on one track and to simultaneously monitor the playback on that track while recording on the other track. The recorder achieved relative equalization of intensity himself on the VU meters providing level readings for the record mode of the tape recorder. Satisfactory equalization of levels and synchronization of onset were thus obtained. Possible inequalities were compensated for by repeating the task with the earphones reversed.

Instructions indicated that subjects were to repeat as many digits as they could, in any order they liked. Enough time was provided between trials for subjects to repeat the digits. However, if they needed more time, the tape recorder was stopped appropriately. Scores were assigned to each ear according to the number of digits repeated correctly.

On all tests, the subject was seated in a sound proof room (I.A.C.) and equipped with stereo earphones (Telephonics, Model TDH 39). The examiner was in another room where he controlled a speech audiometer (Maico Model MA-24). The output from the two channels of the tape recorder fed the two-channel speech audiometer. The two VU meters on the control panel of the latter permitted an ongoing evaluation of the strength of the signal feeding both earphones.

Also, concurrent with every DDT, a pure tone audiogram was administered to each ear, thus permitting an evaluation of the effects of hearing loss, if any, on the subject's performance.

The following were regarded as inconstancies: language used on the tapes, number of digit pairs within each trial, length of the test, number of test administrations per subject and length of interval between test administrations.

To accommodate both linguistic groups, there were two French and two English tapes. The majority of the testing was done in English (French DDT's were administered to only four of our 36 subjects). The operations involved in the construction of both sets of tapes were identical except for the language used.

Within each language set, one tape consisted of forty 3-digit pairs and the other of thirty 4-digit pairs. The test consisted of two presentations of these forty or 30 pairs, earphones being switched around for the second presentation. Consequently, in each case, the total number of digits presented was 480, i.e., (2 x 40 x 6) or (2 x 30 x 8).

The records showed that from January 1967 to May of 1971, the (2 x 40 x 6) administration was constant. After this date, the (2 x 30 x 8) occurred as well as shortened versions of both tests, i.e., (2 x 20 x 6) and (2 x 15 x 8). The 4-digit pair test was usually administered to older children and to those younger children whose total score was quite high on the 3-digit pair test. The shorter form was used as a function of time pressure or of the testee's cooperative and attentional abilities.

The number of test administrations is related to the amount of time the child spent at the Child Study Centre, and therefore varies. Figure 1 illustrates the frequency of the various number of DDT administrations including the test administered just prior to the experiment.

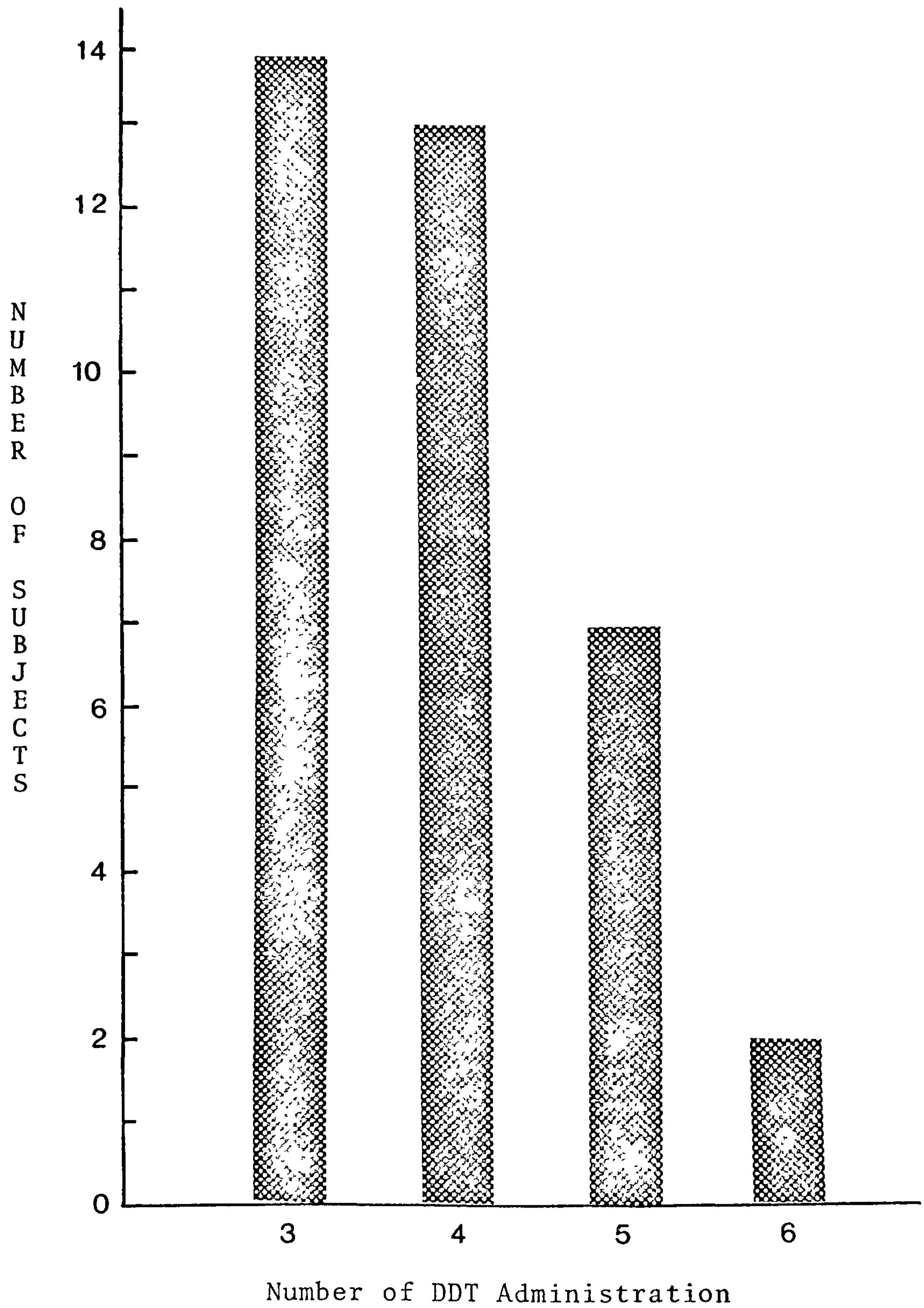

14
12
10
8
6
4
2
0
NUMBER OF SUBJECTS
3
4
5
6
Number of DDT Administration

Figure 1.

Also, since the data was not collected with the experiment in view, the length of the interval between DDT administrations was a function of other decisions. The size of this interval was markedly reduced after 1970 when the DDT was used not only for initial diagnostic appraisal but for regular follow-up assessments. Figure 2 provides a frequency distribution of the various interval lengths between DDT administrations.

Twelve of the 13 one-month and nine of the 13 two-month intervals between tests refer to the interval of the test just prior to the experiment and the DDT administered before that. Consequently, the frequent occurrence of these intervals do not reflect a testing policy but rather that the DDT for this study happened to occur, within the ongoing testing program, at these intervals in approximately half the subjects.

In all intervals above fourteen months, at least one of the dichotic tasks involved in the calculation was administered prior to 1970 when the DDT was not used as yet as part of a follow-up program.

To render this pool of data comparable, raw scores were converted into percentages using the formula:

$$\frac{\text{Right ear digits reported accurately}}{\text{Total number of digits reported accurately}} \times \frac{100}{1}$$

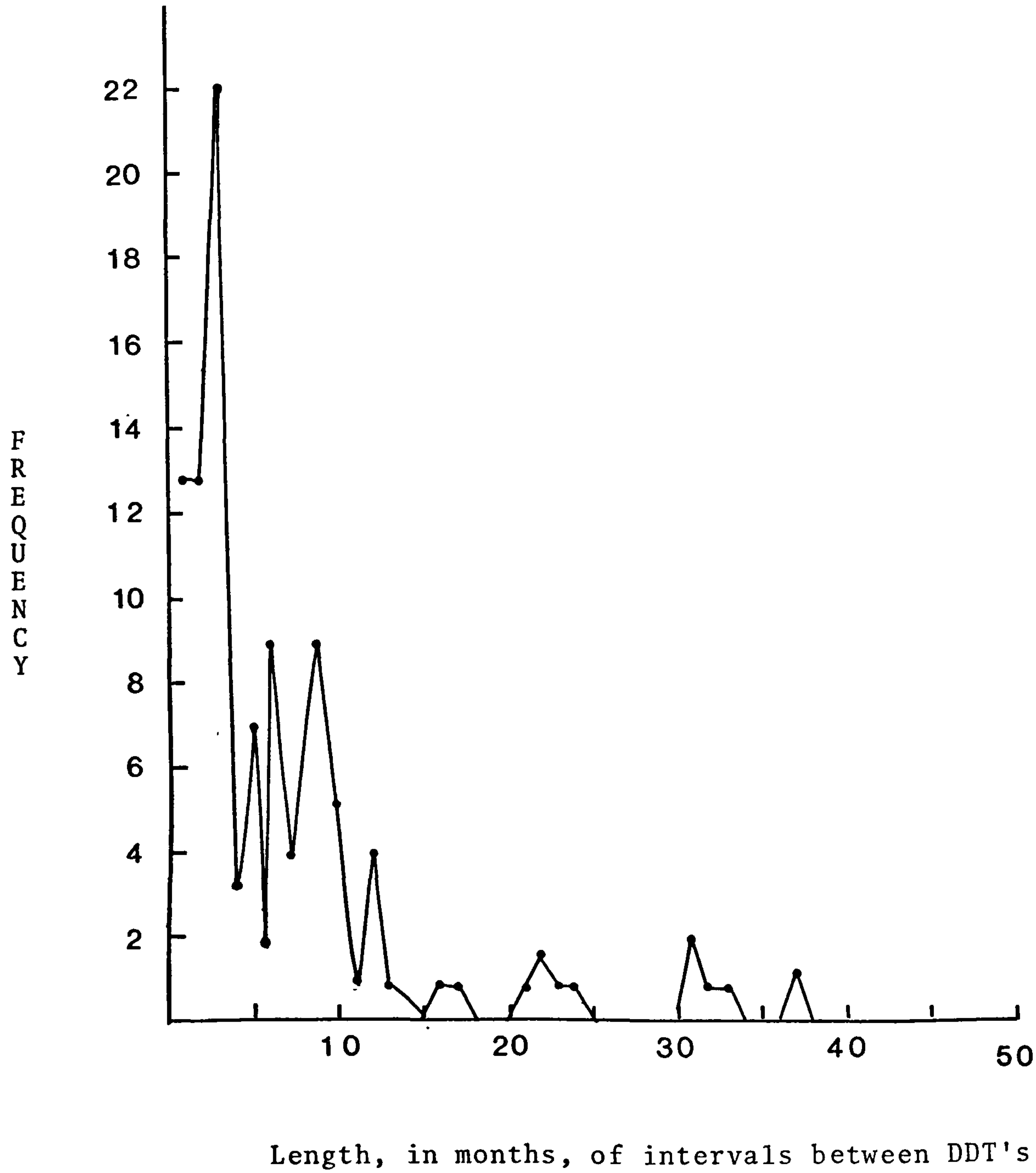


Figure 2. Frequency distribution of interval lengths between dichotic digit administrations.

The left ear percentage score was obtained by subtracting the right ear score from 100.

With the data organized in this fashion, definite patterns emerged from the records which suggested a longitudinal definition of auditory dominance that could advantageously be built into the design.

b) Criteria for the formation of groups.-

Inspection of the records revealed that the majority of the children showed a right ear superiority on the DDT. However, there were enough left ear dominant children to constitute a group in the study. Furthermore, it was found that the majority of children maintained the same auditory dominance (whether right or left) over the various testing sessions while a smaller group shifted from a right to a left ear dominance and vice versa. Consequently, the notion of stability of auditory dominance was integrated into the design of the study which was then to deal with four groups: stable right ear dominant, stable left ear dominant, unstable right ear dominant and unstable left ear dominant.

The following criteria were decided upon for inclusion into the stable group: including the DDT immediately prior to the experiment, the DDT had been administered at least three times and that in all these testing sessions the subject's dominant ear (right or left) was at least three percent superior to the non-dominant ear. If more than three test results were available, the three percent difference had to be maintained. The number of subjects reaching this criterion in the stable right ear dominant group was eighteen and in the stable left ear dominant group was 5.

Criteria for inclusion in the unstable group were the following: including the DDT immediately prior to the experiment, at least three DDT test results were available, and that on at least one occasion, the superior digit recall shifted from the right to the left or vice versa. Inclusion into the unstable right or unstable left group was a function of the test results obtained on the DDT immediately prior to the experiment.

The number of subjects reaching this criterion in the unstable right ear group was seven and in the unstable left ear group was 6.

Table I and II complete the description of the DDT performance of the various groups. The first table indicates that the stable groups show larger ear asymmetry scores than the unstable groups. Table II shows that the considerably reduced asymmetries in the unstable groups are not due to excessively high total accuracy scores, which by definition would have precluded the emergence of

Table I.-

Mean Between Ears Difference Scores, in Percentages, of Stable and Unstable Right and Left Ear Dominant Groups, Based on Repeated Evaluations on a Dichotic Digit Test.

Groups	N	$\bar{X}$	S.D.
Stable Right	18	21.2	17.2
Stable Left	5	23.2	16.2
Unstable Right	7	10.6	11.7
Unstable Left	6	5.4	3.9

Table II.-

Mean Total Recall Scores, in Percentages, of Stable and Unstable Right and Left Ear Dominant Groups Based on Repeated Evaluations on a Dichotic Digit Test.

Groups	N	$\bar{X}$	S.D.	$\bar{X}$ No. of admin. per person
Stable Right	18	65.3	10.4	3.6
Stable Left	5	63.6	9.6	3.9
Unstable Right	7	68.3	15.4	4.0
Unstable Left	6	73.6	9.4	4.2

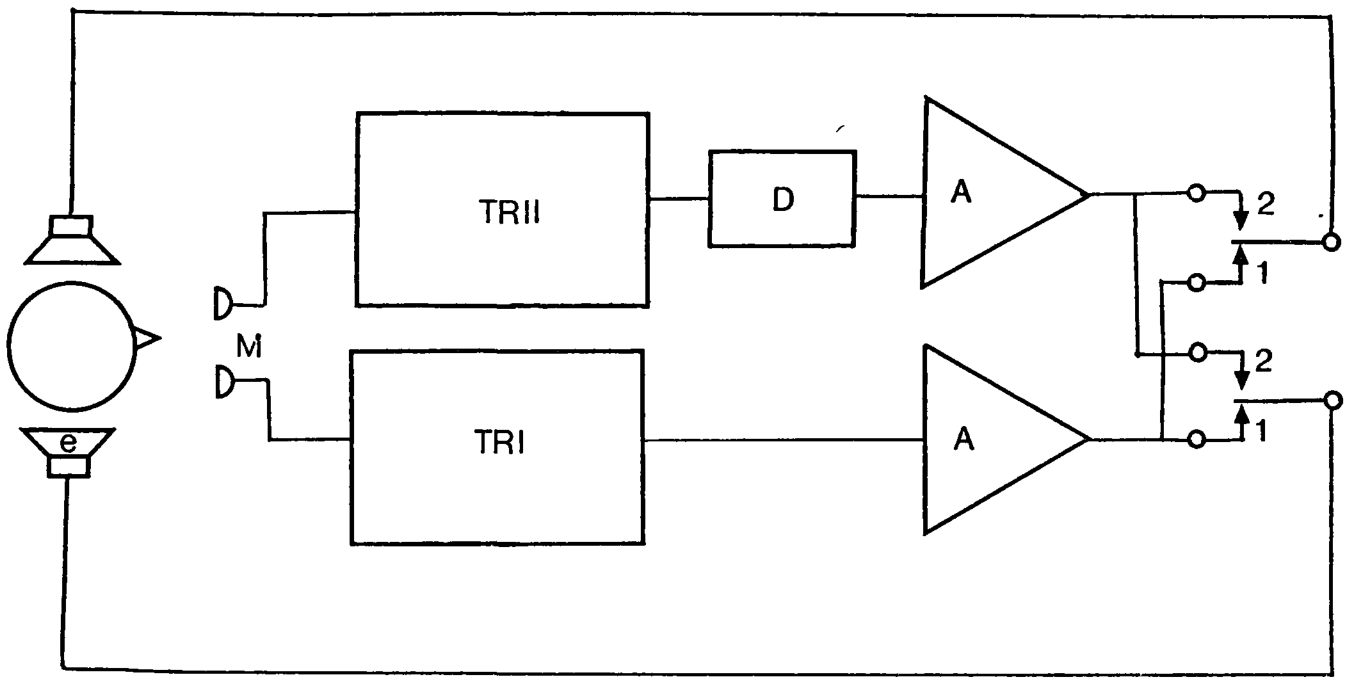
larger asymmetries.

2. Instrumentation.

Instrumentation for the experiment consisted of two Electrovoice microphones, model 635 A; two Revox tape recorders, model A 77; a KLH stereo amplifier, model 16; a constructed metal switch box and a set of Telephonics stereo earphones, model TDH 39. Figure 3 contains a circuit diagram.

The extra amplifier was needed in order to obtain greater signal amplification. Tape recorder I was set at the input mode, thus acting only as an amplifier for the subject's voice. Output from tape recorder I thus provided for the condition of normal feedback. Tape recorder II was set on the simultaneous record-playback mode. Consequently, the subject's voice was first recorded, then picked up by the playback head a fraction of a second later and relayed to the amplifier. The output from tape recorder II thus provided for the delayed feedback condition.

The switch box contained two switches, each capable of selecting either normal or delayed feedback output for both earphones, the right ear and left ear switches respectively. With both switches in position 1, both headphones received the output from tape recorder I, thus providing the condition of direct feedback to both



A - KLH Stereo amplifier, model 16.

D - Delay 0.175 seconds.

M - Two Electrovoice microphones, model 635 A

e - Telephonics stereo earphones, model TDH 39.

TRI - Revox tape recorder, Model A 77, Input mode.

TRII - Revox tape recorder Simultaneous Record - Playback Mode.

Figure 3. Block Diagram.

ears (Baseline Trial). With both switches in position 2, both earphones received the output from tape recorder II, thus providing for binaural delayed feedback, a condition not used in this study. With the left ear switch on position 1 and the right ear switch on position 2, the condition of delayed feedback to the right ear and direct feedback to the left ear was obtained. The reverse of the above provided delayed feedback to the left ear and direct feedback to the right ear. When monaural delayed auditory feedback (MDAF) occurs on the dominant ear as defined by the DDT, it will be called Condition 1. When MDAF occurs on the non-dominant ear, it will be called Condition 2.

To estimate the magnitude of the delay caused by the difference between the record and playback heads of the Revox, the output of tape recorder I was fed into channel 1 of a dual trace Tektronix Oscilloscope, model RM 564. This model provides for simultaneous storage and display of both traces. The output of tape recorder II, in the simultaneous record-playback mode, was connected to channel 2 of the oscilloscope. Then, a sharp noise was displayed on the screen. The delay in transmission of tape recorder II relative to tape recorder I was thus recorded as a spatial difference between the two traces on the scope. The size of this difference was measured and converted into time by taking the scanning speed of the beam into account. Therefore, at a tape speed of 7.5 inches per second, the speed used throughout the study, the delayed feedback interval was estimated to be 0.175 seconds.

The equipment referred to in the circuit diagram was checked for linearity in the range from 50 to 15,000 Hz. and found satisfactory. It was therefore assumed that the signals, whether direct or delayed, were undistorted, at least within the range of normal hearing. Equalization at the level of the headphones was achieved with the use of an artificial ear (Bruel and Kjaer, model 4152), on which a microphone was mounted (Bruel and Kjaer, model 14132), the output of which was fed into a frequency analyzer (Bruel and Kjaer, model 2107). The source was a pure tone fed into a speaker located two feet in front of the microphones mentioned in the circuit diagram. This testing was done in two acoustically controlled chambers (I.A.C.) so that the artificial ear was only exposed to signal from the headphones while the signal source from the speaker was located in a separate chamber.

Equalization of both sources was achieved by adjusting the levels of both tape recorders until a reading of 95 db. SPL was obtained at both headphones. Testing was done at 1,000, 2,000, 3,000 and 4,000 Hz. At all these frequencies, the headphones were found to have equal levels between each other.

It was found that no discomfort was experienced at this high level. The levels were loud enough to maximize disruption due to MDAF, but within the limits of safety and comfort to the subject.

The positions of the various controls were noted and periodically checked throughout the experiment. Also, after every four subjects, the experimenter verified the system by speaking into it under the various conditions to control for possible instrument failure. The speech samples were recorded on Ampex tape, type 434.

3. Testing Procedure.

On arrival, the subject was escorted to a sound proof room (I.A.C.) where he was already well acquainted with audiometric as well as dichotic testing procedures.

For the audiometric test, he was to press a button as long as he heard the sound and to let go when he no longer heard anything. The button pressing activated a light on the examiner's control panel in another room. The examiner was the technician who usually did the dichotic and audiometric testing for the children of the Child Study Centre and knew the children well.

Pure tone (air conduction) audiograms were thus obtained on both ears. The test was begun at 1,000 Hz. and followed by the other frequencies in the order mentioned: 8,000, 6,000, 4,000, 3,000, 2,000, 1,500, a reliability check at 1,000, followed by 500, 250 and 125 Hz. At least two trials were given at each frequency, beginning at -5 db. SPL and ascending in 5 db. steps until the subject responded.

Subjects with known hearing loss had been eliminated prior to the study. However, these audiograms were administered as an extra precautionary measure.

The DDT followed immediately. The children were given the instructions to repeat as many numbers they heard as they could in any order. The test consisted of either forty trials of 3-digit pairs or thirty trials of 4-digit pairs (described above), depending on the proficiency the child had attained on the previous DDT. Regarding the subjects used in the study, the four pair task was given 31 times and the three pair task 5 times.

At this point, two subjects were dropped because they obtained identical scores on both ears and three more were dropped because, on the last DDT, they failed to meet stability criteria mentioned above.

After completion of the auditory tests, the child was given a copy of the text he was to read and made to practice it until he achieved fluency.

Four different passages were used in the experiment (Appendix I). The children's reading levels were estimated by their teachers and the passages selected from classroom readers. Two levels of reading difficulty, both in English and in French, were chosen so as to be neither too difficult or too easy for the children. Those not able to attain a relative fluency in handling the easier text were omitted from the study.

While he was familiarizing himself with the text, the child was asked to read out loud and any words which he did not know or mispronounced were corrected, so that he was well acquainted with the text at the beginning of the experiment. He was then escorted into another acoustically controlled chamber (I.A.C.) where the equipment for the experiment was located. He was informed that he was participating in a study that the experimenter, whom the children knew, was doing and that his cooperation would be appreciated. He was further told that the study dealt with how people read under different conditions and that it was only required of him to read as he normally did.

He was then seated comfortably in front of the microphone and at a distance of approximately sixteen inches from the text he was to read. The latter was typed in large print on white paper and mounted on a piece of cardboard. In order to habituate himself to the experimental condition where he would be wearing headphones and speaking through the microphone, and also as a final check on his initial fluency, he was asked to read the passage out loud while wearing the phones but with the tape recorder off.

When he was finished, he was told that he was doing fine and that this was all that was required of him. He was asked if he had any questions and then told to begin. He was reminded to keep a distance of approximately five inches from the microphone at all times. When all was clear, the tape recorder was started and he was given the signal to begin.

After completion of the first baseline trial, where the subject was exposed only to direct feedback, he was instructed that the same procedure would be repeated twice more, but that on the following two trials he would probably experience some difficulty in reading. He was asked not to laugh or stop but to continue reading as normally as he could under the circumstances. Treatment conditions one and two were then administered in the same way. When this first trial block was completed, the subject's earphones were removed and he was given a rest period of five minutes. The whole procedure was then repeated a second time. In this way, speech samples were obtained for one baseline and two treatment conditions over two trial blocks. When the testing was completed, the child was asked not to tell the other children about details of the experiment.

For all subjects, each trial block began with the baseline assessment. Treatment conditions 1 and 2 were rotated between subjects and within subjects over trial blocks to control for order effects. Consequently, the two possible order sequences to which subjects were exposed were the following: (B1)(C1)(C2)-(B2)(C2)(C1) and (B1)(C2)(C1)-(B2)(C1)(C2). The baseline trial was not rotated since the aim was to obtain a base rate measure of normal speech which would not be contaminated by prior exposure to MDAF conditions. To compensate for task inequalities, difference scores were calculated, subtracting the baseline scores of the dependent variables from the scores on the two MDAF conditions.

4. The Dependent Variables - Analysis of Speech Samples.

Three voice variables were extracted from the taped speech samples. Two of these are related to temporal factors and the other to errors in reading. Procedures for quantification of the temporal variables will be discussed first.

The tapes were placed on a Revox tape recorder (model A 77), which fed a Bruel and Kjaer Level Recorder, type 2305. A writing speed of one hundred millimeters per second was used for the pen and was sufficient to react to quick changes in the output and also permitted a clear transcription that could be easily analyzed. The paper speed was ten mm per seconds.

The recordings were then transcribed on paper while the experimenter monitored the output. The beginning and ending of each condition was identified with a pencil mark to facilitate analysis. However, the condition itself, either (B), (C1) or (C2) was not indicated on the paper, in order to avoid scoring bias. In this fashion, only the baseline trials could be identified as they always occurred first and fourth in the sequence.

The order of conditions was recorded during the experiment and the scores were identified with their respective conditions only after the time analysis was completed.

Two temporal measures were derived from the scoring of these graphic transcriptions: Phonation Time and Error Free Mean Syllabation Time. The latter will be discussed separately.

a) Phonation Time.

Total time was obtained by measuring the distance on the horizontal axis from the point where the pen left the zero mark to the point where it returned to the zero mark after the subject had finished the reading. Then the subject's pause time was measured by adding all the distances where the pen had travelled along the zero mark, thus corresponding to no speech. Finally, phonation time was derived by subtracting the pause time score from the total time score. All temporal measurements were expressed in units of 1/32 of an inch.

Pen lag obviously causes the phonation time measure to be over-estimated. However, since the bias is systematic, comparisons across groups and conditions are valid and this is the point of the experiment.

b) Error Free Mean Syllabation Time.

Extraction of this variable was decided upon after completion of the error analysis (cf. below). It was felt that a temporal comparison of speech samples which contained no errors would be highly relevant to the hypotheses formulated in this study.

The procedures for securing this variable were obtained by using the error analysis as a guide. A phonation time analysis was performed on sub-sections of the speech samples where there was no recorded error on either of the two baseline or four MDAF conditions. The speech units analyzed were either sentences or phrases that were well isolated in the speech flow, thus making their isolation on the graphic transcription possible. On all protocols, all sub-sections of the speech samples meeting these criteria were graphically transcribed and analyzed using phonation time criteria.

The samples varied from seventy to 25 words of error free speech per subject on each of the conditions. To render these units comparable, their temporal measurement was divided by the number of syllables contained in the sample, thus obtaining an error free mean syllabation time.

c) Error Analysis.

Any deviation from the text was scored as an error. The corollary in Appendix 1 describes the types of errors scored and criteria for error units. The reliability coefficient for two judges was .95.

5. Statistical Design and Hypotheses.

The general statistical approach used in this study was that of a four-way classification analysis of variance. The four independent variables used were Stability (S), Dichotically Classified Auditory Dominance (D), Trial Blocks (T), and MDAF Conditions (C).

Since the main interest of this study involves a comparison of the MDAF Conditions, the main null hypothesis is stated as follows:

1. There is no significant difference on either of the three-voice variables between MDAF to the dominant ear and MDAF to the non-dominant ear.

However, as the previous chapter has shown, left ear dominant groups have been less predictable in producing reliable differences between Conditions. Consequently, another major source of interest in this study is stated in the form of an interaction:

2. There is no significant interaction, on either of the three-voice variables, between Conditions and groups differing in direction of auditory dominance.

Finally, though no predicted direction is suggested for the effects of Stability, as no prior empirical evidence is available, another major interest of this study was to explore possible differences between stable and unstable groups, also formulated as an interaction.

3. There is no significant interaction, on either of the three-voice variables, between Conditions and groups differing in stability of auditory dominance.

When, in the main analysis, there were other indications of variation of the conditions effect with the different independent variables, these results were further analyzed. The procedures will be described in the following chapter where a presentation will be given of the analyses and results.

CHAPTER III

PRESENTATION OF RESULTS

This chapter will present results stemming from the research findings in terms of hypotheses formulated in the previous chapter. The summaries of all analyses of variance of the speech measures will be shown and commented upon utilizing individual comparisons for the experimental variables used in the study. Additional analyses, involving regrouping of the data, will be presented when clarification of results from the main analysis is required. Finally, the stable right ear dominant group will be studied separately.

1. The Statistical Findings.

Prior to presentation of the results, problems directly affecting the analyses should be considered.

As mentioned in the previous chapter, difference scores, involving a subtraction of the baseline from the treatment conditions, were used to compensate for task inequalities. It was decided to use only the scores of the first baseline trial to calculate difference scores for the treatment conditions in both trial blocks, as analysis of variance of baseline data suggested that the baseline measures were not consistent over trial blocks.

Although such a baseline analysis is not mathematically legitimate, since task inequalities are not compensated for, the suggestion of significant differences between trial blocks for baseline measures appeared to warrant the use of a single basal measure. Consequently, the difference scores used in the analyses are derived from the same basal quantity. Furthermore, the difference scores for all dependent measures were square root transformed and the data to be reported are based on these transformations.

Table III provides correlations between the dependent measures for both Trials and Conditions. It reveals that articulation errors are not significantly correlated with temporal measures and are thus considered independent of time. As expected, the two measures of time correlate quite highly and reflect that the selected samples of speech chosen for the derivation of the Error Free Mean Syllabation Time variable are representative of Phonation Time as a whole.

The correlations displayed in Table IV represent reliability coefficients for the dependent variables over Trials and Conditions. These variables will now be analyzed sequentially with additional analyses for each when clarification is required.

Table III.-

Pearson Product Moment Correlations Between the Three Dependent Variables for Both Levels of Trials (T) and Conditions (C). N = 36.

Measures Correlated	T1C1	T1C2	T2C1	T2C2
1[a] - 2[b]	.83	.93	.85	.88
1 - 3[c]	-.05	-.01	.04	-.18
2 - 3	-.09	-.12	.03	-.29

a = Phonation Time
b = Error Free Mean Syllabation Time
c = Articulation Errors

Table IV.-

Reliability Coefficients for Phonation Time (Variable 1), Error Free Mean Syllabation Time (Variable 2), and Articulation Errors (Variable 3) over Trial Blocks (T) and Conditions (C).

Variable		T1C1	T1C2	T2C1	T2C2
(1).	T1C1	1.0			
	T1C2	.84	1.0		
	T2C1	.78	.80	1.0	
	T2C2	.70	.85	.82	1.0
(2).	T1C1	1.0			
	T1C2	.75	1.0		
	T2C1	.54	.75	1.0	
	T2C2	.61	.75	.92	1.0
(3).	T1C1	1.0			
	T1C2	.28	1.0		
	T2C1	.54	.48	1.0	
	T2C2	.27	.46	.29	1.0

a) Phonation Time.

The summary of the square root transformed analysis for phonation time is presented in Table V. The significant Conditions Main Effect ($F(1,32)=6.204$; $p<.03$) merits rejection of the first null hypothesis; that is, MDAF to the dominant ear increases the subject's phonation time relative to MDAF to the non-dominant ear. However, this finding is further elucidated in terms of the reliable TXC interaction ($F(1,32)=5.685$; $p<.03$) illustrated in Figure 4. Application of Scheffe's Test of Multiple Comparisons indicates that the Conditions Effect for Phonation Time is only statistically significant within the first trial block ($p<.01$) and not the second.

However, inspection of the DXTXC interaction illustrated in Figure 5, although not significant ($p>.35$), suggests a further clarification. The predicted direction of the Conditions Effect occurs in both trial blocks of the right ear dominant groups but only in the first trial block of the left ear dominant group. This suggests that the TXC interaction illustrated in Figure 4 is due mainly to phonation time variability over Trials of the left ear dominant group.

Since significant variations in the consistency of the predicted Conditions Effect for different groups are highly relevant to the questions investigated in this

Table V.-

Square Root Transformed Table of Variance for Phonation Time-Main Analysis.

Source	Sum of Squares	df	Est. of Variance	F	P
S	0.32043166D 03	1	0.32043166D 03	3.9581	0.05525
D	0.44828709D 02	1	0.44828709D 02	0.5537	0.46222
SxD	0.86266419D 02	1	0.86266419D 02	1.0656	0.30968
S/G Error	0.25905606D 04	32	0.80955019D 02		
T	0.18693853D 00	1	0.18693853D 00	0.0261	0.87261
SxT	0.57584828D 01	1	0.57584828D 01	0.8047	0.37638
DxT	0.10914655D 00	1	0.10914655D 00	0.0153	0.90248
SxDxT	0.76555823D 00	1	0.76555823D 00	0.1070	0.74573
S/G Error	0.22898298D 03	32	0.71557182D 01		
C	0.45439592D 02	1	0.45439592D 02	6.2039	0.01813
SxC	0.10571008D 00	1	0.10571008D 00	0.0144	0.90513
DxC	0.47627534D 01	1	0.47627534D 01	0.6503	0.42597
SxDxC	0.17869293D 01	1	0.17869293D 01	0.2440	0.62473
S/G Error	0.73244157D 01	32	0.73244157D 01		
TxC	0.14857621D 02	1	0.14857621D 02	5.6848	0.02321
SxTxC	0.77572033D 01	1	0.77572033D 01	2.9680	0.09458
DxTxC	0.23215773D 01	1	0.23215773D 01	0.8883	0.35301
SxDxTxC	0.41076648D 00	1	0.41076648D 00	0.1572	0.69441
S/G Error	0.83634640D 02	32	0.26135825D 01		

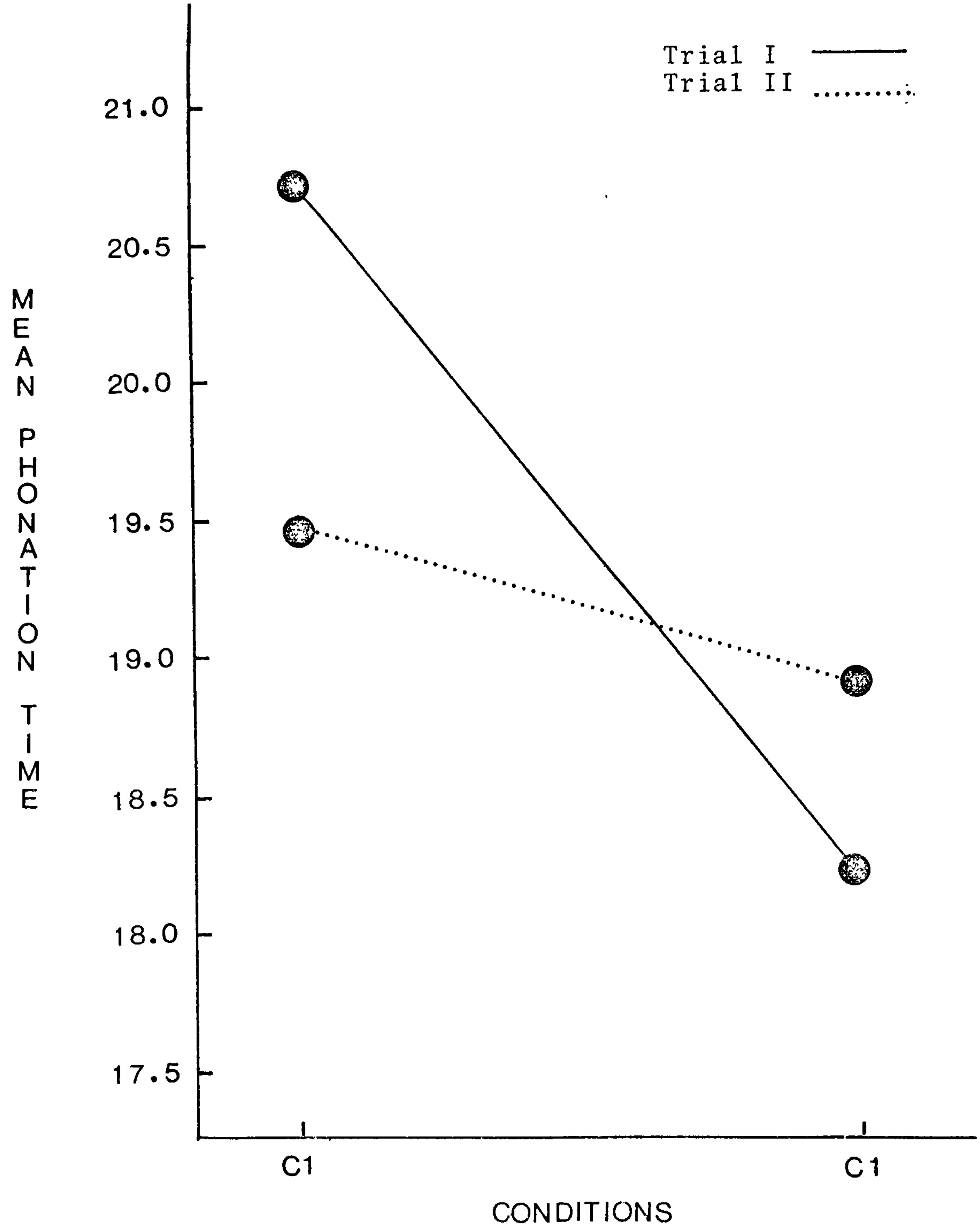
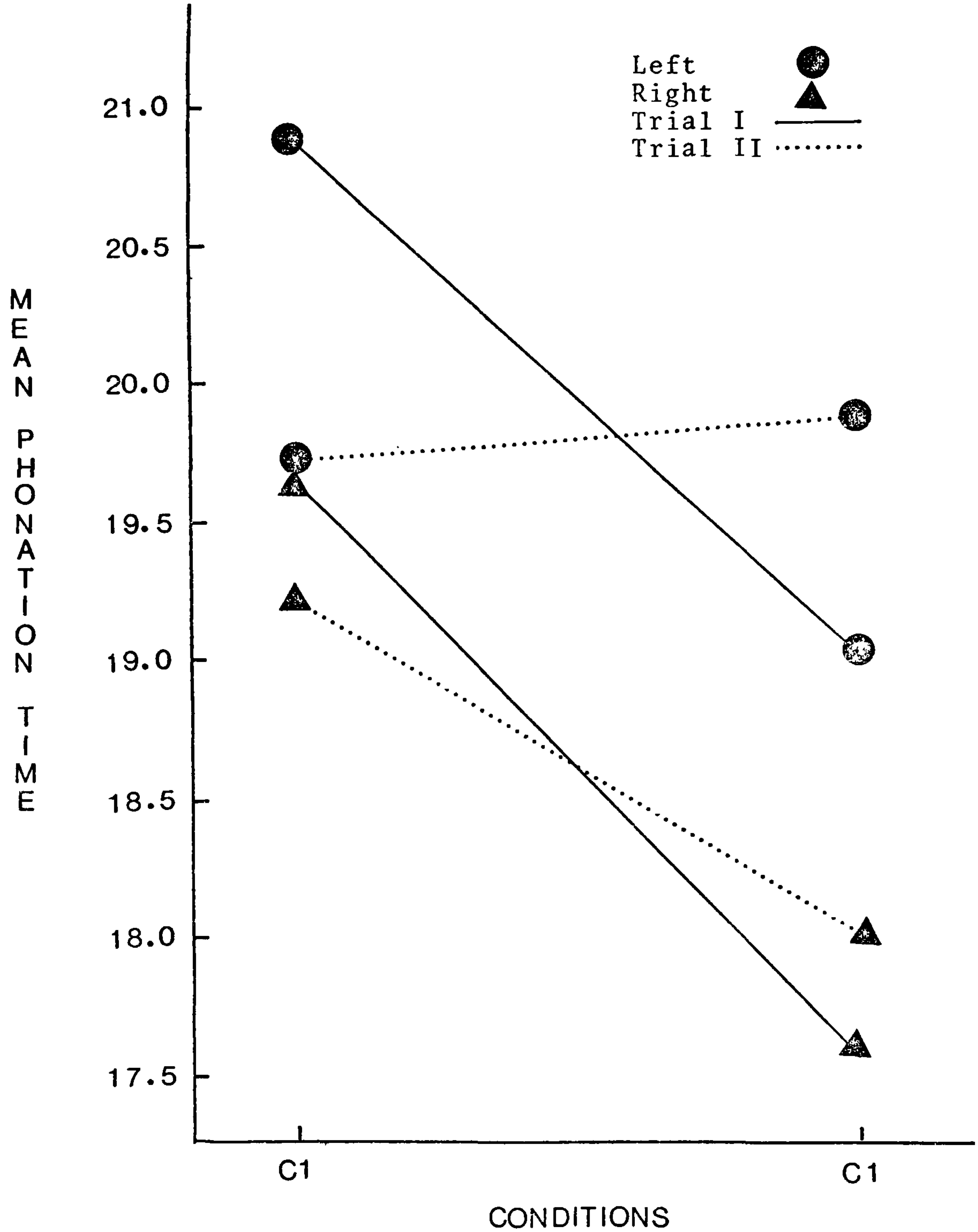


Figure 4. - Representation of Mean Phonation Times for First and Second Trial Blocks under Treatment Conditions.



Fighre 5. - Representation of Mean Phonation Times for Right and Left Ear Dominant Groups under Trials and Conditions.

study, an attempt was made to statistically verify the trends indicated in the DXTXC interaction illustrated in Figure 5. The stability factor was collapsed and separate analyses of variance were performed on right and left ear dominant subjects over Trials and Conditions. The summaries of these analyses are presented in Tables VI and VII respectively.

Inspection of the analysis for right ear dominant subjects reveals a highly significant Conditions Main Effect ($F(1,24)=8.5623$; $p<.01$) and no indication of a TXC interaction ($F(1,24)=.6049$; $p>.40$). On the other hand, the analysis for left ear dominant subjects does show a definite trend towards a TXC interaction ($F(1,10)=5.2417$; $p<.05$) at a higher level of probability than the Conditions Main Effect ($F(1,10)=4.5438$; $p<.10$). These analyses seem to support the hypothesis mentioned above, namely that the variability of the Conditions Effect over Trials is due to the left ear dominant groups.

b) Error Free Mean Syllabation Time.

Results on this second temporal variable used in the study are presented in Table VIII. A highly significant Conditions Main Effect ($F(1,32)=11.4893$; $p<.005$) was obtained, thus rejecting the first null hypothesis; that is, on a temporal measure which is not confounded by

Table VI.-

Square Root Transformed Table of Variance for Phonation Time of Right Ear Dominant Subjects: Stability Collapsed.

Source	Sum of Squares	df	Est. of Variance	F	P
T	0.15826892D 01	1	0.15826892D 01	0.2115	0.64974
S/G Error	0.17960844D 03	24	0.74836849D 01		
C	0.77492286D 02	1	0.77492286D 02	8.5623	0.00739
S/G Error	0.21721024D 03	24	0.90504266D 01		
TxC	0.16995692D 01	1	0.16995692D 01	0.6049	0.44433
S/G Error	0.67437387D 02	24	0.28098911D 01		
Ss	0.17467728D 04	24	0.72782198D 02		

Table VII.-

Square Root Transformed Table of Variance for Phonation Time of Left Ear Dominant Subjects: Stability Collapsed.

Source	Sum of Squares	df	Est. of Variance	F	P
T	0.31562215D 00	1	0.31562215D 00	0.0545	0.82011
S/G Error	0.57905232D 02	10	0.57905232D 01		
C	0.86168730D 01	1	0.86168730D 01	4.5438	0.05886
S/G Error	0.18963824D 02	10	0.18963824D 01		
TxC	0.12576501D 02	1	0.12576501D 02	5.2417	0.04505
S/G Error	0.23993397D 02	10	0.23993397D 01		
Ss	0.11814094D 04	10	0.11814094D 03		

Table VIII.-

Square Root Transformed Table of Variance for Error Free Mean Syllabation Time: Main Analysis.

Source	Sum of Squares	df	Est. of Variance	F	P
S	0.72812967D 00	1	0.72812967D 00	1.6737	0.20520
D	0.49989994D-04	1	0.49989994D-04	0.0001	0.99151
SxD	0.29064499D 00	1	0.29064499D 00	0.6681	0.41976
S/G Error	0.13921102D 02	32	0.43503444D 00		
T	0.12124509D 00	1	0.12124509D 00	1.6163	0.21278
SxT	0.19950253D-01	1	0.19950253D-01	0.2659	0.60961
DxT	0.20617926D-01	1	0.20617926D-01	0.2748	0.60371
SxDxT	0.78834992D-01	1	0.78834992D-01	1.0509	0.31298
S/G Error	0.24005096D 01	32	0.75015925D-01		
C	0.25216295D 00	1	0.25216295D 00	11.4893	0.00187
SxC	0.13930200D-01	1	0.13930200D-01	0.6347	0.43151
DxC	0.80494188D-02	1	0.80494188D-02	0.3668	0.54905
SxDxC	0.33017409D-01	1	0.33017409D-01	1.5044	0.22895
S/G Error	0.70232517D 00	32	0.21947662D-00		
TxC	0.30804527D-02	1	0.30804527D-02	0.1311	0.71968
SxTxC	0.29083572D-01	1	0.29083572D-01	1.2377	0.27421
DxTxC	0.18396828D-04	1	0.18396828D-04	0.0008	0.97785
SxDxTxC	0.25128539D-01	1	0.25128539D-01	1.0694	0.30884
S/G Error	0.75194756D 00	32	0.23498361D-01		

articulation errors, MDAF to the dominant ear, as defined by a dichotic listening test, causes a significant increase in the amount of phonation time needed to read a text relative to MDAF to the non-dominant ear. No other statistically significant effects were obtained.

c) Articulation Errors.

The results of this measure are presented in Table IX. Unlike measures of time, a highly significant Trials Main Effect ($F(1,32)=11.5723$; $p<.005$) occurs on the articulation errors variable, indicating that subjects read the passage in the second trial block with significantly fewer errors than in the first.

Of more direct interest to this study, however, is the reliable DxC interaction ($F(1,32)=4.3913$; $p<.05$) illustrated in Figure 6. This figure suggests that MDAF to the dominant ear causes significantly more articulation errors in right ear dominant subjects and the reverse in left ear dominant subjects; that is, left ear dominant subjects appear to produce more errors when their right ear is being exposed to interference.

Stated differently, this interaction suggests that the physical right ear is a better predictor of a reliable conditions effect for the articulation errors variable than classification of auditory dominance on the

Table IX.-

Square Root Transformed Table of Variance for Articulation Errors: Main Analysis.

Source	Sum of Squares	df	Est. of Variance	F	P
S	0.55742052D-01	1	0.55742052D-01	0.0544	0.81703
D	0.69230210D 00	1	0.69230210D 00	0.6759	0.41709
SxD	0.34425279D 00	1	0.34425279D 00	0.3361	0.56616
S/G Error	0.32777674D 02	32	0.10243023D 01		
T	0.25085977D 01	1	0.25075866D 01	11.5723	0.00181
SxT	0.19061956D-01	1	0.19061956D-01	0.0880	0.76869
DxT	0.43597165D-01	1	0.43597165D-01	0.2012	0.65768
SxDxT	0.45622643D-01	1	0.45622643D-01	0.2105	0.64944
S/G Error	0.69340349D 01	32	0.21668859D 00		
C	0.20021637D-01	1	0.20021637D-01	0.0733	0.78832
SxC	0.13446933D 01	1	0.13446933D 01	4.9235	0.03371
DxC	0.11993533D 01	1	0.11993533D 01	4.3913	0.04412
SxDxC	0.27465158D 00	1	0.27465158D 00	1.0056	0.32348
S/G Error	0.87398043D 01	32	0.27311889D 00		
TxC	0.20544022D 00	1	0.20544022D 00	0.7342	0.39791
SxTxC	0.83664919D-02	1	0.83664919D-02	0.0299	0.86381
DxTxC	0.43507029D-02	1	0.43507029D-02	0.0155	0.90155
SxDxTxC	0.33718281D 00	1	0.33718281D 00		
S/G Error	0.89544531D 01	32	0.27982666D 00		

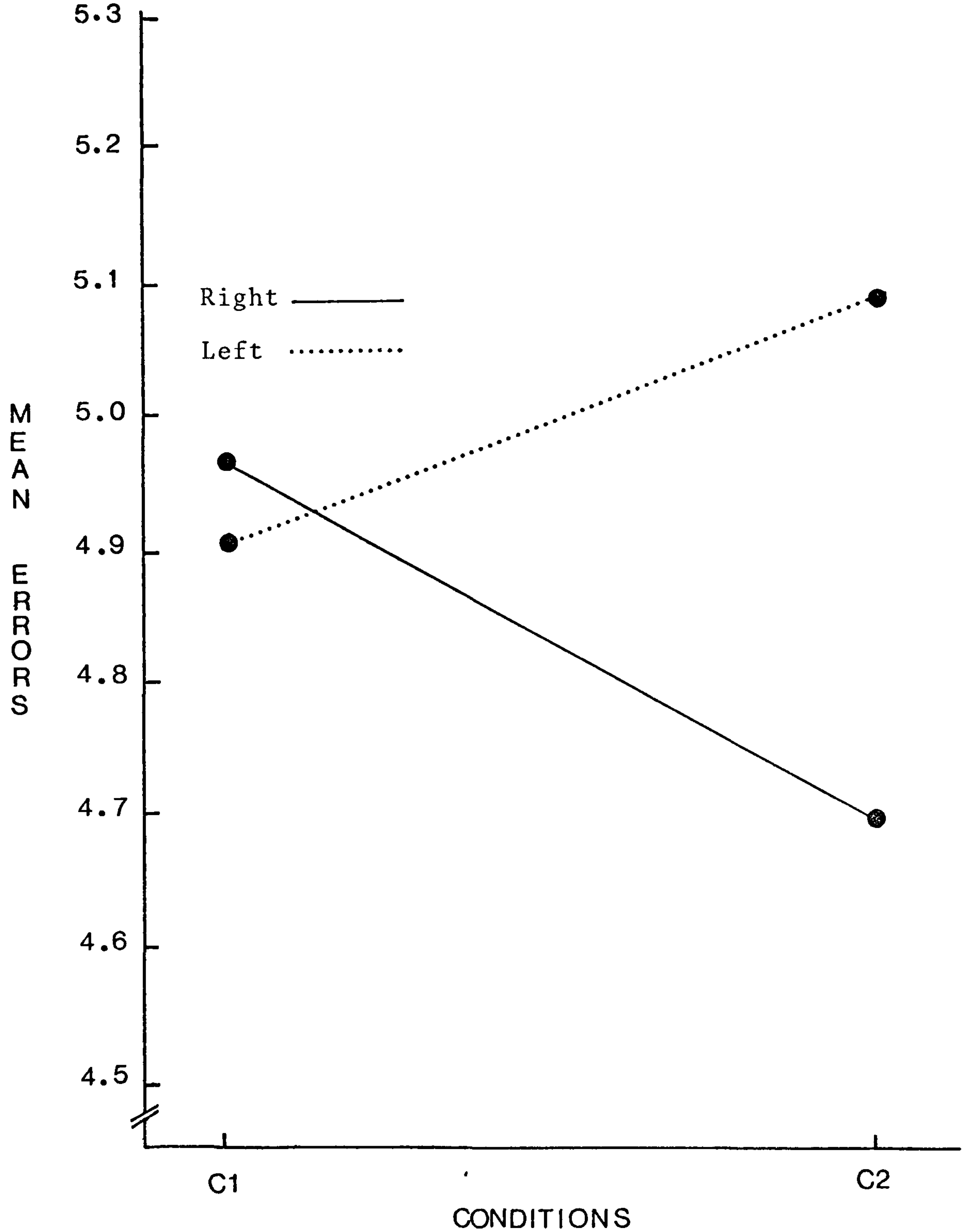


Figure 6. - Representation of Mean Errors for Right and Left Ear Dominant Groups under Treatment Conditions.

basis of dichotic listening performance. Since it is not mathematically feasible to test between cell differences of the type involved in Figure 6, the hypothesis suggested by this figure and mentioned immediately above, can be statistically verified by a regrouping of the data for the two levels of the Conditions variable. This involves inverting Condition 1 and 2 for both stable and unstable left ear dominant groups such that Condition 1 always involves MDAF to the physical right ear and Condition 2, MDAF to the physical left ear.

The analysis of variance carried out on this reclassification of cells, called a right-left classification, is presented in Table X. Only the bottom half of this table is presented since the top half is identical to Table IX. In Table X, D in Source (test defined dominant ear) is replaced by E (physical ear). The significant Conditions Main Effect ($F(1,32)=4.3913$; $p<.05$) confirms the hypothesis that MDAF to the physical right ear causes significantly more articulation errors than MDAF to the left ear, regardless of test defined auditory dominance.

Also of interest to this study is the reliable SXC interaction ($F(1,32)=4.9235$; $p<.05$) illustrated in Figure 7. This figure suggests that the stable group shows the predicted Conditions Effect while the unstable group manifests a significant Conditions Effect in the reverse

Table X.-

Square Root Transformed Table of Variance for Errors:
Right-Left Classification

Source	Sum of Squares	df	Est. of Variance	F	P
C	0.11993533D 01	1	0.11993533D 01	4.3913	0.04412
SxC	0.27465158D 00	1	0.27454158D 00	1.0056	0.32348
ExC	0.20021637D-01	1	0.20021637D-01	0.0733	0.78832
SxExC	0.13446933D 01	1	0.13446933D 01	4.9235	0.03371
S/G Error	0.87398043D 01	32	0.27311889D 00		
TxC	0.43508029D-02	1	0.43507029D-02	0.0155	0.90155
SxTxC	0.33718281D 00	1	0.33718281D 00	1.2050	0.28052
ExTxC	0.20544022D 00	1	0.20544022D 00	0.7342	0.39791
SxDxTxC	0.83664919D-02	1	0.83664919D-02	0.0299	0.86381
S/G Error	0.89544531D 01	32	0.27982666D 00		

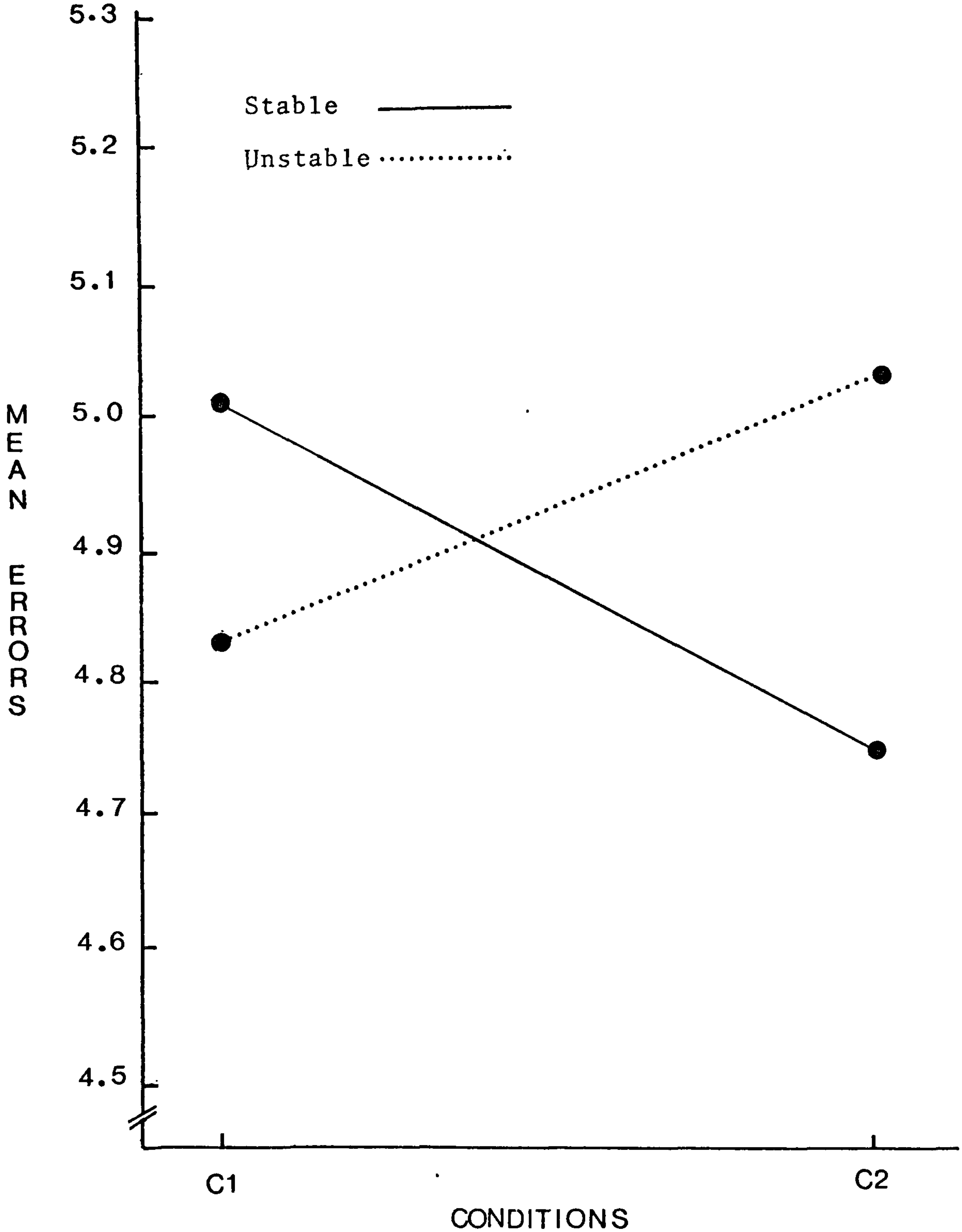


Figure 7. - Representation of Mean Errors for Stable and Unstable Groups under Treatment Conditions.

of the predicted direction. A predicted Conditions Effect would mean that MDAF to the test defined dominant ear causes significantly more articulation errors than MDAF to the non-dominant ear, and would thus require that Condition 1 be greater than Condition 2. In view of the previously described DXC interaction displayed in Figure 6, these results appear contradictory, and a clarification of the meaning of both the SXC and DXC interactions of Table IX can be obtained by inspecting the SXDXC interaction ($F(1,32)=1.0056$; $p>30$) of the same table and illustrated in Figure 8.

Inspection of this figure reveals that only the stable right ear dominant group shows the predicted Conditions Effect. However, it appears quite marked and thus accounts for the position of the stable group in the SXC interaction as well as that of the right ear dominant group in the DXC interaction. It can be seen that the stable left ear dominant group does not contribute to the obtaining of the predicted Conditions Effect of the stable groups in the SXC interaction, nor does the unstable right ear dominant group contribute to the obtaining of the predicted Conditions Effect of the right ear dominant groups in the DXC interaction.

The combination of the minor, reversed direction of the predicted Conditions Effect of the stable left ear

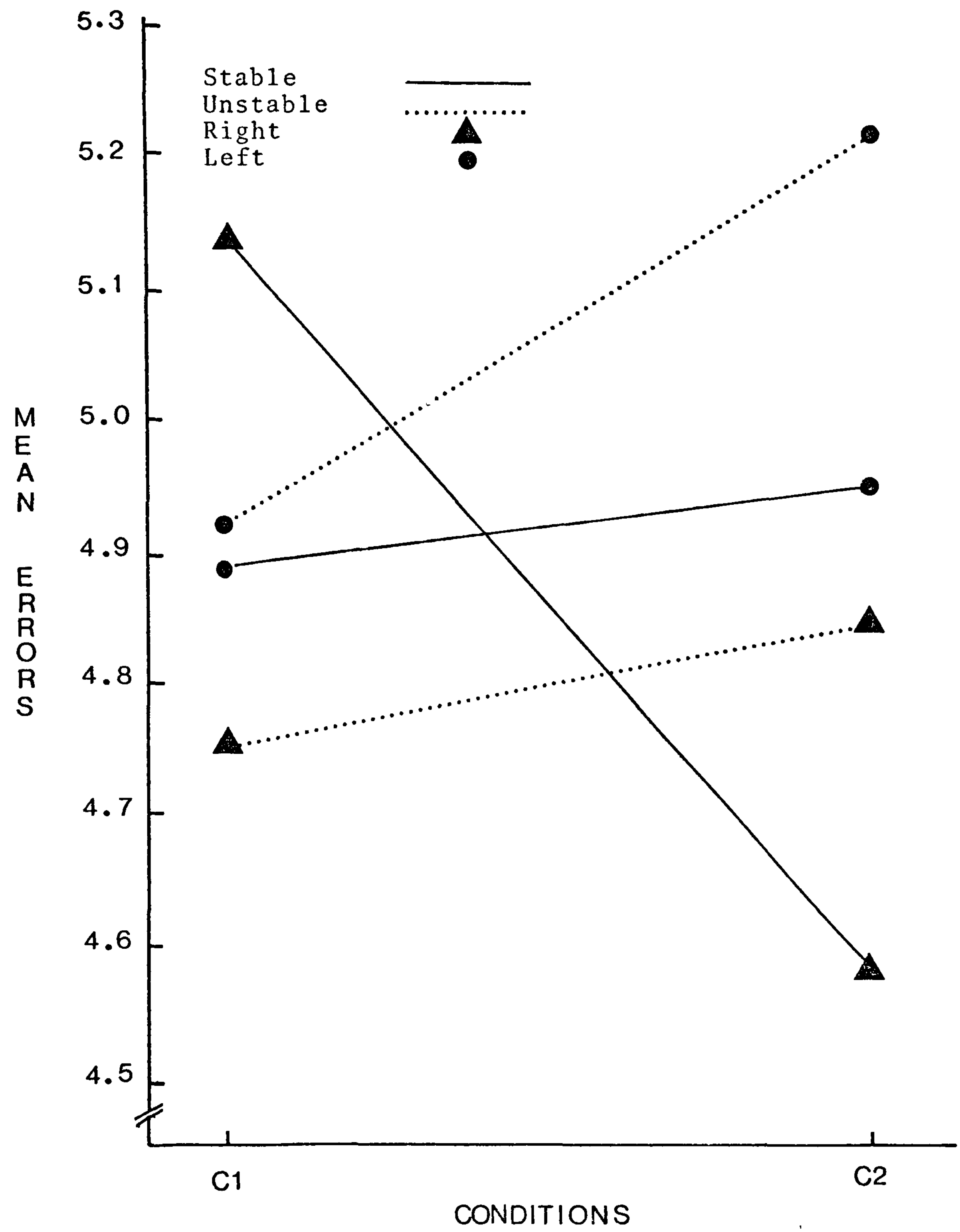


Figure 8. - Representation of Mean Errors for Stable and Unstable Right and Left Ear Dominant Groups under Treatment Conditions.

dominant group combined with the more substantial reversed Conditions Effect of the unstable left ear dominant group are additive in accounting for the position of the left ear dominant group in the DXC interaction. Likewise, the minor reversed Conditions Effect in the unstable right ear dominant group and the more substantial one in the unstable left ear dominant group are additive in accounting for the position of the unstable group in the SXC interaction. Whatever the contributions of the stable left and unstable right ear dominant groups to the SXC and DXC interactions for articulation errors, Figure 8 strongly suggests that most of the variation is due to the stable right and unstable left ear dominant groups.

d) Stable Right Ear Dominant Subjects.

The square root transformed summaries of the analyses of variance for the three dependent measures are presented in Table XI, XII and XIII respectively. Significant Conditions Main Effects in the predicted direction were obtained for Phonation Time ($F(1,17)=5.7320$; $p<.03$), Error Free Mean Syllabation Time ($F(1,17)=5.3611$; $p=.03$) and Articulation Errors ($F(1,17)=16.4182$; $p<.001$). These results indicate that subjects belonging to this category consistently show, at statistically significant levels, the predicted speech monitoring asymmetries. This is especially relevant for the articulation errors variable, which, in this group

Table XI.-

Square Root Transformed Table of Variance for Phonation Time of Stable Right Ear Dominant Subject.

Source	Sum of Squares	df	Est. of Variance	F	P
T	0.63989354D 01	1	0.63989354D 01	0.8043	0.38233
S/G Error	0.13524645D 03	17	0.79556733D 01		
C	0.66274633D 02	1	0.62746331D 02	5.7320	0.02846
S/G Error	0.18609361D 03	17	0.10946683D 02		
TxC	0.22140323D-01	1	0.22140323D-01	0.0084	0.92815
S/G Error	0.44934122D 02	17	0.26431836D 01		
Ss	0.87155325D 03	17	0.51267837D 02		

Table XII.-

Square Root Transformed Table of Variance for Error Free Mean Syllabation Time of Stable Right Ear Dominant Subjects.

Source	Sum of Squares	df	Est. of Variance	F	P
T	0.26927477D-02	1	0.26927477D-02	0.0312	0.86186
S/G Error	0.14666483D 01	17	0.86273432D-01		
C	0.14411048D 00	1	0.14411048D 00	5.3611	0.03334
S/G Error	0.45696998D 00	17	0.26880587D-01		
TxC	0.25417593D-02	1	0.25417593D-02	0.1197	0.73357
S/G Error	0.36089635D 00	17	0.21229197D-01		
Ss	0.45274769D 01	17	0.26632217D 00		

Table XIII.-

Square Root Transformed Table of Variance for Articulation Errors of Stable Right Ear Dominant Subjects.

Source	Sum of Squares	df	Est. of Variance	F	P
T	0.22179560D 01	1	0.22179560D 01	8.7855	0.00870
S/G Error	0.42917677D 01	17	0.25245693D 00		
C	0.54215756D 01	1	0.54215756D 01	16.4182	0.00083
S/G Error	0.56136851D 01	17	0.33021677D 00		
TxC	0.14867429D-01	1	0.14867429D-01	0.0678	0.79767
S/G Error	0.37267348D 01	17	0.21921970D 00		
Ss	0.24088796D 02	17	0.14169880D 01		

only, shows a highly significant predicted Conditions Effect.

CHAPTER IV

DISCUSSION OF RESULTS

This chapter will deal with the more important findings presented in the previous chapter. Since the main concern of this study involves the comparison of the two MDAF conditions and the interaction of other independent variables with Conditions, these findings will be emphasized and evaluated in their relationship to other studies bearing directly on the problem considered. The temporal and articulation error variables will be discussed separately for all groups combined, followed by a discussion of the stable right ear dominant group.

1. Discussion of the Effect of Conditions on Temporal Variables.

It was shown in the previous chapter that the formally stated null hypothesis: there is no significant difference on either of the three voice variables, between MDAF to the dominant ear and MDAF to the non-dominant ear, was rejected for both Phonation Time ($p<.03$) and Error Free Mean Syllabation Time ($p<.005$).

This study thus further corroborates the validity of Tomatis' concept of a "leading ear", at least with regard to the greater efficiency of one ear in monitoring temporal aspects of speech output. Similar results have been reported by Roode[1] and Dionne,[2] as described in the first chapter of this study. In view of the accumulating evidence, it is appropriate to extend the notion of laterality differences in auditory perception to such laterality differences in the control of speech.

Furthermore, consistent with Dionne's[3] previous study, this experiment offers information which may account for the lack of significant differences obtained on the Total Speaking Time variable used by Abbs and Smith.[4] Though not reported in the previous chapter, analysis of variance was performed on both Total Speaking Time and Pause Time using difference scores, with essentially the same results obtained in this author's previous study[5] with adults. That is, Total Speaking Time showed only a trend toward the predicted Conditions Effect ($p<.10$) because of the results on Pause Time, which gave no indication of being reliably related to Conditions ($p>.80$).

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1 C.D. Roode, An Experimental Study of Auditory Asymmetry and Cerebral Language Laterality, Unpublished Doctoral Dissertation, University of Ottawa, 1963.

2 M. Dionne, Degree of Auditory Asymmetry in the Control of Phonation, Upgrading Paper, University of Ottawa, 1974.

3 Ibid.

4 J. Abbs and K.U. Smith, "Laterality Differences in Auditory Feedback Control of Speech," Journal of Speech and Hearing Research, Vol. 13, 1970, p. 298-303.

5 Dionne, Op. cit.

Aside from other important differences between this study and the Abbs and Smith design described in the first chapter, these results suggest that the use of Total Speaking Time as a temporal measurement may tend to mask significant differences between Conditions. Unfortunately, Abbs and Smith do not report the results of their time analysis.

As stated in the first chapter of this study, these authors, basing themselves on the lack of significant differences obtained on their time variable, suggested that auditory asymmetry in speech monitoring might occur only for consonants and not for vowels, where most elongation under delayed feedback occurs.[6] It would now appear necessary to reject this hypothesis in favor of Tomatis' statement[7] to the effect that interference with the monitoring functions of the leading ear causes an elongation of the duration of the verbal flow. Rejection of the Abbs and Smith suggestion relies not only on the significant results obtained on Phonation Time in Roode's,[8] Dionne's[9] and the present study, but also because of the highly

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6 Abbs and Smith, Op. cit., p. 302.

7 A. Tomatis, L'Oreille et le Langage, Paris, Editions du Seuil, 1963, p. 137.

8 Roode, Op. cit.

9 Dionne, Op. cit.

significant Conditions Main Effect obtained for Error Free Mean Syllabation Time ($p<.005$). The latter clearly shows that the predicted Conditions Effect for time is not due to confounding by articulation error variability. This statement receives further corroboration because of the lack of correlation between phonation time and articulation errors. (Cf. Table III).

Whereas the existence of auditory asymmetry in the control of temporal aspects of speech has been repeatedly demonstrated, the relationship of perceptual asymmetries, as determined by dichotic listening, to speech monitoring asymmetries, has received little attention. The results discussed thus far suggest a direct relationship; that is, the speech of dichotically classified right ear dominant subjects suffers more temporal disruption when MDAF is administered to the right ear, while the speech of left ear dominant subjects is more disturbed by MDAF to the left ear. Since the review of the literature strongly suggests that right ear dominance on verbal dichotic listening tasks indicates left hemisphere representation of speech, while left ear dominance indicates the reverse, and since it has been demonstrated that the ear contralateral to the dominant hemisphere is more efficient in transmitting information, it is reasonable to expect that this contralateral ear would be more efficient in monitoring speech. The results obtained for time are thus consistent with the model that generated the predictions.

Roode's[10] study also provided for successful predictions in both directions; that is, his right sided subjects had significantly greater mean syllabation times (phonation time divided by a constant) with MDAF to the right ear, the reverse being true of his left sided subjects. Though he did not use dichotic tests to classify his subjects, his stringent sidedness criteria for inclusion into the right or left dominant group closely resemble those used in the study by Knox and Boone,[11] who found a "strong relationship" between sidedness measures and dichotic test results, even for left sided subjects. It is therefore not an unreasonable assumption that Roode's groups would have had dichotic test results which were closely related to the sidedness measures. Consequently, though the connection is only inferential, Roode's study also seems to support this direct relationship between perceptual and speech asymmetries for temporal variables.

However, Dionne's[12] previous study, dealing directly with this relationship, does not appear to support

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10 Roode, Op. cit.

11 A. Knox and D.R. Boone, "Auditory Laterality and Tested Handedness," Cortex, Vol. 6, 1970, p. 172.

12 Dionne, Op. cit.

dichotically classified left ear dominance as a reliable predictor of temporal speech asymmetries. In that experiment, time measurements for the left ear dominant group were actually greater when MDAF was administered to the right ear. The findings did seem to support some relationship between perceptual and speech asymmetries, however, as Degree of Auditory Asymmetry, measured by right ear percentage scores on a Dichotic Word Test, did correlate with the magnitude of the demonstrated speech asymmetries on the Phonation Time variable ($r=.21$, $p<.10$) but especially on Total Speaking Time ($r=.30$, $p<.05$).

Neither is this study unequivocal in demonstrating the speech predictive value, with regard to time, of dichotically classified left ear dominance. Though the relationship is clear-cut for Error Free Mean Syllabation Time, the reliable TXC interaction ($p<.03$) for Phonation Time appears to complicate the picture. When, in the previous chapter, this interaction was broken down and further analyzed, the results seemed to indicate that the lack of appearance of the predicted statistically significant Conditions Effect in the second trial block was due to inconsistency in temporal speech behavior of the left ear dominant group, the right ear dominant group being consistent over trials. These differences between groups as reliable predictors of speech asymmetries are much more pronounced on the Articulation Errors variable. To avoid redundancy, discussion of the possible meaning of these differences, will be dealt with in the next section.

2. Discussion of the Effect of Conditions on Articulation Errors.

As stated in the previous chapter, results on the Articulation Errors variable did not reject the main null hypothesis. Rather, Conditions were found to interact with both Dichotically Classified Auditory Dominance and Stability, in an apparently conflicting manner. The DXC interaction, illustrated in Figure 6, showed that MDAF to the right ear caused subjects to produce more articulation errors, regardless of their dichotically classified auditory dominance. The SXC interaction illustrated in Figure 7, suggested that the groups who were stable in their dichotically assessed auditory dominance demonstrated, on the Articulation Errors variable, speech monitoring asymmetries which were consistent with their perceptual asymmetry, while the unstable group demonstrated these asymmetries in the reverse of the predicted direction.

To clarify this apparent contradiction, the relationship of the four groups to the two levels of Conditions, the SXDXC interaction, was plotted separately in Figure 8. This figure showed that most of the variability over Conditions for the measure under consideration, was displayed by stable right ear dominant subjects in the predicted direction, and by unstable left ear dominant subjects in the reverse of the predicted direction. Consequently, for purposes of this discussion, the stable left ear dominant and unstable right ear dominant groups will be considered as having demonstrated no reliable differences on the Conditions variable. Viewed in this way, the apparent contradiction between the DXC and SXC interactions can be evaluated as a further interaction of the stability variable with dichotically classified auditory dominance. In other words, amongst right ear dominant subjects, only the stable group shows a reliable Conditions effect in the predicted direction, while only the unstable group, within left ear dominant subjects, demonstrates a reliable Conditions effect in the reverse of the predicted direction.

Prior to further discussion of these results, it must be stressed that these findings require replication before they can be properly evaluated. This is especially true of all groups save the stable right ear dominant group, to be discussed separately further on, which is considerably larger and provides more consistent results, both empirically and as regards their relationship to theory. However, the findings for the other three groups, and especially the unstable left ear dominant group, suggest several interesting problems which the present discussion will attempt to elucidate.

The results for Articulation Errors indicate that the relationship between speech monitoring and perceptual asymmetries may be quite complex, the left ear dominant group especially behaving in an unpredicted fashion. This unreliability in the speech predictive aspect of dichotically classified left ear dominance was already suggested in the temporal analysis, where, on the Phonation Time variable, the Conditions Effect, though in the predicted direction, was not consistent over trials.

A finding of apparently even greater interest is the inverse relationship of speech monitoring asymmetries for time and errors, found in the unstable left ear dominant group. These subjects behave as if their left ear is functionally superior for temporal control and their right ear is dominant for articulatory control. Dionne's[13] earlier study appears to have some bearing on this finding. Though Degree of Auditory Asymmetry correlated with the magnitude of speech monitoring asymmetries on temporal variables, this was not the case for articulation errors. Dichotically classified left ear dominant

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13 Dionne, Ibid.

subjects in that study displayed right ear superiorities as prominent as that of the other groups.

This suggests that laterality difference in the feedback systems used for the control of articulation are more invariant than the control of temporal factors. There exist as yet no studies having demonstrated a left ear superiority in the monitoring of the articulatory aspects of speech, even in perceptually left ear dominant subjects, indicating a relatively pervasive right-ear left-brain cooperation in this respect. However, laterality effects for the monitoring of time are directly related to perceptual asymmetry, and this study raises the question as to whether they may shift over time in synchrony with the shift of perceptual asymmetries. Clearly, what is needed is a study which would involve a longitudinal replication of this experiment, where subjects would be tested regularly and simultaneously for both perceptual and speech asymmetries. This would answer the question as to whether shifts in perceptual asymmetry predict shifts in temporal aspects of speech control, while the lateralized control of articulatory aspects remains stabilized to the right.

Generally, proper evaluation of these findings awaits longitudinal studies of laterality differences, which might vary stimulus materials and perceptual modalities. For example, such a study might involve the longitudinal assessment of LD's in both auditory and visual perception for verbal and non-verbal material. Such cross-modality studies would help to assess if there is an actual shift in the division of labor of the two hemispheres, at least in certain subjects, over time.

Despite the empirical gap, some speculation as to the possible meaning of instability of perceptually assessed auditory dominance and its relationship to speech monitoring asymmetry appears warranted. The only present rationale for LD's in the auditory perception of dichotic verbal materials lies in hemispheric specialization for language. Instability in the direction of LD's in auditory perception would thus presumably reflect a fluctuation in the cortical representation of speech functions over relatively short periods of time. Though not impossible, this interpretation appears unlikely, unless some form of cortical injury intervened, which is not the case in this study.

If such fluctuation demonstrated by the unstable groups were due to measurement error, one would not expect stability to have been related to significant group variation in speech monitoring asymmetries, as was the case in this study. If variation in stability in our subjects is true variation, then a reasonable hypothesis would be that other factors, besides cerebral dominance, may be operative in accounting for LD's and may even counteract the effect of the latter. It was stated earlier in the section "Mechanisms in Dichotic Listening" that the right ear's stronger contralateral connections to the left hemisphere as well as the necessity of left ear input having to travel across the corpus callosum to get to the speech hemisphere accounted for the laterality effect because of the greater signal value accruing to right ear input. Though not tested by this design, it is not unfeasible to suggest that some subjects neither listen to externally produced speech nor monitor their own speech in the most "economical" manner, and despite left hemisphere dominance for speech, obtain LD's favoring the left ear. This could be due to listening biases to the left side which in turn could be due to a further cluster of factors. It is suggested that it would be these "listening biases" which are unstable over time. It is also possible that instability of auditory asymmetries would be a more probable occurrence under free as opposed to ordered recall conditions, where the effect of "listening biases" would be controlled for. As described in the second chapter, DDT scores in this study are all based on free recall procedures.

The latter statement is advanced in view of evidence gathered within the confines of clinical practice. During the longitudinal testing program, there have been instances of marked shifts in perceptual auditory asymmetry, from right ear percentages of thirty-five to 70 percent, which parallelled a shift in communicativity, away from self-absorption and excessive emotionality. Such marked shifts have occurred, for example, after a considerable change in the child's life situation, such as insertion into a residential therapy program. Furthermore, Tomatis has advanced in his ontogenetic theory of the leading ear, that some subjects may adopt left ear control under stress of various sorts such as fatigue, anxiety, etc.[14] It must be emphasized, however, that Tomatis infers auditory dominance in monitoring from variation in speech performance, including involvement of the facial musculature, but has not used the dichotic technique in his assessments.

Clearly, much of the information presented here is too new to be evaluated adequately and requires further investigation with varying methodologies. However, it is the hypothesis of this paper that the results obtained in this study, and essentially the differential control of temporal and articulatory factors for different groups, appears to be a reliable as well as a challenging phenomenon for future investigation. It casts doubt on the hypothesis raised in the previous section of this chapter, that left ear dominance in temporal control, combined with

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14 Tomatis, Op. cit.

the same asymmetry in perception, indicates right hemisphere dominance for language in that group. Similarly, Roode's conclusion, which was essentially the same for his left-siders, deserves to be re-evaluated since he did not perform an error analysis. Also, combined with the instability of perceptual asymmetries over time, it raises the question of the possible multiple causation of laterality differences. Finally, it suggests that the mechanisms for monitoring speech output differ in both unstable and left ear dominant groups as compared to stable right ear dominant groups.

3. Discussion of the Effect of Conditions on Stable Right Ear Dominant Subjects.

Unlike the complex variation of results in other groups, a clear pattern emerges for the stable right ear dominant subjects: the main null hypothesis was rejected for all three dependent variables. This seems especially noteworthy for the Articulation Error measure as this was the only group where the predicted Conditions Effect was obtained, and at highly statistically significant levels ($p<.001$).

These unequivocal results indicate that the predicted lateralization of auditory monitoring systems, for both temporal and articulatory parameters, is readily demonstrable in right ear dominant subjects, when a strong criterion of auditory dominance is used.

SUMMARY AND CONCLUSIONS

A survey of the literature dealing with cerebral dominance for language, asymmetry of temporal lobe functions, laterality differences in auditory perception and the importance of auditory monitoring in the control of speech, provided the empirical and theoretical framework conducive to a hypothesis of auditory asymmetry in the control of phonation. The final section of this survey dealt with studies bearing directly upon and supporting this hypothesis.

The main concerns of this study were fourfold:

1) To provide further evidence testifying to the existence of a "leading ear" in the control of speech output.

2) To clarify which speech parameters displayed a laterality effect: temporal measures, articulation error measures, or both.

3) To investigate the relationship of laterality differences in auditory perception to laterality differences in the control of phonation.

4) To bring to bear the effect, if any, of stability versus fluctuation of laterality differences in auditory perception on laterality differences in the control of phonation.

Based on a longitudinal assessment of their scores on a dichotic listening task using digits, subjects were classified as either stable or unstable right or left ear dominant in perceptual asymmetry. It was assumed that higher left ear scores reflected right cerebral dominance for language and higher right ear scores, the reverse. In view of the stronger contralateral connections of the ear and brain, it was predicted that disturbance of the monitoring function of the right ear would cause more speech disturbance in right ear dominant (presumably left hemisphere dominant for speech) subjects than disturbance to the left ear. The reverse prediction was proposed for left ear dominant (presumably right hemisphere dominant for speech) subjects. Predictions for groups unstable in auditory dominance, a previously unstudied dimension which presumably begged the question of the cerebral dominance interpretation of laterality differences in auditory perception, at least for individual scores, were left open-ended.

Interference with the ear's monitoring function was obtained using monaural delayed auditory feedback and the results analyzed on three voice variables: phonation time, error free mean syllabation time and articulation errors. To compensate for task inequalities, difference scores were calculated between delayed feedback conditions in both trial blocks and the first baseline condition.

The results on temporal variables showed a direct relationship between perceptual asymmetries, whether right or left, and asymmetries in speech monitoring, regardless of the longitudinal stability of the perceptual asymmetries. This was true especially on the Error Free Mean Syllabation Time variable. On the Phonation Time variable, the left ear dominant group was less reliable in that it did not demonstrate a statistically significant speech asymmetry, in the predicted direction, in the second trial block.

On the Articulation Errors variable, results were more complex, asymmetries in speech monitoring interacting with both perceptual auditory dominance and its stability over time. Only the stable right ear dominant group showed the predicted speech asymmetry, at highly significant levels. The stable left and unstable right ear dominant groups demonstrated no reliable speech asymmetries, while the unstable left ear dominant group demonstrated such an asymmetry in the reverse of the predicted direction. Overall, interference to the right ear was the more potent factor in obtaining speech asymmetries for errors, regardless of perceptual auditory dominance.

With respect to the main questions raised in this study, the following conclusions and suggestions for future research are proposed:

1) The presence of a "leading ear" in the control of speech output has received still further empirical demonstration.

2) This asymmetry in monitoring applies both to temporal and articulatory parameters of speech output. Future research in this area would benefit from a more differentiated, or microscopic analysis of these parameters, by incorporating such technologies as electromyography, sonography, etc.

3) This study has demonstrated a direct relationship between perceptual asymmetries and the lateralized control of temporal aspects of speech while suggesting, however, that left ear dominance in auditory perception is possibly a less reliable predictor of these asymmetries than right ear dominance. Lateralized control of articulation errors appears to be predictably related to perceptual asymmetries only in stable right ear dominant subjects.

Generalization from the results of the three smaller groups would have to stand on a replication of this study on larger samples. Also, much more needs to be known regarding how laterality differences in perception behave over time. Proper evaluation of some of the results obtained here awaits such longitudinal studies. However, this study offers evidence that certain subjects use speech monitoring systems where the auditory control of temporal and articulatory parameters is not located on the same side. That is, in the same subject, the monitoring of time is more efficiently performed by the left ear, whereas the monitoring of articulation reveals a right ear superiority.

BIBLIOGRAPHY

Abbs, James H., and Karl U. Smith, "Laterality Differences in the Auditory Feedback Control of Speech," Journal of Speech and Hearing Research, Vol. 13, 1970, p. 298-303.

The results of this study supported the existence of a right ear asymmetry in the control of phonation on an articulation errors variable, but not on a total speaking time variable. Criteria for selection of the sample (eight females) are not mentioned.

Dionne, Maurice, Degree of Auditory Asymmetry in the Control of Phonation, Upgrading Paper, University of Ottawa, 1974.

This study demonstrated a right ear superiority for the control of temporal and articulatory errors in three groups differing in direction and degree of auditory dominance on a Dichotic Word Test. The study thus supported the existence of a "leading ear" but found only a minor relationship, on temporal variables, between auditory perceptual and auditory speech monitoring asymmetries.

Haydon, Shane P., and Frank J. Spellacy, "Monaural Reaction Time Asymmetries for Speech and Non-Speech Sounds," Cortex, Vol. 9, 1973, p. 288-294.

This study demonstrated that reaction time to both a pure tone stimulus and to speech sounds was faster when the stimulus was presented to the right ear. However, no laterality effect was obtained when subjects were pre-advised as to which ear would be stimulated.

Kimura, Doreen, "Functional Asymmetry of the Brain in Dichotic Listening," Cortex, Vol. 3, 1967, p. 163-178.

In her review article, the author presents evidence indicating the stronger contralateral connections of the ear to the cerebral cortex and the differentiation of function of the two cerebral hemispheres along the verbal-non-verbal dimension, thus providing a neurophysiological rationale for laterality differences in auditory perception obtained under dichotic listening. She also describes applications of the dichotic technique to questions such as the development of cerebral dominance and to further specification of function of the left and right hemisphere.

--------, "Manual Activity During Speaking-I. Right Handers," Neuropsychologia, Vol. 11, 1973, p. 45-50, and "Manual Activity During Speaking-II. Left Handers," Neuropsychologia, Vol. 11, 1973, p. 51-55.

In these two studies, Kimura examines the relationship between laterality differences on a dichotic listening task and asymmetries in the free movements of the hands in right handed and left handed subjects.

Roode, Christian D., An Experimental Study of Auditory Asymmetry and Cerebral Language Laterality, Unpublished Doctoral Dissertation, University of Ottawa, 1963.

The results of this study supported the existence of an auditory asymmetry in the control of phonation on a temporal measure (mean syllabation time) for both right and left sided groups. Group selection was based on stringent criteria of sidedness preference and an auditory acuity measure. No errors variable was used.

Simon, J. Richard, "Ear Preference in a Simple Reaction-Time Task," Journal of Experimental Psychology, Vol. 75, No. 1, 1967, p. 49-53.

This study examined the relationship of auditory laterality to speed of reaction time. The results demonstrated that reaction time to a pure tone stimulus was faster when the stimulus was presented to the right ear. However, no laterality effect was obtained when subjects were informed in advance as to which ear would be stimulated.

Sussman, Harvey M., "Laterality Effects in Lingual Auditory Tracking," Journal of the Acoustic Society of America, Vol. 49, 1971, p. 1874-1880.

This study demonstrated a right ear superiority, in right handed subjects, on an auditory pursuit tracking task. When a tongue cursor tone was presented to the right ear and the externally controlled target tone to the left ear, tracking performance was more efficient than in the reverse condition. The author emphasizes that this study points beyond laterality differences in auditory perception to the importance of laterality differences in the regulation of speech.

Tomatis, Alfred, L'Oreille et le Langage, Paris, Editions du Seuil, 1963, 192 p.

In this book, Tomatis discusses the development of his research and ideas concerning the relationship of audition, laterality and language, including the concept of the "leading ear."

APPENDIX 1

READING PASSAGES USED IN THE EXPERIMENT

1. English: Grade Two Level.

Billy was watching Mr. Brown plant seeds in his garden.

When Mr. Brown had finished his planting, he gave Billy a seed.

"Go and ask your mother if you may plant it in her flower garden," he said.

Billy ran all the way home. He told his mother about his seed. She helped him to plant it in the garden.

Every day, Billy watched the spot where his seed was planted. But there was nothing to see. Everyone said, "It will take a little time for your seed to grow."

So Billy waited and waited and waited.

Everyone said, "Soon, soon it will start to grow."

And one day there was a little bit of green coming through the ground. Billy watched it grow and grow and grow.

One day Billy had a talk with the mailman. The mailman talked all about flowers. He had a garden of his own. He liked Mr. Brown's flowers and he liked Billy's mother's flowers.

2. English: Grade Four Level.

They rode out of the yard while the morning dew was still sparkling on the grass. The north road they took today wasn't at all like the one leading to the sheep herds. There were large wheat fields and rye fields on both sides. Narrow paths forked out of the main road, leading to white cottages nestling under shade trees. From the distance, they looked like small white mushrooms under their heavy thatched roofs. The scenery was changing gradually. There were more and more trees. They crossed many small wooden bridges, spanning brooks. Soon they could see the river, like a wide blue ribbon on the green velvet of the fields. Jim rode ahead. Suddenly, he waved and cried, "The ferry is in. Hurry, Father, they're waiting for us." They spurred their horses and clattered on to the floating ferry. It was attached to stout ropes on both sides. The ropes stretched across the river and were wound on large wooden pulleys. There were several wagons and riders on the wide platform.

3. French: Grade Two Level.

C'était une planète toute petite, bien sage, bien gentille. Elle tournait depuis des milliers d'années autour d'une étoile qui n'était pas le soleil. Il ne poussait rien sur cette planète. Rien n'y vivait non plus. Il n'y avait rien que du sol, de l'eau, et de l'air.

Notre petite planète lointaine et sage, s'ennuyait. Depuis le temps qu'elle tournait, et qu'elle parcourait toujours le même chemin dans le même espace autour de la même étoile, rien de nouveau ne se produisait, rien de différent n'arrivait.

Or, un jour, la petite planète entendit un bruit étrange, et une fusée, venue de loin, se posa sur son dos. Quelle nouvelle! La petite planète était tout excitée, et aussi un peu inquiète.

Dans cette fusée, il y avait des hommes. Ils descendirent, se promenèrent et inspectèrent les environs. Cela ne ressemblait pas du tout à ce qu'ils connsaissaient.

4. French: Grade Four Level.

C'était au pays des insectes et des fleurs. Ce matin-là, on avait surpris une chenille verte, saoule de miel, dans la corolle d'un lis blanc. Une araignée avait donné l'alerte. Deux abeilles policières étaient accourues pour arrêter la voleuse de miel.

Pauvre chenille! On l'avait roulée au cachot, dans une galerie souterraine, chez les fourmis. L'araignée lia la prisonnière avec son fil. La voleuse avait l'air d'une momie.

Le juge de la place, un gros barbeau, avait déclaré: "Nous lui ferons son procès demain matin."

De bonne heure, le lendemain, tout un peuple d'insectes attendait sur le terrain: des criquets du voisinage, avec leurs petits manteaux noirs; des faux-bourdons en vestes jaunes; des araignées, des pucerons, et bien d'autres.

Les cigales voyaient à l'ordre. Enfin, le barbeau-juge entra, solennel.

COROLLARY:

DESCRIPTION OF SCORING SYSTEM FOR THE ARTICULATION ERRORS VARIABLE.

Any variation from an accurate reading of the text was scored as an articulation error. However, elongation of a phoneme without discrete breaks in fluency, was not scored. Also, pauses at any point in the text were not scored as errors.

Types of errors scored in this text would be covered by the following definition: repetition, omission, substitution or addition of either a phoneme, a syllable or a word. The word was the largest error unit used. Consequently, repetition or omission of a three word phrase, for example, would count as three errors.

APPENDIX 2

ABSTRACT OF

Stability of Auditory Asymmetry in the Control of Phonation[1]

This study was concerned with demonstrating the existence of auditory asymmetry in the control of phonation and to asses the relationship of this asymmetry in the monitoring of speech, to the direction (right or left) and stability of laterality differences in auditory perception, defined by longitudinal assessment using a dichotic digits test. The voice variables used were Phonation Time, Error Free Mean Syllabation Time, and Articulation Errors. Groups were classified as stable right ear dominant (N=18), stable left ear dominant (N=5), unstable right ear dominant (N=7) and unstable left ear dominant (N=6).

The subjects read a passage under three different conditions which consisted of direct feedback of their voice through earphones and two conditions of monaural delayed auditory feedback to the right or left ear with direct feedback on the opposite ear.

It was hypothesized that speech would be more seriously disrupted by delayed feedback to the dominant

1 Maurice Dionne, doctoral thesis presented to the Faculty of Psychology of the University of Ottawa, Ontario, Fall, 1974; x-158 p.

ear, as defined by dichotic test scores. The existence or direction of the effect of stability of auditory dominance on speech asymmetries could not be predicted. Repeated measures were obtained in order to deal with order affects and to double the conditions under which the hypothesis was tested. To compensate for task inequalities, measures for the delay conditions were subtracted from the first baseline measurement and the analyses were performed on these difference scores.

The results showed that speech monitoring asymmetries were related to laterality differences in auditory perception in the predicted fashion for temporal variables. On the articulation errors variable, however, only the stable right ear dominant group showed a significant speech monitoring asymmetry in the predicted direction. In the unstable left ear dominant group, a significant right ear superiority for the monitoring of errors was obtained. Reliable speech asymmetries for errors were not evident in the other two groups.

ADDENDUM

Table XIV.-

Description of Groups According to Language Used in Reading, Age, and Sex.

Groups	N	Language Used		Age		Sex	
		E	F	$\bar{X}$	S.D.	M	F
Stable Right	18	17	1	10.2	1.67	10	8
Stable Left	5	3	2	9.4	1.14	3	2
Unstable Right	7	6	1	9.7	1.88	4	3
Unstable Left	6	6	0	11.0	1.98	4	2