AUDIOLOGICAL AND INFORMATION PROCESSING CONSIDERATIONS IN DICHOTIC LISTENING

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

STUART J. AGRES

1971

This is to certify that the

thesis entitled

AUDIOLOGICAL AND INFORMATION PROCESSING
CONSIDERATIONS IN DICHOTIC LISTENING

presented by

STUART J. AGRES

has been accepted towards fulfillment
of the requirements for

PH.D. degree in PSYCHOLOGY

Major professor

Date 2/22/71

O-169

ABSTRACT

AUDIOLOGICAL AND INFORMATION PROCESSING CONSIDERATIONS IN DICHOTIC LISTENING

By

Stuart J. Agres

An experiment testing for the effects of sound pressure level (SPL) on dichotic listening performance (DLP) was conducted to ascertain the degree to which monaural threshold differences between the two ears influenced typical DLP. In the first part of the experiment, 18 right handed, normal hearing subjects (Ss) were tested for monaural thresholds for each ear using both Speech Spectrum Noise (SSN) and Speech Reception Threshold (SRT) materials. It was found that the right and left ears had significantly different language thresholds (SRTs) relative to their non-language (SSN) thresholds, with the right ear requiring 2.64 dB less additional sound pressure to reach SRT than the left ear ($p<.001$). This demonstrated the existence of a right ear superiority on this monaural task. Such a finding lends further support to theories of cerebral dominance, and especially to theories of left hemisphere language dominance.

In the second portion of the study a language task was administered in which the Ss were required to construct a single sentence using two successively presented AA-rated Thorndike-Lorge nouns. Of 16 Ss so tested, 13 gave sentences utilizing the words in the same order as they were presented (p=.01). The remaining 3 Ss were inconsistent in that their responses were only 40%, 50%, and 60% consistent. These Ss were included in the remainder of the study, but their responses for the further sections were analyzed with this inconsistency noted.

With the assumption that such time-ordered output was indicative of a processing ordering of the successive input, with the first input being the first output; dichotic presentations of similar materials was expected to evidence results similar to those obtained by investigators utilizing other dichotic techniques; namely, right ear initial output.

There were two major hypotheses for the remainder of the study: (a)Sentence construction using dichotically presented words would demonstrate results similar to those obtained in other DLP studies, and (b)Monaural threshold differences would affect the resulting DLP.

To test these two hypotheses, two dichotic tasks were administered. In Condition 1 each S was presented with the dichotic pairs of nouns at 45 dB SL (re: each ear's SSN threshold). Under this condition, typical right ear superiorities were found for order of word output in the produced sentences ($p=.059$). In Condition 2, S was presented with similar pairs of nouns at 40 dB SL (re: each ear's SRT level). Under this condition no ear superiorities were found ($p=.50$).

From these data it was suggested that balancing for language material thresholds significantly reduces demonstrable right ear superiority in dichotic listening. Further analysis showed that shifting away from ear dominance in DLP from Condition 1 to Condition 2 was highly related to the magnitude of ear superiority found monaurally ($p<.01$).

These findings indicated that of three non-interactional models for ipsilateral pathway inferiority: (a) time delay, (b) attenuation, and (c) "noise"; only the model of attenuation was viable. Time delay would not explain monaural threshold differences and "noise" would not account for other observed behaviors.

Approved ______________

Date 2/22/71

AUDIOLOGICAL AND INFORMATION PROCESSING CONSIDERATIONS IN DICHOTIC LISTENING

BY

Stuart J. Agres

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

1971

To Pat

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the members of my committee: Paul Bakan, Lester Hyman, Donald Johnson, John McKinney, William Rintelmann, and Jack Wakeley; without whose help and varied talents, this dissertation study could not have been conducted.

Special thanks is extended to Dr. Bakan, chairman of this committee, for his special help throughout this project, and to Dr. Rintelmann for his assistance and advice on those points which have not yet become well integrated into the area of psychology.

I should also like to acknowledge the cooperation of the Department of Audiology and Speech Sciences for the use of the apparatus, acoustical rooms, and other assistance without which this study would have proved impossible; and to the technical staffs of both the Psychology and Audiology Departments: Gary Connor and Donald Riggs; for their invaluable help in the design and calibration of the apparatus.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF TABLES AND FIGURES (cont.)

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

The issues surrounding laterality differences in perception have taken on various forms over the years. Recently, investigations of right-left differences in visual recognition of language material (beginning with Mishkin and Forgays, 1952) and subsequent studies utilizing nonlanguage materials (Harcum and Dyer, 1962; Bryden, 1966c; Wyke and Ettlinger, 1961; and others) have yielded explanatory theories ranging from "learned behavior" to "general cerebral dominance." During these same past two decades, studies of auditory laterality have appeared which show results similar in many ways to those of the corresponding visual phenomena. Many of these recent studies of auditory laterality have been conducted using a technique which has come to be called "dichotic listening."

The dichotic listening task has become more precise with the advances made in the audio-electronics industry. The stereo tape recorder allowed for the first time, what should have been, truly simultaneous presentations of auditory materials to the two ears; but concurrent techniques for the actual simultaneous recordings of these materials took additional years to develop. Until just recently, with the advent of specially designed computer facilities, non-simultaneity was more often the case than not; and as such, many of the early studies were much less controlled than would be expected today. But while the stimuli are better controlled than they were at the beginnings of the dichotic listening studies, the task itself has changed very little since its introduction by Broadbent in 1954.

Origin and Development of the Task

Broadbent, since 1952, has published reports dealing with the possibility of a person being forced to respond to an overabundance of non-redundant information. He envisioned the possibility that "individual human beings will find themselves at the meeting place of several (communication) systems and be required to listen and speak on all of them" (1952a, p.267).

The reason he saw this as a potential problem, was that he believed that the behavioral mechanisms used for speaking and those used for listening might be needed simultaneously in such instances; and under conditions of a limited human information processing system, excessive strain would be placed on the individual. In his experimentation then, he intended to test the results of such competition, and to do so, presented messages to individual listeners in rapid succession. His subjects' task was to respond to these messages with relatively simple answers ("Yes" and "No") preceded by the type of ritualistic call signals and notifications used in radio communications. As a logical continuation of this type of research, Broadbent presented two messages at the same time to his subjects; one was to be ignored for not containing an initial key phrase, and the other to be answered. When he did this he found that performance was greatly reduced.

In other investigations he found that spatially separated signals could be better coped with than spatially close signals. To Broadbent this suggested that spatially separated signals could be "heard" successively rather than simultaneously and it was with this hypothesis in mind that he devised the currently used dichotic listening task. The nature of the task was to have a person listen to two strings of spoken digits, one series presented to each ear with the onset of the digit pairs being simultaneous.

As was predicted, when the study was carried out, the results showed an ear-ordered output rather than a time-ordered one. That is, if for example the digits presented were 247 to one of the ears and 538 to the other, the typical output would be 247538 or 538247 but not, 254378 or 523487. This successive processing between the two ears was most prevalent for fast presentation rates, with little time between stimulus pairs; but as the rate was slowed, it began to be possible for the subjects to switch to a time-ordering output, and the percent of digits correctly recalled increased (Broadbent, 1954).

Broadbent continued his research, and continued to develop his model of human information processing which was put forth in his 1958 book and was subsequently modified (elements of Broadbent's models are presented in the next chapter). Soon after Broadbent's research became known, other investigators became interested in using the technique he developed and studies appeared with increasing regularity in the mid- to late 1960s.

In the period between Broadbent's initial investigations and up to and including the later rush of articles, numerous investigators have looked at variables which they felt might be influencing the results. Webster and Thompson (1954, cited in Broadbent, 1958) found that the louder message coming through two audio speakers was more likely to be heard correctly, and Tolhurst and Peters (1956) confirmed this finding under headphone presentation of dichotic material.

In the 1960s, as has already been mentioned, investigators saw the possibility of using this method for testing other hypotheses. Inglis (1960) used the method to study memory disorders, and in 1961, Kimura published an article and an immediate follow-up, which appears to be the beginning of the great upsurge of articles in the literature.

Kimura felt that the dichotic listening task might be beneficial in investigating the effects of unilateral temporal lobe damage on auditory perception. Based on previous investigations, she believed that the ability to perform on the dichotic task should be influenced by such damage; in that, temporal lobe damage should result in an "impairment in recognition of stimuli arriving at the contralateral ear...(and) an impairment specific to certain kinds of stimuli, an effect which in man appears to vary with the laterality of the lesion"(1961a, p.157).

To test this idea, Kimura presented the split-digit span (dichotic listening) test to subjects pre- and post-operative for temporal lobe surgery. She found that with left temporal lobe damage patients the overall recall score was less than that found with right damage patients, which indicated that the left hemisphere of the brain is more important than the right hemisphere for this task. She also found that when the ipsilateral vs. contralateral ear (with respect to the site of lesion) was looked at, the temporal lobectomy resulted in significant losses in the contralateral ear. Further, when compared to a control condition in which the digits were presented alternately rather than simultaneously, the findings indicated that the loss in the contralateral ear became evident only with simultaneous presentations (Kimura, 1961a).

In the discussion section of that article she stated what has come to be the explanation held by many persons for the observed dichotic listening performance. Basing her conclusions at least in part upon animal neurophysiology, she pointed out studies which had demonstrated a greater evoked cortical response on the side contralateral to the ear stimulated; and several studies on human subjects which indicated the same to be true. With this fact she went on to postulate that in the case of competing stimuli presented to brain damaged patients, there is effectively a case of two pathways (an ipsilateral and a contralateral) going to a single functioning hemisphere, with the ipsilateral pathway being weaker than the contralateral. Further, she stated that since the superiorities of the ear contralateral to the intact hemisphere (ipsilateral to the damaged) were evidenced only under simultaneous presentations, then there must be some point of overlap between the pathways ipsilateral and contralateral to one cortex, at which point the contralateral pathway predominates.

In this study, Kimura found that in patients with unilateral brain damage of the temporal lobe, the dichotic task resulted in depressed scores for those patients with left hemisphere damage in excess of those obtained by right hemisphere damage patients. This finding gave additional support to theories of cerebral dominances, which stated that the left hemisphere of the brain is language dominant. A fuller discussion of laterality dominances is given in a later section of this chapter.

A following article by Kimura (1961b) went farther in demonstrating that the results and conclusions of the first study did extend as expected. The further testing described in this article resulted in findings of deficiencies in recalling digits presented to the ear ipsilateral to the intact hemisphere, with left-lesion patients having worse recall than did right-lesion patients. Though the differences were small (about 5%), the results were clearly confirming to her hypothesis. In addition, this study included the testing of 13 normal subjects in which there was a 2% difference favoring the right ear (contralateral to the left, language dominant, hemisphere).

To further substantiate these results, in 1964, Kimura described a study in which she presented normal subjects both melodies and spoken digits in the same dichotic fashion. On the digits test, the results showed a superiority of the right ear, but on the dichotically presented melodies, left ear dominance was found. Kimura concluded that the findings were related to the verbal and nonverbal roles of the two hemispheres.

Kimura has continued to publish studies in dichotic listening and has investigated the effects of: controls on output (1967), recall vs. recognition (1967), backwards speech materials (Kimura and Folb, 1968), and age variables (1963b).

Another of the more prolific experimenters in the area of dichotic listening is Inglis, who, as has already been mentioned, began publishing research in this area in 1960. In general, his reports have dealt with age-related differences in dichotic listening performance, but his conclusions have more far reaching implications.

Inglis (Inglis and Tansey, 1967) pointed out that there were at least two reasonable hypotheses regarding the nature of the information processing which resulted in the observed dichotic listening performance.

> Broadbent (1958) has suggested that the material recalled second in series (i.e., from the delayed channel) may have been held in some short-term store while the material recalled first (from the immediate channel) has only passed through a kind of perceptual system.... (In an) alternative view, both half-spans have entered (different) storage systems, but the delayed half-spans have been held in store longer and have been subject to more recall interference, hence more errors appear.

He went on to point out that in Hebb's terms, the first hypothesis required an "activity trace" for the immediate channel and a "structural trace" for the delayed. The alternative hypothesis suggested a "structural trace" for both channels. These two theories anticipated different results for his reported study. He argued that repetition would facilitate a "structural trace" but not an "activity trace," and consequently, if "cumulative improvement could be shown for all the repeated series, both immediate and delayed, this would provide evidence in support of the notion that a structural change, and hence short term storage, underlies performance on both channels." His findings demonstrated that there was similar improvement in both immediate and delayed channels and hence support for the alternative model he proposed.

Other of Inglis' studies have shown aging effects on dichotic listening performance (Inglis, 1962; Inglis and Caird, 1963; Inglis and Sanderson, 1961; Inglis, Ankus and Sykes, 1968); and still others have been involved, to a large extent, with the reason for dichotic listening performance (Inglis, 1965, 1968; Inglis and Sykes, 1967).

A fourth investigator, Bryden, has been responsible for the bulk of the remaining literature in the area of dichotic listening. Bryden (1962) reported on a study designed to more carefully look at order of report in the dichotic task. He found, as did Broadbent (1954, 1956), that ear-order predominated over temporal-ordering for the subjects' outputs. In addition, increasing the amount of material presented led to an increase in random, unsystematic responding; and slowing the rate of presentation allowed subjects to successfully adopt temporal-order reporting. In fact, when ear-order report was used, accuracy declined with slower presentation rates.

In 1963, Bryden took the step of combining expectations from Broadbent's and Kimura's research. While Broadbent had discovered a preference for ear-order output over time-ordered, Kimura had demonstrated a right ear--left hemisphere superiority in dichotic listening. It seemed logical to conclude that if both accuracy of report and order of report were looked at, one would find that the material presented to the right ear would be more accurately recalled and more likely to be reported out first.

The major problem with such a hypothesis is that if true, it would be difficult to determine if the superior recall was due to the order of output with concurrent short-term memory losses to the other channel. To investigate this possibility, Bryden (1963) controlled for order of output by instructing his subjects to report all the material they heard in one (instructed) ear before reporting any they heard in the other ear. The results showed that controlling for which ear was first, still maintained a right ear superiority in recall.

The following year, Bryden (1964) reported on a study which tested several variables affecting report strategies. The first experiment reported, used monosyllabic words (AA, Thorndike-Lorge) rather than digits. Results similar to those obtained with digits were found. The second experiment showed that word associations affect the order of report.

There have been numerous other investigations of variables and their possible effects on dichotic listening performance. These are given in Appendix A of this paper (due to the large number of such articles).

Cerebral Dominance

As has already been mentioned, dichotic listening results lend themselves to several alternative explanations. Kimura insisted that such results were due to differences on a perceptual level, influenced largely by dominances of pathways and cerebral hemispheres. Inglis argued that dichotic listening demonstrated differential processing based on channel selection; and Bryden has argued that there might be some combination of these two which yields the observed results. Bryden and others have demonstrated that controlling for order of output still resulted in small, but statistically significant residual effects in accuracy (Bryden, 1963, 1965; Borkowski, *et al.*, 1965; Satz *et al.*, 1965).

In many ways these arguments are based in theories of cerebral dominance. Kimura, in fact, talked about cerebral dominance specifically, as she attributed the superior recall of digits and other language materials presented to the right ear as being due to that ear's superior connections to the language dominant, left hemisphere. While the exact theoretical arguments for dichotic listening are given in the following chapter, it is appropriate here to review some of the past and current thinking about cerebral dominance and how dichotic listening may be related.

There are three recently published articles which present views on cerebral dominance from historical as well as current bases (Benton, 1965; Giannitrapani, 1967; Zangwill, 1964). No attempt is made here to duplicate the efforts of these authors, nor to extend their works for the intervening few years; rather a brief summary of these works is presented to familiarize the reader with certain aspects of cerebral laterality which are useful for interpreting arguments on dichotic listening which are presented in this paper.

The notion of cerebral dominance has existed in one form or another for many years. Giannitrapani (1967) traces its history from the Hippocratic School to the Renaissance and through to the early 1960s. While during this period thinking on the issues has changed, we still find ourselves unable to answer the most basic questions of how dominance operates: on recall, storage, input, etc. We are still forced to settle for classifications of functions which appear to be determined more by the functioning of one hemisphere than the other. Historically, even this is a big step.

From a starting point where observers spoke of motor activity being affected by contralateral cerebral damage, modern investigators have discussed the role of "The Dominant Hemisphere" in terms of handedness and more recently in terms of language functioning. The notion of there being one dominant hemisphere is still clearly with us, even though Hughlings Jackson (1868, cited in Zangwill, 1964) spoke about viewing the two hemispheres as being differentially functioning rather than one being strictly dominant. To Jackson, language was bilaterally represented, with more primitive language (emotional) being on one side and higher level on the other.

Certainly the problem of defining dominance for the hemispheres is nowhere near being resolved. Various functions seem to "reside" in the two hemispheres with differing strengths, but neither hemisphere seems clearly dominant.

In terms of dichotic listening, hemispheric language dominance clearly plays at least some part in the performance of the task. One of the stronger reasons for accepting the notion of hemispheric dominance in dichotic listening is that, while digits and words presented to the right ear are better recalled or recognized, musical material is better remembered when it is presented to the left ear (Kimura, 1964; Shankweiller, 1966; Spellacy, 1970). Of course, studies utilizing brain-damaged subjects also lend support to the notion that the hemispheres operate differentially on both verbal and nonverbal materials.

That cerebral dominance is a necessary factor for the observed dichotic listening performance can be easily deduced. Since it has repeatedly been shown that right ear verbal material is better recalled than left ear verbal material, it becomes necessary to conclude that one hemisphere is in some way dominant over the other. If this were not so, it would be impossible to explain this finding with any of the current theories of information processing. If the two hemispheres were identical, even if one of the two auditory pathways from each ear was totally nonfunctional as a language transmitter, each ear would be represented in equally good hemispheres of the brain and no differences should be observed. Necessary also, is that one of the two pathways be dominant. If the two auditory pathways were equally good, each ear would have equally good means of being represented in the language dominant hemisphere, and hence no differences for the two ears could be observed.

It is possible, of course, that the two hemispheres are equally good receptors of language messages but are not equally good processors. Nevertheless, in such a case one hemisphere would still have to be labled as being "dominant" for the task involved.

Monaural Tasks

With the growth of interest in dominance of cerebral functioning, came investigations into methods of demonstrating laterality differences and more recently, categorization of these lateral superiorities. Kimura's adaptation of Broadbent's task must be considered a pioneering step in this light, as it allowed for observations of laterality differences in people's language functioning without the dangerous and complex procedures of surgery or inter-carotid artery injections. It also allowed for observations of laterality with normal subjects.

The dichotic listening techniques grew in popularity throughout the 1960s, as investigators came to accept the notion that only by dichotic stimulation of the two ears could auditory laterality differences be shown for normal subjects. While there have been studies that showed lateral superiorities in hearing monaurally, these have typically been discounted as weak and not convincing.

For example, testing at the Wisconsin State Fair in 1954 (Glorig, Wheeler, Quiggle, Grings, and Summerfield, 1957) yielded slightly lowered thresholds for both pure tones and language materials for the right ear than for the left. These differences were very slight, and as Palmer (1964) pointed out, reached significance more because of the large sample (3,465 subjects) than because of the magnitude of the difference observed. Other investigators failed to find any differences for monaural thresholds (Jerger, Carhart, Tillman, and Peterson, 1959; Calearo and Antonelli, 1963; Palmer, 1964) while investigations of a non-threshold nature have yielded marginal results.

Bakker (1967) demonstrated a left ear superiority for Morse-Code like materials to children aged six through nine, but failed to get even left ear trends for children aged 10 and 11. Spoken digits under this same paradigm yielded right ear superiority for 6 and 11 year olds, but not for 7 to 10 year olds. In no single age category did results for verbal or nonverbal materials differ significantly from chance.

In 1969, Bakker reported a further study looking at the method of recall as the major variable. His results are confusing, as the data reach significance only when specific groups are combined and then tested within a single condition (5-letter series). Under an alternate condition (4-letter series) the results were opposite In summary, the total picture for monaural laterial superiorities was not compelling.

In part, because of these findings, Kimura's model and explanation for dichotic listening (which is more fully discussed in the following chapter) makes specific reference to auditory pathway interactions; that is, the right ear to left hemisphere (contralateral) pathway is said to interact and partially occlude the signals being transmitted along the left ear to left hemisphere (ipsilateral) pathway. Such a system of interaction is a necessary inclusion for Kimura's model, for her to explain why there are dichotic results on the one hand, but no monaural threshold or major non-threshold differences on the other.

Kimura (1967) states:

> It fairly early became clear that the normal auditory asymmetries could be demonstrated only with dichotic presentations. ...When digits are alternated rapidly between ears, but do not actually overlap, there is only a non-significant trend for the right ear to be better. ...The slight trend for the right ear to be better under our alternating condition is probably due to the fact that it permits some competition between ears which is not present under straightforward monaural presentations.

It's a well known fact that arguing from an improbable null-hypothesis carries with it certain risks which are equal to the criterion level set by the experimenter for rejection of that hypothesis. It is equally well known, though less often considered, that the non-rejection of the null-hypothesis also carries with it certain risks. Unfortunately the level of this risk is rarely, if ever, known exactly ($\beta \neq 1-\alpha$). Because of this, it is hazardous to make predictions based on "non-results". Nonetheless, such non-result findings do occasionally get published and discussed in the scientific literature when combined with treatment effects which do reach significance levels. Close examination of such non-result studies have, to this investigator, demonstrated methodological issues which, if corrected, would potentially reduce β-error probabilities.

Palmer's (1964) monaural threshold study is one such methodologically inaccurate investigation. In his attempt to measure thresholds, Palmer duplicated too well the clinical audiologists' techniques, which, while adequate for clinical evaluations fall far short of the rigorousness needed for experimental investigations. While clinical evaluations of hearing can and do allow tolerances of up to ± 5 dB, it is very possible that such gross measurements becloud any small but real differences in thresholds for the two ears.

It can be well understood why Kimura (and others) would tend to build models which maintain that there is no difference between the two ears monaurally. Certainly there has been little evidence to suggest otherwise. However, it should be kept in mind that to this point investigators didn't know what magnitude of difference to expect, and therefore latitude in methodological rigor could have been accounting for the "non-findings" on which these models are based.

The Physiology of Dichotic Listening

Kimura has continually made reference to physiological studies to support her theoretical model. While the actual model was not presented until 1967, the basis for it was put forward without change since her initial investigations in 1961.

In the preceding section of this introduction, it was pointed out that an interaction was necessary to explain why monaural threshold differences were not detectable. If it were simply a matter of a dominant hemisphere for language and a dominant acoustic pathway, then monaural differences should be noted; if however, no monaural differences are detected, an interaction of the pathways must be postulated. At this point then, it is appropriate to analyze the physiological evidence for the binaural interaction which Kimura has put forward as one of the more important processes for the observed dichotic listening behaviors.

In 1946, Tunturi performed an investigation looking at the evoked cortical response generated by electrical stimulation of the ears of 15 anesthetized dogs. He found that the "amplitude of responses to contralateral stimulation, in general, appeared to be greater than those of the ipsilateral side... ." Further, he reported that,

> The responsive areas in one cerebral hemisphere to contra-lateral and ipsi-lateral stimulation of symmetrical groups of nerve fibers, corresponded in latency, duration, wave form and initial sign.... This evidence suggests the presence of a neurone common to both ears from the medial geniculate body to all three acoustic areas of the cerebral cortex from each symmetrical group of nerve fibers in opposite cochleas.

Rosenzweig (1951) took issue with the claim of Tunturi that the neurons are common from the medial geniculate. In his study, Rozenzweig used click stimuli presented to the two ears of anesthetized cats. He maintained that "at a given (cortical) electrode location, the larger the amplitude of the response, the larger the number of units that have been excited." With this in mind he found and arrived at the following conclusions:

> The response of each ear tends to be larger at the contralateral hemisphere. At the left hemisphere the response of the right ear tends to be the larger of each pair. ... The contralaterality of cortical representation is apparent for every animal.

While Tunturi seemed to suggest that all neurons are in common, Rosenzweig suggests that his findings of significantly larger responses contralateral than ipsilateral, evidences the fact that the overlap is not total. In concluding, Rosenzweig stated,

> At the auditory cortex of both cerebral hemispheres, each ear is represented by a population of cortical units. The population representing the contralateral ear is larger than the population representing the ipsilateral ear. The two populations overlap; that is, some units belong to both populations. These conclusions may apply also to the medial geniculate body.

Moushegian, Rupert and Whitcomb (1964) give a brief review of the kinds of findings that have been reported with single-cell recordings: When clicks are binaurally presented and units in the accessory nucleus are recorded from, several things may occur depending on the specific unit looked at. A unit may respond to binaural but not monaural clicks, another may respond to both monaural and binaural but with different amplitudes. Others will exhibit inhibition within some range of time differences of click onset and interactions may produce shifts in the latency of a unit's response.

The study they reported on (Moushegian, et al., 1964) was done to assess response patterns to monaural and binaural clicks. They found that some units show inhibited responses to the left ear when right ear click followed shortly afterwards, even though a right ear click alone did not show a response for that unit. The degree of inhibition was related to the time delay between clicks.

Further, units seemingly were different from one another with regard to what delays caused maximal inhibition, with some units giving maximum inhibition at absolute simultaneity and others at 0.25 milli-seconds.

One earlier study conducted, using human subjects, bears mentioning at this time. Bocca _et al_.(1955) used human subjects with "supratentorial tumours," presenting them with live voice filtered through a low pass filter (1000 Hz). They report that in 13 of 18 cases studied, the articulation score for distorted voice of the two ears showed greater loss in the ear contralateral to the site of lesion than in the ear ipsilateral to it. They state in addition:

> Our research method for the discrimination of speech does not give support to ... (the claims of) the prevalence of one hemisphere for the reception and expression of speech. As a matter of fact, we have not noticed any difference of behavior between right and left temporal lesions.

It is from these and similar studies that Kimura has grounded her behavioral observations with physiological support. In summary, these studies suggest that the contr-lateral hemisphere is the one that receives the primary signal from an ear; that is, the contralateral pathway is in some way superior to the ipsilateral. Secondly, the two ears signal the same neurons at some point and a message of binaural simultaneity is transmitted to the cortex in terms of a diminished evoked response.

It should also be pointed out however, that according to the study by Moushegian, _et al_., fibers in the accessory nucleus respond differently, with some excited and some inhibited by either ipsilateral or contralteral clicks. This implies that a model (such as Kimura's) which neces-sitates that the contralteral signal occludes the ipsilateral is somewhat inaccurate, as the opposite also occurs. The extent to which each of these occur is not, however, known.

A further point should be interjected here. The time of maximal inhibition discussed by Moushegian et al. ranges from 0 to ± 250 micro-seconds. In most studies of dichotic listening, and certainly in the earlier ones (which first demonstrated the phenomenon) exact simultaneity in presentation was not achieved, and delays of up to 50 msec most probably were the rule rather than the exception to it. Thus the physiological support for the proposed models of dichotic listening is off by a factor of 10^2 or more in terms of pathway interactions.

CHAPTER II

THEORIES OF DICHOTIC LISTENING

Dichotic listening has been used to develop several theories of information processing. Unfortunately, while these theories differ from each other along several dimensions, this fact has been obscured in the literature with the result being so-called theoretical arguments. In fact, little actual disagreement in the models themselves exists. This being the case, analysis of the various models will be undertaken here and then several "collapsed models" borrowing from the individual models will be presented with the assumptions and implications they elicit.

The Initial Models

Broadbent, the initial user of the dichotic listening technique being discussed in this paper, arrived at a model for information processing based on the ear-order output he observed for his subjects. The model can be diagrammed approximately as shown in Figure 1.

In this model, Broadbent did not speak of a specific ear as being better coupled to the language processor, but rather about the order of processing in general, regardless of which ear led. Basically the model states that the

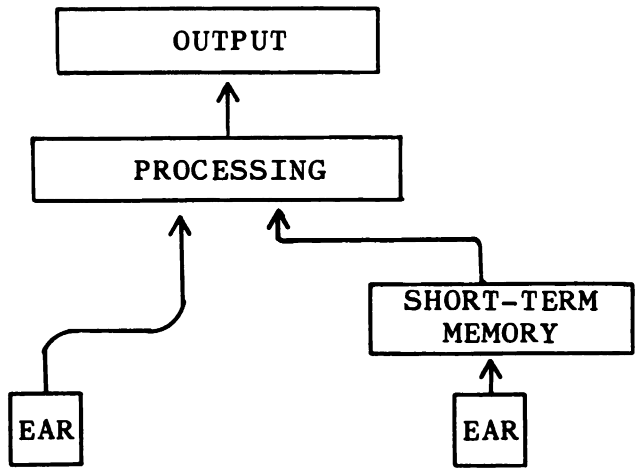

Fig. 1. An approximation of Broadbent's model. In this model, the message from one ear is held in short-term memory, while the message from the other ear is allowed immediate access to processing and output.

message arriving at one of the ears (the one not attended to) is delayed in short-term storage, while the other is allowed immediate access to the processor. The result of this selection procedure is the ear-order output obtained when the pairs of digits or other materials are presented rapidly, with little time between pairs. With the selector unable to shift rapidly enough, all the material from one ear reaches processing before any of the material presented to the other ear.

When the time between stimulus pairs is sufficiently long, however, the processor can complete its operation on the first message and switch to the message that had been held in short-term storage; all before the next pair is presented. In this condition, with long periods between pairs of stimuli, a subject should report the dichotically

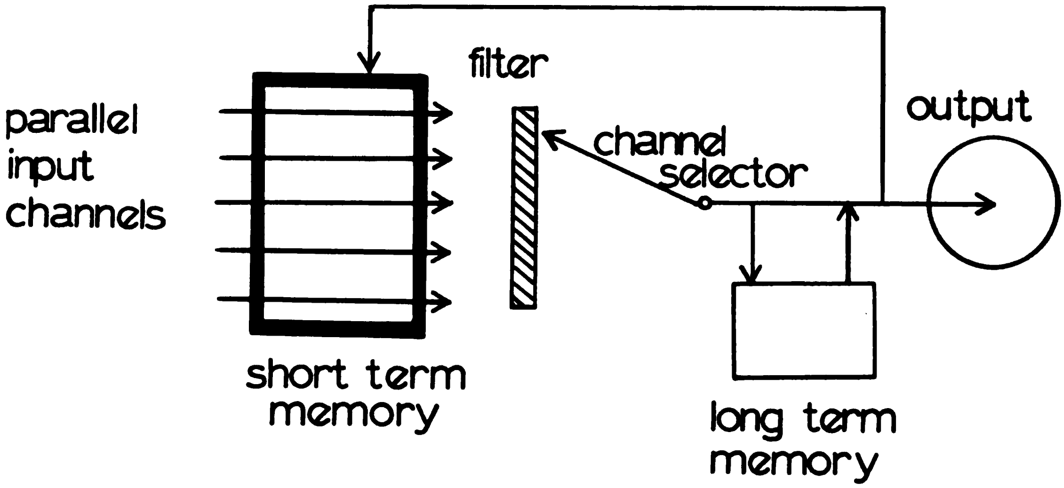

Fig. 2. A modification of Broadbent's original information processing model. In this model, all input channels pass through a short-term memory system and then are allowed access to long-term memory and output on a one-at-a-time basis.

presented material on a time-ordered rather than an ear-ordered basis.

In later development of his model, Broadbent allowed for all input channels to pass through a short-term memory system. (See Figure 2.) With this model, the immediate channel was one that passed through first, while the delayed channel was kept in short-term storage. This later model answers one of the issues raised by Inglis (1967) where Inglis demonstrated that both input messages benefit from repetition, which would not necessarily be true if one input went directly to output processing.

Kimura was the first investigator to look at the effect of brain damage on dichotic listening performance. In her studies she found that right-ear recall was superior to left-ear recall for digits, and that left hemisphere damaged patients were worse at recalling information from either ear than were right hemisphere damaged patients. Based on these findings, she concluded that dichotic listening was another means of demonstrating left hemisphere, language dominance. To clarify her point as to why the contralateral ear to the site of lesion was most affected, she utilized information of evoked cortical response (on animals) and some research using other materials with brain damaged human subjects. She verbally presented a model that could be diagrammed as follows:

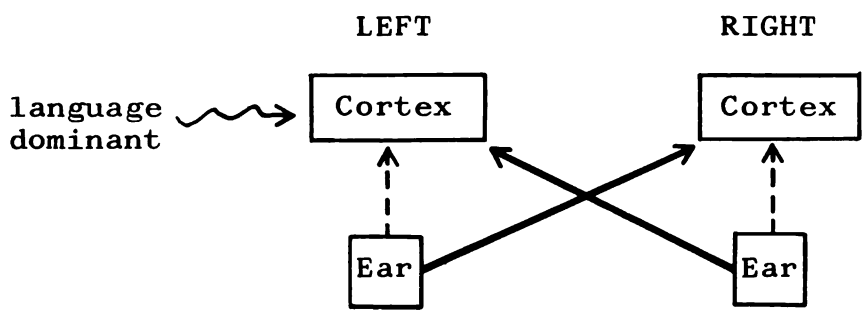

Fig. 3. An approximation to Kimura's early model for dichotic listening. In this model, the contralateral pathways are seen as being stronger than the ipsilateral, and the left hemisphere is considered dominant for the digits task.

This model implies that the contralateral (crossed) pathways from the ear to the cortex are superior to the ipsilateral (uncrossed) pathways, and therefore the messages arriving at the left, language dominant hemisphere via the right ear are more salient. She felt that it was because of the pathway dominances that the right ear superiority developed. Kimura went on to state that while she felt the above to be true, the pathway superiority only became evident in situation of competition, when the system was heavily taxed. She states, "These data suggest that there is overlap, at some point, between pathways ipsilateral and contralateral to one cortex, and at this point of overlap the contralateral units predominate over the ipsilateral" (1961a, p.164).

The exact nature of the overlap and competition was not discussed in that article, but later, in 1967, in her review of her dichotic listening research, she became more explicit. The following schematic is modified from one presented in that later article:

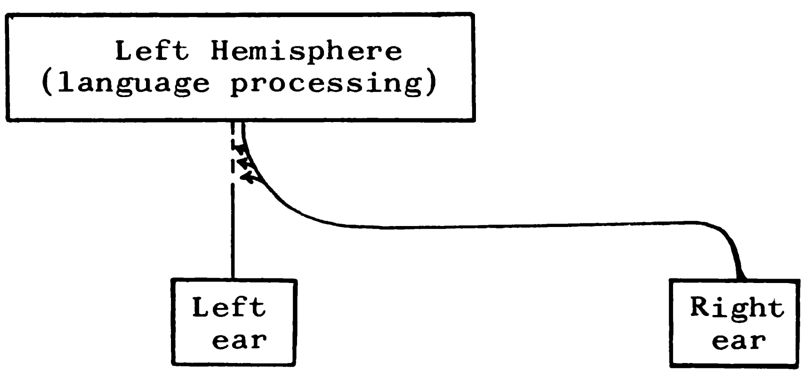

Fig. 4. An adaptation of Kimura's interaction model. In this model, Kimura postulates that the contralateral pathway, at some point, at least partially occludes impulses traveling along the ipsilateral pathway.

For an explanation of this overlap, she refers to Rosenzweig (1951) who, according to Kimura

> has proposed that there is in addition (to a slightly greater number of fibers from the contralateral than from the ipsilateral), a point of overlap between the two pathways, and at this point of overlap the contralateral pathways are capable of occluding impulses arriving along the ipsilateral pathways. (p.171)

Actually in Rosenzweig's 1951 article there is no mention of contralateral pathway occlusion of ipsilateral pathway signals. Such a statement by Kimura, is apparently a misinterpretation of the statement actually made by Rosenzweig; that,

> Simultaneous stimulation of the two ears usually results in partial summation; that is, the (total) response is somewhat larger than the response of the contralateral ear, but it is not so large as the sum of the contralateral and ipsilateral responses.

This statement does not hold that it is the ipsilateral response that is being reduced, or the contralateral, or both.

While Broadbent and Kimura had been viewing dichotic listening behavior from their own perspectives, other investigators, notably Inglis and Bryden, had been studying the relative merits of each of these models. Inglis, in his efforts to understand dichotic listening, came to some conclusions which when published shook the area into a substantial controversy, but one without a great deal of merit. He found that apparently much more of the dichotic listening performance behavior was attributable to the ear-order output than it was to the correctness of recall.

Because of this he stated that Kimura's scoring method which did not take into account order of recall, but only correctness, was fallacious. Since a later appearing digit (in output) would have been stored longer, it would tend to be less well recalled in terms of correctness than a digit recalled earlier in the output sequence.

Almost immediately, this became an issue to which other authors addressed themselves (i.e., see Perl, 1968), when actually such an argument seems trivial; especially in light of other published research available at that time which showed that controlling for output ordering still yielded right ear superiority in correctness of recall for digits (Bryden, 1963, 1965; Borkowski, _et al_., 1965; Satz, _et al_., 1965).

In effect, Inglis arrived at the conclusion that output was a more important variable than input. Or more appropriately, that processing was more important than perception in a task that is at least partially perceptual. When viewed without further explanation, which was never given in Inglis' literature, it seemed to imply that differential processing could take place on information that was not differentially perceived.

Inglis has since modified his position somewhat, he has more recently stated:

> It would certainly be misleading to maintain that laterality effects in dichotic listening are necessarily reducible to order-effects, or vice versa. I would only insist that adequate analysis of DLP (dichotic listening performance) data must certainly attend to _all_ the sources of variation that seem likely to be of importance, two of which have often been confounded in previous studies (Inglis, 1968, p.421).

In an attempt by this author to place Inglis' argument on somewhat firmer ground, it seems reasonable to

assume that a possible model that he could have proposed would claim that laterality effects are due to directional scanning of the two hemispheres (from the left hemisphere to the right hemisphere). That is, if input was to be considered identical and both inputs stored temporarily (which he has claimed to be true--Inglis and Tansey, 1967a) the output order effect could be due to a left hemisphere scan prior to a right hemisphere scan for stored verbal information. (See Figure 5.)

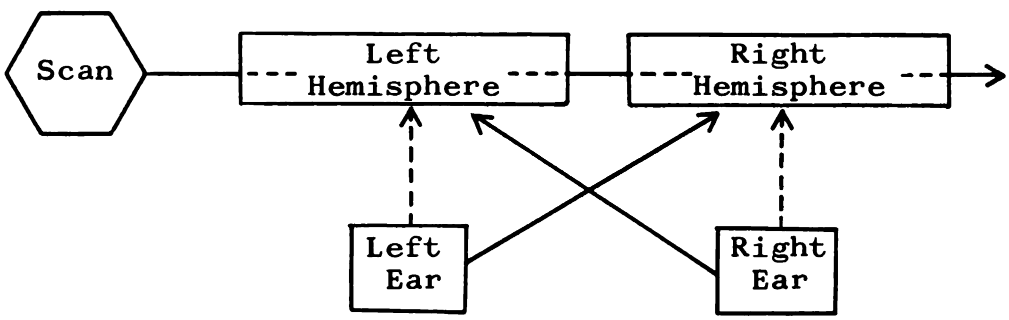

Fig. 5. A possible model for dichotic listening based on Inglis and Tansey, 1967a. In this model, a scan mechanism would operate sampling from the left hemisphere before sampling from the right, thus allowing for the left hemisphere superiorities found.

When no specific output order is specified by the experimenter, the left hemisphere, containing the stored information from the right ear would produce the first output. When left ear output is specified as being required first, this model would allow for expectations of slightly reduced ability for the left ear as an immediate channel than for the right ear as an immediate channel, but the left ear as an immediate channel would be expected to be better than the right ear as a delayed channel. This being true if left ear immediate report required a double scan pass:

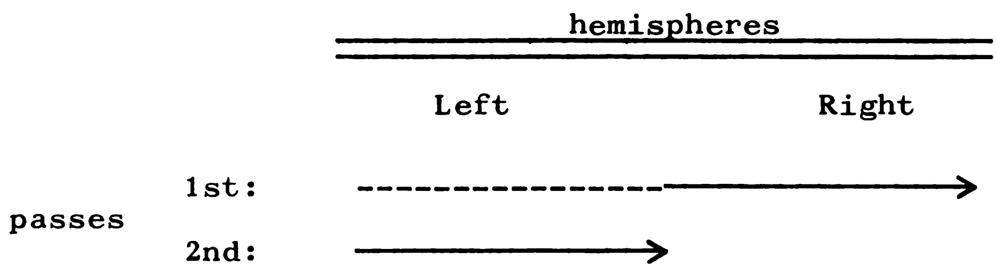

Fig. 6. How a double scan pass would account for observed behavior in dichotic listening. Empirical results supporting this have been obtained by Bryden (1967).

At the height of this controversy, Bryden (1967) published an article in which he discussed several possible models for laterality effects in dichotic listening. The four models discussed are reproduced in Figure 7, and summarization of their major points follows:

Model A (Order-effect model). This model is attributed to Inglis by Bryden. This model states that "accuracy decreases as a function of time since input." This implies that right ear superiority on recall is not due to better perception, but only to order of report. Right ear superiority should then disappear under controlled order of report. (Note that this model is not equivalent to the one I say Inglis may have meant.)

Under the model previously proposed for Inglis, recall would not be the same for the two ears solely dependent on which ear was called upon for output first. Rather

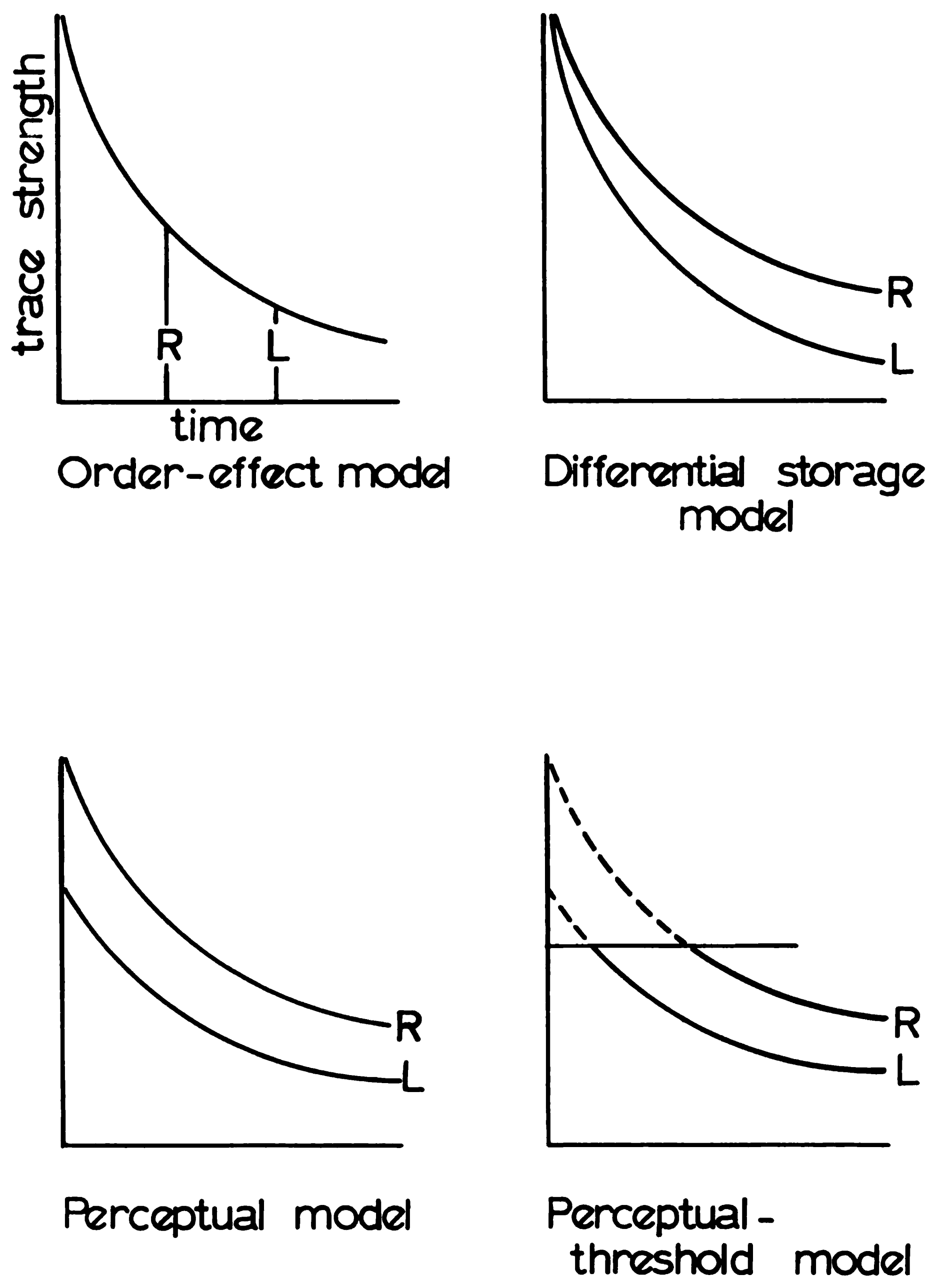

Fig. 7. Bryden's models of dichotic listening. From Bryden, 1967 (see discussion in text).

the previous model would necessitate a double scan for left ear report first, thus making the left ear somewhat worse than the right ear as an immediate channel.

Inglis, in replying to Bryden has stated that such a model (Model A) is an inaccurate representation of what he had proposed.

Model B (Differential storage model). This model states that input arriving at the dominant hemisphere is less subject to spontaneous decay than is input arriving at the non-dominant hemisphere (i.e., short-term memory processes may be more efficient in the left hemisphere than in the right). Expectations are that there will be a right ear superiority with both free-recall and ordered-recall situations. By this model, lateral asymmetries will increase as a function of time between storage and recall.

Model C (Perceptual model--Kimura, 1961). This model expects that right ear material is better under both free and ordered report. This model has an advantage of providing a simple explanation for why most people prefer to report the material from the right ear first; it provides a stronger or more active neural trace than does the left ear input.

Model D (Perceptual threshold model--Bryden). In this model "it is assumed that the neural activity set up by the input must fall below a fixed threshold before any errors are made.... This model generates the same predictions as the differential storage model (B), but is based on a perceptual difference rather than a storage difference" (p. 597).

As has already been pointed out in this paper, there is considerable evidence on which to discard the first model (Model A), as ear superiority is maintained under controlled report conditions. Unfortunately there is little reason to discard any of the three remaining models, as they would all produce almost identical expectations. As Bryden pointed out, there is no difference in expectations between models B and D, even though the reasons for these expectations would be different.

A Combination of Models

Thus far, models incorporating dichotic listening have been discussed. These models, it should be noted, do not all talk about the same portions of the information processing process. For example, Broadbent's model is one of selective attention for input and speaks more directly to upper level processing and output. Kimura's model on the other hand, is basically one of input differences, attributing any processing that goes on to the left hemisphere (for language). This does not mean that the two models are contradictory, but rather, only that they address themselves to different parts of the process.

While the various investigators may see this as contradictory, the following combination model will, I believe, show why this need not be so.

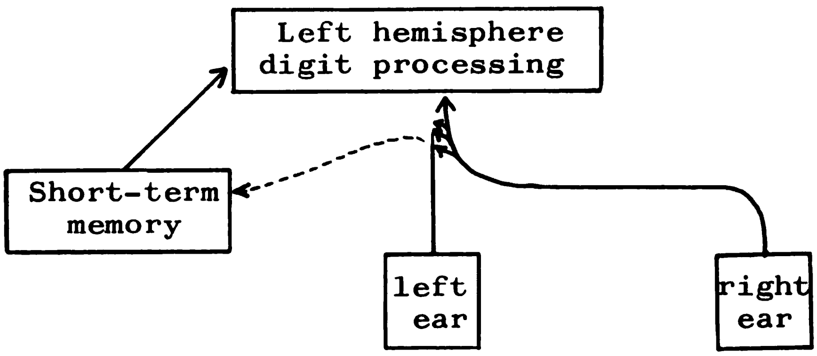

Fig. 8. A possible combination of Broadbent's and Kimura's models.

In this model (a combination of Broadbent's and Kimura's), the occluded digits message is transferred to short-term storage while the unoccluded arrives and is processed by the left hemisphere.

If at this point, Bryden's model is included, the following model might be obtained:

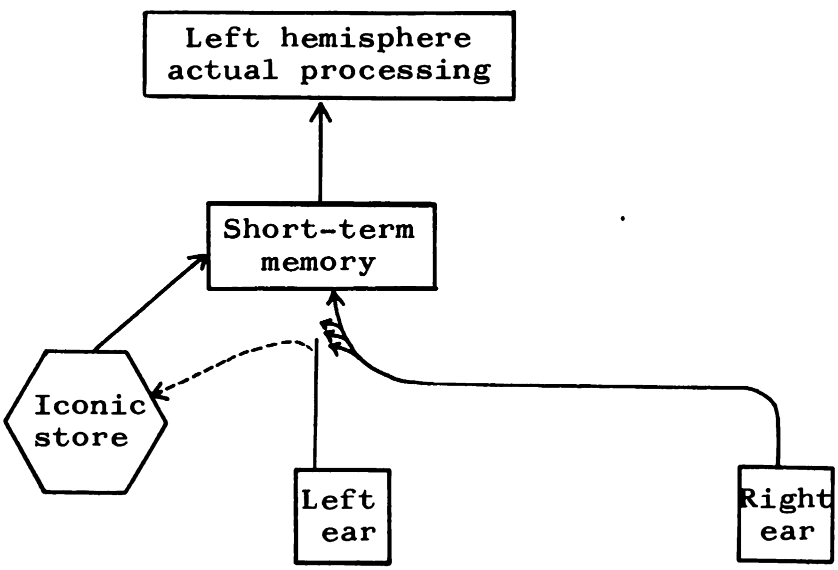

Fig. 9. A combination of Broadbent's, Kimura's, and Bryden's models for dichotic listening.

In this model (see Figure 9), information from the left ear is momentarily shunted into a very short-term storage (perhaps a lower level short-term memory). Because of this it is perceptually weaker than the other signal which has already moved into more advanced processing.

While these models can be made to coexist relatively well, Inglis' scan model (the model attributed to him in this paper which he has never claimed) would necessitate a more complex arrangement. The closest that can be made, incorporating all the models might look something like the following:

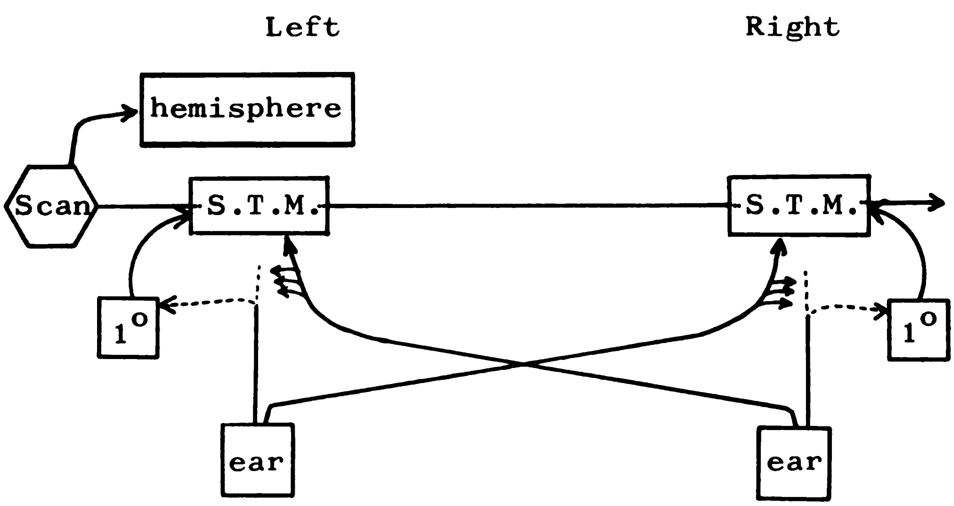

Fig. 10. A possible combination model based on Inglis, Kimura, Broadbent, and Bryden.

In this model the scan picks up information for the major processing hemisphere with each short-term store containing material essentially from the contralateral ear.

At this point it becomes clear that such extension models are limited only to the imagination, and that no good purpose is to be served by continuing. Just as past investigators forced theories to fit ever increasingly complex data regarding the sun's rotation about the earth, so does this type of model building necessitate an ever increasing number of parts and subparts of the human brain to explain its processing.

From this it becomes evident that at least one crucial part of the model has not yet been discovered; that part which would enable us to eliminate some wrong segments of the model and substitute some new portions; allowing us to arrive at one model that would parsimoniously deal with the data at hand.

While the purpose of the present study is to attempt to do this, it is necessary to reflect on several points at this time. First, and most importantly, no investigator has behavioral knowledge of the nature of the superiority of the contralateral pathways in humans. It is accepted by most investigators in the area of dichotic listening that the contralateral pathway is superior, but the nature of the superiority has only been explained by Kimura (1961a&b, 1967), and this explanation is based in large measure on the lack of significant findings which might demonstrate the nature of the superiority. Since no studies have conclusively shown the existance of monaural threshold differences in the two ears (Palmer, 1964), an interactional model was proposed by which the contralateral pathway occluded the ipsilateral.

There is reason to expect that if such monaural differences do exist, they may have influenced the results of the dichotic listening studies, since controls for sound pressure levels presented to the two ears have been rather sketchy. (For example, the following studies did not even mention "volume": Kimura, 1961a, 1961b, 1964; Kimura and Folb, 1968; Bryden, 1962, 1963, 1964, 1966; Broadbent, 1954; Oxbury and Oxbury, 1969; Shankweiler, 1966; Inglis, 1968; Inglis and Sykes, 1967; etc.)

In those studies where controls are mentioned for either sound pressure or simultaneity of onset of the stimulus pairs, these controls often appear less than totally adequate. The following are quotations from various articles where specific references to controls are made:

> The material consisted of spoken digits, most of which were presented in pairs in such a way that different digits arrived simultaneously at the two ears. (Kimura, 1963)
>
> Each channel of the tape recorder was set at a comfortable standard volume.... (Kimura, 1963)
>
> In testing, approximately half the subjects heard channel 1 at their left ear and half at their right ear. In this way the effects of any differences between the two channels of loudness or quality of recording were minimized for the sample as a whole. (Bryden, 1962)
>
> The earphones are reversed for half the subjects, to cancel out the effect of any discrepancy between the two input channels. (Milner, Taylor, and Sperry, 1968)
>
> The materials were presented at a comfortable loudness level.... The loudness balance of each channel was adjusted when necessary to maintain equal loudness between ears. (Carr, 1969)

CHAPTER III

PURPOSE

While the general purpose of this study has already been mentioned; to develop a more inclusive model of the information processing which takes place in dichotic listening; this study was specifically designed to test three major hypotheses. The first hypothesis was that there are monaural threshold differences for the two ears and that these differences could be observed when proper controls are placed on the task. The second hypothesis was that these monaural differences would at least in part account for the dichotic listening results usually obtained. Third, determination of the behavioral nature of the pathway dominance, if not interactional, could be ascertained from the results of this study.

More specifically, it was felt that since the left hemisphere of the brain is believed to be dominant for language processing (at least for right handed persons) and since the contralateral pathways appear to predominate over the ipsilateral, then it would follow that the right ear would be a better receptor of verbal messages and that this difference would be detectable at threshold. If such monaural threshold differences could be observed, the implications for the nature of the pathway dominances would become clearer.

There are three basic hypotheses that could be made regarding the behavioral nature of the contralateral pathway's superiority (if it is not an interactional superiority). First, it is possible that the ipsilateral pathway is "time-delayed" relative to the contralateral. This would cause its signal to arrive at the processing hemisphere at a later time than the signal being transmitted along the contralateral pathway, with consequences of the delayed signal being forced into temporary storage.

A second possibility is that the ipsilateral pathway is attenuated (resisted) relative to the contralateral so that the signal traveling along the ipsilateral is less salient in terms of signal strength by the time it reaches the dominant hemisphere. The third possibility that exists is that the ipsilateral pathway is "noisier" than the contralateral resulting in its signal being less discernible (see Figure 11).

It's clear that the dichotic listening task is itself unable to distinguish between these three possibilities, as each of these would account for the typically observed dichotic listening results.

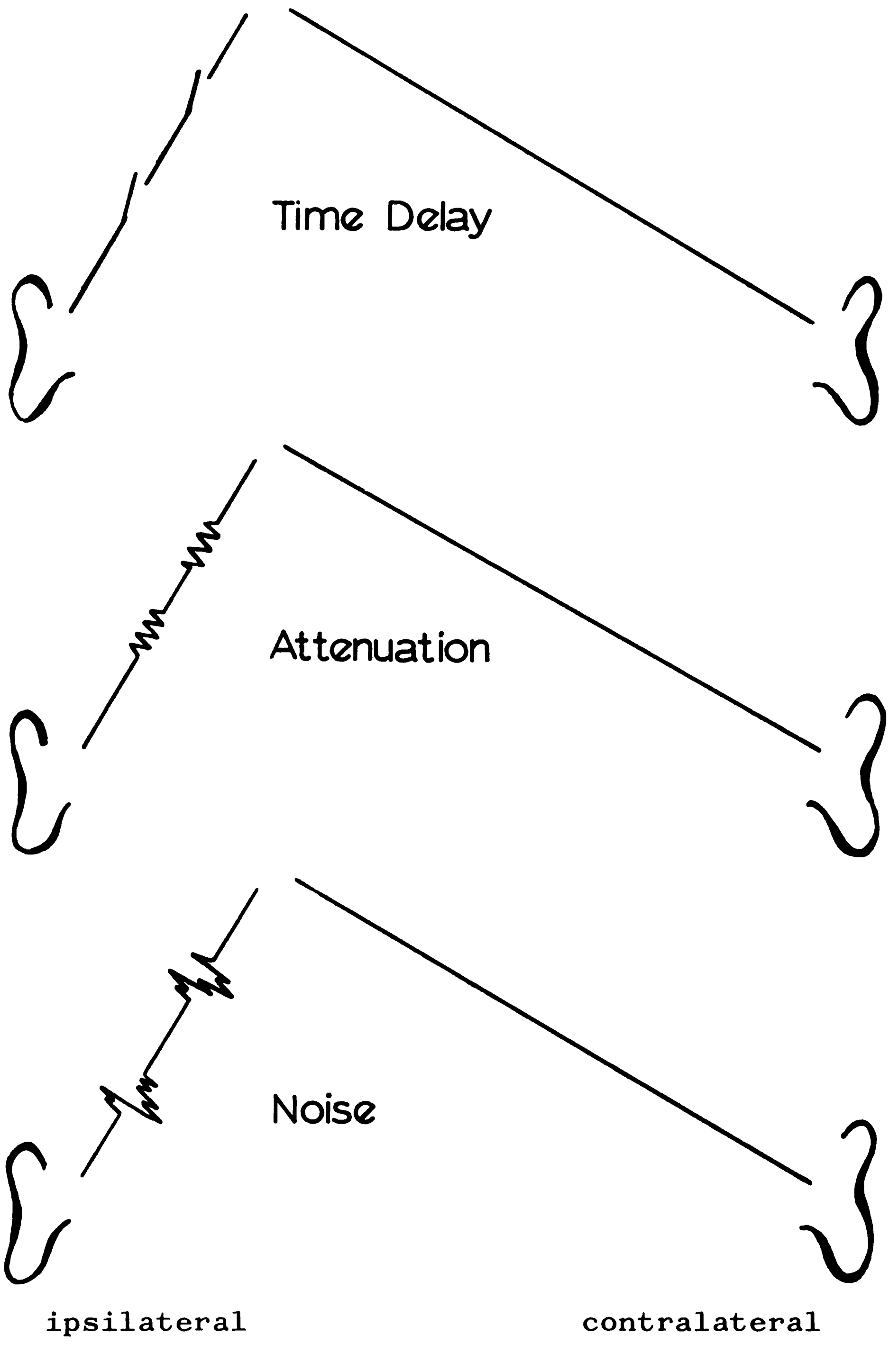

Fig. 11. Three possible models of ipsilateral acoustic pathway inferiority.

CHAPTER IV

METHOD

Subjects

A total of 18 college students between the ages of 18 and 25 served as subjects (Ss) for this study. All Ss were right handed as determined by a 10 item questionnaire; also, all reported having normal hearing abilities in their two ears and had never had a punctured eardrum or serious infection of the middle ear. No S was used who displayed pathological hearing for the speech material presented.

Two Ss were eliminated from the second portion of the study. One because of experimenter error and the other because of that S's failure to respond within the time limits set for that portion of the study.

Analysis of the audiological testing which was conducted on the participating Ss showed a slightly elevated average threshold for the two ears (see Table 1). These average thresholds were, however, still well within the normal range.

Materials

Dichotic stimulus materials (monosyllabic, AA-rated Thorndike-Lorge noun pairs) were first recorded on a stereo

Wollensak, model 5730, tape recorder using a tape loop. One word was recorded on Channel 1 and was allowed to play back continuously while E paced his speaking of the paired word onto the other channel (Channel 2). When E felt that the two words were simultaneous, the recorder was stopped and the pair of words was checked for onset simultaneity by recording tracings of the words onto an Offner type 542, 2-channel Dynograph-Amplifier-Recorder. With the tape playback at $\frac{1}{4}$speed and tracing done at 100mm/sec., each mm of paper travel equalled 2.5 msec. of tape playing. No pair of words was accepted if the onset was judged to be greater than 7.5 msec. in delay for the two-word pair. The pair, if accepted, was re-recorded onto another tape and rechecked for simultaneity, using the same criterion.

To balance all pairs for peak amplitude, the tape containing the twenty pairs of words was played back on an Ampex AG-600 tape deck and recorded onto an Ampex AG-500 tape unit balancing for peak sound pressure by the use of a Bruel & Kjaer 2305 Power Level Recorder. Amplitude of the peaks of all words was maintained $\pm$1 dB. A calibration tone of 1000 Hz was recorded on both channels at the same level as the speech material by the use of a Hewlett-Packard 4204A oscillator connected to this previously described system.

For the Speech Reception Threshold (SRT) materials, the Central Institute of the Deaf auditory test W-1 words

(CID W-1) lists A and B were recorded, with the two syllables of each spondee ±1 dB. These words were then recorded on the same master tape as the test tones and the dichotic presentation pairs, within ±0.50 dB for the greater level of the two syllables and at the same level as the calibration tones.

The master tape therefore consisted of 1000 Hz calibration tones, CID W-1 spondees, and dichotic pairs, all within 1 dB peak amplitude. The stimulus tape used was a copy of the master tape with the addition of all instructions for each test and the "successive word task" (described below).

Apparatus

Testing of Ss was conducted on an individual basis in a double-walled Industrial Acoustics Company (IAC) sound attenuated suite (series 1600). Speech Spectrum Noise (SSN) was presented via a Grason-Stadler noise generator (model 901B) in conjunction with a MAICO audiometer #MA-24, which incorporates a 1 dB step interval attenuation system. The taped materials, recorded as previously described, were presented through this same audiometer. TDH-39 headphones mounted in MX/41 AR cushions were used for the presentations under headphones, and MAICO speakers for presentation of the instructions and the successive word task.

Calibration of Equipment

The MAICO audiometer was calibrated to 22 dB SPL (re: 0.0002 dyne/cm^2) using SSN, with the actual levels found to be 23.5 dB SPL (re: 0.0002 dyne/cm^2). The audiometer was checked for linearity in attenuation and was found to be accurate $\pm$0.5 dB at every setting. The ambient noise level in the test room as measured on the C scale of a sound level meter was sufficiently low so as not to interfere with the test results.

Procedure

Monaural threshold determination. The present study consisted of two main portions: (a) threshold determination for the right and left ears of each S, and (b) dichotic processing analysis. The monaural threshold determination was conducted using both SSN and SRT materials. Dominance in processing was determined by administration of pairs of monosyllabic words presented dichotically under two conditions of SPL balance and by administration of a similar (though not all monosyllabic) set of word pairs, presented successively rather than dichotically.

It seemed apparent that even with strict controls on the threshold stimulus materials it might be possible that monaural differences would not appear for either of two reasons. First, the materials being used for testing might not be suitable for unilateral processing. Second, it may be that the two ears of an individual really are different; that is, a given individual may have a hearing loss (minor pathology) in one or the other ear or both, thus causing his hearing to be different in the two ears for reasons other than dominance.

To control for these possibilities, two hearing tests were administered to each S. The first test was a determination of the S's monaural hearing ability for SSN. This material was selected to closely approximate actual speech material with respect to the speech frequency spectrum, and was felt to be a more satisfactory alternative to pure-tone averaging for non-verbal threshold measurement in this study. Such a measure (SSN) allowed determination of what, if any, hearing loss a subject had on a non-verbal task. The second monaural threshold determination for the two ears was conducted using the CID W-1 list of spondees. These words are bisyllabic with supposed equal emphasis on each syllable. The words were recorded onto tape (male voice) as previously described.

Prior to administration of this task, each S was given an alphabetical list of the words (see Appendix B) with which to familiarize himself, and was allowed to study this list while E rechecked calibration of the apparatus (approximately two minutes). This procedure was done to counteract the effects of learning from the testing of one ear to the testing of the other. Tillman and Jerger (1959) have shown that without preliminary exposure to the test materials on an SRT task, scores tend to improve an average of $2\frac{1}{2}$ dB from the first ear tested to the second. With previous knowledge of the test materials, increases were found to be minimal (-0.3 dB).

Since the amount of difference to be expected due to hemispheric dominance was not known, it was decided to use this technique rather than simply counterbalance, with the associated increase in error variance. (Counterbalancing was maintained throughout the experiment nonetheless.) Analysis of hearing differences between the two ears could then be looked at as the difference in dB necessary to go from a hearing threshold of SSN to a "repetition" threshold of SRT.

Threshold was determined by beginning presentations of the SSN at a level of 40 dB on the attenuation dial (calibration showed that a 60 dB dial setting was $83\frac{1}{2}$ dB SPL re:0.0002 dyne/cm^2) for an actual level of $63\frac{1}{2}$ dB. Subsequent presentations were in 5 dB steps in decending order until <u>S</u> could not report hearing SSN. At this time presentations were continued in 1 dB steps, with two presentations at each step, starting from the last correct report of hearing (5 dB up). Presentations were continued in decending order until <u>S</u> failed on 5 of 6 presentations in a row. Threshold was determined as being the level at which <u>S</u> correctly responded to both presentations at a single intensity level plus $\frac{1}{2}$ dB for each additional correct response (see Appendix C). Speech reception threshold was administered and scored in this same manner.

Dichotic listening. Following the monaural threshold determinations for the two sets of materials on each ear, S was instructed that he was going to be given practice for a new hearing test (see Appendix D for complete instructions). His next task consisted of hearing pairs of AA-rated Thorndike-Lorge (1944) nouns having common concepts (see Appendix E for these materials) via a single loudspeaker. S was instructed to listen to both words (presented one at a time) and immediately respond with a single sentence using them both. The purpose of this segment of the experiment was to determine the Ss normal mode of responding (processing) sequentially presented information.

Pilot studies had indicated that most Ss respond consistently, producing sentences using the two words in the same order in which they had been presented. For example, if the two words presented were "man" and "husband" the response might have been, "The man is my husband." On the other hand, if the words had been presented in the reverse order a response might be, "My husband is a man." In addition to ascertaining the degree to which a subject gave a response in the same order as it was presented to him, this task allowed analysis of S's consistency in responding to a sentence formation task.

After 10 pairs of successive nouns were presented, S was presented with the instructions for the dichotic listening tasks. These tasks consisted of presentations of pairs of monosyllabic nouns simultaneously, one pair at a time, with each ear getting one of the words in the pair. The S's task was identical to the practice task, though the presentation of the stimuli was different (dichotic under headphones rather than successive in the sound field). This task was felt to have two distinct advantages over the more usual dichotic listening task (digit presentations). First, it necessitated real language processing of the materials, since sentences had to be generated using these stimuli rather than simple repetition. Second, perception and processing were assured, since the response required output of each word presented. In digit studies, where a subject is asked to repeat what digits he has heard, any omission might be due to improper perception, insufficient processing, or forgetting. In the present task, none of these difficulties could be encountered because of the amount of material being below memory span limitations.

Presentation of 10 pairs of such nouns (see Appendix E) were administered at 45 dB sensation level (SL) re: SSN for each ear; that is, if the SSN threshold was 30 dB SPL in the left ear, the SPL of the word presented to the left ear in this portion of the study was 75 dB SPL. These settings are very close to normal conversation levels (normal conversation considered to be 70 dB SPL). Because the presentations were at equal sensation levels for the two ears, it can be assumed that the words were perceived as being equal in "loudness." Ss who were asked about the intensity of the words presented, stated that they thought they were equally "loud." (Similar perceived equality statements were obtained from Ss regarding the next set of word presentations.) Score was kept of which of the two words presented appeared first in the response sentence.

The next 10 pairs of words were similar to the previous 10, but were presented at 40 dB SL re: SRT for each ear. This presentation level is also perceived as equal in intensity for the two ears. By presenting at a set level above SRT, the results of monaural speech hearing differences in the two ears could be ascertained. Comparison of responses on the first set of 10 pairs could be done with those obtained in this condition and analysis for shifts in report tendencies could be made.

In summary, each S was tested individually as follows:

1. Monaural threshold determination for Speech Spectrum Noise (SSN).

2. Visual presentation of CID W-1 list of words.

3. Monaural threshold determination for Speech Reception Threshold (SRT).

4. Instructions for successive word usage task.

5. Presentation of 10 pairs of words successively via a single loudspeaker in a sound field.

6. Instructions for dichotic pairs.

7. Presentation of 10 pairs of words dichotically at 45 dB SL re: SSN thresholds.

8. Brief instructions to continue in task.

9. Presentation of 10 pairs of words dichotically at 40 dB SL re: SRT thresholds.

The presentations of all materials except the successive word task and instructions were under headphones, with headphones rotated between and within subjects. All threshold materials were presented through one channel of the audiometer and headphone set only, to reduce the possibility of equipment bias.

CHAPTER V

RESULTS

The results of the present study are presented in parts, as they were previously described. Actual data is tabulated and presented in Appendix F of this paper.

Monaural Thresholds

(See Table 1 for summarization of the findings of this portion of the study.)

Expectations. It was expected that monaural thresholds for the two ears would be found to differ for language material, especially when language level above noise threshold was used as the measure. Such an expectation is contrary to the results obtained by Palmer (1964) but was anticipated for the present study because of the more rigorous controls placed on the stimuli and the presentations.

Findings: SSN. When monaural thresholds on the nonlanguage material (SSN) were analyzed, no differences between the two ears were found. The average threshold levels for the two ears with this material were found to be 16.6 dB SPL and 16.9 dB SPL (re: 0.0002 dyne/cm^2) for the left and right ears respectively, yielding a mean difference of 0.3 dB favoring the left ear ($\underline{t}$=0.916, $p>.10$, df=17). This clearly is nonsignificant, though speculation regarding the direction of the difference is of some interest. With an increase in sample size, it may be that the trending found here would continue to be evidenced, implying a right hemisphere dominance for this material. Because this explanation is so speculative, an alternative explanation of the two hemispheres of the brain being undifferentiated for such noise would appear a more logical explanation.

TABLE 1

MONAURAL THRESHOLDS IN dB SPL (re: 0.0002 dyne/cm^2) FOR THE TWO EARS UNDER VARYING CONDITIONS

source		L-ear	R-ear	difference	$\underline{t}$ value
SSN	$\bar{X}$ =	16.61	16.92	-0.30	0.91
	S =	3.62	3.28		
SRT	$\bar{X}$ =	27.25	24.92	2.33	4.26*
	S =	3.33	3.45		
SRT less SSN	$\bar{X}$ =	10.64	8.00	2.64	4.43*
	S =	2.75	2.23		

* $p < .001$

Such non-differential findings (nonsignificant "*t* value") should not however be construed as evidence for such a lack of specialization in the hemispheres. This non-finding should not be construed as *firm* evidence, and arguments based on this should not be propogated to include or exclude certain considerations in further model building.

Findings: SRT. Monaural threshold comparisons for the two ears on language material (SRT) yielded significant differences between the two ears, with means of 27.25 dB SPL for the left ear and 24.92 dB SPL (re: 0.0002 dyne/cm^2) for the right ear. This difference of 2.33 dB SPL favoring the right ear is significant in the direction expected for left hemisphere language dominance (t=4.26, $p<.001$, df=17). It should be noted that this difference is well within the testing intervals used by Palmer (3 dB) and as such would have been obscured in that study.

Findings: SRT minus SSN. When the dB SL increase necessary to reach language threshold (from a base level of that ear's noise threshold) was viewed, it was found that the two ears differed significantly from each other, with mean gains of 10.64 dB SL and 8.00 dB SL for the left and right ears (see Figure 12). This difference of 2.64 dB yields a correlated t value of 4.434 ($p<.001$, df=17) which is greater than that obtained when SRT alone was viewed. This implies that the slight differences noted for SSN

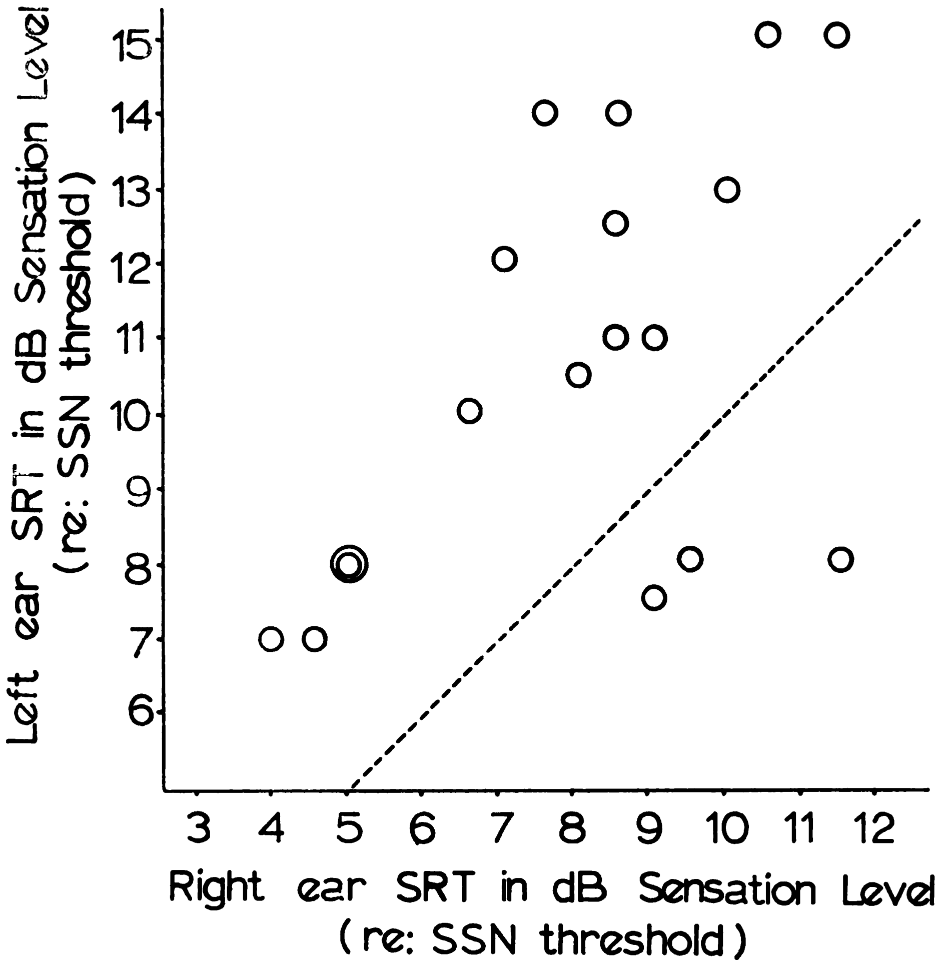

Fig. 12. Plot of the relationship between right and left ear thresholds. Above dashed line shows right ear superiority in terms of lower threshold; below dashed line shows left ear superiority.

operated so as to elevate the relative threshold of the left ear and depress the threshold of the right ear, as hypothesized.

Successive Input--Successive Output

Expectations. When two words were presented successively to a subject who was instructed to use them both in a single sentence as quickly as possible, the expectations were that S would process information on a first input being first output basis. Thus it was expected that the two words would appear in the sentence in the same order as that in which they were presented to S.

Findings. Of 16 Ss, 13 demonstrated this input--output processing 2/3 or more of the time (sign test, $p=.01$). The remaining three Ss utilized this processing procedure 60%, 50%, and 40% of the time, which was considered to be essentially random responding. Because of this, their responses to the dichotic material are discussed separately.

Dichotic Input Balanced for SSN

Expectations. This part of the study was expected to yield results closely conforming to those obtained in other dichotic listening studies (right ear superiorities).

Results. The results of this part of the study were that 11 of 15 Ss who demonstrated an ear superiority were right ear dominant on this initial dichotic task (sign test, p=.059) in that the sentence generated used the word presented to the right ear first, and the word presented to the left ear second. This demonstrated that this language task did in fact approximate other dichotic listening tasks using language materials.

Dichotic Input Balanced for SRT

Expectations. It was hypothesized that once monaural language threshold differences were balanced for, dichotic listening differences would be reduced.

Results. The results of this portion of the study showed that of 11 Ss demonstrating an ear preference, 6 were right dominant and 5 were left dominant (sign test, p=.50). This result supports the hypothesis of reduction of dichotic listening performance under language threshold-balance conditions.

Combined Findings

Analysis of shifts away from dichotic listening performance with balance for SRT was conducted using a unidirectional t test, with the expectation that shifting should occur in the direction opposite to that of the dominant ear (based on monaural threshold). That is, right language threshold dominant Ss should shift away from right dichotic listening performance when language threshold balance is introduced in the dichotic task, and left language threshold dominant Ss should shift away from left dichotic listening performance.

A fuller explanation of the hypothesis could be stated as follows: While previous investigators have found that right ear superiorities exist in dichotic listening tasks, it was hypothesized that such right ear superiorities are determined at least in part by the fact that the two ears are differentially capable of responding to verbal materials in terms of monaural thresholds alone. A test of this hypothesis would be to present dichotic materials at two levels of intensity: (a) at equal levels above a non-language threshold (monaural) for each ear, and (b) at equal levels above each ear's language material, monaural threshold. If the dichotic listening results were to show a decline in terms of right ear superiority from one set of intensities to the other, this would be supportive of the hypothesis. Secondly, it would be expected that the amount of shift away from right ear superiority in these two dichotic listening tasks would be related to the amount of difference in the two ears on monaural tasks with language and non-language materials.

Analyses of the data showed that Ss who were right ear dominant on monaural tasks showed a shift away from right ear superiority on the two dichotic listening tasks (SSN balance vs. SRT balance) and that Ss who were left ear dominant on the monaural language task shifted toward right ear superiority on the two dichotic listening tasks. This

analysis was done as a correlated t test on the percentage shift in right ear responding under the two dichotic listening presentation conditions ($t=3.3074$, $.005>p>.0005$, $df=15$). Arc Sin transformations of the percentage data yielded essentially identical results ($t=3.1294$, $.005>p>.0005$, $df=15$).

From these results it is clear that controlling for monaural language thresholds decreased demonstrable dichotic listening performance. As a further check on the hypothesis previously stated, a correlation (and a chi-square analysis) was calculated on monaural threshold differences and the degree of dichotic shifting from the noise-balance to the language-balance conditions (see Figure 13).

It is appropriate to point out that all previously discussed results were computed using all Ss tested under these conditions. It should be remembered however, that 3 of the 16 Ss did not perform consistently on the successive task. When the data for the currently discussed chi-square were tabled, it became evident that analysis on this part demanded examination of the consistent Ss independently of those who were inconsistent. Figure 13 shows that the three inconsistent Ss were the only ones to show results not in line with original predictions; that is, even though they were all right ear dominant on the monaural language tasks, two of the three went to increased dichotic performance rather than decreased performance. Analysis

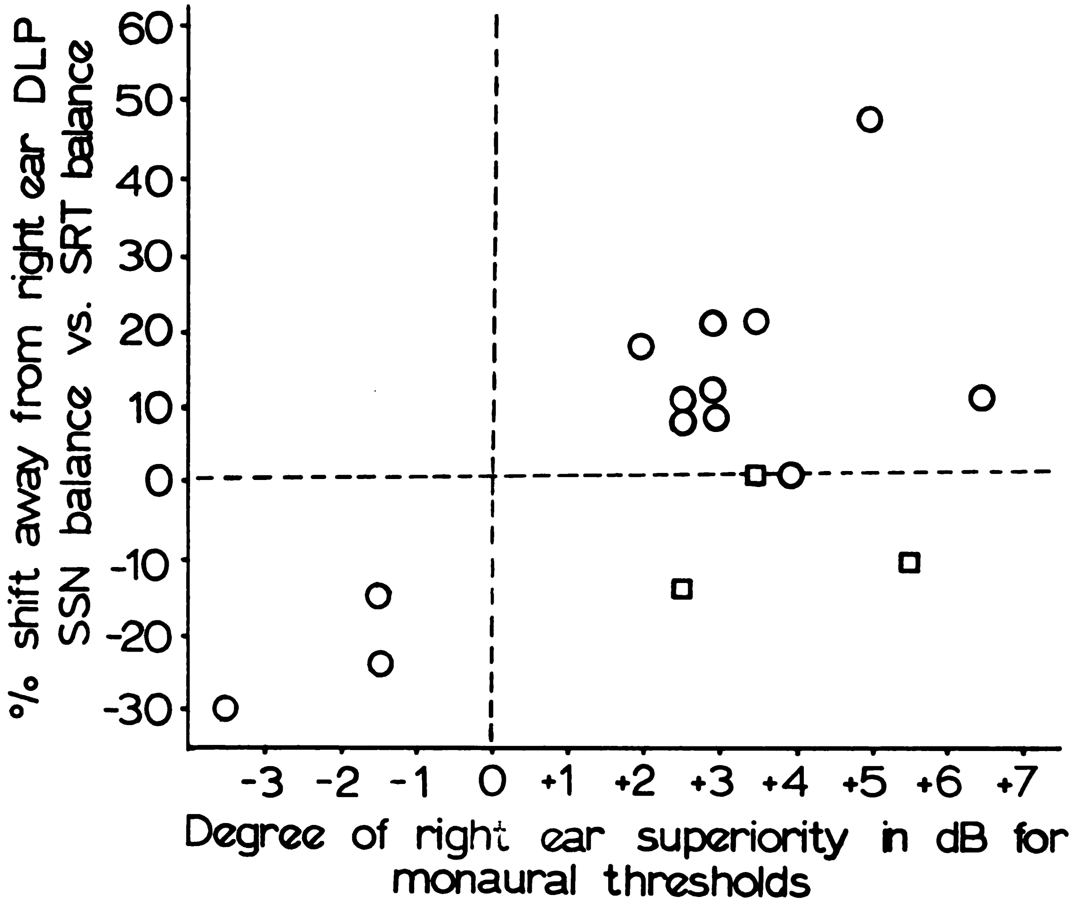

Fig. 13. Plot of the relation between monaural threshold results and dichotic listening results obtained from the same Ss. The correlation represented in this figure demonstrates the degree to which monaural differences between the two ears could account for observed dichotic listening results.

In this figure, circles represent Ss who were consistent responders on the successive word task. Squares represent Ss who were inconsistent on the successive word task.

of the current findings, then, are done twice; once including these three Ss and once excluding them from the analysis.

Including all Ss, the correlation between monaural threshold and dichotic shifting as previously described was 0.648 ($p<.01$, $df=14$) accounting for approximately 42% of the observed variability. Chi-square analysis calculated as a Fisher Exact Test for small samples is also significant ($p<.05$). When the three inconsistent Ss were excluded from the analysis, the correlation was increased to 0.81 accounting for approximately $65\frac{1}{2}$% of the observed variability.

CHAPTER VI

CONCLUSIONS AND DISCUSSION

Monaural Thresholds

The results of the first part of this study indicated that there are monaural threshold differences for the two ears, and that these differences, like the ones found dichotically, are related to the language processing function of the left hemisphere of the brain, for most right handed persons. It was found that the absolute thresholds in terms of speech-spectrum noise (SSN) were not consistently different for the two ears (across Ss). However, language threshold differences (using SRT) were found, which indicated that the right "ear" is a better ear-brain system for operating on language materials. The combined findings seem to imply that the two ears themselves may be considered identical in terms of hearing "sounds," but that their connections to the language processor are different. It seems possible to conclude that this differential connecting to the processor is accomplished through differences in the two types of pathways originating at each ear (actually at the superior olivary complex) which procede to the two cortices.

Since no differences were found for non-language material, which corresponded in frequency spectrum to the language materials, it may be tentatively concluded that simple determination of "on" or "off," "present" or "not present" is a more primitive ability of the system not showing lateral differentiation. This result, coupled with the significant differences in additional sound pressure necessary for the two ears to reach Speech Reception Thresholds, lends support to the growing body of literature suggesting laterality differences in language processing for the two hemispheres. While the differences between the two ears for SRT threshold was clearly significant, it was nonetheless small in absolute magnitude. This difference of 2.6 dB SPL is unfortunately within the tolerances used for measurement by Palmer (1964) and as such was most likely obscured by the methodology used.

As a partial check on the magnitude of threshold and threshold differences obtained in the present study, it should be noted that the obtained thresholds for the Ss corresponded closely to other investigations. For example, the mean gain in SPL necessary to obtain SRT thresholds from a base of nonverbal thresholds is considered to be approximately 8 dB. In the present study, values of 8 dB and 10.6 dB were obtained for the right and left ears respectively.

Monaural Thresholds and Dichotic Listening

One of the major purposes of this study was to investigate the relationship between monaural thresholds for the two ears and dichotic listening performance. The first part of the experiment, just discussed, demonstrated a monaural threshold difference for the two ears when speech material was used as the stimulus. To determine the relationship between such monaural results and dichotic results, a correlation was computed between the amount of right ear superiority monaurally (left ear threshold minus right ear threshold in dB SL re: SSN thresholds) and the degree of right ear superiority in the dichotic listening tasks (percent right ear output in part 1 minus percent right ear in part 2). The correlation was found to be 0.65 when the results of all Ss were analyzed, and 0.81 when the three inconsistently responding Ss (from the successive task) were eliminated from the analysis.

A second indication of the relationship between monaural and dichotic performance was, that when looked at individually, all Ss who were left ear dominant on the monaural tasks, shifted away from left ear reporting on the dichotic task when monaural language threshold balance was introduced. The fact that shifting did occur in terms of number of ear-ordered reports, is evidence that slight SPL differences considerably alters the performance observed in dichotic listening.

It is not surprising that previous investigators

had not noticed this effect. In most other studies, no rigid controls were placed on the levels at which the dichotic materials were presented, and those studies which did "control" for this, used physically balanced inputs to the two ears. The present study found a mean difference in hearing for speech materials (SRT) of 2.3 dB favoring the right ear. With this being the case, balancing for actual SPL would tend to favor material presented to the right ear (perhaps making it more salient) and hence may account for such "controlled" studies demonstrating right-ear effects in dichotic listening.

Actually, as has already been mentioned, <u>gross</u> differences in the amplitude of two inputs in dichotic listening had been demonstrated as being an important variable (Tolhurst and Peters, 1956). It may be assumed that investigators since that time had felt that their presentation levels were not different enough for the two ears to be affected by this variable, although it is also possible that most were unaware of the existence of this as a variable at all, since this reference is not found in most of the articles (one notable exception is Broadbent, 1958).

Pathway Considerations

As this study was intended to describe more fully the differences between the two acoustic pathways--ipsilateral vs. contralateral--the present findings should be viewed with this in mind. If it can be assumed that major language processing, at least for this task, takes place mainly in the left hemisphere of the brain (for most right handed persons), then differences in output for the materials presented to the two ears can be viewed as being primarily due to differences existing in the two types of auditory pathways.

It was previously postulated that there are three basic non-interactional models (contrasted to Kimura's interactional model) possible to account for ipsilateral pathway inferiority: time-delay, attenuation, and "noise." Analysis of the implications of these three models and the results of the present experiment allow for several conclusions to be made.

If time-delay were to be operating, thus causing the observed contralateral superiority, it would be expected that dichotic listening studies would yield a right ear superiority for language materials, but that monaurally there would be no differences for the two ears. Simple time-delay in the ipsilateral pathway from the left ear to the left hemisphere would allow a signal, traveling along that pathway, to reach the language processor at a somewhat delayed time, but with equal strength, to a similar signal presented to the other ear (not dichotically). As such, no differences in the thresholds of the two ears should be observed for language materials. Since this study has demonstrated that such monaural differences do occur, it is appropriate to eliminate this model from further consideration.

The second model, attenuation, would necessitate that the signal being transmitted along the ipsilateral pathway be reduced in strength relative to the same signal (or similar signal) presented to the contralateral ear. In this model not only would dichotic results be expected, but threshold differences would similarly be anticipated. Further, when dichotic materials are presented at equal sensation levels (re: SRT), such typical dichotic listening results as right ear superiority for language material should be eliminated. It therefore appears that this model does fit the obtained data.

The third model, "noise," would allow for both dichotic results and monaural threshold differences. Even though the signal strengths of the two messages (presented to the left and right ears) would be identical, the signal to noise ratio (S/N) would be lower for the ipsilateral than for the contralateral pathways, and as such, signal detection theory would allow for a prediction of an elevated threshold for the ipsilateral ear. How such noise would operate in an increased amplitude situation is less clear and depends on the model chosen for how "noise" behaves in the auditory system. There are four distinct possibilities for this (see Figure 14) which are: (a) noise drops out, (b) noise remains at a constant level, (c) noise is maintained at a constant S/N ratio, or (d) noise increases linearly with the signal.

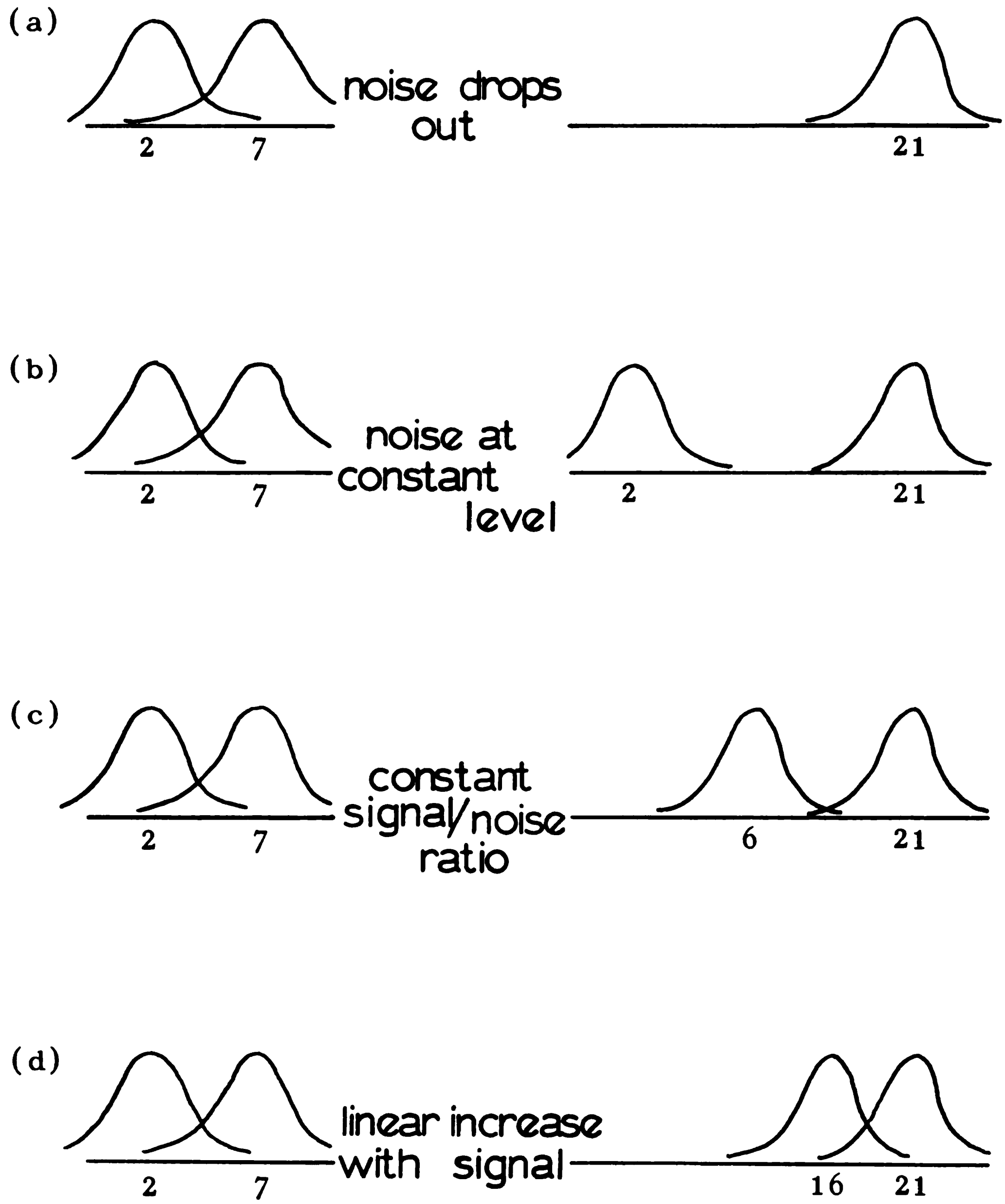

Fig. 14. Four possibilities of what happens to noise with increases in signal strength.

Were the ipsilateral pathway noise induced, the first possibility (noise drops out) would not account for dichotic listening results, since all dichotic listening studies have utilized presentations of materials at well above threshold levels.

The second possibility, that of noise remaining at a constant level, could similarly not account for the dichotic listening results, since the various studies have certainly been conducted at various sound pressure levels but have yielded essentially identical results. Such a model would necessitate that above some sound pressure level presented to both ears, the usually observed dichotic listening behavior would cease. Further, this model could not account for the high correlation between monaural threshold differences and shifts in dichotic listening performance, when all the dichotic presentations were well above threshold. That is, at threshold, the ipsilateral pathway may evidence a small S/N ratio relative to the contralateral pathway and hence monaural threshold differences; but at increased presentation levels (+40 to 45 dB, SL) the differences in S/N ratios between the two pathways would be greatly reduced, and the correlational results of the present study would not be expected.

The constant S/N model is more complex and at first might be considered an appropriate one. However this model like the ones for noise already discussed, could not fit the data obtained in the present experiment; that is, both threshold levels and shifts away from dichotic listening at greatly increased volumes could not be explained by a constant S/N model. If there was a S/N ratio of say 7/2, at threshold the distribution for the perception of signal above noise and the perception of noise might greatly overlap. But at above threshold levels, the distance between the two distributions would be greater, and as such, signal detection would become easier. This implies that it would indeed be strange for the same difference necessary to make the two ears equivalent at threshold be required to make them once again the same at above threshold levels (with respect to randomizing ear preference).

Finally, a linear increase model would apparently not be in keeping with the obtained results. Increasing the level of the message to the left ear by an amount X, would also increase the noise level by X amount, decreasing the signal to noise ratio still more, thereby making detection of the true signal from the accompanying noise more difficult and not allowing for shifting away from typical dichotic listening performance with an additional small increase in sound pressure level.

In reviewing the three models proposed, only the attenuation model fits all the data and as such merits tentative acceptance. There is always the possibility, however, that attenuation accounted for the data better than either noise or time-delay because, in effect, attenuation was the major variable in the present study. In other words, were the study to be conducted using time delays to the two ears, it could be hypothesized that the time-delay model would account for the results then obtained.

Actually there are two reasons for rejecting the time-delay model, aside from those already mentioned in this discussion. (There is no simple way in which "noise" could operate, according to the previous discussion, that would allow for both dichotic listening results and monaural threshold differences, so this model will not be discussed again in the present analysis.) With respect to time-delay, it should be remembered that actual simultaneity was rarely achieved in early studies (and is even now not well definable), therefore if differences were due to time-delay, they should have become apparent long ago. Along these same lines, a second objection is that a recent study has been reported in which dichotic listening behavior was observed under conditions of varying time delays, for the materials presented to the two ears, with no significant results (Satz, _et al_., 1970).

Models of Dichotic Listening

With the above results and conclusions, it becomes possible to analyze the various processing models proposed, which use dichotic listening as a base. Beginning once again with Broadbent's model for information processing under conditions of message competition, it can be observed that the model has little that needs be altered on the basis

of the present experimental study. However inclusion of a salience seeking filtering mechanism seems appropriate.

While Broadbent's model did include a filtering action which selected one channel of the many available, the present addition (or redefinition) would necessitate that the filter operate to allow the "loudest" (also possibly clearest), most salient signal priority in processing.

In contrast to Broadbent's model, Kimura's model seems less viable. Rather than the interactional model which she has proposed, the current results suggest that a noninteractional model of attenuation of the ipsilateral pathway more adequately and parsimoniously represents the auditory pathway system. If it is assumed that the left hemisphere of the brain is the primary processor of real language materials, the following model is suggested:

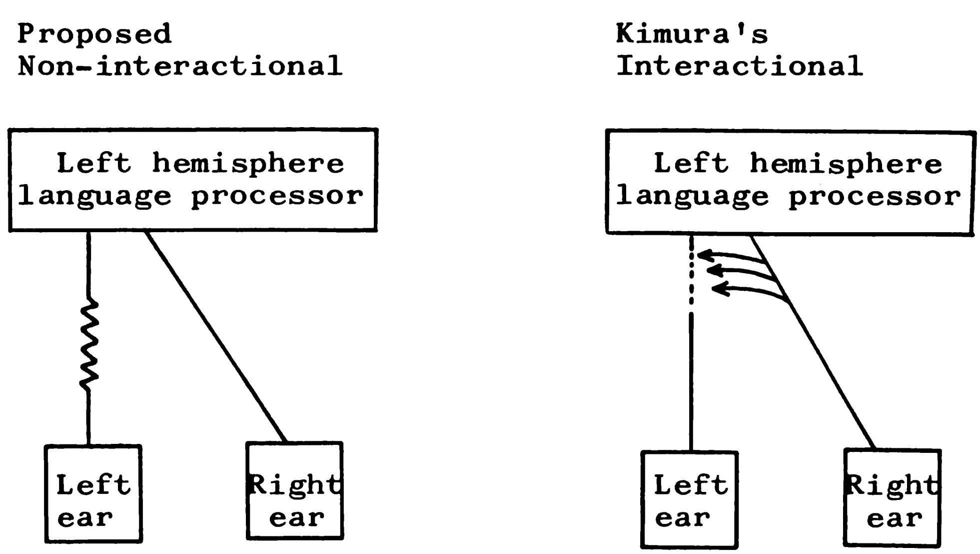

Fig. 15. Comparison of non-interactional and Kimura's interactional model.

A combination of both Broadbent's and the presently proposed model might then be:

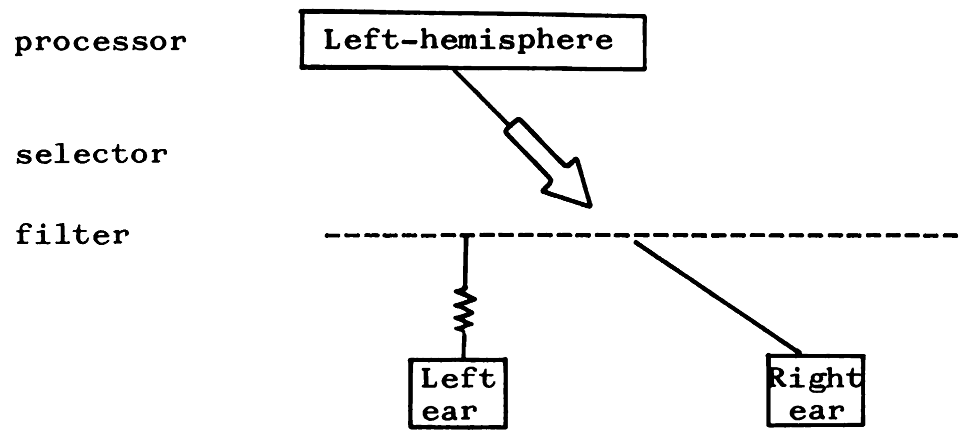

Fig. 16. A combination model: Broadbent's and non-interactional.

The model proposed earlier in this paper, suggested to allow for Inglis' theories appears implausible in light of the results of the present study. The model of directional scan does not account for why dichotic messages, balanced for monaural language threshold would fail to demonstrate right ear superiority--certainly the scan would be operating in the same direction. If not; that is, if the scan switched directions to pick up the stronger signal first, or if the scan acted itself as a short-term store while it picked up both messages and then allowed the stronger one access to the processor, it would be identical to Broadbent's filter in the preceding model.

Bryden's analysis of dichotic listening models also becomes interesting in light of the present findings (see pp. 31-34). Of the four models that he proposed, three could potentially account for dichotic listening and related performances. When viewed with knowledge of monaural threshold differences, however, the models become trivial.

The first of the four models was discounted as being inaccurate; the second can now be seen as being equally inaccurate, as a slight monaural shift tended in this study to balance the two ears for the dichotic task. This implies that the two curves of this second model (for the right and left ear) must be parallel, since this effect happened significantly across subjects. But if the two curves are in fact parallel, with the additional explanation that the differences between them are due to attenuation in the system, not only do the remaining two models fit (they are parallel curve models), but become trivial.

Bryden's suggestion according to his forth model is that the two ears feed information to their respective contralateral hemispheres, but that the right hemisphere is somehow less able to receive this information than is the left, and consequently its message trace is at a lesser initial strength. This lesser trace strength, according to Bryden, accounts for both ear-order of report and the resulting recall errors. Bryden apparently does not give consideration as to how the hemispheres get attended, to allow for output of the information, but does seem to imply that the more salient trace is reported from first; that is, gets selected. This model then too becomes identical with Broadbent's as far as the processing, though it does put storage in two different hemispheres (a doubtful advantage).

It can now be seen that the only model thus far proposed that adequately accounts for the data of the present study, is Broadbent's which was put forth in 1958; ironically, when less than 1% of the studies now available in dichotic listening were done.

Often in psychophysical investigations of perception, an interesting effect is noted in terms of duration of stimulus and intensity of the stimulus. Typically, there is something referred to as a time-intensity trade-off; that is, with increased time, less intensity is required for perception and vice versa.

It is important to point out that such a trade-off does not occur in dichotic listening--at least not within the limits tested. In the Satz, et al. study of 1970, in which delays between the two dichotic channels was a variable, no differences were found up to 25 msec. This finding lends support to the notion that the filtering mechanism operates on a "loudness" bias with a steady resting state on the contralateral pathway from the right ear, and that switching time is greater than 25 msec. In fact, due to the crudeness in methodologies of earlier studies, it is more likely the case that the switching time excedes 50 msec.

It can be postulated then, that the filtering mechanism used in selecting a pathway on which to operate, functions so as to allow the typically "louder" channel first access, but that increased loudness in the other pathway would also be noted and selected for, should the perceived loudness be greater than that in the contralateral pathway. Certainly no message being transmitted along the usually louder contralateral pathway would allow for the filter to select a message coming along the ipsilateral. Because of the type of mechanism postulated, it becomes apparent that other "attentional" variables would affect dichotic listening performance.

Physiological Considerations

Physiologically, the auditory system is extremely complex, and while exact correlation between anatomy and psychological behavior is not necessary, a correlation between physiological studies and psychological behavior is often hoped for. Early investigators of dichotic listening, and especially Kimura, made extensive use of the physiological studies to "ground" their more psychological models. As has already been pointed out, however, the studies that were most crucial to the explaining of these models were misinterpreted (and unfortunately, reinvestigation of cited literature, especially of "peripheral studies" is rarely done).

It was previously discussed that the physiological evidence supported two major notions in dichotic listening, but to varying extents. Contralateral response was found to be greater than ipsilateral for all studies reviewed using evoked cortical response. Similarly, response data on brain damaged human Ss implied similar superiority of the contralateral pathways. It should also be remembered that these studies found the superiorities to be in terms of increased amplitude, with time-delay of response and wave form identical for both pathways.

Investigations of pathway interactions are more difficult to interpret. While there is evidence of interactions within a single pathway to stimuli presented to both ears simultaneously or with small delays (less than 1 msec.); such results apparently have more significance for sound localization, which operates at those delays, than it does for dichotic listening where longer delays are usually encountered.

The results of the present study indicate that the physiological evidence pertaining to acoustic pathways is most likely correct when used as an explanation for dichotic listening. More importantly, such physiological studies allow psychological investigators better starting points from which to develop behavioral theories in this area.

Implications for Further Research

With the major findings now discussed it is appropriate to view the possible extensions for further research in this area. As the results of this study suggest a relatively simple model for verbal auditory information receiving, consideration should be given to similar studies using non-verbal materials and for studies with non-normal subjects (i.e., the partially deaf).

<u>Non-verbal materials</u>. Dichotic listening studies have been conducted using non-verbal materials in the past, with results opposite to those found with verbal materials. Rather than a right ear superiority, Kimura (1964), Shankweiller (1966), and Spellacy (1970) have found left ear dominances. Explanation of these results has been one of attributing processing to the right hemisphere for this type of material. The results of the present study suggest that such dichotic behavior may be due to right hemisphere dominances which can be evidenced on a monaural task.

The parallel study to the one reported on here would be more difficult to conduct, as little is known about normal occurrence of various non-verbal sound patterns, and as such, adequate matching of sound patterns for dichotic presentations would be difficult. Further, different frequencies are themselves differently responded to in terms of hearing thresholds. Nonetheless, with adequate on-line computer facilities, such controls could be maintained and the study conducted.

<u>Non-normal subjects</u>. Although the present study was conducted with normal hearing <u>S</u>s, the results obtained and the conclusions imply that similar results would be obtained from persons with certain types of hearing losses. That is, relative to a non-verbal (SSN) base level, the dB SL necessary to reach SRT should be differential in favor of the right ear for most right handed persons. If hearing loss

is occurring because of middle ear or inner ear pathology, similar results to those obtained in the present study would still be expected. On the other hand, "central deafness" would lead to expectations of results different from those obtained here. Study of this threshold differential effect on patients with various medically confirmed hearing losses could potentially lead to new techniques for diagnosis of hearing disorders.

REFERENCES

REFERENCES

Note: Entries preceded by an asterisk are cited in the main body of the dissertation; all entries are cross referenced in Appendix A by "task" and other variables.

*Bakker, D. J. Left-right differences in the auditory perception of verbal and non-verbal material by children. Quart. J. exp. Psychol., 1967, 17, 334-336.

________. Ear asymmetry with monaural stimulation. Psychon. Sci., 1968, 12, 62.

*________. Ear asymmetry with monaural stimulation: Task influences. Cortex, 1969, 5, 36-42.

Bartz, W. H., Satz, P., and Fennell, E. Grouping strategies in dichotic listening: the effects of instructions, rate, and ear asymmetry. J. exp. Psychol., 1967, 74, 132- .

Bartz, W.H., Satz, P., Fennell, E., and Lally, J. R. Meaningfulness and laterality in dichotic listening. J. exp. Psychol., 1967, 73, 204- .

*Benton, A. L. The problem of cerebral dominance. Canad. Psychol., 1965, 6a(4), 332-348.

*Bocca, E., Calearo, C., Cassinari, V., and Migliavacca, F. Testing "cortical" hearing in temporal lobe tumors. Acta Otolar., 1955, 45, 289-304.

*Borkowski, J. G., Spreen, O., and Stutz, J. Z. Ear preference and abstractness in dichotic listening. Psychon. Sci., 1965, 3, 547-548.

Branch, C., Milner, B., and Rasmussen, T. Intracarotid sodium amytal for the lateralization of cerebral speech dominance. J. Neurosurgery, 1964, 21, 399-405.

*Broadbent, D. E. Speaking and listening simultaneously. J. exp. Psychol., 1952a, 43, 267-273.

________. Failures of attention in selective listening. J. exp. Psychol., 1952b, 44, 428-433.

*________. The role of auditory localization in attention and memory span. J. exp. Psychol., 1954, 47, 191-196.

*________. Successive responses to simultaneous stimuli. Quart, J. exp. Psychol., 1956, 8, 145-167.

________. Immediate memory and simultaneous stimuli. Quart. J. exp. Psychol., 1957, 9, 1-11.

*________. Perception and Communication. New York: Pergamon Press, 1958.

________. Attention and the perception of speech. Scientific American, 1962, 206, 143-151.

Broadbent, D. E., and Gregory, M. Accuracy of recognition for speech presented to the left and right ears. Quart. J. exp. Psychol., 1964, 16, 359-360.

________. Some confirmatory results on age differences in memory for simultaneous stimulation. Br. J. Psychol. 1965, 56, 77-80.

*Bryden, M. P. Order of report in dichotic listening. Canad. J. Psychol., 1962, 16, 291-299.

*________. Ear preference in auditory perception. J. exp. Psychol., 1963, 65, 103-105.

*________. The manipulation of strategies of report in dichotic listening. Canad. J. Psychol., 1964, 18, 126-138.

*________. Tachistoscopic recognition, handedness, and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

*________. Short-term memory for unbalanced dichotic lists. Psychon. Sci., 1966a, 6, 379-380.

*________. Recall strategies in dichotic listening. Paper presented at the Midwest Psychological Association, Chicago, May, 1966(b).

*________. Left-right differences in tachistoscopic recognition: Directional scanning or cerebral dominance. Percept. mot. Skills, 1966c, 23, 1127-1134.

*________. An evaluation of some models of laterality effects in dichotic listening. Acta Otolar., 1967, 63, 595-604.

Caird, W. K. Effects of age on the recall of dichotic words. Nature, Lond., 1965, 207, 109.

*Calearo, C. and Antonelli, A. R. "Cortical" hearing tests and cerebral dominance. Acta Otolar (Stockholm), 1963, 56, 17-26.

Craik, F. I. M. The nature of the age decrement in performance on dichotic listening tasks. Quart. J. exp. Psychol., 1965, 17, 227-240.

*Carr, B. M. Ear effect variables and order of report in dichotic listening. Cortex, 1969, 5, 63-68.

Chaney, R. B. Jr. and Webster. J. C. Information in certain multidimensional sounds. J. acoust. soc. Amer., 1966, 40, 447.

Currey, F. K. W. Comparison of left and right handed subjects on verbal and non-verbal dichotic listening tasks. Cortex, 1967, 3, 343-352.

Currey, F. K. W. and Rutherford, D. R. Recognition and recall of dichotically presented verbal stimuli by right and left-handed persons. Neuropsychologia, 1967, 5, 119-126.

Day, R. S. Fusion in dichotic listening. Unpublished Ph.D. Dissertation, Dept. of Psychology, Stanford Univ., Stanford, Calif., 1968.

Dirks, D. Perception of dichotic and monaural verbal material and cerebral dominance in speech. Acta Otolar., 1964, 58, 73-80.

Dodwell, P. C. Some factors affecting hearing of words presented dichotically. Canad. J. Psychol., 1964, 18, 72-91.

Emmerich, D. S., Goldenbaum, D. M., Hayden, D. L., Hoffman, L. S. and Treffts, J. L. Meaningfulness as a variable in dichotic listening. J. exp. Psychol., 1965, 69, 433-436.

*Giannitrapani, D. Developing concepts of lateralization of cerebral functions. Cortex, 1967, 3, 353-370.

Gloning, I., Gloning, K., Haub, G., and Quatember, R. Comparison of verbal behavior in right-handed and non right-handed patients with anatomically verified lesion of one hemisphere. Cortex, 1969, 5, 43-52.

*Glorig, A., Wheeler, D., Quiggle, R., Grings, W., and Summerfield, A. 1954 Wisconsin State Fair Hearing Survey. Rochester, Minn.: American Academy of Opthalmology and Otolaryngology, 1957.

Goodglass, H. Binaural digit presentation and early lateral brain damage. Cortex, 1967, 3, 295-306.

Gray, J. A. and Wedderbaum, A. A. I. Grouping strategies with simultaneous stimuli. Quart. J. exp. Psychol., 1960, 12, 180-184.

*Harcum, E. R. and Dyer, D. Monocular and binocular reproduction of binary stimuli appearing right and left of fixation. Amer. J. Psychol., 1962, 75, 56-65.

*Inglis, J. Dichotic stimulation and memory disorder. Nature (london), 1960, 186, 181-182.

*________. Effect of age on responses to dichotic stimulation. Nature (London),1962a, 194/4833, 1101.

________. Dichotic stimulation, temporal-lobe damage, and the perception and storage of auditory stimuli--a note on Kimura's findings. Canad. J. Psychol., 1962b, 16, 11-17.

*________. Dichotic listening and cerebral dominance. Acta Otolar., 1965, 60, 231-238.

*________. On the relative effects of different sources of variation in dichotic listening performance. Br. J. Psychol., 1968, 59(4), 415-422.

Inglis, J. and Ankus, M. Effect of age on short-term storage and serial rote learning. Br. J. Psychol., 1965, 56, 183-195.

*Inglis, J., Ankus, M., and Sykes, D. H. Age-related differences in learning and short-term memory from childhood to senium. Human Development, 1968, 11, 42-52.

*Inglis, J. and Caird, W. K. Age differences in successive responding to simultaneous stimulation. Canad. J. Psychol., 1963, 17, 98-105.

*Inglis, J. and Sanderson, R. E. Successive responses to simultaneous stimulation in elderly patients with memory disorder. J. abnorm. soc. Psychol., 1961, 62, 709-712.

*Inglis, J. and Sykes, D. H. Some sources of variation in dichotic listening performance in children. J. exp. child Psychol., 1967, 5, 480-488.

*Inglis, J. and Tansey, C. Perception and short-term storage in dichotic listening performance. Psychon. Sci., 1967a, 7(8), 273-274.

________. Age differences in dichotic listening performance. J. Psychol., 1967b, 66, 325-332.

*Jerger, J. F., Carhart, R., Tillman, T. W., and Peterson, J. L. Some relations between normal hearing for pure tones and speech. J. Speech and Hearing Res., 1959,2, 126-140.

Jones, D. and Spreen, O. T. Dichotic listening by retarded children: The effect of ear order and abstractness. Child Devel., 1967, 38, 101-105.

*Kimura, D. Some effects of temporal lobe damage in auditory perception. Canad. J. Psychol., 1961a, 15, 156-165.

*________. Cerebral dominance and the perception of verbal stimuli. Canad. J. Psychol., 1961b, 15, 166-171.

________. Perceptual and memory functions of the temporal lobe: A reply to Dr. Inglis. Canad. J. Psychol., 1962, 16, 18-22.

________. A note on cerebral dominance in hearing. Acta Otolar., 1963a, 56, 617-631.

*________. Speech lateralization in young children as determined by an auditory test. J. comp. physiol. Psychol., 1963b, 56, 899-902.

*________. Left-right differences in the perception of melodies. Quart. J. exp. Psychol., 1964, 16, 355-358.

*________. Functional asymmetry of the brain in dichotic listening. Cortex,1967, 3, 163-169.

*Kimura, D. and Folb, S. Neural processing of backwards speech sounds. Science, 1968, 161, 395-396.

Milner, B. Intellectual functions of the temporal lobes. Psychol. Bull., 1954, 51, 42-62.

________. Laterality effects in audition. in Mountcastle: Interhemispheric Relations and Cerebral Dominance, 1962, (John Hopkins Univ. Press, Baltimore, Md.).

*Milner, B. Taylor, L. and Sperry, R. W. Lateralized suppression of dichotically presented digits after commissural section in man. Science, 1968, 161, 184-186.

*Mishkin, M. and Forgays, D. G. Word recognition as a function of retinal locus. J. exp. Psychol., 1953, 43, 43-48.

Morey, N. Attention in dichotic listening: Affective cues and the influence of instructions. Quart. J. exp. Psychol., 1959, 11, 56-60.

*Moushegian, G., Rupert, A., and Whitcomb, M. A. Medial Superior Olivary-unit response patterns to monaural and binaural clicks. J. acoust. soc. Amer., 1964, 36(1), 196-202.

*Oxbury, J. M. and Oxbury, S. M. Effects of temporal lobectomy on the report of dichotically presented digits. Cortex, 1969, 5, 3-14.

Oxbury, S. M., Oxbury, J. M., and Gardner, J. Laterality effects in dichotic listening. Nature, 1967, 214, 5089, 742-743.

*Palmer, R. D. Cerebral dominance and auditory asymmetry. J. Psychol., 1964, 58, 157-167.

*Perl, N. The recall of dichotic stimuli--Is order or laterality more important? Papers in Psychol., 1968, 2(1), 25-27.

*Rosenzweig, M. R. Representation of the two ears at the auditory cortex. Amer. J. Physiol., 1951, 167, 147-158.

Satz, P. Laterality effects in dichotic listening. Nature, 1968, 218, 277-278.

*Satz, P., Achenbach, K., Pattishall, E., and Fennel, E. Order of report, ear asymmetry and handedness in dichotic listening. Cortex, 1965, 1, 377-396.

*Satz, P., Levy, M., and Tyson, M. Effects of temporal delays on the ear asymmetry in dichotic listening. J. exp. Psychol., 1970, 84(2), 372-374.

Schulhoff, C. and Goodglass, H. Dichotic listening, side of brain injury and cerebral dominance. Neuropsychologia, 1969, 7, 149-160.

*Shankweiller, D. P. Effects of temporal lobe damage in the perception of dichotically presented melodies. J. comp. physiol. Psychol., 1966, 62, 115-119.

Shankweiller, D. P. and Studdert-Kennedy, M. Identification of consonants and vowels presented to the left and right ears. Quart. J. exp. Psychol., 1967, 19, 59-63.

Sparks, R. and Geshwind, N. Dichotic listening in man after section of neocortical commissures. Cortex, 1968, 4, 3-16.

*Spellacy, F. Lateral preferences in the identification of patterned stimuli. J. acoust. soc. Amer., 1970, 47 (2, part 2), 574-578.

*Thorndike, E. L. and Lorge, I. The Teacher's Word Book of 30,000 Words. New York: Columbia University Press, 1944.

*Tillman, T. W. and Jerger, J. F. Some factors affecting the spondee threshold in normal hearing subjects. J. speech & hearing res., 1959, 2, 141-146.

*Tolhurst, G. C. and Peters, R. W. Effect of attenuating one channel of a dichotic circuit upon the word reception of dual messages. J. acoust. soc. Amer., 1956, 28, 602-605.

Treisman, A. and Geffen, G. Selective attention and cerebral dominance in perceiving and responding to speech messages. Quart. J. exp. Psychol., 1968, 20, 139-150.

*Tunturi, A. R. A study on the pathway from the medial geniculate body to the acoustic cortex in the dog. Amer. J. Physiol., 1946, 147, 311-319.

*Webster, J. C. and Thompson, P. O. Responding to both of two overlapping messages. J. acoust. soc. Amer., 1954, 26, 391-396.

Weinstein, E. A. Affections of speech with lesions of the non-dominant hemisphere. in Rioch and Weinstein: Disorders of Communications, 1964, 220-228.

White, M. J. Laterality differences in perception: A review. Psychol. Bull., 1969, 72(6), 387-405.

*Wyke, M. and Ettlinger, G. Efficiency of recognition in left and right visual fields. Archives of Neurology, 1961, 5, 659-665.

*Zangwill, O. L. The current status of cerebral dominance. in Disorders of Communications (Proceedings of the assoc.: Assoc. for Res. in Nervous and Mental Disease) Rioch & Weinstein (eds.), New York, Williams and Wilkins Co., 1964.

APPENDICES

APPENDIX A

REFERENCES BY CATEGORIES

Note: This listing is not intended to represent a complete representation; neither by categories (some references belong to more than one category) nor by being exhaustive (it is obvious that there is considerable literature not presented here). This listing is intended only as a quick reference and a starting point for those interested in the research area of dichotic listening.

I. Physiological articles related to theoretical issues:

Bocca, et al., 1955
Branch, et al., 1964
Calearo & Antonelli, 1963
Moushegian, et al., 1964
Rosenzweig, 1951
Tunturi, 1946

II. Theoretical issues:

Benton, 1965
Broadbent, 1952a (not dichotic)
" 1952b (not dichotic)
" 1954 (original dichotic study)
" 1956
" 1957
" 1958
" 1962
Bryden, 1962
" 1963
" 1966b
" 1967
Giannitrapani, 1967
Inglis, 1962b
" 1965
" 1968
Inglis and Sykes, 1967
Kimura, 1961a
" 1961b
" 1962
" 1963a
" 1967
Milner, 1962
Oxbury, et al., 1967
Satz, et al., 1970

APPENDIX A (cont.)

III. Monaural tasks:

Bakker, 1967
" 1968
" 1969
Bocca, _et al_., 1955
Dirks, 1964
Glorig, _et al_., 1957
Jerger, _et al_., 1959
Palmer, 1964

IV. Non-verbal meterials in dichotic listening

Bakker, 1967 (monaural)
Currey, 1967
Kimura, 1964
Kimura & Folb, 1968
Shankweiller, 1966
Spellacy, 1970

V. Brain damage and surgery

Bocca, _et al_., 1955 (monaural)
Branch, _et al_., 1964 (not dichotic)
Gloning, _et al_., 1969
Goodglass, 1967
Jones & Spreen, 1967 (retardates)
Kimura, 1961a&b
Milner, _et al_., 1968
Oxbury & Oxbury, 1969
Schulhoff & Goodglass, 1969
Shankweiller, 1966
Sparks & Geshwind, 1968
Weinstein & Thompson, 1954 (not dichotic)

VI. Visual dominances

Bryden, 1966c
Harcum & Dyer, 1962
Mishkin & Forgays, 1953
Wyke & Ettlinger, 1961

APPENDIX A (cont.)

VII. Children as subjects

Bakker, 1967
Bakker, 1969
Inglis & Sykes, 1967
Jones & Spreen, 1967 (retardates)
Kimura, 1963b

VIII. Age (general)

Broadbent & Gregory, 1965
Caird, 1965
Inglis, 1962a
Inglis & Ankus, 1965
Inglis, Ankus & Sykes, 1968
Inglis & Caird, 1963
Inglis & Tansey, 1967b

IX. Aged subjects

Craik, 1965
Inglis, 1960
Inglis & Sanderson, 1961

X. Task Considerations

Bakker, 1967 (Morse-code information--monaural)
" , 1969
Bartz, et al., 1967 (73)
Bartz, et al., 1967 (74)
Borkowski, et al., 1965 (matching for initial phonemes)
Broadbent & Gregory, 1964 (recognition, not recall)
Bryden, 1964 (words instead of digits)
Bryden, 1966a (unbalanced dichotic lists)
Caird, 1965 (words)
Carr, 1969
Chaney & Webster, 1966
Currey, 1967 (handedness of subject)
Currey & Rutherford, 1967 (")
Day, 1968 ("fusion" of dichotic materials)
Dodwell, 1964
Emmerich, et al., 1965
Kimura, 1964 (melodies)
Morey, 1959
Satz, et al., 1970
Spellacy, 1970
Tolhurst & Peters, 1956 (attenuation of one channel)

APPENDIX A (cont.)

XI. General and Related articles

Branch, et al., 1964
Broadbent, 1952a
" , 1952b
" , 1958
" , 1962
Bryden, 1965
Currey, 1967
Currey and Rutherford, 1967
Day, 1968
Giannitrapani, 1967
Gloning, et al., 1969
Glorig, et al., 1957
Gray & Wedderbaum, 1960
Inglis & Tansey, 1967a
Jerger, et al., 1959
Milner, 1954
" 1962
Oxbury, et al., 1967
Perl, 1968
Satz, 1968
Satz, et al., 1965
Shankweiller & Studdert-Kennedy, 1967
Thorndike & Lorge, 1944
Tillman & Jerger, 1959
Treisman & Geffen, 1968
Webster & Thompson, 1954
Weinstein, 1964
White, 1969
Zangwill, 1964

APPENDIX B

ALPHABETICAL LIST OF CID W-1 SPONDEES

airplane

armchair

baseball

birthday

cowboy

daybreak

doormat

drawbridge

duckpond

eardrum

farewell

grandson

hardware

headlight

horseshoe

hotdog

hothouse

iceberg

inkwell

mousetrap

mushroom

northwest

oatmeal

padlock

pancake

playground

railroad

schoolboy

sidewalk

sunset

toothbrush

whitewash

woodwork

workshop

APPENDIX C

METHOD OF DETERMINING THRESHOLD

To determine threshold, two presentations were administered at each dB level. The point at which the S missed more than 5 of 6 presentations was the stopping point. The base level for threshold was the lowest level where both items (at a given level) were responded to correctly. Additional credit was given at the rate of $\frac{1}{2}$ dB for each additional correct response beyond that base level. The following example illustrates this scoring method:

Hearing Level in dB	Presentations 1st	Presentations 2nd	Threshold Determination
10	X	X	
9	X	X	
8	X	X	
7	X	0	
6	X	X	"6" = base
5	X	0	"$5\frac{1}{2}$"
4	0	X	"5"
3	0	0	"5"
2	0	0	"5"

APPENDIX D

INSTRUCTIONS TO SUBJECTS

All subjects were first tested for monaural thresholds on Speech Spectrum Noise, given the list of CID W-1 words and had them removed. At this time the following instructions, presented via tape, were played:

I'd like to thank you for participating in this study. We will be doing several different hearing tests--some established and some experimental. The instructions for each test will be given to you immediately preceding the test. The first test you will hear consists of a set of words--these are the set of words, some of which you have been looking at. What I would like you to do is simply repeat each word as you hear it. They will start out relatively loud(ly) , and get softer as we go on. Just repeat what you hear. We will test your hearing one ear at a time in this task. Do you have any questions?

----
presentation of CID W-1s

The next set of words on this tape constitute a practice session for what will follow. You will two words, one word and then another. You will hear them through the speakers so you may remove the headphones now. Your task for this set of words is to make up a single sentence using both words, and to do so as quickly as possible. In other words, as soon as you hear the second word, give a sentence using them both. You will have no difficulty in doing this as the words are all familiar, simple nouns.

This is preliminary to a new kind of hearing test, and is not in any way a personality test, IQ test, or a language test. So just give the first sentence that you can, as quickly as you can. Do you have any questions?

----
pause for Qs

We will now begin, so sit comfortably, relax, and give the very first sentence that comes to mind that uses both of the words you will hear.

----
presentation of successive words

Thank you. The next set of words will require you to listen through the headphones, but please don't put them on yet--listen to the instructions first. Your task is the same as it was during the last practice series. You will hear two words and you should once again try to p put them into a sentence as quickly as you can. This time, however, the words will be presented to you at the same time--one word to each ear. The task is therefore a little harder, but you should still be able to do well at it. The words are all simple, common, nouns. Once again, make up a single sentence using both words as quickly as you can. Please, put on the headphones now.

This is channel #1--in what ear are you hearing it?

---
await response

This is channel #2--in what ear are you hearing it?

---
await response

We will now begin.

presentations

The next set of words are similar to the ones you have just heard. Your task is the same. Make up a single sentence using both words. Once again let me remind you that this is not a personality test, IQ test, etc., but rather a new test of hearing. We will now begin this set of words. Are you ready?

presentations

This concludes the hearing tests. If you'll take off the headphones now, I'll be in the other room to be with you. Thank you once again.

APPENDIX E

THORNDIKE-LORGE WORDS USED IN THIS STUDY

Successive presentations	
Husband	Person
Ocean	Music
Animal	Dog
Hole	Shoe
Lake	Sea
Train	Ship
Stone	Road
Spot	Skin
City	Town
Idea	Thought

Order#2 used these same word-pairs in the reverse order, i.e., Person--Husband.

Dichotic presentations	
Arm	Neck
Inch	Mile
Book	Word
Hand	Heart
Girl	Child
Game	Job
Bed	Chair
Hat	Head

Dichotic presentation words continued

Moon	Sun
Boy	Man
Knee	Leg
Boat	Car
Trip	Camp
Mouth	Voice
Wave	Rock
Bird	Horse
House	Home
Glass	Cup
Tree	Road
Grass	Cloud

APPENDIX F

TABLE OF DATA BY SUBJECT

Subject	Left Ear Thresholds* SRT	SSN	diff.	Right Ear Thresholds* SRT	SSN	diff.	Difference Between Ears
A.H.	5.0	-7.0	12.0	-1.0	-8.0	7.0	5.0
M.G.	1.0	-9.5	10.5	0.0	-8.0	8.0	2.5
C.F.	-1.0	-9.0	8.0	-0.5	-10.0	9.5	-1.5
S.B.	5.0	-10.0	15.0	0.0	-10.5	10.5	4.5
J.B.	2.0	-12.0	14.0	-2.5	-10.0	7.5	6.5
D.O.	3.5	-3.5	7.0	-0.5	- 5.0	4.5	2.5
J.D.	10.0	2.0	8.0	6.5	1.5	5.0	3.0
K.B.	1.5	-5.5	7.0	-1.0	-5.0	4.0	3.0
J.F.	6.0	-2.0	8.0	7.0	-4.5	11.5	-3.5
J.N.	6.0	-9.0	15.0	2.0	-9.5	11.5	3.5
A.A.	4.0	-8.5	12.5	3.5	-5.0	8.5	4.0
N.D.	2.0	-9.0	11.0	0.0	-8.5	8.5	2.5
D.D.	12.5	-0.5	13.0	10.0	0.0	10.0	3.0
P.S.	0.0	-10.0	10.0	-2.0	-8.5	6.5	3.5
D.E.	1.5	-6.0	7.5	4.0	-5.0	9.0	-1.5
S.W.	0.5	-7.5	8.0	-1.5	-6.5	5.0	3.0
D.J.	4.0	-7.0	11.0	3.0	-6.0	9.0	2.0
P.H.	4.0	-10.0	14.0	-1.5	-10.0	8.5	5.5

APPENDIX F (cont.)

Subject	Successive task %1st=1st	Dichotic % R-ear 1st balance=SSN	Dichotic % R-ear 1st balance=SRT	diff.
A.H.	66.66	80	33.33	46.66
M.G.	66.66	30	20	10
C.F.**	77.77	44.44	60	-15.55
S.B.	--	--	--	--
J.B.	100	60	50	10
D.O.	50	55.55	70	-14.44
J.D.	70	22.22	12.50	9.72
K.B.	--	--	--	--
J.F.**	80	40	70	-30
J.N.	71.43	60	40	20
A.A.	90	70	70	0
N.D.	90	55.55	50	5.55
D.D.	70	70	50	20
P.S.	40	50	50	0
D.E.**	70	55.55	80	-24.44
S.W.	70	55.55	44.44	11.11
D.J.	100	66.66	50	16.66
P.H.	60	55.55	66.66	-11.11

*Threshold = X + 23.5 dB SPL re: 0.0002 dyne/cm^2

**These subjects are left ear dominant on monaural thresholds and as such, scores for dichotic performances should be subtracted from 100% to ascertain their shifting from their dominant ear. The difference score in the last column should be read with the reverse sign (i.e., + for -).