

THE RELIABILITY OF EAR ADVANTAGE AND ATTENTIONAL
CAPACITY IN DICHOTIC LISTENING

by

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ABSTRACT

The main theoretical assertion of the study was that neuropsychological research has concentrated primarily on the experimental model of enquiry. It was argued that due to the questions of interest and environmental constraints, the individual differences approach is probably more appropriate than the experimental approach for the development of neuropsychological theory. Therefore, a commonly used and accepted neuropsychological test, the dichotic listening task, was examined in terms of an individual differences model. The dichotic listening technique has been used extensively to infer speech dominance or more generally, cerebral asymmetries of function. Competing stimuli (eg., words) are presented simultaneously to each ear and the subject repeats what was presented. After a series of trials, the number of correct responses for the respective ears are counted and compared. If one ear is superior in performance, then it is argued that the contralateral hemisphere mediates that function (eg., language).

With respect to the dichotic listening task, it was argued that the test may measure two aspects of cognitive processing, namely ear preference and attentional capacity. Moreover, it was shown that traditional measures of ear preference are confounded with overall accuracy or attentional capacity. The current study employed a measure of ear advantage which is independent of accuracy.

Second, the published papers concerning the reliability of dichotic listening tasks were reviewed. All of the reviewed studies used a confounded measure of ear preference while none of the studies examined all aspects of reliability or used experimental procedures consistent with the individual differences model. Therefore, the current study examined the internal consistency of dichotic items, the test/retest reliability of dichotic tapes and the parallel form reliability of two different dichotic tapes for the attentional capacity and ear preference variables. Sampling and experimental procedures were consistent with the individual differences approach. The test/retest period was one week. The findings suggest that both the attentional capacity and ear preference variables can be measured reliably. However, the absolute value of the attentional capacity is tape dependent and improves over time. The absolute value of the ear advantage variable did not change over tapes or sessions. In contrast to the experimental studies which suggest a right ear advantage is typical, the majority of subjects in the study did not exhibit an ear advantage. Finally, on the second session, a significant inverse relationship between ear preference and attentional capacity was found. Specifically, the greater ear advantage, the lower the attentional capacity. Such a finding may provide insight into changes in subject processing strategies.

In conclusion, it was argued that the individual differences approach is necessary for development of a comprehensive theory of neuropsychology. By concentrating on findings from the experimental model, a rather biased model of brain processes has developed. For

example, the results of the current study clearly contradict the assertion that most individuals do exhibit an ear advantage. Finally, the position was presented that only by closer examination of the statistical properties of the data set, can more generic theories be developed.

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CHAPTER ONE

THE PROBLEM

The Two Disciplines of Scientific Inquiry in Psychology

In 1957, Cronbach suggested that there are two distinct types of scientific inquiry in psychology. The first employs the experimental methodology developed by Fisher (1925) whereas the second uses an individual differences approach based on the work of Spearman (1904, 1910, 1913). Although Cronbach and others (e.g. Bindra and Scheir, 1953) have argued that the discipline of psychology would benefit from an integration of these two approaches, Cronbach also demonstrated that these two approaches are contradictory in terms of interest area and hence in their underlying assumptions.

The individual differences approach assumes that an individual is consistent in terms of an attribute; thus by understanding how, and then perhaps why, individuals differ, our knowledge of human behavior is enhanced. Specifically, the approach defines an attribute of interest and then attempts to show that the attribute is stable over time for an individual and that individuals differ on the attribute. In the study of individual differences, the first step is to define and then reliably measure an attribute of interest. The second step is to determine the relations between two reliable measures or attributes of interest. These two steps form the basis for models of individual differences. Fundamental to the approach is the assertion that variability in

the measurement of a particular attribute on a given individual is a function of inaccurate measurement and hence is treated as error.

In contrast to the individual differences approach, the experimental model examines group changes under specific treatment conditions. Variability in subject performance from time one to time two is assumed to be a treatment effect. Individual differences in performance on the dependent variable within a treatment condition are assumed to be random error. The comparison of treatment variability (i.e., consistent subject changes with treatment) to random error determines whether the treatment was effective.

Due to these different assumptions, Cronbach suggested that one man's error term is another man's interest area. Specifically, the individual differences approach considers subject changes over time to be error whereas the experimental approach considers the changes to be treatment effects. Similarly, the experimental approach considers inter-individual differences as error whereas such differences are the variable of interest in the individual differences approach.

The first tenet of the current study is that the experimental paradigm has been the major method of enquiry employed in the neuropsychological research. The second tenet is that the assumptions of the experimental model are usually violated when the approach is applied to neuropsychological problems. The third tenet is that as the variables of interest in most

neuropsychological studies are attributes of the subject (e.g., visual-spatial ability, verbal reasoning), the individual difference approach is probably more appropriate. The fourth tenet is that by concentrating on the experimental form of enquiry, the conclusions drawn concerning the nature of brain/behavior relations are at least limited and perhaps erroneous. The final tenet is that by applying the individual differences model to neuropsychological problems, a more generic and broad understanding of brain/behavior relations may be possible.

In order to illustrate the above assertions, a popular test in neuropsychology, the dichotic listening technique, will be considered in terms of previous experimental studies and inferences. The dichotic listening technique was developed by Broadbent (1954) in order to examine information processing. The technique consists of simultaneously presenting a different digit or word to each ear by means of headphones. For example, a number four may be presented to the right ear and the number five to the left ear. The rate of presentation of the dichotic pairs as well as the number of pairs may be varied dependent upon the experimental technique. After the presentation of a number of pairs, (in Broadbent's case, three pairs of digits) the subject is asked to recall as many of the six digits or words as possible. The instructional set for recall may also be varied in terms of ear order of reporting.

Kimura (1961a) applied the dichotic listening technique to the neuropsychological problem of determining speech dominance.

Basically, Kimura argued that because one ear appears to be more efficient in terms of the recall of dichotically presented verbal stimuli, the more efficient ear is contralateral to the speech dominant hemisphere. The first purpose of this first chapter is to review Kimura's finding and to argue that her inferences are suspect. The second purpose is to argue that the empirical examination of ear preference or advantage should be done by means of the individual differences model of inquiry, not the experimental model. The final purpose is to describe the individual differences approach in greater detail and then to outline the current study, which applied the individual differences model to the ear advantage variable. In addition, it will be argued that the dichotic listening technique may measure two different cognitive attributes.

The Experimental Approach and Dichotic Listening

Kimura (1961a) used the dichotic listening technique of Broadbent (1954) and employed thirty-two groups of three simultaneously presented pairs of digits presented to 120 epileptic patients and thirteen normal subjects. These 133 subjects were divided into seven groups dependent upon their medical status. Speech dominance had been determined by the sodium amytal test (Wada and Rasmussen, 1960). The data and the site of seizure origin are presented in Table I. Kimura reported that the comparisons of accuracy rates of the right versus the left ear were significantly different from zero for the seven groups in Table I. No variances or t-values were reported. From the findings she infers: "when speech is

TABLE I

Kimura's Original Data¹

<u>Speech Dominance</u>	<u>Origin of Seizures</u>	<u>Left Ear</u>	<u>Right Ear</u>	<u>Difference</u> ²
	1. Left Temporal	76.8	81.5	4.7
	2. Right Temporal	83.4	88.0	4.6
Left	3. Bitemporal	77.9	80.2	2.3
	4. Frontal	82.7	86.4	3.7
	5. Subcortical	76.5	85.5	9.0
Right	6. Not specified	85.0	74.9	-10.15
Not tested	7. Normals	90.25	92.25	2.0

¹ From Kimura (1961a)² The critical probability associated with each difference was less than 0.005.

represented in the left hemisphere, the right ear is more efficient" (p.168).

This inference is suspect on two grounds. First, since in the dichotic listening tasks (including Kimura's) three pairs of words or digits are presented in rapid succession, one member of a pair to each ear, the true experimental unit of the dichotic listening task is the presentation and recall of three pairs of digits. Kimura summed the thirty-two presentations of three pairs each to derive the respective ear scores for each group. When the scores of normals are considered, the mean overall accuracy rates were 92.25 and 90.25 correct responses of ninety-six possible for the right and left ear respectively. The figures suggest that the right ear advantage was not apparent on every presentation for all subjects. Had this been the case, then the minimal mean difference score would have been thirty-two (i.e., the number of presentations), not two. Specifically, if each subject had a right ear advantage on each presentation, the smallest possible mean difference score would be the number of presentations, in this case thirty-two. Rather, her data indicate that on the majority of presentations, the number of words recalled was equal for the two ears. Hypothetically, her mean values could have been obtained from the following responses: On twenty-six presentations, all three digits presented to each ear were recalled; on four presentations, two of three digits presented to each ear were recalled; and for two presentations, the three digits presented to the right ear were

recalled whereas only two of the three presented to the left ear were recalled. In this case, it is apparent that on thirty of the thirty-two presentations, the performance between the two ears was equal. For the two exceptions, the right ear performance was superior.

With respect to the epileptic groups, the right-left differences were larger but overall accuracy decreased as well (range 82.3 to 88.1% in comparison to 95.1% for the normals). Two of the reported right/left difference scores are considerably larger than in the normals (i.e., 10.15 and 9.0) but the remaining four are not (range 2.3 to 4.9). As the subjects were pre-operative surgical cases with longstanding histories of epilepsy, the decrease in overall performance is probably as noteworthy as the right-left differences. However, the ear advantage has been the variable of interest in later research. Subsequent research on the dichotic listening task has shown that size of the right ear advantage may be increased by presenting more pairs before recall or by using words rather than digits (Bryden, 1964). Moreover, the effect can be increased by selective sampling of subjects on specific attribute variables such as sex and handedness.

However, the relative magnitude of the effect is small in that it has only been shown in within group designs (i.e., subject as their own control), with one exception (Kimura, 1967). Inglis (1962) presented data on between group designs (i.e., groups of subjects are compared) that suggest: 1) the right ear advantage

would not be found consistently in a between group design; and
2) ear of first report contributes more systematic variance than
overall ear advantage.

Within this context, the experimental model as it has been applied to dichotic listening requires two properties in order to reject the null hypothesis, an effect different from zero and minimal subject variance. Therefore, in order to produce the desired effect, researchers have increased the difficulty of the test and applied selective sampling techniques, such as only examining right handed males. The first manipulation is valid but the second is questionable. First, the neuropsychological literature has suggested that there is not an invariant relation between an attribute variable such as handedness and speech laterality (e.g., Kennedy, 1916; Smith, 1966). Second, although it is accepted that speech is lateralized more often to the left hemisphere than the right, there is minimal evidence, if any, to suggest that left hemisphere dominance for speech is the better or the more natural state of affairs. Rather, speech laterality may be determined by a complex set of interactions of genetic, pre-natal or environmental factors (Bakan, Dibbs and Reed, 1973; Levy, 1977; Nottebohm, 1979). By selecting subjects who are more likely to exhibit minimal between subject variance and a right ear advantage, conceptual inference is automatically limited. Furthermore, it can be argued that subjects who would disconfirm the hypothesis being tested (in the inferential sense) are systematically excluded. In Popper's model of scientific

inquiry, this scientific procedure would never allow knowledge to advance, because little if anything of scientific significance is learned through validation in a limited setting (Magee, 1973).

The advantage of the individual differences model in the study of ear advantage and its relation to other cognitive attributes or abilities is that all subjects should be studied so that the interrelations of function can be established for individuals rather than for specific or pre-selected groups.

The second difficulty of applying the experimental approach to dichotic listening lies in limitations of inference in terms of causation. For example, Kimura (1961a) speculates on the cause of the observed right ear advantage. The weakness of the experimental or, in this case, the quasi-experimental approach in substantiating hypotheses or theory generation is well-illustrated here. The logical fallacy of inference in the quasi-experimental approach has been discussed in detail by Meehl (1978). In the case where a well defined and consistent treatment is applied, and threats to both internal and external experimental validity are well controlled, inferences can be drawn with some confidence (Campbell and Stanley, 1963). However, in Kimura's case, the treatment or what causes the right ear advantage is not known. Hence, no real hypothesis is being tested. Rather, the researcher can only speculate on the possible cause of the difference. For example, Kimura argued that the right ear advantage is a function of the relative efficacy of the crossed auditory pathways. Subsequently, Sparks and Geschwind (1968) argued that the right ear

advantage is a function of the time of stimulus arrival at the verbal processor in the brain. Kinsbourne (1974) offers a third explanation, that "the right ear advantage...is a product of the fact that the right ear receives the message from the right side of space," (p. 273). He argues that the side of space a stimulus arrives from primes the contralateral hemisphere for future action. Kimura's explanation is confined to the sensory input system. Sparks and Geschwind's explanation involves this system as well as the corpus callosum, which synapses on the auditory association cortex of both hemispheres. Functionally, the corpus callosum may relay auditory information from one hemisphere to the other. At this time, the reason for the right ear advantage is still under debate. Moreover, it will remain under debate because the 'treatment' is an act of nature or chance, not a manipulated and well controlled experimental treatment.

Restating the presented arguments, ear advantage or preference is an attribute of the subject, not a controlled experimental treatment. Therefore, inference is suspect. When the experimental model is employed to examine ear advantage, selective sampling techniques are used in order to reduce subject variability and thereby produce the desired effect. Selective sampling limits the generalizations of findings. The fact that a particular population, in the dichotic experiment usually right-handed males, exhibits a particular behavior does not imply that the behavior is necessary for normal functioning. Finally, although subsequent research has confirmed Kimura's findings when selective sampling procedures are

used and the stimulus load is increased, her findings are weak because of the magnitude of the reported differences. Moreover, the total number of digits recalled may be as important a variable as ear advantage. However, no systematic studies on overall accuracy could be found.

The Application of the Individual Differences Approach to Dichotic Listening

In the previous section, it was argued that ear advantage is a subject attribute and therefore that the individual differences approach is the model of choice for examining the phenomenon. However, the individual differences approach has other specific advantages. First, the sampling procedure should yield as heterogeneous a sample as possible. Hence, generalization of findings would not be as limited as in the experimental model. Second, because the actual cause of the right ear advantage cannot be delineated by applying the experimental model, the question of import is what relation does the direction or magnitude of ear preference have to or for other cognitive behaviors? In order to examine the relation between two variables, the statistic of interest is the correlation of subject performance on the two variables. Therefore, the individual differences approach allows statements concerning individuals and theoretical constructs to be made, rather than statements about groups and theoretical constructs as in the case of the experimental model.

In order to apply the individual differences approach, the first step is to construct reliable measures of the constructs of

interest. Subsequently, validity questions may be addressed. Once reliable tests have been constructed, the validity questions provide meaningful insight into the strength of relations between constructs. In the individual differences model, the discovery that two constructs are or are not related may have equally important ramifications for theory.

Reliability

The first step in the development of the individual differences model is to estimate the reliability or, in fact, the reliabilities of a test. The test is assumed to measure the variable of interest although this measurement assumption may be verified, for example, by agreement of judges or specialists. For the ear advantage variable, considerable debate has occurred as to how to measure ear advantage due to the relations between the ear advantage score and total accuracy. However, with few exceptions (e.g., Colbourn, 1978), most neuropsychologists contend that ear advantage is related to hemispheric asymmetries of cognitive function (Studdert-Kennedy, 1974). Both the measurement and theoretical issues are reviewed in the next chapter.

Thorndike (1967) suggested that there are four major procedures for assessing the reliability of a test: 1) parallel or equivalent forms - the administration of two equivalent tests and the correlation of the resulting scores; 2) test/retest - the repeated administration of a test and the correlation of the resulting scores; 3) split half - the subdivision of a single test into two presumably equivalent groups of items, each scored

separately and the correlation of the resulting two scores; and 4) analysis of the variance among individual items and determination of the error variance therefrom. Stanley (1971) has shown that Thorndike's third type is mathematically a degenerate case of the general analysis of variance model of Hoyt (1941). Both procedures provide an estimate of the internal consistency of a test. With the availability of computer technology, the analysis of variance procedure is the method of choice because it is more versatile and makes full use of all test data. In addition, the problem of what 'splitting' method to use is avoided. Therefore, Thorndike's four procedures may be reduced to three: parallel forms, test/retest and internal consistency.

The development of a reliable test is best approached in hierarchical fashion. Specifically, a set of internally consistent items should be derived. Internal consistency refers to the consistency of subject performance over items. The items should be drawn randomly from a content area and be independent of other items (Guttman, 1945). The estimate of the internal consistency coefficient (R_{IC}) can be stated as follows:

$$R_{IC} = 1 - \frac{MS_{\text{error}}}{MS_{\text{persons}}} \quad (\text{eq. 1})$$

The derivation of the mean score for the error term and the mean square for the persons term comes directly from a two-way analysis of variance, subjects by items. The interaction term is the mean square error. The $MS_{\text{error}}/MS_{\text{persons}}$ term is the proportion of the variance due to errors of measurement (Stanley, 1971).

The internal consistency estimate of a test is the theoretical upper limit for the test/retest reliability coefficient (Cronbach, 1970). Hence, if the internal consistency of a test is low then the test/retest reliability is constrained. Although the magnitude of the internal consistency coefficients is a function of the homogeneity and number of items, for a theoretical construct to be meaningful, reliable measurement of the construct should be possible with a limited number of items (Nunnally, 1967). The argument of upper limits of correlation also holds for the parallel forms reliability coefficient. If the two parallel forms are not internally consistent then the correlation between the forms will also be low.

As can be seen from equation (1), the internal consistency is increased by reducing the errors of measurement. Such a reduction may be achieved by: 1) increasing the number of items; 2) sampling a heterogeneous subject population; 3) increasing systematic item variance; 4) using homogeneous items (i.e., representative of the same content domain); and 5) reducing the error variance associated with the testing situation. Increasing the number of items may interact with factors that may reduce reliability, namely boredom and fatigue. Sampling a heterogeneous population is probably the major advantage of the psychometric approach in terms of neuropsychological research because of the increased generalization of findings. Increasing the systematic item variance is accomplished by first manipulating

the difficulty level of a test to 50% correct and by meeting the fourth condition of using homogeneous items. The property of homogeneous item content is not a major sampling problem in the dichotic listening task because the stimuli are typically very similar. In addition, the technique of item analysis permits the empirical examination of these two properties. Moreover, insight into the stimulus characteristics determining ear advantage may be gained by examining the item correlations with the total score. Finally, the reduction of error variance can be accomplished by not applying certain experimental control procedures such as switching or counterbalancing ear order of presentation.

The Current Study

The purpose of the proposed study was to examine the reliability of two variables measured by the dichotic listening technique, ear advantage and attentional capacity. Attentional capacity was defined as overall accuracy. The number of published studies concerning the reliability of the ear advantage variable is few and each has severe methodological flaws. The published studies are reviewed in the next chapter; all failed to employ the methodology and conceptual model of the individual differences approach. The current study evaluated the internal consistency of two commonly used dichotic tapes. The test/retest reliability of the two tapes was assessed for a one week interval. In addition, the two tapes were considered to be parallel forms and the inter-correlations between the two forms were estimated.

The experimental and sampling techniques were designed to conform to the individual differences approach. Specifically, the sample was heterogeneous in terms of attribute variables such as gender, handedness, education and occupation. Experimental conditions were designed to reduce sources of variance that would deflate the reliability estimates. For example, unlike the experimental model where the channels are counterbalanced or reversed in order to reduce equipment bias, the channels were not reversed in the current study. Therefore, if bias existed in the equipment, it was constant for all subjects.

In addition, the efficacy of the dichotic listening technique in separating subjects in terms of ear advantage was evaluated. Specifically, if the obtained data were normally distributed then using a dichotomous or trichotomous classification model for ear advantage is inappropriate. The final consideration of the current study was the relation between ear advantage and attentional capacity. The relation between ear advantage and attentional capacity was considered from two perspectives. First, a directional model of ear advantage was considered; and second, a magnitude model was assessed.

CHAPTER TWO

CONCEPTUAL AND METHODOLOGICAL ISSUES

Overview

The purpose of this chapter is to restate the problem outlined above within a historical context both conceptual and methodological. The first topic will be a brief review of the early studies employing the dichotic listening technique in terms of their theoretical interest. Second, the subsequent application of the dichotic technique to neuropsychological theory will be reviewed. Third, the statistical problems associated with the measurement of ear advantage will be considered. Fourth, reliability theory will be reviewed in terms of conceptual and experimental ramifications for dichotic listening. Fifth, the previous studies on the reliability of the dichotic listening task will then be reviewed with respect to the measurement of ear advantage, reliability theory and experimental methods. Finally, the interaction between the individual differences approach and the experimental approach will be considered in terms of the effect of test reliability on experimental findings.

Development of the Dichotic Listening Technique

Broadbent (1954) developed the dichotic listening task in order to examine the construct of attention and human information processing generally. His original procedure consisted of presenting three pairs of digits, one to each ear, to a subject and then testing for recall. Correct recall was defined as the

repetition of the six presented digits. If a subject could not recall the entire list of six digits then the response was considered incorrect. Each presentation of a six digit list was defined as an experimental unit. Broadbent manipulated the time between the presentation of digit pairs and required the subject to employ one of two recall strategies: channel by channel or alternating channel. In the channel by channel condition, subjects were asked to recall one channel (e.g., the right ear) and then the other (e.g., the left ear). For the alternating channel condition, the subjects were required to switch from channel to channel during recall (e.g., RLRLRL). Broadbent found that at a presentation rate of one pair per one and a half seconds, there was no difference between the two recall conditions with approximately 88% of the digit lists being recalled correctly. However, at a faster rate of presentation, one pair per half second, performance in the alternating channel condition fell dramatically to 20% correct recall. In contrast, the subjects in the channel by channel condition still were able to recall over 80% of the list correctly.

Later, Bryden (1962, 1964) employed a free recall procedure rather than the fixed instructional set on similar dichotic stimuli. He found the same relations between rate of presentation and efficacy of recall method as Broadbent. Moreover, he found that subjects altered their recall strategy dependent upon the rate of presentation. Specifically, subjects tended to employ a channel by channel strategy for the faster rates and an

alternating set when the rate was slower.

Broadbent's original (1957, 1958) interpretation of the findings was that both ears, or more generally all sensory channels, have access to a central processor. The processor switches among sensory channels dependent upon input demands. Therefore, when dichotic stimuli are presented, the processor may only attend to one channel at a time. For slow rates of dichotic presentation, the processor has enough time to either attend to one channel and then switch to the other (channel by channel recall) or switch between channels (alternating recall). However, for the faster rates, there is not enough time for the processor to switch the five times required by the alternating condition (i.e., R L R L R L). In contrast, the channel by channel condition only requires one switch (i.e., RRR LLL). Therefore, this recall strategy is effective for the fast presentation rate while the alternating strategy is not. Broadbent posited two sensory systems, the S-system or short term sensory store and the P-system or processing system. For fast presentation rates, information from one channel is processed immediately (i.e., P-system) while information from the other ear is held in a short term sensory store (S-system) and then processed when the central processor is free. The two determinants of which recall mode is used are the number of switches required by the task and the amount of time available to switch and process. Finally, Broadbent suggested that the S-system is fragile in terms of memory or retention. For example,

if the material in the sensory store is not processed, it will decay rapidly.

Subsequent to Broadbent's formulations, several investigators experimentally examined specific aspects of the theory.

Moray (1960) questioned the concept of switching time. He monaurally presented words to his subjects but with minimal time between presentations. Moray showed that the subjects could recall the words correctly, hence suggesting that they were able to switch from channel to channel in less time than Broadbent's fast rate of presentation provided. In addition, Moray (1968) suggested that Broadbent's method of scoring (i.e., number of lists correctly recalled) obfuscates the actual processing mechanisms. Specifically, Broadbent based his theory on the successful completion of the task and thus suggested that failure to remember the list correctly is consistent with unsuccessful processing. However, both Moray (1969) and Bryden (1964) reported successful recall of the list but the recall strategies were neither channel by channel nor alternating strategies; rather they were hybrids of the two strategies.

Treisman and Geffen (1968) questioned Broadbent's assertion of independent sensory channels. They found that dichotically presented nonsense syllables (e.g., poduct, roduct) were often fused into a meaningful word (e.g., product). The finding suggests that: 1) the S and P-systems are not independent; and 2) they are not purely sensory in function, because the fusion of nonsense syllables into meaningful words implies processing.

Several investigators have argued that Broadbent's model did not consider stimulus variables and their relation to information processing. Gray and Wedderburn (1960) employed dichotic stimuli that consisted of embedded syllables and sentences as well as digits. For example, the stimuli for one channel would be "mice, seven, cheese", while for the other, "three, eat, nine". Subjects tended to report the embedded sentence (e.g., mice eat cheese) and then the digits. Dodwell (1964) found that recall for words was in part dependent upon the frequency of their usage and concreteness. Emmerich, Goldenbaum, Hayden and Treffets (1965) also found that channel performance was dependent upon the meaningfulness and emotional content of the presented words.

The contradictory findings lead to modifications to Broadbent's initial formulations. Specifically, because the two channels are not independent as evidenced by fusion, and since both accuracy of recall and recall strategies are influenced by stimulus variables, all presented information must be processed at some level. Moreover, the findings suggested that if the presented material interacts with a memory system then the information is processed differentially. If the presented stimuli were neutral or equivalent (e.g., digits) then, as Broadbent suggested, one channel would be processed in preference to the other. However, if the stimuli could be grouped in a meaningful manner (e.g., embedded sentences) then a grouping strategy could be employed. Grouped material would be processed first, followed by unrelated material. Variants of

the basic processing model have been suggested by Inglis (1960), Yntema and Trask (1963), and Murray and Hitchcock (1969). The basic model is similar to Broadbent's in that it distinguishes two stages but the emphasis has shifted from sensory holding or delay to memory. Murray and Hitchcock (1969) suggested that one memory system is actively processing material while the other holds the material until processing. They suggest that the two systems, labelled iconic and echoic memory, are similar in terms of function to Broadbent's P and S-systems. Like Broadbent, Murray and Hitchcock argued that the echoic or S-system is fragile and susceptible to interference and decay. Bryden (1971) showed that if a subject was instructed to attend to one channel, overall recall for the unattended channel was poorer. Moreover, the first words presented in the unattended channel were more likely to be forgotten than the last. For four-word pairs, he reported an overall accuracy rate of 41% for the first word on the unattended channel and 86% for the fourth word. For the attended channel, the accuracy rates were not related to serial position.

One of the first clinical applications of the dichotic listening technique was reported by Inglis (1960). Inglis hypothesized that memory disorders were a function of impairment of the S-system. He argued that as subjects report channel by channel when fast rates of presentation are used, the ear of first report estimates the efficacy of the P-system while the ear reported second estimates the efficacy of the S-system. Therefore, if memory disorders are a function of impairment of the S-system,

patients with memory disorders should perform as well as normals in terms of the ear of first report but should be worse than normals for the ear of second report.

Application of Dichotic Listening to Neuropsychology

Kimura (1961a,b) used the dichotic listening technique and found that overall the accuracy for the right ear was better than the left ear for right handed subjects under free recall instructions. Although ear preference had been noted by previous investigators (e.g., Broadbent, 1954), Kimura's interpretation differed from previous models of cognitive processing. Rather than explain her results in terms of channel capacity and a two stage memory theory, she argued that the right ear superiority was a function of differences in the crossed auditory neural pathways and access to a speech processor in the brain. She suggested that the ear contralateral to the speech dominant hemisphere was more efficient in processing and recall of digits because the auditory pathway from the contralateral ear to the speech dominant hemisphere was stronger or better in terms of processing verbal stimuli. Moreover, she provided supportive evidence for her position by showing that for groups of epileptic patients, the ear advantage was dependent upon the speech dominant hemisphere. Specifically, for epileptic patients who were right hemisphere dominant for speech on the Wada amytal test, the average difference score of the right minus left ear score was indicative of left ear superiority. In contrast, the average difference of patients who were left hemisphere dominant for

speech was indicative of right ear superiority. In addition, electrophysiological evidence from cats suggested that evoked potentials for the crossed auditory pathways were stronger and faster than for the ipsilateral pathways (Rosenzweig, 1951).

Kimura's interpretation of her data led to other experimental applications and formed a theoretical basis for the dichotic listening paradigm. Specifically, auditory asymmetries were assumed to imply hemispheric differences in cognitive functions. Initial criticism of Kimura's approach to interpretation was made by Inglis (1962). He suggested that the ear of first report is always more accurate than the ear of second report. Therefore, if there is an inborn bias to report the right ear first, in a free recall situation the right ear will be more accurate because it will tend to be the ear of first report. Bryden (1963) examined the criticism by presenting the dichotic material to his subjects twice. On the first presentation, they were instructed to recall one ear then the other. On the second presentation, the instructional set was reversed. He then summed the two right ear scores and compared these scores to the sum of the two left ear scores. Bryden's dichotic stimuli were three-, four-, and five-digit pairs. For the four- and five-digit pairs, he found a right ear superiority. In a later study, Bryden (1969) presented six pairs of words and manipulated the recall set. One group of subjects was, prior to presentation, instructed to recall from a specified ear, whereas the second group was instructed to recall from a specified ear after the stimulus presentation.

For both conditions, he found a right ear advantage. It can be concluded from Bryden's two studies that manipulating the ear of first report will not completely suppress the right ear advantage. However, the robustness of the right ear advantage is dependent on the number and type of stimulus pairs presented.

Inglis's second criticism of Kimura's work was that the magnitude of the ear advantage effect is minimal in comparison to the ear of report effect. Using his own data, Inglis argued that if a between group design was employed the right ear advantage probably would not be found but the ear of report effect would be. Therefore, the ear of report effect is of more psychological import than the ear advantage effect in terms of understanding cognitive processing.

Although Inglis reported that the ear advantage effect was not consistently significant in his between group design, Kimura (1967) summarized a study where subjects were instructed to recall only one channel of a tape consisting of four pairs of mono-syllabic words matched on the middle vowel. The between groups difference of right versus left ear recall was significant. The only difference between the two studies appears to be the type of dichotic stimuli. Other than the study by Kimura, no studies could be found that employed between group designs.

Kimura's reply (1962) to Inglis's criticisms was based primarily on her right as a scientist to employ the model of her choice for explanation. Specifically, she argued that an experimental technique is not tied to a theoretical position.

Therefore, she was not bound to earlier theoretical positions because she had used the dichotic listening technique.

Kimura's interpretation of her results provided a relatively simple means of inferring hemispheric function or specialization without the risk of medical intervention procedures. Prior to this time, the majority of neuropsychological theory about hemispheric function was based on evidence from clinical samples. For example, Sperry's evidence for hemispheric specialization of function was derived from observations of a small number of intractable epileptics subsequent to severing the corpus callosum (Sperry, 1964). Similarly, Penfield and Roberts' (1959) cortical mapping of language functions was done on epileptic patients prior to ablation of epileptic brain areas. Other clinical sources of information include stroke and trauma patients but unless neurosurgical, radiological and/or autopsy reports were available, the specification of the actual size and locus of lesion was not possible. Examination of normal subjects had to be excluded because of the potential physical discomfort and risk of complications/mortality associated with these procedures. In contrast, the dichotic listening technique, by Kimura's argument, could establish the hemisphere of speech/language dominance without physical discomfort or risk. Therefore, the dichotic technique rapidly gained popularity as a neuropsychological test.

Subsequent research suggests that the fit between dichotic listening predictions and other clinical techniques for assessing speech dominance is not perfect. For example, Branch, Milner and

Rasmussen (1964) estimated that at least 90% of right handers are left hemisphere dominant for speech. Speech dominance was tested by means of the sodium amytal test (Wada and Rasmussen, 1960) and surgical confirmation. In contrast, Satz (1977) estimated that only 70% of right handers exhibit a right ear advantage on the dichotic listening test. Two problems arise from the comparing of methods. First, there is some evidence that speech may be represented bilaterally rather than unilaterally in some individuals (Subirana, 1958; Branch, Milner and Rasmussen, 1964). Second, the dichotic listening technique was not constructed as an effective psychometric test for predicting speech dominance. Rather, the original test was constructed to have minimal, if any, variance. In other words, the subjects were expected to recall the digit list perfectly. Both Bryden (1963) and Satz (1968) have shown that increasing the difficulty of the items, either by using more pairs or word pairs rather than digits, increases the magnitude of the right ear advantage. Related to the problem are the questions of what should be the measure of ear advantage, and what deviation from a theoretical zero point constitutes an ear advantage, not just random variation? Finally, what are the stimulus attributes of an item which are most likely to produce an ear advantage and hence reduce non-specific variance?

With respect to these questions, neuropsychological research has proceeded mainly on the basis of an experimental, not a psychometric model. Moreover, the majority of experimental work

has been limited to the following three research questions:

1) what stimuli other than digits produce auditory asymmetries;
 2) what causes the right ear advantage; and 3) what is the relation between ear advantage and other variables or types of individuals? With regard to the first question, right ear superiority for the processing of digits and words has already been discussed. In addition, a right ear advantage has been shown for competing initial consonants (Shankweiler and Studdert-Kennedy, 1966, 1967). Shankweiler and Studdert-Kennedy found that when subjects were presented with dichotic consonant-vowel sounds (e.g., da-ba) and asked to write down what they heard, right ear accuracy was significantly higher than left ear accuracy. A weak right ear advantage for vowels has also been shown but usually with experimental manipulation, for example, by presenting vowels in noise (Weis and House, 1973; Godfrey, 1974), sound effects (Curry, 1967) and pitch contours (Spellacy, 1970). Based on replications of Kimura's findings and the findings of other stimulus specific ear advantages, Studdert-Kennedy (1974) concluded:

"Most investigators have accepted Kimura's proposal that these (i.e., auditory) asymmetries reflect the asymmetric functions of the cerebral hemispheres. There is, in fact, so much evidence in favor of this hypothesis that it would be difficult to do otherwise. However, not everyone has accepted the structural account of each input's privileged access to its contralateral hemisphere." (p. 123)

At present, there are three major models to account for the observed right/left ear advantages. All three assume that the advantage does reflect differences in the function of the two cerebral hemispheres. However, two, Kimura's original model and

Sparks and Geschwind's (1968) subsequent interpretation, are confined to physiological or structural accounts. In contrast, Kinsbourne's (1974) interpretation is based on environment/hemisphere interaction. Figure I depicts a schematic representation of the auditory sensory input system (Gaddes, 1980). Kimura's explanation is confined to the sensory input system. Sparks and Geschwind's explanation involves this sensory system as well as the corpus callosum, which synapses on the auditory association cortex of both hemispheres. Functionally, the corpus callosum may relay auditory information from one hemisphere to the other.

Kimura (1967) argues that because stimulus competition is a necessary condition for an ear advantage to be observed, the ear advantage is probably a function of the arrangement of the auditory pathways. First, a stimulus presented to one ear is transmitted to both hemispheres by means of ipsilateral and contralateral pathways. However, a slightly greater number of fibres project onto the respective gyri of Heschl from the contralateral pathways than from the ipsilateral pathways. Based on Rosenzweig's proposal (1951) that contralateral pathways could occlude or suppress the ipsilateral pathways, Kimura argued that the contralateral are stronger than the ipsilateral pathways. Therefore, if the competing stimuli are words and the subject is left hemisphere dominant for speech, the words presented to the right ear would be conveyed to the speech processors by means of the contralateral pathways whereas the words presented to the left ear would be conveyed by the ipsilateral pathway. The contralateral pathway would occlude the

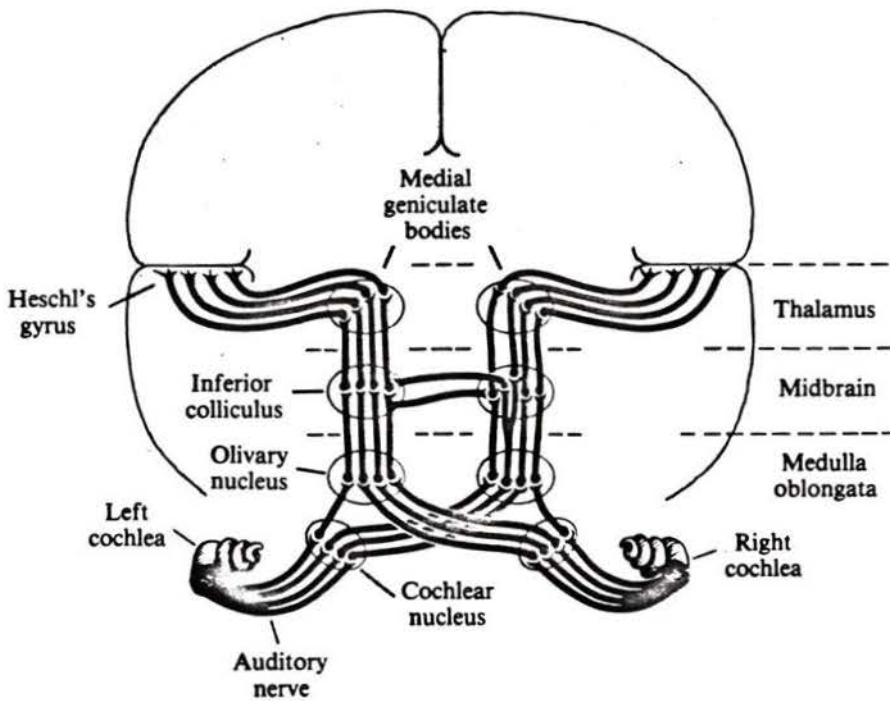


FIGURE I: Schematic Representation of Auditory Sensory Input System (from Gaddes, 1980)

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 see his letter to C. Clark of 6 December, 1983.

ipsilateral pathway and hence a right ear advantage would occur. In a sense, the model has some similarities to Broadbent's initial formulations. First, a central processor is hypothesized except that in this case it is stimulus specific and located in a cerebral hemisphere, in most cases the left. Second, the suppression or management of the stimulus is accomplished by the sensory pathways or channels prior to processing.

Sparks and Geschwind (1968) questioned Kimura's interpretation after examining patients with severed corpus callosum. They found that these patients performed equally well on both ears with monaural presentation of stimuli. However, with dichotic presentation, there was suppression, often complete, of left ear responses. In order to explain the phenomenon, they argued that the input from either ear travels via the contralateral auditory pathways to the respective hemisphere. Therefore, information from the left ear travels via the crossed auditory pathways to the right hemisphere and then via the corpus callosum to the left hemisphere. In a dichotic situation, a split brain patient cannot process successfully information presented to the left ear because the callosal fibres have been severed. The authors suggested that in the dichotic situation, the crossed auditory pathways are the major input pathways. They argue that for normal right handed subjects, the message received by the left ear arrives at the left hemisphere later and in a more degraded form than that from the right ear. The later time of arrival at the speech centre is explained by the circuitous route input must follow. In addition,

because of these extra synapses, the message is degraded. Consistent with this model, it has been shown that degrading the right ear stimuli in terms of intensity, band width or signal to noise ratio does reduce or eliminate the right ear advantage (Cullen, Thompson, Hughes, Berlin and Samson, 1974). Spreen and Boucher (1970) found that by filtering high frequency sounds from words, the right ear advantage could be eliminated. Specifically, the higher frequencies are associated with consonants, while low frequencies are associated with vowels.

Kinsbourne (1974) argued that both explanations are structural, not interactive. His theory is based on hemispheric specialization but the extent of specialization may be increased or decreased by priming from environmental cues. For example, Morais and Bertelson (1973) did a dichotic experiment using loud speakers rather than headphones. They found that if the speakers were at the side of each of the ears, then a right ear advantage was found for competing consonant/vowel syllables. However, if one speaker is placed in front of the subject, then recall of this centre speaker's input is superior to recall of the other speaker (i.e., either right or left). Kinsbourne suggested that each hemisphere serves the contralateral half of space. Activation of one hemisphere thus causes attention to turn to the contralateral space. He suggested that the activation of one hemisphere inhibits activation of the other. Therefore, the right ear advantage is a function of the side of the stimulation, not of structural/physiological differences in the auditory pathways. Although not cited by

Kinsbourne, Goldstein and Lackner (1974) showed that the magnitude of the right ear advantage is reduced or increased if subjects wear prisms that displace the visual environment to the left or right respectively. The findings suggest that there is an interaction between spatial attention and the magnitude of the ear advantage. Kinsbourne (1974) argued that variations in the right ear advantage cannot be explained by a structural or wiring model. Rather, the ear advantage is dependent on the nature and the external activation of a hemisphere.

Of interest to the current study is that all three models suggest that the ear advantage is an attribute of the subject. However, all three models examine the attribute by using group statistics, not a psychometric model. Specifically, subject variance is considered error and right/left differences are considered treatment. The individual dichotic items are summed to estimate a subject's right and left ear scores. Then subject scores are averaged to determine a mean right and left ear score. The scores are then compared using the respective variations about the means as estimates of error. A stronger argument would be to demonstrate empirically that subjects are consistent across similar dichotic items and consistent across sessions. If stability of subject performance could be shown, then ear advantage could be assumed to be an attribute variable.

Measurement of Laterality

In order to examine the stability of ear advantage, a measure of ear advantage must be defined. Kimura originally used

difference scores (i.e., Right - Left) but subsequently other measures of ear advantage or laterality have been suggested. With the exception of one, suggested by Marshall, Caplan and Holmes (1975), all measures including difference scores are related to the actual accuracy rates in very complex ways. The following section will first review the arithmetic derivation of each estimate of laterality and then propose a general method of evaluating each of the ear advantage estimates in terms of scaling properties and the relations of scaling properties to accuracy levels.

Five measures will be considered. The first is differences scores, which are derived by merely subtracting the left ear score from the right. The second corrects for accuracy level by dividing the difference score by the sum of the right and left ear score. The third, often called the percent correct, is derived by dividing the right ear score by the sum of the left ear score and right ear score. The fourth, percent error, is computed by dividing the number of left ear recall errors by the total number of recall errors. The fifth, suggested by Marshall et al. (1975), uses the formula $(R_c - L_c) \div (L_c + R_c)$ if the accuracy score is less than 50% and the formula $(R_c - L_c) \div (L_e - R_e)$ if it is greater than 50%, where c and e stand for the number of correct responses and errors, respectively.

The following discussion is designed to show that the first four of these methods have serious problems in terms of the heteroscedacity of variance for the underlying scale. Although

most dichotic studies sum scores over presentations, the true experimental unit of a dichotic listening study is the presentation and recall of a dichotic item (i.e., one or more pairs of digits, words, etc.). The discussion will be confined to the one item case using three dichotic pairs. However, it generalizes to the presentation of any number of pairs as well as to the sum on unlimited numbers of presentations.

For the three pair case, there are seven possible outcomes for total score, namely, 0, 1, 2, 3, 4, 5, or 6 words correctly recalled. However, there are sixteen possible ways of achieving the score. For example, a total score of three may be achieved in four different ways. Table II contains the possible response outcomes with the associated total score. It is readily apparent that there is a difficulty gradient running from the upper left hand corner to the lower right hand corner in the matrix. Therefore, if the laterality estimates for a given measure are computed for all outcomes of the three pair case and placed in the respective response outcome cell in the matrix, the relation between accuracy and laterality for that measure can be evaluated. The procedure was applied to the five laterality estimates described.

Table III contains the distribution of laterality estimates for difference scores. The outside rows and columns represent the maximal ranges of laterality for specific accuracy rates. For example, if an individual scores one correct response, then the maximal range for the laterality estimate is -1 to +1. In contrast, if an individual recalls three words then the potential range is

TABLE II

Possible Response Outcome and Associated Total Score

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	0	1	2	3
	1	1	2	3	4
	2	2	3	4	5
	3	3	4	5	6
		Total Score			

TABLE III

Distribution of Difference Scores by Response Outcome

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	0	-1	-2	-3
	1	1	0	-1	-2
	2	2	1	0	-1
	3	3	2	1	0
Ear Advantage Measure		(R-L)			

-3 to +3. For the difference score measure, high and low total scores are related to constricted ranges of laterality.

Table IV summarizes the laterality estimates for the $(R-L)/(R+L)$ method. For this estimate, the maximal laterality range for total scores less than or equal to 3 is -1 to +1. However, for total scores greater than 3, the range is constricted. Therefore, high scorers cannot be as lateralized as low scorers.

Table V and VI contain the results for the percent correct and the percent error estimates of laterality. For the percent correct estimates, the maximal laterality for total scores of 1, 2, or 3 ranges from 0 to 1. For total scores greater than three, the range becomes constricted. For the percent error estimate, the constriction has reversed orientation. Specifically, for the total scores 3 to 5, the maximal laterality range is 0 to 1.0 while for the scores 0, 1, and 2 the range is constricted.

Two methods have been suggested to solve the problem of restricted score ranges. The first method (suggested by Bryden and Sprott cited in Segalowitz and Orr, 1981) is to apply a mathematical transformation to laterality scores in order to rescale the scores so that homogeneity of variance and normality are obtained. Given the myriad of possible experimental outcomes and transformations, the approach is in all probability situation specific. The second alternative put forward by Marshall et al. (1975) is to derive a scale of laterality where the range of the laterality estimate is mathematically independent of accuracy. The results of their formulae are given in Table VII. For total

TABLE IV

Distribution of $(R-L)/(R+L)$ by Response Outcome

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	a	-1	-1	-1
	1	1	0	-.6	-.75
	2	1	.6	0	-.6
	3	1	.75	.6	0
Ear Advantage Measure		$(R-L)/(R+L)$			

a - the laterality estimate cannot be derived.

TABLE V
 Distribution of Percent Correct Estimates by Response
 Outcomes

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	a	0.0	0.0	0.0
	1	1.0	.5	.3	.25
	2	1.0	.6	.5	.4
	3	1.0	.75	.6	.5
Ear Advantage Measure		$R_c / (L_c + R_c)$			

a - the laterality estimate cannot be derived

TABLE VI
 Distribution of Percent Error Estimates by Response
 Outcomes

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	.5	.4	.25	0.0
	1	.6	.5	.3	0.0
	2	.75	.6	.5	0.0
	3	1.0	1.0	1.0	a
Ear Advantage Measure		$Le / (Re + Le)$			

a - the laterality estimate cannot be derived

accuracy scores of either six or zero, laterality coefficients cannot be computed. However, the range of their estimate is independent of total accuracy for the score from 1 to 5 with a laterality range from -1 to +1.0. What is apparent from the outcome matrix is that there are only two occasions where the laterality score is not -1, 0, or 1. These two scores occur when the individual recalls two of the three words presented to one ear and one word from the other ear. In these two cases, the assigned laterality scores will be ± 0.3 .

From the examples, it can be argued that laterality scores can be assigned based on the outcome or method. The actual formulae presented become unnecessary. Rather, scores are assigned to ensure the mathematical independence of the laterality estimate and to test the laterality theory of interest. For example, one could argue that a total score of one correct response is a more lateralized response than a score of two for one ear and one for the other. The Marshall et al. formula supports such a position by assigning to a total score of one a laterality coefficient of either ± 1 , and to a score of (2,1) or (1,2) a laterality coefficient of either ± 0.3 .

In contrast to Marshall's position, Colbourn argues that laterality is an either/or proposition. That is, on an item, an individual exhibits either a right, left or no ear advantage. Using his method of assigning scores, the resulting laterality estimates are given in Table VIII. Except for the four cases of (1,2) or (2,1) and (0,0) or (3,3) Colbourn's method is identical to Marshall's. For the latter two cases, laterality estimates

TABLE VII
 Distribution of Marshall et al Laterality Estimate by
 Response Outcome

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	a	-1.0	-1.0	-1.0
	1	1.0	0.0	-.3	-1.0
	2	1.0	.3	0.0	-1.0
	3	1.0	1.0	1.0	a

a - the laterality estimate cannot be derived

cannot be derived in Marshall's method. However, for the first two cases, dichotic listening experiments usually employ several dichotic items. If the items have the same difficulty level, then both methods are acceptable. However, if the item difficulties vary, then in Marshall's method variability in laterality may be a function of variations in item difficulty or in subjects. For Colbourn's model, the variations would reflect shifts solely in ear preference. For example, if on a difficult item an individual scores (2,0) and on the next item, an easier one, he/she scored (2,1) then by Marshall's method, there would be a difference in lateralization score between the two items of 0.6. The question arises whether the change in laterality is a function of the item structure or the individual's lateralization. Given that laterality or ear advantage is supposed to be an attribute of the subject, it seems reasonable not to adjust the score unless there is a shift in the actual ear advantage. For the above reasons, Colbourn's scoring method was chosen for the current study.

Reliability Theory

Two approaches have been taken to the logical formulation of reliability theory. The more common approach considers reliability to be a relative concept. Stanley (1971) stated that:

"There is no single, universal and absolute reliability coefficient for a test," (p.363).

Rather, he argued that the true value of the coefficient varies dependent upon the type of reliability of interest, the population of interest and the experimental setting. The three types of

TABLE VIII

Distribution of Colbourn's Laterality Estimate by Response Outcome

Number Correct		Left Ear			
		0	1	2	3
Right Ear	0	0	-1	-1	-1
	1	1	0	-1	-1
	2	1	1	0	-1
	3	1	1	1	0

reliability are internal consistency, test/retest and parallel forms. Internal consistency will vary dependent upon the number of items whereas test/retest reliability will vary depending upon the test/retest interval. Similarly, parallel form reliability will vary depending upon the sampling of the content domain. The variability among individuals in the population of interest will also affect the magnitude of the reliability coefficient. If the experimental setting is not conducive to error-free measurement or varies from session to session, then the reliability coefficient will be affected. In contrast to Stanley's approach to reliability, Guttman (1953) argued that the reliability is a property of the test. Moreover, Guttman (1945) suggested that the estimation of test reliability should be a maximal lower bound. Guttman's argument for test reliability being an absolute property is that decreases in reliability are caused by different samples or time. However, the content of the test has not changed; rather the samples are different in the internal consistency case or the subjects have changed with time as in the test/retest case (Guttman, 1953). Guttman (1953) argued that for any test, there are an infinite number of test/retest or parallel form coefficients. Differences in the coefficients do not represent changes in the test but rather changes in the experimental setting. Guttman (1945) also suggested six methods for estimating the reliability of a test. Each of the estimates is a lower bound for the true reliability of a test. He suggested that the maximal lower bound be the absolute test reliability.

In order to circumvent the problem of variations in the reliability coefficient, Cronbach, Gleser, Nanda and Rajartman (1972) argued that the standard error of measurement should be the statistic of interest. Cronbach argued that although the reliability coefficient of a test may vary dependent upon the heterogeneity of the sample, the standard error of measurement will not. The formula for the standard error of measurement is

$$\text{S.E.M.} = \text{S.D.} (1 - R_{xx})^{\frac{1}{2}} \quad (\text{eq. 2})$$

where

S.E.M. = standard error of measurement
 S.D. = standard deviation of the sample on the test
 R_{xx} = estimated reliability coefficient for the test on the sample.

Cronbach argued that if the sample has little between subject variability on the test, then both the standard deviation and the reliability coefficient will be low. On the other hand, if the sample has considerable between subject variability, then both the standard deviation and the reliability coefficient will be large. In the first case, the magnitude of the standard error of measurement is constrained by the small standard deviation whereas in the second case, the high reliability coefficient will reduce the standard error of measurement. Cronbach shows mathematically that the standard error of measurement for a test is theoretically constant regardless of the sample. However, the magnitude of the reliability coefficient is sample dependent. Cronbach also argued that there are two different questions of interest in terms of reliability coefficients. Specifically, he suggested that when tests are used in a decision-making process, the appropriate

type of reliability coefficient should be applied. For example, if an individual is to be classified as to his membership in a group of people, the test reliability must be based on an appropriate population in a similar setting. However, if the test is used within a theory generating model, then the question of interest is the allocation of variance to the respective sources.

Estimation of Reliability Coefficients

As mentioned earlier, the standard statistical estimates of reliability coefficients are the analysis of variance for internal consistency and the Pearson product moment correlation for test/retest or parallel form coefficients. However, Guttman (1945) suggested six methods for estimating the reliability of tests. Each of the estimates is a lower bound estimate of the true test reliability. The method for computing each estimate is given below. Guttman (1945) argued that the values of the coefficients would vary dependent upon the structure of the inter-item covariance matrix. He suggested that the largest obtained value is the maximal lower bound for the test reliability. Guttman's equations for the six lower bounds are as follows:

$$1) \quad L_1 = 1 - \frac{\sum Si^2}{Sp^2} \quad (\text{eq. 3})$$

where Si^2 = variance of persons for i^{th} item of the test
 Sp^2 = variance over persons on the sum of the items;

$$2) \quad L_2 = L_1 + \frac{\sqrt{\frac{N}{N-1} C}}{Sp^2} \quad (\text{eq. 4})$$

where N = number of items
 C = twice the sum of the squares of the item
 covariances;

$$3) \quad L_3 = \frac{N}{N-1} L_1 \quad (\text{eq. 5})$$

$$4) \quad L_4 = 2 \left(1 - \left(\frac{S_a^2 + S_b^2}{S_p^2} \right) \right) \quad (\text{eq. 6})$$

where S_a^2 , S_b^2 = variances of two halves of the test;

$$5) \quad L_5 = L_1 + \frac{2 \sqrt{\bar{c}}}{S_p^2} \quad (\text{eq. 7})$$

where \bar{c} = largest single item sum of the sum of
 squares for each item's covariances;

$$6) \quad L_6 = 1 - \frac{\sum e_i^2}{S_i^2} \quad (\text{eq. 8})$$

where e_i^2 = variance of errors of estimate of item i
 from its multiple regression with the
 remaining items.

According to Guttman, the following relation holds: $L_1 < L_3 \leq L_2$.
 The third estimate is Cronbach's Alpha (Cronbach, 1951) and
 represents the average inter-item correlation. The fourth estimate,
 L_4 , is a generalized version of the split half formula. The
 relationship between L_2 and L_5 is dependent on the structure of
 the item covariance matrix. For example, if the respective item
 covariances are equal, then L_2 will be greater than L_5 . If the

covariances are not equal and one item is highly correlated with the remaining items, then L_5 will be greater than L_2 . Similarly, if the items have low inter-item correlations, but high multiple correlations, then L_6 will be greater than L_2 . However, if the inter-item correlations are relatively high, then L_2 will be greater than L_6 .

With respect to the current study, both Guttman's maximal lower bound and the common reliability estimate were calculated for three types of reliability, internal consistency, test/retest and parallel forms. With respect to the theoretical positions of Guttman (1945, 1953), Stanley (1971) and Cronbach (1972), all the reliability coefficients as well as the standard errors of measurement are reported.

Experimental Maximization of Reliability Coefficients

The obtained value of a reliability coefficient may be increased or decreased by the statistical properties of the instrument, the number of items, the sampling technique and the experimental setting. Statistically, reliability can be maximized when there is full scale usage and the mean of the distribution is close to the scale mid-point. Previous studies indicate that for dichotic word pairs, three pair items yield total accuracy rates around fifty percent at standard rates of presentation and normal loudness levels without distortion (Bryden, 1963; Satz, 1968). Three pairs also would allow the ear advantage to obtain maximal variance because floor or ceiling effects can be avoided. In order to ensure full scale usage, heterogeneous rather than

homogeneous samples should be employed. Specifically, a heterogeneous sample of subjects should yield large inter-individual differences. A third method of increasing the inter-individual differences is to employ more items. Therefore, in order to ensure an optimal reliability coefficient, the sample should be heterogeneous and the scores should be distributed fully on the scale. If the conditions are not met, then the estimate of reliability is attenuated.

In order to maximize the reliability coefficient, certain precautions with respect to experimental setting must be taken. With respect to the dichotic listening task, it is essential that the instructions are understood and that the subject has practice with the item format. The practice items are required because to most subjects the task itself is novel, thus causing initial variations in performance. Moreover, as the task demands are high, and constant, the actual test length should not be excessive or there may be fatigue and loss of motivation.

In experimental studies using dichotic listening, the headphones or channels are reversed or the right/left ear presentations counterbalanced in order to control bias in volume between the two channels. Although such precautions are appropriate if differences from a theoretical zero point are of interest, the procedure is not suitable for reliability studies. Specifically, the counterbalancing or reversal of channels introduces noise in the psychometric sense which is considered error when the noise is the result of a bias in the tape or equipment.

Previous Studies of Reliability in Dichotic Listening

In 1974, Pizzamiglio, DePascalis and Vignati commented that with respect to the dichotic listening task they: "could not find any systematic study (of reliability) in the past twelve years," (p.203). The review for the current study found four published papers including the study by Pizzamiglio et al. The methods and results of these studies are presented in Table IX. The current review was confined to studies employing either words or digits as the dichotic stimuli. A first criticism of all available studies is that their measure of ear advantage is confounded with overall accuracy. The problems inherent in each of the methods employed have been discussed previously. The second criticism is that all studies used selection criteria for subjects in terms of handedness. Except for Teng's (1981) study, the subjects of all studies were university students. Hence, rather than using heterogeneous samples, the studies used homogeneous samples, thus possibly deflating the obtained reliability coefficients. Finally, each of the studies examined only one aspect of reliability, either test/retest or internal consistency. Three of the studies reversed headphones during the task while in the fourth this experimental procedure was not specified. Given these methodological problems, it is difficult to evaluate the actual findings.

For example, Teng (1981) argues from her data that "the low retest reliabilities clearly indicate that, other than hemispheric asymmetry, input asymmetry and attentional, additional factors contribute to a relatively large error variance in the ear

TABLE IX

Experimental Studies on the Reliability of Dichotic Listening
Study

Aspect	Pizzamiglio, De Pascallis, Vignati (1974)	Hines, Satz (1974)	Hines, Fennel, Bowers, Satz (1980)	Teng (1981)
Stimulus	3 pairs of digits	6 pairs of digits	3 pairs of words	2 pairs of words
Accuracy	not given	48.8%	not given	72%
Subjects	right handed male university students	right and left handed university students	1) 16 right handed university students 2) 20 left handed university students	right handed males and females
Measure of Ear Advantage	percent error	difference score	$\frac{R-L}{R+L}$	$\frac{R-L}{R+L}$
Type of Reliability	test/retest	internal consistency	test/retest 4 times a week apart	test/retest 1-6 month interval
Result	70% did not change ear advantage	$r=0.86$ (split half)	\bar{r} left=0.59 ¹ \bar{r} right=0.74	$r=0.60$
Practice Items	yes	yes	yes	yes
Channel Alternation	yes	yes	yes	yes

¹ \bar{r} is the average test/retest correlation

difference score" (p. 239). The question must be raised whether these additional factors may be solely the result of poor methodological and experimental procedures.

Interaction of the Experimental and Individual Differences Methods

In all three types of reliability, the statistic of primary concern is the correlation coefficient among subjects over items, time or forms. Essentially, this statistic evaluates the stability of individuals in terms of position across a specific distribution of scores. For internal consistency, the relative position of subjects is evaluated across a number of items. For test/retest reliability, the relative position of subjects in the two distributions of scores is assessed whereas for parallel forms, the relative position across two tests is examined. It is apparent that high reliability can be obtained even if the distributions shift along the underlying scale as long as the relative position of the subjects does not change.

Although the point was made earlier that the two areas of interest for the experimental and individual differences model are paradoxically opposed in a statistical sense, the question arises as to what effect the reliability of tests has on results derived from an experimental study? The effects of test reliability on the results of an experimental study are dependent upon the type of experimental design employed. For example, in the case where the design consists of evaluating treatment effects on two randomly selected and assigned groups, the higher the reliability of the dependent measure, the more

confident a researcher can be that any observed difference is real. Specifically, if the two groups are compared post-treatment by means of an independent t-test, subject variability is partitioned into the error term. Moreover, as the test is reliable, the subjects' scores consist primarily of true score components, not errors of measurement. Therefore, significant mean differences imply that on the average, the true scores have been changed by the treatment. However, if the test is not reliable, then the significant mean differences may only reflect shifts in the errors of measurement. In general, for between group designs, the more reliable the dependent measure, the more likely that the treatment effects are real.

In contrast, for within group designs, the converse is true because subject variability is partitioned out of the error term for testing the within group effects. For illustrative purposes, the paired or correlated t-test will be considered because it is a special case of the typical repeated measures design. A formula for the paired t-test is:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{(\bar{S}_1^2 + \bar{S}_2^2 - 2r_{12} \bar{S}_1 \bar{S}_2)^{1/2}} \quad (\text{eq. 9})$$

where \bar{X} = means of the respective observations
 \bar{S} = standard error of means for the respective means
 r_{12} = the correlation of subject performance from time 1 to time 2.

Assume that $\bar{S}_1 = \bar{S}_2$; then the formula becomes:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{(2\bar{S}^2 - 2r_{12}\bar{S}^2)^{1/2}}$$

Essentially, r_{12} is the test/retest coefficient for the interval

between time one and two. As r_{12} approaches one, the denominator of the equation approaches zero. Therefore, very small difference between X_1 and X_2 will be significant. Basically, the reliable aspect of the test scores has been partitioned from the error term. Cronbach (1970) argued that the testing of difference scores, as shown here, is the testing of the unreliable aspects of the subject scores. It should be noted that the term $2r_{1.2} \bar{S}^2$ is, at the conceptual level, the error term that would be used to test a between groups effect in a true repeated measures design. Therefore, in a between groups repeated measures design, the partitioning of error variances into the two error estimates for testing between and within group effects is dependent upon the reliability of the dependent measure.

Within the context of the individual differences model, the problem of mean differences over time or forms is delineated by the terms parallel or strictly parallel. Specifically, if the relative distributions do not change and the means are not different, then the test(s) are strictly parallel. If the relative distributions do not change but the means are different then the tests are parallel.

CHAPTER THREE

METHODS

Overview and Design

The purpose of the current study was to examine the reliability of two measures, ear advantage and attentional capacity, by means of the dichotic listening task. The three types of reliability that were considered are internal consistency, test/retest and parallel form. In order to examine these types of reliability, two different dichotic tapes were administered twice, in sessions approximately a week apart, to a relatively large and heterogeneous sample (N=60). Each tape consisted of eighteen dichotic items. An item consisted of the presentation and recall of three word pairs. Attentional capacity was measured by the total number of words recalled for each item. Ear advantage was measured by scoring a left ear preference as one, no ear advantage as two and right ear advantage as three.

The experimental procedure for all subjects was: first, a practice session of four items, followed by tape 1, and then tape 2. The procedure was identical for the first and second sessions. In addition, all stimulus materials were presented to all subjects in the same manner in terms of tape recorder, tape channel and headphone arrangement. All dichotic materials were recorded on the same tape. The design and the resulting reliability coefficients are given in Table X. The design employed resulted in ten reliability estimates for the two measures.

TABLE X
Generation of Reliability Coefficients

<u>Session</u>	<u>Tape</u>	I		II	
		1	2	1	2
I	1	I.C.	E.F.	T/R	EF'
	2		I.C.	EF'	T/R
II	1			I.C.'	EF''
	2				I.C.'

Legend:

- I.C. = internal consistency
- I.C.' = internal consistency after exposure to testing situation
- E.F. = equivalent forms
- E.F.' = equivalent forms with one week between testing
- E.F.'' = equivalent forms with previous experience
- T/R = test/retest

The design resulted in two internal consistency (I.C.) estimates for each tape on each measure. The coefficients reflect the inter-item consistency within the actual presentation of a tape. High coefficients of internal consistency suggest that items are homogeneous but not necessarily that the subjects' scores are consistent over time or tapes.

In order to establish that ear advantage or attentional capacity are lasting or general characteristics of the subjects, the test/retest coefficients (T/R) were examined. The design resulted in a test/retest estimate for each tape on each measure. Given that the test/retest estimates are theoretically bound by the internal consistency estimates, high test/retest coefficients would indicate that the estimates of ear advantage and attentional capacity are stable over time and thus probably stable characteristics of the subjects for a specific tape.

The final consideration in the reliability of the dichotic listening technique was the generalization over different tapes or forms. The property of generalization was determined by examining the four equivalent form (E.F.) coefficients. The first coefficient (E.F.) estimates the shared variance between tape I and II for the first session. If the coefficient is high, it can be concluded that in the first session, the subjects were consistent in terms of ear advantage or attentional capacity regardless of dichotic materials. The coefficient, EF'' , also examines the same question but after the subject has had previous exposure to the experimental setting. However, as with the internal consistency coefficients,

the result does not indicate whether the property of generalization is stable over time or session dependent. To examine the relationship between the two tapes over time, the two between session equivalent form coefficients (E.F.') were considered. Specifically, if the two coefficients are high, then it can be concluded that the dichotic listening task is stable over forms and time.

If the obtained coefficients are high, then the question arises as to whether the two measures should be considered parallel or strictly parallel. If the means for each measure across the four presentations were not significantly different, then the measures will be considered strictly parallel. If the means were significantly different, the measures will be considered parallel.

Besides estimating the reliability of the dichotic listening task, the item statistics were also used to examine the stimulus determinants of variations in performance on either of the two dependent variables. By means of item analysis, the item correlations with the total score were used to identify items that are or are not homogeneous. Moreover, as each item is given twice, items were identified that were consistent over time in terms of subject response.

Empirical Criteria for Reliability Coefficients

Unlike the experimental model, where a conceptual hypothesis is translated into a statistical hypothesis and the null hypothesis is then tested, the psychometric approach is primarily based on the

magnitude of the coefficient obtained. Ideally, reliability coefficients should be 1.0. Unfortunately, errors of measurement occur which reduce the values actually obtained. The question of what are acceptable values for reliability coefficients is primarily determined by what is considered an acceptable value in the subsequent use of the test. As reviewed earlier, the actual obtained value of the coefficient is dependent upon the number of items, the number of subjects and the heterogeneity of the population sampled. Therefore, establishing acceptable values is arbitrary and situation dependent. In the current study, values greater than 0.8 were considered acceptable for internal consistency coefficients, greater than 0.7 for test/retest coefficients and equivalent form coefficients. Given the actual number of items presented, the specified values would support the conclusion that the dichotic listening test is reliable for the three types of reliability.

Subject Selection

The only two criteria for acceptance into the study were age and hearing acuity. To be included in the study, subjects had to be older than nineteen and younger than sixty years. Sampling was done on a voluntary basis. All volunteers had their hearing tested by means of a Maico Model MA-17 Audiometer. The following frequencies were tested: 500, 1000, 2000, and 4000 Hz. The testing procedure consisted of ascending unilateral trials beginning at -5 dB and increasing by 5 dB until the subject reported hearing the tone. Any subject who had a loss of 35 dB or greater at any

frequency for either ear was excluded from the study. In addition, any subject exhibiting a 15 dB difference between the right ear and the left ear for any frequency was also excluded. Of the 66 volunteers, a total of four were excluded because of hearing deficiencies.

Subject Characteristics:

Of the 62 subjects who met the audiometric criteria and completed the first experimental session, two were unavailable for retest. Therefore, the final sample size for the study was 60. The sample consisted of 36 females and 24 males. The mean age was 32.8 years with a standard deviation of 10.4 years and a range from 20 to 60 years. The mean educational level was 14.6 years with a standard deviation of 2.6 and a range from grade eight to four years of graduate or medical school. Although the figure suggests a well-educated sample, it may be misleading in that trade or technical training subsequent to completion of grade 12 was included as further education. However, in cases where a degree was completed in longer than the expected time, only actual level of achievement was recorded. Handedness was determined first by self-report; the subjects were then asked whether they had ever changed handedness. In cases where the subject reported change or initially replied mixed or both, a separate classification was made of mixed. Fifty of the subjects were right handed, 5 left handed and 5 were mixed. The figures are reasonably consistent with expectancy from the general population (Coren and Porac, 1980).

Current occupational status is summarized in Table XI. At the

TABLE XI
Distribution of Occupational Status

	f	%
Professional	2	3.3
Managerial	7	11.7
Skilled/Technical	13	21.7
Clerical/Semi-skilled	11	18.3
Unskilled	5	8.3
Housewife	10	16.7
Student	12	20.0

time of testing, all subjects were employed. The overall distribution suggests a broad sampling with students being slightly over-represented.

Materials and Procedure

Both tapes consisted of eighteen three word pairs or items. The first tape (Tape 1) was provided by Dr. P. Satz and originally consisted of sixteen test items and two practice items. In the present study, the practice items were included in the actual test. The word pairs are composed of common, concrete nouns. The presentation time for each three word pair from onset to completion was 1.5 sec. The recall time was 10 sec. The second tape (Tape 2) was developed by Hayden and Spellacy (1969) and consisted of twenty-two items. Four of the items were employed as practice items. Similar to tape 1, the tape consists of common nouns but the nouns were matched in terms of initial phoneme (e.g., port-pack). The presentation time for an item was 2 seconds for a three word pair with a 12 second recall period. The two original tapes were edited as described and then copied onto a single tape (Audiotape, Type 1867). The actual word lists are given in Appendix A. Subjects were given free recall instructions and four practice items. The instructions were as follows:

"On this tape, a different word is recorded on each channel. You will hear one word in one ear and a different word in your other ear. For example, the word to your right ear might be dog and the word to the left ear might be cat. You will hear both words at exactly the same time. After hearing three pairs of words, I would like you to tell me as many of the six words as you can remember.

We will begin with four practice items and then do two sets of eighteen items each. If you have any problems with the practice items, you can stop and go over the instructions and practice items again."

If any difficulty was experienced, the instructions and the practice items were repeated. Tape I and Tape II were then presented. The presentation of Tape I and Tape II was separated by a break. The minimum break time was two minutes but the subject could wait longer if desired.

The dichotic materials were presented by means of a Sony Bidirectional Recorder Model TC-580 and Sony DR-45 headphones. The headphone channels were balanced and checked after every six sessions. The channels were balanced by averaging the peak volume for the respective channels on the first two 3 pair items using a Scott 200 sound level - meter positioned against the earphone. If the average peak volumes were within 4 dB of each other, the channels were considered balanced. The actual estimation of peak volume was done visually. The average peak volume was approximately 80 dB. The headphone arrangement was identical for all subjects on both sessions.

Wherever possible, there was a one week period between test and retest. For 70% of the sample, the period was exactly one week. For 20%, the period was less than one week and for the remaining 10% it was greater than one week.

Scoring

For the measurement of attentional capacity, the number of correct responses for the right and left ear on each 3 pair item

was summed. Therefore, each tape yielded eighteen scores of this variable. The range of the item scores was zero to six. Therefore, the total score range for a tape was between 0 and 108 words. For the scoring of ear advantage or preference, the number of correct responses for the right ear was compared to the number of correct responses for the left ear on each item. If the left ear score was greater than the right ear score, then a score of one was assigned. If the two ear scores were equal, then a score of two was assigned. If the right ear score was greater than the left ear score, then a score of three was assigned. The range of the scores was one to three where one implies a left ear advantage; two, no advantage; and three, a right ear advantage. Therefore, for each presentation of a tape, the possible range of scores was 18 to 54 where a score of 36 represented no overall ear advantage.

Examination of the Distribution Characteristics

The purpose of the following analyses was to determine if the distribution of scores for each presentation on the two variables was appropriate for the subsequent reliability analysis. Two aspects of the distributions were examined: 1) conforming to normality; and 2) equality of variance. For each variable, four distributions were obtained; i.e., Session I Tape 1, Session I Tape II, Session II Tape 1, Session II Tape 2. Each distribution was tested against the normal distribution by means of the Kolmogorov-Smirnov Test of normality (Kraft and Van Eeden, 1968). The maximal, adjacent or diagonal distance was compared to critical value. The equality of variance was tested by means of Hartley's

Fmax (Winer, 1971). If no significant differences ($p < 0.05$) are found, then the distributions meet the assumptions of a conventional reliability analysis.

Reliability Analysis

Reliability analyses were done using two computer programmes, LERTAP (Nelson, 1974) and SPSS Reliability (Hull and Nie, 1979). The SPSS programme provides Guttman's maximal lower bound estimates. The LERTAP programme was used for item analysis, and estimates of the standard error of measurement. Both variables were assumed to be continuous. The assumption is tenable if the distributions do not differ significantly from the normal distribution and the variances are not significantly different.

For each variable, the four internal consistency coefficients were computed by Hoyt's ANOVA and Guttman's maximal lower bound. Similarly, test/retest and equivalent form coefficients were estimated by Pearson product moment correlations and Guttman's bound. In addition overall reliability coefficients were calculated as follows: 1) Hoyt's ANOVA over all 72 items; 2) Cronbach's Alpha for the composite consisting of the four presentations; and 3) Guttman's bound for the four presentations.

Parallel versus Strictly Parallel Measures

In order to determine if the presentation means were different for the respective measures, a two factor within group analysis of variance was done using the SSPS Reliability programme. The two within factors were subjects by presentation. If a significant difference was found across presentations, then the

following comparisons were made: 1) each tape was compared with itself across sessions; 2) tape 1 was compared with tape 2 within each session. The first comparisons determine if there is a change in performance after previous experience with the materials. The second comparisons determine if the two tapes differ in overall difficulty.

For the overall analysis of the scores of each measure across the four presentations, the critical alpha level was 0.05. If the null hypothesis was not rejected, then the measures were considered strictly parallel. If the null hypothesis was rejected, then the measures were considered parallel. Because the four comparisons outlined were not orthogonal and hence the probability of a type I error was increased, the alpha level for rejection of the null hypothesis on the comparisons was decreased to 0.01.

Consistency of Ear Advantage

As mentioned earlier, the classification of ear advantage has been treated in the past as a two or three group classification. Moreover, the cutting points for classification have been made based on a judgmental rather than a statistical procedure. If it is assumed that the outlined experimental procedures removed any artificial response bias in terms of ear advantage, then a score of 36.0 represents no ear advantage for each of the four presentations. If the score of 36.0 is bounded by a confidence interval of plus/minus two standard errors of measurement for each presentation, then it can be concluded with 95 percent confidence that the scores falling outside the bound represent a true ear

preference or advantage. As the sample size of this study was 60, the number of individuals falling outside the range should exceed the chance expectancy of five percent or three individuals. If the test is unreliable (i.e., $R_{xx} = 0$) then the condition will not hold because the standard error of measurement will equal the standard deviation of the test. However, as the reliability of the test increases, the magnitude of the standard error of measurement decreases relative to the standard deviation. The outlined procedure was applied to each presentation as well as the total test score. In addition, individuals who exhibited a consistent ear advantage across the four presentations were identified.

Relation Between Ear Advantage and Attentional Capacity

Although the relation between ear advantage and total score is outside the actual questions of interest of the study, the obtained data provided an opportunity to examine the relation. Moreover, since the ear advantage variable in the current study is independent of the total accuracy score, if a relation were found, then it would suggest that ear advantage is a function of subject processing strategies. Two models of ear advantage were examined. The first is the directional model where the actual ear advantage scores were correlated with the total scores for each presentation. The second is the non-directional model. Here, the ear advantage scores were reflected so that each subject had a score representing only the magnitude of ear advantage, not of direction. The data were transformed as follows: thirty-six was subtracted from the

ear advantage score and the absolute value was taken. The transformed or reflected ear scores were then correlated with the total score for each presentation.

Item Analysis

On each variable, the respective item scores were correlated with the total score for each presentation. Therefore, items could be identified that were consistent or inconsistent across the two sessions. An arbitrary correlation value of 0.3 was chosen as a cut-off between good (i.e., correlated) and poor (i.e., uncorrelated) items. If, on both presentations, an item's correlations with the total score was greater than or equal to 0.3, the item was considered both good and consistent. Conversely, if the item correlations were less than 0.3 on both presentations, the item was defined as poor. Finally, items were identified that exhibited variability between the two presentations.

CHAPTER FOUR

RESULTS

Distributional Characteristics of the Data

The means, standard deviations and results of the distributional tests for the four measures of ear advantage are given in Table XII. The results of the Kolmogorov-Smirnov (K.S. in table) test of normality on the four estimates of ear advantage indicated that none of the distributions was significantly different from the normal distribution. The critical value for rejection of the null hypothesis with a sample size of 60 is 0.114 at $p < .05$. The obtained maximal differences for the four distributions were 0.075, 0.104, 0.097 and 0.082 respectively. The obtained value for Hartley's F-max was 1.6 with four and sixty degrees of freedom. The value is below the critical value for rejection of 1.96 at $p < .05$. Therefore, it can be concluded that the variances for the ear advantage variable were not significantly different either between the two tapes or across the two sessions. Therefore, the planned reliability analysis was appropriate for the data.

The means, standard deviations and the Kolmogorov-Smirnov maximal differences for the four measures of attentional capacity are given in Table XIII. On the Kolmogorov-Smirnov tests for normality, the obtained maximal differences were not greater than the critical value of 0.114 at $p < .05$. The four obtained maximal differences were 0.083, 0.069, 0.088 and 0.096 respectively. Therefore, it was concluded that the four distributions were not

TABLE XII

Means, Standard Deviations and Distributional
Characteristics of the Ear Advantage

Tape	Session I		Session II	
	1	2	1	2
Mean	37.2	36.3	37.3	37.4
S.D.	6.2	7.0	7.5	7.9
K.S. values	0.075	0.104	0.097	0.082
Critical K.S. value	0.114	0.114	0.114	0.114
F-Max	1.6	p<0.05		

TABLE XIII

Means, Standard Deviations and Distributional
Characteristics of the Attentional Capacity Variable

Tape	Session I		Session II	
	1	2	1	2
Mean	59.2	52.0	64.8	57.1
S.D.	9.4	8.1	9.7	9.1
K.S. values	0.083	0.069	0.088	0.096
K.S. critical values	0.114	0.114	0.114	0.114
F-max	1.42	p<0.05		

significantly different from the normal distribution. The obtained value of Hartley's F-max was 1.42 with 4 and 60 degrees of freedom. As the critical value for the test is 1.96 at $p < 0.05$, it was concluded that the variances were not significantly different either between tapes or across sessions. Therefore, the data are appropriate for the reliability analysis outlined above.

Reliability Analysis of Ear Advantage

The results of the reliability analysis of the ear advantage variable are given in Table XIV. The four estimates of internal consistency using Hoyt's ANOVA ranged from 0.74 to 0.86. The value of 0.74 was found on Tape 1 in the first session. The remaining estimates were all above the criterion value of 0.80. In contrast, the Guttman estimates were higher than those derived from Hoyt's method and were all higher than 0.80 (range 0.82 - 0.89). Given the small number of items, the results suggest that subject performance within a session and on a specific tape was consistent.

The test/retest coefficients were also above the criterion value of 0.7 suggested in the hypothesis section. The Pearson product moment correlations were 0.79 and 0.82 and Guttman's maximal lower bounds were 0.88 and 0.90 for Tapes 1 and 2 respectively. The results indicated that ear advantage is stable over time, at least if no intervention occurs in the interim.

The four parallel or equivalent form estimates were also above the stipulated criterion of acceptance of 0.70. The Pearson product moment correlations ranged from 0.70 to 0.83 and Guttman's

TABLE XIV

Reliability Coefficients for Ear Advantage

I	Internal Consistency		Hoyt's ANOVA (Cronbach's Alpha)	Guttman
	Session I	Tape 1	0.74	0.82
		Tape 2	0.84	0.88
	Session II	Tape 1	0.82	0.88
		Tape 2	0.86	0.89
II	Test/Retest		Pearson r	
		Tape 1	0.79	0.88
		Tape 2	0.82	0.90
III	Equivalent Form within session			
	I:	Tape 1 with 2	0.76	0.86
	II:	Tape 1 with 2	0.83	0.90
	Between Sessions I and II			
		Tape 1 with 2	0.70	0.81
		Tape 2 with 1	0.70	0.82

maximal lower bounds ranged from 0.81 to 0.90. The findings suggest that although there are differences between the two tapes in terms of stimulus material, these differences are not reflected in changes of ear advantage.

Estimates of a composite reliability, that is reliability over items (Hoyt's ANOVA) or tests (Cronbach and Guttman), are presented in Table XV. The resulting values were 0.95 using Hoyt's procedure, 0.93 using Cronbach's Alpha for the Composite Score and 0.95 using Guttman's maximal lower bound. The findings suggest that ear advantage, using the measure outlined earlier, can be measured reliably. Moreover, this advantage is stable over time and across the two tapes employed in the current study.

Strictly Parallel versus Parallel Reliability for Ear Advantage

The results of the outlined two within factor analyses of variance are given in Table XVI. As the F-value for the test of mean differences across the four presentations was not significant, it was concluded that the ear advantage variable had the property of strictly parallel reliability.

Classification of Ear Advantage

The Kolmogorov-Smirnov tests of normality and the obtained mean values suggested that ear advantage may be distributed normally with a mean close to the mid-point of the scale (i.e., 36). However, as previous uses of the dichotic test have been aimed at classifying individuals and inferring cerebral asymmetries, the question of how many individuals exhibit an ear advantage was specifically investigated. To calculate the values, the mid-point

TABLE XV

Overall Reliability for Ear Advantage

Hoyt's ANOVA over 72 items	0.95
Cronbach's Alpha for the presentations	0.93
Guttman's Maximal Lower Bound	0.95

TABLE XVI

Analysis of Variance for Ear Advantage Across
the Four Presentations

Source	df	MS	F	p
Between Subjects	59	170.4		
Between Presentations	3	13.2	1.06	$p > 0.05$
Residual	177	12.4		

of each scale was bounded by ± 2 standard errors of measurement; the number of individuals falling outside the range were counted. Therefore, for each individual falling outside the range, the confidence level for the subject exhibiting a true ear advantage is 95%. The results of the classification are presented in Table XVII. For Session I, Tapes 1 and 2, 68.3% of the subjects exhibited no ear advantage. On the second session, 56.6% and 51.6% of the subjects exhibited no ear advantage on Tapes 1 and 2 respectively. When all tapes were combined to produce a scale with 72 items and a resulting internal consistency coefficient of 0.95, the percentage of subjects exhibiting no ear advantage dropped to 35%. In contrast to the above approach, when the number of subjects exhibiting a consistent pattern across all four tapes was considered, 6.6% exhibited a consistent left ear pattern, 10% a consistent right ear pattern, 30% no advantage and 53.3% did not exhibit a consistent pattern.

It should be noted that the subjects did not exhibit a strong overall right ear advantage in terms of raw scores. The means and standard deviations for the right and left ear scores are given in Appendix B. The reason for the lack of the expected strong right ear advantage is probably the heterogeneous sample in the current study. Specifically, the sample was not selected based on the a priori probability of exhibiting a right ear advantage. Rather, they were selected to maximize the range of obtained scores on the ear advantage variable; thereby increasing the reliability coefficients. However, regardless of whether a

TABLE XVII
 Classification of Ear Advantage

	S.E.M.	Left Ear		No Advantage		Right Ear	
		f	%	f	%	f	%
Session I							
Tape 1	3.08	7	11.7	41	68.3	12	20.0
Tape 2	2.92	11	18.4	41	68.3	8	13.3
Session II							
Tape 1	2.86	11	18.4	34	56.6	15	25.0
Tape 2	2.92	12	20.0	31	51.6	17	28.4
Over 72 items	6.06	15	25.0	21	35.0	24	40.0

homogeneous or heterogeneous sample is employed, the standard error of measurement theoretically should be constant.

Reliability Analysis of Attentional Capacity

The reliability estimates for the attentional capacity variable are given in Table XVIII. All four of Hoyt's internal consistency coefficients were equal to or above the criterion for acceptance of 0.80. Similarly, the two Pearson product moment correlations for the test/retest reliability were 0.84 for Tape 1 and 0.85 for Tape 2. The estimates were well above the criterion value of 0.7. Only one of the equivalent form correlations fell below the value of 0.7. The correlation between Tape 2 on Session I with Tape 1 on Session II was 0.68. In contrast, all Guttman maximal lower bounds were equal to or above 0.80, ranging from 0.80 to 0.91.

Table XIX contains the overall reliability estimates. Overall reliability estimates were 0.95 for Hoyt's ANOVA over the seventy-two items, 0.93 for Cronbach's Alpha over the four presentations and 0.95 for Guttman's maximal lower bound over the four tests. From the results it was concluded that the attentional capacity variable could be estimated reliably by either tape.

Parallel Versus Strictly Parallel Reliability for Attentional Capacity

Table XX contains the two within factor analysis of variance for the attentional capacity variable. Because the F-value for the test of overall mean differences across the four presentations was significant, the four subsequent analyses were done comparing:

TABLE XVIII

Reliability Coefficients for Attentional Capacity

I Internal Consistency	Hoyt's ANOVA (Cronbach's Alpha)	Guttman
Session I Tape 1	0.84	0.89
Tape 2	0.80	0.85
Session II Tape 1	0.85	0.89
Tape 2	0.85	0.85
II Test/Retest	Pearson r	
Tape 1	0.84	0.91
Tape 2	0.85	0.91
III Equivalent Form Within Session		
I: Tape 1 with 2	0.74	0.84
II: Tape 1 with 2	0.75	0.85
Between Session I & II		
Tape 1 with 2	0.79	0.88
Tape 2 with 1	0.68	0.80

TABLE XIV

Overall Reliability Coefficients for Attentional Capacity

Hoyt's ANOVA over 72 items	0.95
Cronbach's Alpha for the 4 presentations	0.93
Guttman's Maximal Lower Bound	0.95

TABLE XX

Analysis of Variance for Attentional Capacity
Across the Four Presentations

Source	df	MS	F	p
Between Subjects	59	276.0		
Between Presentations	3	1695.3	88.5	p<0.05
Residual	177	19.2		

TABLE XXI

Analysis of Variance Within and Between Tapes
for Attentional Capacity

Within Tapes

Tape 1

Source	df	MS	F	p
Between Subjects	59	169.2		
Between Sessions	1	940.8	63.9	p<0.01
Residual	59	14.7		

Tape 2

Between Subjects	59	137.6		
Between Sessions	1	770.1	64.6	p<0.01
Residual	59	11.9		

Between Tapes

Session I

Between Subjects	59	134.4		
Between Tapes	1	1569.6	75.9	p<0.01
Residual	59	20.7		

Session II

Between Subjects	59	155.7		
Between Tapes	1	1809.6	75.8	p<0.01
Residual	59	22.7		

1) the changes within a tape over time and 2) the differences between tapes within a session. The results of these analyses are given in Table XXI. The F-values associated with the four comparisons indicated that: 1) subject scores increased significantly on both tapes from session I to session II; and 2) on both sessions, the scores on Tape I were significantly higher than the scores on Tape II. Due to the differences between tapes and over sessions, it was concluded that the attentional capacity variable did not conform to the strictly parallel model of reliability.

The Relation Between Ear Advantage and Attentional Capacity

The relation between ear advantage and attentional capacity was examined from two points of view. In the first model, the ear advantage variable was correlated with the attentional capacity to determine if the direction and magnitude of ear advantage was related to the attentional capacity. In the second model, the ear advantage scores were transformed so that only magnitude was correlated with attentional capacity. The results of the analyses are given in Table XXII. For the first analysis, none of the calculated correlations was significantly different from zero. In the second analysis with the reflected ear advantage variable, the correlations on the first session were not significant. However, both correlations on the second session indicated that a significant inverse relation existed between reflected ear advantage and attentional capacity. Specifically, the greater the exhibited ear advantage, the lower the attentional

TABLE XXII

Correlation of Ear Advantage with Attentional Capacity

Session I	Directional Model	Magnitude Model
Tape 1	0.15	0.04
Tape 2	0.08	-0.06
Session II		
Tape 1	0.13	-0.35*
Tape 2	0.04	-0.39*

* $p < 0.05$

capacity. Although both relations are not large, accounting for only 12.25% and 15.21% of the total variance, it is of interest to note that both occurred after previous experience with the task with a week's interval between sessions. The only other statistical value that changed significantly over sessions was the mean accuracy levels for the two estimates of attentional capacity.

Item Analysis

The results of the item analysis for the ear advantage measure are given in Table XXIII. For the purposes of interpretations, item correlations with total score of 0.3 or greater were considered acceptable. Ten of the eighteen items on Tape 1 and 14 of the items on Tape II meet this criterion on both sessions. Only one item on each tape, item 6 on Tape 1 and item 1 on Tape 2, fell below the criterion on both sessions. For some items, for example, items 3 and 16 on Tape 1 and item 14 on Tape 2, the correlations between the two sessions fluctuated markedly. Item 16 on Tape 1 had a correlation of 0.17 with the total score on session I whereas on session II the correlation increased to 0.54.

The results of the item analysis on the attentional capacity measure are given in Table XXIV. Fifteen of the items on Tape 1 and 13 of the items on Tape 2 were above the criterion of 0.3 on both sessions. No item on either tape fell below this criterion on both occasions. For items 8, 12, 13 and 16 on Tape 2, the correlations between sessions varied considerably.

Overall no item was found that could be labelled a poor item for both ear advantage and attentional capacity. Whether the

TABLE XXIII

Item Analyses on Ear Advantage
(Correlation Coefficient of Item with Total Score)

Item	Tape 1		Tape 2	
	Session I	Session II	Session I	Session II
1	0.39	0.40	0.19	0.28
2	0.42	0.48	0.50	0.49
3	0.26	0.56	0.43	0.44
4	0.40	0.49	0.52	0.58
5	0.19	0.35	0.63	0.54
6	0.25	0.21	0.45	0.36
7	0.23	0.40	0.41	0.47
8	0.45	0.45	0.46	0.49
9	0.27	0.32	0.44	0.58
10	0.30	0.39	0.43	0.45
11	0.02	0.33	0.27	0.36
12	0.33	0.52	0.59	0.54
13	0.34	0.50	0.54	0.49
14	0.33	0.25	0.24	0.52
15	0.52	0.32	0.36	0.28
16	0.17	0.54	0.40	0.31
17	0.47	0.53	0.52	0.56
18	0.40	0.40	0.44	0.52

TABLE XXIV

Item Analyses on Attentional Capacity
(Correlation Coefficient of Item with Total Score)

Item	Tape 1		Tape 2	
	Session I	Session II	Session I	Session II
1	0.32	0.29	0.30	0.37
2	0.37	0.43	0.55	0.55
3	0.46	0.42	0.32	0.45
4	0.50	0.60	0.47	0.40
5	0.50	0.52	0.40	0.49
6	0.39	0.45	0.43	0.48
7	0.45	0.32	0.42	0.46
8	0.36	0.52	0.17	0.53
9	0.48	0.39	0.34	0.50
10	0.30	0.54	0.45	0.45
11	0.65	0.41	0.31	0.41
12	0.25	0.42	0.60	0.28
13	0.52	0.67	0.27	0.57
14	0.40	0.41	0.28	0.44
15	0.56	0.31	0.33	0.40
16	0.24	0.38	0.28	0.52
17	0.51	0.52	0.46	0.48
18	0.50	0.49	0.55	0.30

fluctuations in specific item correlations can be attributed to chance or whether the fluctuations represent systematic change could not be determined. Because of the high reliability and the lack of poor items, it must be concluded that the items are representative of the same content domain regardless of whether ear advantage or attentional capacity is measured.

CHAPTER FIVE

CONCLUSIONS AND DISCUSSION

The Findings of the Current Study

The purpose of the current study was to provide estimates of the reliability for ear advantage and attentional capacity on the dichotic listening task. Three points of criticism were raised against previous studies examining the problem. First, the choice of dependent measures for estimating ear advantage was questioned due to the inherent relation between the ear advantage and total score. The inherent relation between measures of ear advantage and total score will affect the resulting reliability coefficients in a complex manner. Therefore, Colbourn's (1978) measure of ear advantage was employed in the present study because it is mathematically independent of the total score. In addition, the reliability of the total score was assessed because the limited previous research (Kimura, 1961a) indicated that individuals with brain dysfunction do not perform as well as normals in terms of overall accuracy. The second point of criticism was the failure of previous studies to employ the individual differences methodology for the examination of reliability. Specifically, samples tended to be homogeneous rather than heterogeneous. The subjects in the current study were diverse in terms of education, occupation and age. In addition, no selection criteria were applied in terms of handedness or gender. Similarly, previous studies had employed experimental procedures such as channel alternation that would

decrease estimates of reliability. The third point of criticism was that none of the previous studies presented a full reliability analysis; rather, they examined one aspect of reliability, such as internal consistency or test/retest. The current study examined the three types of reliability, internal consistency, test/retest and parallel forms. The extensive use of the dichotic listening task in neuropsychological research and the paucity of empirical information concerning its reliability was the justification for the study.

Specific steps were taken to maximize the estimates of reliability for both ear advantage and attentional capacity. First, three pairs of words were chosen as the experimental stimuli because the three pair format usually has accuracy rates around 50% in normal, healthy subjects. Second, subjects varying in age, education, occupation, gender and handedness, were selected to maximize the variability around these points. In addition, two different dichotic tapes were used in order to estimate the generalizability of the findings. Finally, experimental sources of error variance were minimized by including practice items and not counterbalancing or switching headphone channels.

The results for the ear advantage estimate suggest that this variable is reliable within form, across time (one week) and across forms. Moreover, the analysis of variance on the ear advantage variable across the four presentations indicated that the ear advantage variable was reliable in the strictly parallel

sense. Given that each tape consisted of only eighteen items, the individual estimates of internal consistency for both test/retest and parallel forms were highly satisfactory. The assertion is supported by the fact that when the dimensions were combined, overall reliability coefficients reach 0.95 for Hoyt's ANOVA, 0.93 for Cronbach's Composite Alpha and 0.95 for Guttman's maximal bound.

Teng (1981) asserts that the dichotic listening is not a reliable test over a variable test/retest time in terms of ear advantage. However, Teng's low test/retest correlation may in fact be a function of the high overall accuracy level (72%) and the resulting coarctation of individual variance and the selected sample of right handers, and not of additional factors of subject processing, as the author asserts.

The secondary analysis on the ear advantage variable consisted of examining the classification rates in terms of true ear advantage. The first finding of interest is that none of the four distributions of ear advantage was significantly different from the normal distribution. Accordingly, the majority of subjects (51 to 68%) did not exhibit a definite ear advantage on each presentation. The finding is at variance with Satz's (1967) assertion that 70% of subjects exhibit a right ear advantage. It should be noted that Satz did not supply the empirical criteria on which he based his estimate. Even when the criterion of ± 2 standard errors of measurement is applied over the seventy-two items, 35% of the sample still cannot be classified in terms of ear

advantage. Moreover, when ear advantage consistency is considered over the four presentations, 53.3% of the sample shifted ear preference (e.g., right ear preference to no preference) on at least one presentation.

The findings suggest that attempting to predict language or speech laterality with measures of ear advantage is of questionable value. Since the majority of subjects in the study exhibited no ear advantage, the technique would suggest that the majority of subjects had bilateral speech representation. The finding is in direct disagreement with other techniques for determining speech dominance. For example, the results of the Wada amytal test indicate that 90% of subjects are left hemisphere dominant for language (Branch, Milner and Rasmussen, 1964). It is suggested on the basis of the results that the ear advantage can be estimated reliably by the dichotic listening task but that the test is not appropriate for the classification of language dominance. Rather than being bi-modally distributed in a heterogeneous population, the variable appears normally distributed. In addition, the mean value for the sample in this study is not indicative of a strong right ear preference. However, the statistical properties of ear advantage suggest that it would be appropriate to use this variable in the study of its relation with other cognitive variables.

The reliability analyses on the attentional capacity variable indicate that the variable can be measured reliably over items, time and forms. However, only a parallel model of reliability can be applied to the measure. Specifically, different forms appear

to have different difficulty levels and performance improves with practice. Except for Kimura's publication (1961a), no studies could be found that examined attentional capacity. The results of Kimura's study (see Table I) indicated that the epileptic group's overall performance was lower than for normals. Therefore, the attentional capacity variable may be sensitive to different types of brain dysfunction. The statistical attributes of the variable are appealing in terms of psychometric instrumentation.

A question that this study examined but did not answer is the relation between ear preference and performance. Two basic models of lateralization and performance appear in the literature. The first is usually ascribed to Orton (1928). He argues that in order to function properly, cognitive functions should be well-lateralized. Reading disabled children, he suggested, have difficulties due to poor lateralization of function. However, his model of lateralization is non-directional. In contrast, the directional hypothesis suggests that both the direction and degree of lateralization influence performance. The two hypotheses were examined by correlating, first the degree of lateralization and, second, the direction and degree of lateralization with the total score. The results for the directional hypothesis were that no relation existed between direction of ear advantage and performance. For the magnitude hypothesis, on the first session, no relation existed between magnitude of ear preference and total score. However, for both tapes there was a significant inverse relation between ear

advantage and total score in the second session. In other words, as the degree of preference increased, the total number of words recalled decreased.

Given that this relation only occurred in the second session and the magnitude of the relation was not impressive, the finding must be viewed with caution. The preference increase performance decrease relation may be wholly a function of the size of the stimulus unit. For example, if six-word pairs or two-word pairs were employed, would the relation still be found? For the three-word pair, the findings suggest that after previous experience with the task, performance is inversely related to the absolute degree of ear advantage.

Implications of the Current Study

The findings of this study suggest that to classify individuals in terms of language dominance by means of the ear advantage measure is suspect on measurement grounds. The question arises, what significance has ear advantage in terms of other cognitive behaviors. Before examining the relation of ear advantage to other cognitive variables, the concept of laterality and its measurement will be discussed. Although the underlying mathematical relation between measures of laterality, ear advantage and accuracy have been reported before (eg., Stone, 1980), the theoretical interpretations have taken precedent over the discussion of scaling limitations (Eling, 1981). Some exceptions can be found in the literature where the actual statistical properties of the laterality measure were of concern to the researcher.

However, the majority of papers concerned with the issue of the dependency between accuracy and laterality are theoretical or methodological notes (Marshall et al., 1975; Richardson, 1976; Colbourn, 1978).

The position taken in the current study was that the dichotic listening task may be used to measure two independent variables, attentional capacity and ear advantage. The only way to ensure that the two measures were independent was to employ Colbourn's method of scoring (Colbourn, 1978). Because the two variables were mathematically independent, any relation between the two variables can be considered a valid finding, not a function of the underlying scoring method.

In order to meet the assumption of mathematical independence, laterality was defined in terms of response consistency. In other words, the required mathematical properties of the scale dictated the operational definition of laterality. The theoretical position must be bound by the mathematical realities in order to be able to partial out true from spurious effects. Therefore, the resulting scale for a dichotic item must be solely in terms of preference. A well-lateralized individual is one who has consistent preference (i.e., right or left ear) over a series of items. A poorly lateralized individual is one who either switches preference over items or has no ear advantage on the majority of items. The findings of the current study suggest that: 1) the majority of subjects are poorly lateralized; and 2) after exposure to the task, poor lateralization is weakly associated with higher overall

accuracy scores.

The argument that laterality is a preference which is consistent over behaviors has a long historical basis (Benton, 1967). The problem which has long plagued neuropsychology is the partitioning of overall level of ability from lateral preference. The earlier discussion (Chapter Two, Measurement of Laterality) gives explicit examples of how recognized laterality coefficients are related to overall accuracy levels or general ability with the task. Even with the measure employed in the current study, for individuals who are unable to do the task or individuals who recall all six words on every item, the resulting laterality estimate would be indicative of no preference. However, because of the difficulty level of the three pair item, all subjects were able to do the task and no subject did all the items perfectly.

Within the context of brain-behavior theory, these two constructs, overall ability to do a task and lateral advantage or preference, have received considerable attention. Historically, the dichotic listening research in neuropsychology has confounded these two constructs. Specifically, two conceptual approaches may be employed in examining the results of a dichotic listening experiment. The original approach was in terms of channels, processing and memory. The findings of the information processing approach were briefly reviewed in Chapter Two. In contrast, the second approach, the neuropsychological method, is interested in constructs such as preference and ability. The preferences found have been used to infer cerebral asymmetries (Studdert-Kennedy,

1974). Unfortunately, the measurement of preference has been confounded by overall accuracy level. The findings of the current study indicate that these cerebral asymmetries are not readily apparent in the majority of individuals on the dichotic listening task. However, the current study shows that the construct of laterality can be measured reliably.

The second position taken in this study was that the individual differences approach is more appropriate than the experimental approach for examining neuropsychological functioning. The advantages of this approach in terms of sampling have been discussed earlier. The results of the individual difference approach applied to the two variables of interest, ear advantage and attentional capacity, clearly indicate that the method can be applied to neuropsychological problems. Ironically, for the sample studied, the presence of a definite ear advantage is more unusual than the presence of no advantage. Specifically, abnormal cases in the distribution are found at both tails. In the current study, the abnormal cases were subjects who were highly lateralized. From previous studies with the experimental model, the presence of a right ear advantage has been assumed to be normal.

The question arises as to what are the two measures related to in terms of other cognitive/behavioral measures. The next step in the development of an individual differences model would be to relate the two variables to other cognitive or personality variables. In short, the question of interest becomes that of construct validity. For attentional capacity, the results of the

analysis of variance suggest that performance is stimulus dependent and can improve with experience. A question of interest is whether there is a cognitive set which would maximize performance for all individuals. For example, the relation between attentional capacity and ear advantage suggests that attempting to monitor both channels is associated with higher scores. However, as the instructional set was neutral in the study, the dual monitoring set had to be learned by the subjects. An alternate hypothesis is that the subject adopts the set that will be most successful in terms of his/her monitoring ability. For example, subjects with low attentional capacity, only monitor one channel because their capacity is being over-taxed.

The final aspect of the study was the use of statistical methods for the examination of psychological questions. As mentioned earlier, the experimental method examines changes in overall mean levels whereas the individual differences method examines changes in subject ordering within distributions. Both the experimental and individual differences approach have associated statistical assumptions concerning the variances/covariances and the shape of the distribution when used in a parametric model as was done here. The questions posed by both methods have direct implications for theory generation. However, it has been argued earlier that by concentrating on the experimental approach, the conclusions concerning right ear advantage and laterality are over-statements of the real state of affairs. Moreover, examining shifts in the overall distribution of laterality,

although of interest, does not provide full insight into the phenomenon. For example, Goldstein and Lackner (1974) showed that the magnitude of the ear advantage would vary dependent upon shifting the visual field by means of prisms. In their study, a question of equal import is whether the distribution of scores just shifted or whether subject position in the distributions also shifted. In the first case, the subject's natural preference would be increased or decreased by the prisms. In the second case, the subject's natural preference would be affected by the prisms in terms of the subject distribution of the natural preference. Psychometrically, the first case has the property of being parallel but not strictly parallel. In the second case, the property of parallel is also violated.

What is apparent is that neuropsychology has concentrated on one type of statistical property, namely changes in mean performance. There are, however, four statistical properties which have theoretical import. The second property is the consistency of subject performance over time, tests, or treatments. The current study examined the two measures resulting from the dichotic listening task in the individual differences context. The two other properties of interest are the structure of the variance/covariance matrix and the shape of the distribution of scores. Neither of these two statistical properties has been examined in neuropsychological studies. Although confounded, the two properties may provide insight into the effects of treatment. For example, a treatment may not cause overall mean differences or change the

relative position of subjects within a distribution. However, it may increase or decrease the subject variance substantially or may change the shape of the distribution. Such a finding has just as much theoretical import as changes in mean levels of performance or changes in the relative distribution of subjects.

The objective of the final part of the discussion was to argue that the development of a comprehensive theory of neuropsychology is not possible by solely employing the experimental model and testing for mean differences. The individual differences approach provides additional information necessary for a theory. However, there are additional statistical properties which should also be examined in order to come to a full understanding of a neurobehavioral phenomenon. For example, currently the statistical properties of homogeneity of variance and normality are considered assumptions which have to be met in order to test mean differences by means of parametric tests. If the assumptions are not met, then a suitable correction is applied or the appropriate non-parametric analogue is used. However, the properties of distribution shape and the structure of the variance/covariance matrix as such themselves may have as much or more theoretical import as changes in mean levels of performance.

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APPENDIX A

Dichotic MaterialsPractice Items

	<u>Right</u>			<u>Left</u>		
1.	coop	fog	style	cord	fit	stamp
2.	birth	neck	grain	band	noise	glove
3.	shame	verb	that	sheet	voice	than
4.	male	nudge	coop	mine	nice	cord

Satz Tape

1.	lock	smile	book	sea	stool	club
2.	ball	gun	top	doll	game	bat
3.	plate	ant	coat	door	wind	bus
4.	jet	train	bike	truck	bus	ship
5.	cat	brick	cup	nose	skirt	fly
6.	hail	stair	jeep	foot	horse	blouse
7.	cloud	sleep	cold	sun	snow	rain
8.	fly	wasp	roach	worm	tick	bee
9.	bowl	dish	cup	spoon	pan	knife
10.	arm	floor	dog	gnat	train	fork
11.	ship	dress	wasp	cold	head	dish
12.	truck	pants	dress	hat	skirt	blouse
13.	mouse	rat	sheep	cow	pig	bear
14.	sleep	mouse	tie	bee	boat	cloud
15.	room	wood	hall	brick	stair	door
16.	toe	sock	knife	cow	jet	steps
17.	eye	hand	foot	leg	nose	ear
18.	room	sun	stove	ear	pig	flee

Spellacy Tape

	<u>Right</u>			<u>Left</u>		
1.	port	tea	cow	pack	tent	cat
2.	fur	sale	bee	fame	sum	bond
3.	deck	shoe	gun	duck	ship	gas
4.	vane	zoo	meal	vine	zone	mob
5.	name	plate	trail	nose	pride	track
6.	corn	fleet	sunk	coast	flight	sake
7.	bell	deed	game	bowl	damp	good
8.	sheep	vast	zeal	shine	vent	zest
9.	mill	nail	pace	mass	nine	pin
10.	torn	clock	fresh	tin	cloth	faith
11.	speak	bark	need	spit	belt	night
12.	shore	guest	vault	shell	guard	volt
13.	though	map	note	there	mad	nich
14.	pal	tongue	cream	pig	teeth	crust
15.	flag	send	blown	fault	sand	brain
16.	dawn	give	shift	ditch	glow	shirt
17.	vim	then	mink	view	this	mouth
18.	noun	pan	top	noon	pork	tan

APPENDIX B

Means and Standard Deviations for the Right
and Left Ear Scores Across Presentations

	Right Ear		Left Ear	
	\bar{x}	SD	\bar{x}	SD
Session I Tape 1	30.5	8.33	28.7	7.24
2	27.2	8.89	24.8	7.91
Session II Tape 1	32.4	8.51	32.4	7.74
2	29.9	9.40	27.2	9.15

APPENDIX C

Raw Data

Subject	Ses	Tape	Right Ear	Left Ear
1	1	1	111211123131221233	223221223111222230
1	1	2	213221212322121212	231332212212121032
1	2	1	031121323102312123	203220222122212230
1	2	2	332221211233222112	122222222121312122
2	1	1	011202212212321233	131231132122302122
2	1	2	101111111120011112	022132210212122211
2	2	1	011222332231332232	013231232113310322
2	2	2	101220120131211212	022232322222001212
3	1	1	022021303211221120	222222132101301121
3	1	2	221132202232312212	002210001100121232
3	2	1	002022213321211220	233322231101232101
3	2	2	222132021232311221	012212002001222122
4	1	1	220301211320332033	003030112103101110
4	1	2	322102211222313221	012230321111021222
4	2	1	000112302101222123	233331112123101231
4	2	2	211021331120112111	112321123311331313
5	1	1	002223312220332223	222221112112101121
5	1	2	312231220310122211	121222201011120232
5	2	1	012322233221322133	322112122101101122
5	2	2	312121221122213112	021213210101110332
6	1	1	123312223213202233	000133223031211130
6	1	2	113311223201222111	111231010101200212
6	2	1	123312223213202233	000133223031211130
6	2	2	113311223201222111	111231010101200212
7	1	1	012210103220201130	222131322002301120
7	1	2	111001020121111102	112222013100130121
7	2	1	121310333220201123	213120222112111120
7	2	2	312110121120112212	112212021100020101
8	1	1	121221233322322133	012221302122011031
8	1	2	332331133332313333	012112210011121112
8	2	1	132331333322332233	011222232112202131
8	2	2	332312332232323233	002123111012100111
9	1	1	000122102221122223	232210122113111121
9	1	2	212121120110112201	112121101100220131
9	2	1	021111112222111011	333331123013302331
9	2	2	312221221111223111	022112112110210221
10	1	1	121321322231301213	222121032102102131
10	1	2	211101211131123101	121233022102210031

10	2	1	11222222231322123	122212222112211131
10	2	2	321112311122111201	012221122100320232
11	1	1	021333323332333323	011000000000000000
11	1	2	322322222132323332	001000000100000000
11	2	1	22233323332312323	010000000000000000
11	2	2	322332332232323333	001001000100000000
12	1	1	002311232321332033	233120121012311133
12	1	2	002221021021222313	231220012323111011
12	2	1	002323232320011133	232230322023311232
12	2	2	302232331211122211	022321022112221132
13	1	1	111313313313322233	123221202120101120
13	1	2	312103332211213223	022232002121110121
13	2	1	101332312213331333	223121302120311020
13	2	2	312123221321213212	012331123121121320
14	1	1	101201000033313113	132110333200010130
14	1	2	101002032010101210	021220300212131112
14	2	1	000100312000013111	222221021321310232
14	2	2	100003010000002101	023330222223330231
15	1	1	232211101211331112	113130332033301130
15	1	2	201111111121102101	012222133111121333
15	2	1	301311213201212232	033233223033221230
15	2	2	212102021232312202	122330112100011131
16	1	1	211232122231323233	233311332131302333
16	1	2	222121222221213213	012212111211331233
16	2	1	111131133231312033	223322332123202233
16	2	2	323021330322213312	123323322321232232
17	1	1	001222233202323233	333220222012300131
17	1	2	322203231232121221	031211111111121022
17	2	1	001312222231332233	333122122113300021
17	2	2	322112222232213311	022311111202232112
18	1	1	001211202100312111	233222322023102032
18	1	2	100000011210010000	003333333223222133
18	2	1	0110012021111122113	233321321113313231
18	2	2	001001111100001010	223321223223232233
19	1	1	222331133231333213	223223322132311132
19	1	2	212223031332303211	033221110012230222
19	2	1	132331233322321233	123223122133302232
19	2	2	331313222332222322	023131122221211112
20	1	1	020201322111220012	211121002102102331
20	1	2	311201320121212200	012032003011131133
20	2	1	001201102201201111	333232332123233332
20	2	2	312301110110111110	032022212212232322
21	1	1	122313232231322223	011020212102101020
21	1	2	333233122232213212	102211110100020001
21	2	1	022212332231311123	112030212112101220
21	2	2	321232232233123322	113112010210210330
22	1	1	132232132231331133	121132323212303232
22	1	2	222223232323211123	112221211011232232
22	2	1	123232232222331233	322233323112303121
22	2	2	322223232323220222	012332122121332222
23	1	1	001300213220221113	122131232102102330
23	1	2	201000030111121211	022332211100210012
23	2	1	101320311220210011	223133223133102220
23	2	2	001111120112111210	12222211121221122
24	1	1	001100111200301121	123230331002101021
24	1	2	001011110220111010	022020112101322323
24	2	1	001100112001100131	222120312023210230
24	2	2	001010200111001000	013133022302332333
25	1	1	13333233332232233	00012122222211020
25	1	2	333322132232213332	111211110001110000

25	2	1	13233333332332333	121121222122102031
25	2	2	33333322232223333	000100010000210001
26	1	1	111322133232211122	123110322102312221
26	1	2	312022230133103201	122332012210120232
26	2	1	322322132212201112	123221322132322230
26	2	2	322121320122023303	122333113221330133
27	1	1	210311232122322223	121132112022112130
27	1	2	202231231222213212	222110001100110010
27	2	1	000311232332322213	331131112013312130
27	2	2	212332332132323311	022210100100010031
28	1	1	011220303231310213	223232112112212131
28	1	2	111100131101111102	113233101230131131
28	2	1	021321213331330213	323133113102302030
28	2	2	211201121222101112	113130202020221132
29	1	1	001120222121222231	233313322213323232
29	1	2	212221102212132202	133333312122322232
29	2	1	011211332221231132	233222323223322232
29	2	2	112120111122201322	231332222320233332
30	1	1	000201221221120103	333231221013212230
30	1	2	201100121100012211	132232100201210133
30	2	1	001101212120120002	333322222113312030
30	2	2	201110120111012211	132332101101220132
31	1	1	010110302122320121	323221222112312232
31	1	2	001120121120011212	132233123223221233
31	2	1	011230312100210122	32312122211220232
31	2	2	001121120220111211	12233122222311232
32	1	1	101202202100100010	121220122013322331
32	1	2	101010021121111112	111312211111220321
32	2	1	011212312110221002	22322122221322231
32	2	2	211001010121101101	031331312203210332
33	1	1	011212222231221103	323231212112302120
33	1	2	301321331032111321	122011001110210110
33	2	1	011212332231313223	233231113112111120
33	2	2	312322331232021213	112021001110300020
34	1	1	121321233232323133	323211122011201120
34	1	2	202111221111112201	022321012121120131
34	2	1	111331333331322133	233221223001202221
34	2	2	212221232122113210	022222112211321133
35	1	1	012121222021112223	232113323323332123
35	1	2	112001220110010110	12233232232220223
35	2	1	022221332122112112	233212223122222121
35	2	2	212021220120223110	222233222122221232
36	1	1	011331333232302223	123232112212112021
36	1	2	202101120221212212	121332013110231232
36	2	1	112222333231322223	223132322123302231
36	2	2	232132232221212221	212221023110331222
37	1	1	232221233322331132	321230122101300230
37	1	2	212221313222121222	012112011211211212
37	2	1	133321232322321333	313232222112311230
37	2	2	312223330122322212	123210021101210121
38	1	1	121200212222322112	112132112000000220
38	1	2	102112221121011221	012211010111221000
38	2	1	12121022222202113	11122212200000010
38	2	2	302232222332233232	001001000001100000
39	1	1	022211222332333133	213222312010111332
39	1	2	331222322332113122	012100111100130331
39	2	1	032321331320321133	203122332012322333
39	2	2	301001222233212202	023331111100322233
40	1	1	010102312221231013	223320112123102231
40	1	2	301000110111111100	022332112121220233

40	2	1	111111313231212113	233331223123321332
40	2	2	301111210211012211	032332222121321233
41	1	1	031321223330322233	113220222102111131
41	1	2	332311322112013212	111131021120320211
41	2	1	333323323202331332	112100231200213121
41	2	2	122233022222221231	101101210111122112
42	1	1	000220132122322123	223211322001201230
42	1	2	202112121121011202	022210112110122031
42	2	1	011331332121312333	233211222111301030
42	2	2	212201231121221211	112232111211223131
43	1	1	121322201221311210	213120132123211132
43	1	2	001221011120101202	231123222221220231
43	2	1	111321212121221111	323122233122301232
43	2	2	211011130310011201	132333122131310132
44	1	1	021320232221221121	123131222123301230
44	1	2	221112222233223312	112330212211020022
44	2	1	231331332121321032	213212322213300121
44	2	2	311323222222223122	123022011120301311
45	1	1	011211212121201121	323122132202332333
45	1	2	312210221021012002	013332212211311231
45	2	1	211112222201311132	333322331223323332
45	2	2	312211132131011111	11333222211322231
46	1	1	01022032212222332	220122102102100110
46	1	2	312221031122211222	111011000111010010
46	2	1	112221323322322332	322121022011201030
46	2	2	312101331112112223	101011000111012100
47	1	1	010310221232222113	223023112101100120
47	1	2	211332032112112302	012101001210121031
47	2	1	111311322222322233	22322222102321121
47	2	2	211312111212012302	112122120100232132
48	1	1	000000000000110112	333223322313312232
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48	2	1	111020220001110111	33322223313323233
48	2	2	102101011211102101	032332322110231331
49	1	1	111321323320321123	122022212113212030
49	1	2	222231211232121122	012211112111120121
49	2	1	12222312321320222	222132212113301030
49	2	2	221322221332221201	012223110010120222
50	1	1	222321333323332233	323332312032302232
50	1	2	332103132222120122	122330221222231332
50	2	1	322322333332332233	33333233233311232
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51	1	1	231231213321331133	113111213331201021
51	1	2	323331231212221122	021011110121210021
51	2	1	321331333221322133	223131213122321122
51	2	2	223322332322322222	022022012110120322
52	1	1	121200110202201113	111201022111110120
52	1	2	322311210211201212	011100001110120220
52	2	1	121211222111012133	212011121110301110
52	2	2	202221231222002111	021101000010111200
53	1	1	022200231121212122	111131102121310211
53	1	2	312122321322213212	002222110011211122
53	2	1	210310321231222233	222232112202302232
53	2	2	232122231112313312	122122210120111122
54	1	1	223310312130321333	202212232213302132
54	1	2	222332231312213302	111132211121010222
54	2	1	213321333210322233	212223132123322132
54	2	2	122312332212312212	221231111111131231
55	1	1	020211212221210113	312121222112211031
55	1	2	102111031111122202	012211011122220130

55	2	1	011321212221231113	323121222112211131
55	2	2	201111131221123202	022331011121220132
56	1	1	001221201321213122	233212312123212131
56	1	2	311111322112011211	13213212222321132
56	2	1	011322222101223222	33222322121322233
56	2	2	202201333122111211	133232112232332221
57	1	1	011210232121320120	333222313011302032
57	1	2	212113130211212211	221321223021120122
57	2	1	131220332231211123	323331322103213131
57	2	2	322232231232312122	13222223012212321
58	1	1	002212203232321233	222322122112302331
58	1	2	121112230232122222	013231012000230210
58	2	1	122322233232321233	221331222113302233
58	2	2	322132231232121112	121320022001232230
59	1	1	131211223332332223	103232312103202231
59	1	2	312313332112222321	022322100111321132
59	2	1	221210323331332223	223233322113201231
59	2	2	312223331121212222	013222112111331321
60	1	1	233322332223233022	110111212121311103
60	1	2	122320122201232232	301212120212221211
60	2	1	333322333223202131	111111212120321212
60	2	2	233331123101332333	211222210211112210

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THE RELIABILITY OF EAR ADVANTAGE AND ATTENTIONAL
CAPACITY IN DICHOTIC LISTENING

Author



CAMPBELL MCGILLIVRARY CLARK

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