An Analysis of Validity Constructs in the Dichotic Listening and Hemispheric Competition Procedures

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AN ANALYSIS OF VALIDITY CONSTRUCTS IN THE DICHOTIC LISTENING AND HEMISPHERIC COMPETITION PROCEDURES

by

Wade Addam Kapik

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Psychology

Western Michigan University
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AN ANALYSIS OF VALIDITY CONSTRUCTS IN THE DICHOTIC LISTENING AND HEMISPHERIC COMPETITION PROCEDURES

Wade Addam Kapik, M.A.
Western Michigan University, 1981

This investigation was designed to determine the validity of two categories of neuropsychological measures of cerebral dominance. Forty right-handed subjects were administered two dichotic listening tests and two hemispheric competition tests in a random order. The principal data showed that none of the four tests had sufficient levels of criterion-related and concurrent validity to be considered clinically useful in measuring laterality. In addition, a Bayesian analysis of one of the dichotic listening tests indicated that it possessed a predictive validity of .79. Finally, the assertion that the scoring methods of each test are dynamically different was disputed, and Kinsbourne's interhemispheric competition model was not supported by the data.
ACKNOWLEDGEMENTS

I wish to thank my committee members, Drs. Chris Koronakos, Malcolm Robertson, Paul Mountjoy, and Joetta Long, for the assistance given to me during the preparation of this thesis.

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Wade Addam Kapik
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INTRODUCTION

In most animal species the structure of the nervous system is essentially symmetrical. In mammals this symmetry is made even more striking by the prominence of the uppermost part of the brain: the cerebral hemispheres. In man, however, the two hemispheres appear to differ substantially in both structure and function (Adams and Victor, 1977; Luria, 1973; Wada, Clarke, and Hamm, 1975; Zangwill, 1960). Evidence from neurological research, for example, has shown that the left hemisphere in most individuals is somewhat larger and heavier than the right hemisphere, the size differential being greatest in those cortical areas that mediate language functions (Geschwind and Levitsky, 1968). Research has also revealed that there are lateral plane differentiates between the cortical representation of primary cognitive functions and aspects of behavior as processed by the hemispheres (Gardner, 1974; Luria, 1973; Zangwill, 1960).

The most obvious difference between the hemispheres is that lesions in the left hemisphere commonly give rise to speech and other related types of disorders, or, in the broadest sense, to disorders of symbol formation. On the other hand, communication problems are rarely seen in individuals with right hemisphere damage. Individuals with lesions in the right hemisphere are more likely to experience difficulties in orientation to time and space, in integrating the visual and spatial components of a percept or task, or in handling complex or patterned material that cannot be readily conceptualized verbally (Gardner, 1974; Kimura, 1973).
These observations have led researchers and clinicians to the conclusion that the left hemisphere in most individuals is specialized for tasks requiring sequential or analytic processing, and that the right hemisphere predominates in the mediation of spatial or gestalt transformations and complex nonverbal sensory integration (Marshall, Caplan, and Holmes, 1975; Milner, 1962, 1974; Richardson, 1976; Semmes, 1968).

**Historical Review of the Literature**

Language was the first higher cortical function discovered to be asymmetrically represented in the cerebral hemispheres (Geschwind and Levitsky, 1968; Kimura, 1975; Sperry, 1968). The notion that the left hemisphere is usually functionally dominant for language skills was implied more than 100 years ago by Dax and Broca, and this concept presently remains among the best documented theories in the literature concerning the brain (Gardner, 1974; Geschwind, 1972). Hundreds of studies applying diverse methodologies have been published which confirm that speech and its related functions are lateralized in the left hemisphere in most individuals (Kinsbourne, 1973). A review of the key studies of cerebral dominance may be helpful in illustrating the magnitude of this research.

Until the development of a rudimentary medical technology in the nineteenth century the activities of the hemispheres had to be studied indirectly through observations of behavioral impairments arising from known lateralized or generalized lesions. The identification of the left hemisphere as the major hemisphere usually involved with language skills was first based upon studies of speech
disturbances due to unilateral lesions in certain cerebral areas. On the basis of their examinations of the brains of deceased aphasics, Broca (1861) and Wernicke (1874) both concluded that the temporoparietal area of the left hemisphere was responsible for speech production and comprehension. Later published research by Bastian (1898) and Head (1926) substantiated this finding about the left hemisphere.

Investigators of speech lateralization in the twentieth century initially turned to the study of the deliberate interference of speech through surgical and chemical means. Zollinger (1935) was the first researcher to note that the surgical removal of the left hemisphere in patients with spreading tumors usually led to decompensated speech patterns. Others such as Hillier (1954) and Smith (1961) made similar conclusions concerning this effect of the left hemispherectomy on speech.

In other research, Gazzaniga and Sperry (1966, 1967), working with epileptic patients, observed that a certain radical treatment for epilepsy, the surgical disconnection of the interhemispheric tracts, could be potentially useful in research of the laterality of speech functions. Subsequent research of the left hemispheres of commissuratomy patients has generally supported the notion of that hemisphere's importance in the production of speech (Gazzaniga, 1967, 1970; Kreuter, Kinsbourne, and Trevarthen, 1972; Milner, Taylor, and Sperry, 1968; Rossi and Rosadini, 1967; Sperry, 1968, 1976, 1977; Sperry and Gazzaniga, 1967; Teng and Sperry, 1973; Zurif and Bryden, 1969).
In the area of chemical research, Wada (1949) discovered that an injection of a solution of sodium amytal into the carotid artery leading to the major hemisphere frequently caused temporary speech loss (paraphasia). Using samples of brain-damaged individuals, other investigators subsequently noted that paraphasia occurred most often when the left carotid artery, ipsalateral to the left hemisphere, was injected with the sodium amytal solution (Branch, Milner, and Rasmussen, 1964; Rasmussen and Milner, 1975; Serafetinides, Hoare, and Driver, 1965; Werman, Christoff, and Anderson, 1959).

Only in the past two decades have researchers chosen to develop a behavioral methodology in order to study this issue of cerebral dominance (Berlin, 1971; Gardner, 1974). This movement grew as a direct result of the criticisms of the older methodologies. Satz, Achenbach, and Fennell (1967), for instance, observed that the hazardous risks of the Wada sodium amytal test precluded its practical and ethical use with normal subjects. Interest in the clinical assessment of cerebral dominance was also influential in the development of behavioral procedures (Gardner, 1974; Kinsbourne, 1973).

Broadbent (1954) developed the dichotic listening technique, one of the first behavioral procedures. He noted that when two different words or digits were presented to the left and right ears simultaneously, the stimulus arriving at the ear contralateral to the hemisphere dominant for speech was more accurately identified than the stimulus arriving at the other ear. In an attempt to explain this phenomenon, Kimura (1961) hypothesized that the crossed auditory
pathways of most individuals were often more efficient than the uncrossed one under conditions of biaural stimulation. Therefore, she observed, the right ear would demonstrate an advantage in cases where language was functionally lateralized in the left hemisphere.


Unlike the dichotic listening technique, the hemispheric competition procedure is quite recent in origin. The value of this behavioral tool was determined by Kinsbourne and Cook (1971), who had subjects balance a dowel rod on their index fingers silently and while repeating sentences. They discerned that right-handed dowel balancing was compromised to a greater extent by concurrent linguistic tasks than was left-handed dowel balancing. Kinsbourne (1978) theorized that dual task performance was compro-
mised to the extent that the cerebral programs controlling both
tasks shared the same functional space in the brain. Right-handed
dowel balancing would therefore be disrupted more severely because
the left hemisphere would have to simultaneously process both
linguistic output and the motor control of the contralateral hand.
Using a variety of manual tasks, other investigators have obtained
results supporting Kinsbourne's position (Bowers, Hellman, Satz,
and Altman, 1980; Hicks, 1975; Hicks, Provanzano, and Rybskin,
1975).

Statement of Problem

Over the past two decades an increasing amount of attention
has been devoted to the use of clinical neuropsychological pro­
cedures in research of the brain. Of particular interest to re­
searchers has been the study of the gross differences in function
exhibited by the cerebral hemispheres (Gardner, 1974). It has
been established that the most widely known difference between the
hemispheres is in language function, for which the left hemisphere
plays the predominant role in most individuals. It has also been
demonstrated that the dichotic listening and hemispheric competi­
tion procedures have enjoyed considerable acceptance as behavioral
strategies for measuring cerebral dominance (Kimura, 1975; Kins­

It therefore might be considered highly unusual that the va­
lidity of either behavioral technique is essentially unknown (Bir­
kett, 1977; Bryden and Allard, 1978; Fennell, Bowers, and Satz,
tening procedure as a typical example, Satz (1977), for instance, criticized the "increasing disregard of measurement error and validity constructs in human neuropsychological research" (p. 211). Bryden and Allard (1978) and Kallman (1978) believed that this problem was due to the lack of a practical and direct criterion of cerebral dominance, and concluded that most clinical neuropsychological procedures possessed too much method variance to be useful in research or clinical assessment. In a slightly different vein, Birkett (1977) noted that the rapid development of many dissimilar scoring methods was a direct result of this problem with validity.

An obvious need for validity research in the field of clinical neuropsychology exists, and the data from this present investigation were used to examine the validity of the dichotic listening and hemispheric competition procedures. However, as the concept of validity is a complex and intricate one, it requires definition before the hypotheses of this study are presented.

Anastasi (1979) states that the validity of a test concerns what the test measures and how well it does so. Fundamentally, all procedures for determining test validity are concerned with the relationships between performance on the test in question and other independently observable facts about the behavior or trait under consideration (Anastasi, 1950). The specific methods employed for investigating these relationships are numerous and have been described by various names. In the *Standards for Educational and Psychological Tests* (1974) these methods are classified under three
principal groups: content, criterion-related, and construct validity. This present investigation concerns itself with the latter two concepts.

The data from this investigation were used to examine the following three hypotheses concerning the dichotic listening and hemispheric competition procedures:

1. Criterion-related validity indicates the effectiveness of a test in predicting the presence and nature of a behavior or trait in an individual (Anastasi, 1979). Generally, performance on the test is checked against a criterion, i.e., a direct and independent measure of that which the test is designed to measure. It has been noted elsewhere in this paper, however, that a direct measure of cerebral dominance is currently unavailable in the field of clinical neuropsychology (Bryden and Allard, 1978; Kallman, 1978). Only the surgical or chemical examination of an individual's cerebral hemispheres would provide a direct measure of cerebral dominance, but the procedures involved are both impractical and unethical for usage in clinical research (Satz et al., 1967). On the basis of his examination of a large sample of aphasics, however, Satz (1977) concluded that 95% of all normal right-handed individuals were dominant in the left hemisphere for language. In view of the current unavailability of a direct and easily accessible criterion of cerebral dominance, this percentage has received critical acceptance as an indirect criterion of this trait among normal right-handed adults. The first hypothesis of this present investigation was that it was expected that the per-
percentages of left-hemisphere dominance obtained from the sample data of the targeted tests would approach Satz's (1977) criterion value of 95%.

2. The construct validity of a test is the extent to which the test may be said to measure a theoretical construct or trait (Anastasi, 1979). A variant of this type of validity is convergent validity, which is defined as the extent to which a given set of tests purporting to measure the same construct actually intercorrelate to a significant degree. The second hypothesis of this investigation was that since the dichotic listening and hemispheric competition procedures (and their associated scoring methods) purport to measure cerebral dominance, it was expected that they would correlate among themselves to a significant degree.

3. Another variant of construct validity is factor analysis, a procedure for the identification and definition of constructs or traits. The third hypothesis of this investigation was that it was expected that both procedures measure a general factor of language dominance, and that factor analytical procedures would demonstrate the presence of this factor.
METHOD

Subjects

Forty right-handed subjects (20 males and 20 females) were recruited from several undergraduate psychology classes at Western Michigan University. Subjects were screened twice in order to ascertain their appropriateness to the sample.

During the first screening all potential subjects were administered a modified version of the Annett Handedness Questionnaire (1970) (see Appendix A). Subjects were required to report performing all of the listed manual tasks with their right hands. In addition, any subject with a known familial history of left-handedness was excluded from participation in the study, as was any subject who reported having a known auditory deficit or a neurological disorder.

Those subjects who met the requirements of this initial screening were screened a second time. A brief audiometric test was administered to assess any unrecognized auditory deficits. The presence of a significantly high differential threshold between the ears disqualified a subject from further participation in the study.

Apparatus

The equipment for the two dichotic listening portions of the investigation included a Hollensak stereophonic reel-to-reel tape player, a set of Audio-Technica Signet TK-22 stereo headphones, and two dichotic stimulation tapes. The dichotic tapes were generated by computer in order to accurately present stimuli in terms of loudness and timing to both ears. The tapes were created by the BAURAL program (Satz and Van Den Abell, 1979).
A decimal counter mounted on a wooden platform and six paragraphs from the Gray Oral Reading Test and the Wechsler Memory Scale (see Appendix B) were used in the two competition portions of the study. A stopwatch was used to time the trials.

**Procedure**

Two variations from each laterality procedure were given. Each subject was administered the four tests in an order which had been previously counterbalanced.

The tasks that were used in the two dichotic listening tests are similar to those used by Kimura (1961).

In the 3-pair dichotic listening test, each subject heard played through the headphones 30 trials of three pairs of digits. During each trial the subject heard one list of three digits in one ear and another different list in the other ear. The digit pairs were presented simultaneously at the rate of three per second. Digits selected for the tape were from 1 to 19, with two-syllable digits balanced between the channels. The three-syllable digits "eleven" and "seventeen" were omitted.

The subject was instructed that total recall of the stimuli was impossible, but that he or she should try to remember as many digits as possible, and then report them to the researcher. Oral responses were recorded by the researcher immediately after each trial (see Appendix C for score sheets). The 30 trials were administered twice, with the headphones being reversed after the first administration in order to correct for any nonrandom differences between channels. Each subject was given five practice tri-
als before the first administration. The inter-trial interval was 15 seconds.

In the 4-pair dichotic listening test, each subject heard played through the headphones 20 trials of four pairs of digits. Four practice trials were given before the first administration. Otherwise, the procedure for this test remained identical to that of the 3-pair test.

The tasks that were used in the two hemispheric competition tests are similar to those used by Bowers et al. (1980).

In the verbal fluency test, each subject was given a preliminary exercise in order to practice finger tapping. The subject was instructed to tap the counter lever as rapidly as possible with the index finger while keeping the wrist and the remaining fingers positioned on the board. There were three 10" trials with the right hand followed by three 10" trials with the left hand.

The experimental session consisted of one baseline condition (finger tapping alone) and one dual task condition (finger tapping and verbal fluency performed simultaneously). In the baseline condition, six 20" trials were alternated between the right and left hands in an order which had been previously counterbalanced. In the dual task condition, the subject was instructed to say as many words as possible, excluding proper nouns and direct derivatives, that began with a specified letter, while finger tapping simultaneously. There were six 20" trials in this condition, and a trial commenced with the presentation of one of six letters (A, D, F, R, S, and T), at which time the subject began finger tapping.
and generating words. The subject was instructed to divide his or her attention equally between the two tasks. The order of the presentation of the six letters was determined randomly. The six trials were alternated between the right and left hands in an order which had been previously counterbalanced.

During the experimental session, the subject completed a total of 12 trials, six per condition. Half of the baseline trials were performed prior to the dual task condition, and the other half afterwards. Performance on the dual tasks was thus interpolated between pre- and post-baseline conditions.

In the paragraph reading test, one of the tasks in the dual task condition was changed. The subject was instructed to read aloud one of six paragraphs while finger tapping simultaneously. Otherwise, the procedure for this test remained identical to that of the verbal fluency test.

Scoring Methods

The data obtained from each administration of the dichotic tests were scored using four different methods. These methods have been described in detail by Marshall et al. (1975):

1. $Rc - Lc$. The number of correct responses on the right side minus the number of correct responses on the left side.

2. Percent of Correct (POC). The number of correct responses on the right side divided by the total number of correct responses: $Rc / (Lc + Rc)$.

3. Percent of Error (POE). The number of errors on the left side divided by the total number of errors: $Le / (Le + Re)$.
4. Laterality Coefficient (LC). If performance accuracy exceeds 50%, then LC equals the number of correct responses on the right side minus the number of correct responses on the left side, divided by the total number of errors: \( \frac{(R_c - L_c)}{(L_e + R_e)} \); if performance accuracy equals or is less than 50%, then LC equals the number of correct responses on the right side minus the number of correct responses on the left side, divided by the total number of correct responses: \( \frac{(R_c - L_c)}{(L_c + R_c)} \).

The data obtained from each administration of the hemispheric competition tests were scored using two different methods. These methods have been described in detail by Bowers et al. (1980):

1. Absolute Change from Baseline (AbC). The average number of finger taps during baseline minus the average number of finger taps during the dual task condition.

2. Percentage Change from Baseline (%C). The average number of finger taps during the dual task condition divided by the average number of finger taps during baseline.

Scores were tabulated for left and right hand performance.
RESULTS

The results of this investigation will be presented in terms of the three hypotheses.

Hypothesis 1

Table 1 presents (a) the percentages of left-hemisphere dominant subjects in the sample as indicated by the four laterality tests and their associated scoring methods, and (b) the chi-square values yielded from the statistical analyses of these obtained percentages with Satz's (1977) criterion value of 95%. It should be recalled that it was expected that the percentages of left-hemisphere dominance obtained from the sample data should closely approximate this criterion value. However, the table shows that all four laterality tests, irrespective of the scoring methods, produced percentages significantly lower than this value. The 4-pair dichotic listening test, which identified 82% of the sample as left-hemisphere dominant, still substantially underestimated Satz's base rate of 95% ($x^2 = 13.15, p < .01$). The first hypothesis of this investigation is therefore not supported by the statistical analysis of this data.

It can also be observed in Table 1 that the targeted scoring methods had no differential effects on the obtained percentages of their associated laterality tests.

Hypothesis 2

Table 2 illustrates the matrix of correlations between the values derived from the scoring methods of the four laterality tests. Hypothesis 2 of this investigation states that since the dichotic listening and hemispheric competition tests (and their
Table 1

The obtained percentages of left-hemisphere dominant subjects in the sample and the chi-square values yielded from the statistical analyses of these percentages with Satz's (1977) criterion value of 95%.

<table>
<thead>
<tr>
<th>Test</th>
<th>Percentage</th>
<th>$\chi^2$</th>
</tr>
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<tbody>
<tr>
<td>3-pair dichotic listening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc - Lc</td>
<td>78</td>
<td>25.78*</td>
</tr>
<tr>
<td>POC</td>
<td>78</td>
<td>25.78*</td>
</tr>
<tr>
<td>POE</td>
<td>78</td>
<td>25.78*</td>
</tr>
<tr>
<td>LC</td>
<td>78</td>
<td>25.78</td>
</tr>
<tr>
<td>4-pair dichotic listening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc - Lc</td>
<td>82</td>
<td>13.16*</td>
</tr>
<tr>
<td>POC</td>
<td>82</td>
<td>13.16*</td>
</tr>
<tr>
<td>POE</td>
<td>82</td>
<td>13.16*</td>
</tr>
<tr>
<td>LC</td>
<td>82</td>
<td>13.16</td>
</tr>
<tr>
<td>Verbal Fluency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AbC</td>
<td>50</td>
<td>170.53**</td>
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<tr>
<td>%C</td>
<td>50</td>
<td>170.53</td>
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<tr>
<td>Paragraph Reading</td>
<td></td>
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</tr>
<tr>
<td>AbC</td>
<td>52</td>
<td>152.11**</td>
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<tr>
<td>%C</td>
<td>52</td>
<td>152.11</td>
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* = $p < .01$

** = $p < .001$
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<tr>
<th>TEST</th>
<th>SCORING METHOD</th>
<th>3 - PAIR DICHOTIC LISTENING</th>
<th>4 - PAIR DICHOTIC LISTENING</th>
<th>VERBAL FLUENCY</th>
<th>PARAGRAPH READING</th>
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<td></td>
<td>Rc - Lc</td>
<td>POC</td>
<td>POE</td>
<td>AbC</td>
<td>% C</td>
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<td>AbC</td>
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<td></td>
<td></td>
<td>POC</td>
<td>POE</td>
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<td></td>
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<td>.985*</td>
<td>.948**</td>
<td>.051</td>
<td>.063</td>
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<td></td>
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<td>AbC</td>
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<td>.025 -.073</td>
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<td>.040 .040</td>
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<td>.011 .011</td>
<td>.029</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>.040 .380</td>
<td>.988</td>
</tr>
</tbody>
</table>

TABLE 2

MATRIX OF CORRELATION COEFFICIENTS BETWEEN THE SCORING METHODS OF THE LATERALITY TESTS

- * P < .05
- ** P < .01

3 - PAIR DICHOTIC LISTENING | 4 - PAIR DICHOTIC LISTENING | VERBAL FLUENCY | PARAGRAPHER READING | TEST
associated scoring methods) purport to measure cerebral dominance, then it was expected that they would correlate among themselves to a significant degree. Inspection of the matrix of correlations shows that the two dichotic listening tests, as expected, intercorrelated highly within themselves and between each other. On the other hand, the two competition tests correlated highly within themselves, but not with each other. There were no statistically significant correlations between the dichotic listening and the competition tests, with coefficients ranging from -.110 to .173. Hypothesis 2 is therefore only partially supported by the data, since only the two dichotic listening tests displayed significant levels of convergent validity.

Hypothesis 3

A factor analysis was carried out using the recommendations of Rummel (1970). It should be recalled that it was expected that the four laterality tests would measure a general factor of language dominance, and that factor analytic procedures would demonstrate the presence of this factor. Using the matrix of correlations (Table 2) derived from the data, a principal components analysis identified three factors which accounted for 91.1% of the variance: (a) Factor I, with loadings on the dichotic listening tests; (b) Factor II, with loadings on the hemispheric competition tests; and (c) Factor III, with loadings on the two scoring methods used in the competition tests. No general factor of language dominance, however, was extracted from the data. Table 3 shows the loadings of the three factors. Hypothesis 3 is accordingly not supported by
Table 3
Loadings of the factors derived from the factor analysis of the data.

<table>
<thead>
<tr>
<th>Test</th>
<th>Factor I</th>
<th>Factor II</th>
<th>Factor III</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-pair dichotic listening</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc - Lc</td>
<td>.929</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>POC</td>
<td>.887</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>POE</td>
<td>.937</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>LC</td>
<td>.929</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4-pair dichotic listening</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc - Lc</td>
<td>.952</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>POC</td>
<td>.945</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>POE</td>
<td>.904</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>LC</td>
<td>.942</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Verbal Fluency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AbC</td>
<td>—</td>
<td>.830</td>
<td>-.524</td>
</tr>
<tr>
<td>%c</td>
<td>—</td>
<td>.810</td>
<td>.542</td>
</tr>
<tr>
<td>Paragraph Reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AbC</td>
<td>—</td>
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<td>-.550</td>
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<tr>
<td>%C</td>
<td>—</td>
<td>.834</td>
<td>.542</td>
</tr>
</tbody>
</table>
the sample data, since only method variance was discovered through this statistical analysis.
DISCUSSION

One of the most important indices of the usefulness of any psychological test or assessment tool is the validity of the instrument. It should be intuitively obvious that any test is subject to error; however, in neuropsychological assessment, a situation exists in which the findings of the testing are of crucial importance to the physical welfare of the patient. The nature of a treatment modality frequently hinges upon the test results. Accordingly, test error must be reduced to the absolute minimum before the test can be considered clinically useful.

Unfortunately, the results of the principal investigation, as presented in Tables 1-3, indicate that the dichotic listening and hemispheric competition procedures both lack adequate levels of validity in most respects. For instance, it is very evident from the listed chi-square values in Table 1 that none of the four tests comes even remotely close to predicting the expected percentage of left-hemisphere dominant subjects in the sample. Moreover, compensating for the fact that Satz's (1977) base rate of 95% represents an upper-limit percentage of left-hemisphere dominance, the statistical analyses of the obtained percentages raises grave doubts about the criterion-related validity of these four laterality tests.

It could be considered also that the Annett Handedness Questionnaire (1970) allowed for the selection of the most strongly right-handed subjects. The possibility that the sample is skewed in favor of left-hemisphere dominance must then be strongly considered.
It could be possible that the actual upper-limit percentage of left-hemisphere dominance is not 95% but 97% or more. This possibility, however, only serves to emphasize the severe underestimates of left-hemisphere dominance by the four laterality tests.

In examining the matrix of correlations presented in Table 2, only the two dichotic listening tests intercorrelated to a significant degree. The dichotic listening and hemispheric competition tests failed to correlate to any degree, despite the common belief that they measure cerebral dominance. The results of the correlational matrix accordingly indicated that there is little proof of adequate levels of concurrent validity among these tests. Finally, it can be recalled that the factor analysis was only able to extract three method factors from the data.

The lack of substantial support for the validity of these laterality procedures naturally leads to the conclusion that clinical inferences drawn from them may be highly suspect. In his paper on the inferential problems of laterality testing, Satz (1977) wrote that "the problem...concerns the assumption that because a relationship exists between two variables (e.g., ear asymmetry and speech lateralization) then inductive inferences can be made on individual subjects to classify them into respective hemispheric dominant groups" (p. 208). Satz labeled this assumption as reckless and unwarranted, particularly when the antecedent probabilities concerning hemispheric lateralization were asymmetric in the target population. Satz suggested looking into this induction problem with the use of Bayes' theorem (Mendenhall, 1979; Stilson, 1966). By
utilizing Bayes' works on inverse probability, Satz believed that it was possible to determine the likelihood that an assumption concerning speech laterality in an individual was correct, given the detection signs of the targeted test and the antecedent probabilities of speech dominance in the population.

By using Bayes' theorem, it is thus possible to perform an analysis on one of the four laterality tests examined in the principal investigation: the 4-pair dichotic listening test. This test produced an obtained percentage closest to Satz's (1977) base rate of 95%. Table 4 shows the expected relationship between the predicted and actual frequencies of speech dominance in a hypothetical sample of 100 right-handers. The column totals (CT) refer to the actual frequencies of left- and right-hemisphere dominance in this sample based on the antecedent probabilities suggested by Satz (1977). The row totals (RT) represent the frequency estimates of left- and right-hemisphere dominance based on the results of the 4-pair dichotic listening test in the principal investigation (cf. Table 1). That is, using this test, approximately 82% of the hypothetical sample would be predicted to be left-hemisphere dominant, while the remaining 18% would be predicted to be right-hemisphere dominant.

Given these column and row totals, it is possible, using Satz's (1977) equation RT (CT / 100), to fill in the four cells of the table. For instance, 78 left-hemisphere dominant subjects would be predicted to be left-hemisphere dominant. On the other hand, 17 left-hemisphere dominant subjects would be predicted to be right-
### Table 4

Bayesian frequency table for the 4-pair dichotic listening test.

<table>
<thead>
<tr>
<th>ACTUAL</th>
<th></th>
<th></th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LH</td>
<td>RH</td>
<td></td>
</tr>
<tr>
<td>LH</td>
<td>78(^a)</td>
<td>4</td>
<td>82</td>
</tr>
<tr>
<td>RH</td>
<td>17</td>
<td>(1)^(b)</td>
<td>18</td>
</tr>
<tr>
<td>Totals</td>
<td>95</td>
<td>5</td>
<td>100(^c)</td>
</tr>
</tbody>
</table>

\(^a\) \(p(LH) = \frac{78}{82} = .951\)

\(^b\) \(p(RH) = \frac{1}{18} = .055\)

\(^c\) \(p(Total) = \frac{79}{100} = .79\)

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hemisphere dominant. The cell values represent the expected relationship between the predicted and actual frequencies of language dominance in the present investigation. With these data, the following questions can be answered:

1. What is the probability of correctly predicting hemisphere dominance? \( p(\text{Total}) \)

2. What is the probability of correctly predicting left-hemisphere dominance? \( p(\text{LH}) \)

3. What is the probability of correctly predicting right-hemisphere dominance? \( p(\text{RH}) \)

The results of these three questions are noted in Table 4. The results indicate that the probability of correctly predicting left-hemisphere dominance is extremely high using the 4-pair dichotic listening test \( (p = .951) \). However, the probability of correctly predicting right-hemisphere dominance is very low \( (p = .055) \). This latter value means that the probability of misclassifying a right-hemisphere dominant individual is slightly more than 94%.

In order to fully understand the clinical implications of this Bayesian analysis of the 4-pair dichotic listening test, a hypothetical situation may be created: A neurosurgeon has a right-handed patient who has a midline tumor, and he wants to know whether to surgically enter through the right or left side of the brain to remove this tumor. Not wanting to chance accidental aphasia in his patient, the neurosurgeon's major concern is to avoid the dominant hemisphere during surgery. On one hand, the neurosurgeon may be aware of Satz's (1977) antecedent base rate of 95% among right-handers, and accord-
ingly enter through the right side of the brain. The probability of correctly predicting left-hemisphere dominance in this case is .95. (Therefore, in 100 similar patients, using this strategy will result in only five errors.)

On the other hand, the neurosurgeon may make a referral to a clinical neuropsychologist to administer some laterality testing prior to surgery. Based on the results of Table 4, if the neuropsychologist administered the 4-pair dichotic listening test, his probability of correctly predicting left-hemisphere dominance would be .951. This probability, however, only represents an increase of .001 over always assuming left-hemisphere dominance (p = .95). More importantly, the probability of correctly predicting right-hemisphere dominance with this test is only .055; i.e., the neuropsychologist has a very high probability of wrongly predicting right-hemisphere dominance. Accordingly, the neuropsychologist's probability of simply predicting hemisphere dominance correctly is .79. This means that there is close to a one in five chance that the test will incorrectly determine hemispheric dominance.

It has been frequently suggested within the context of Baysean theory that one way to improve the predictive validity of laterality testing may be to adjust the cutting point used in the computational determination of hemispheric dominance. For instance, the value 0 is used frequently in the scoring method Rc - Lc. Any score greater than zero is indicative of left-hemisphere dominance; conversely, any score less than zero indicates right-hemisphere dominance.
Therefore, if Rc = 79 and Lc = 78, then Rc - Lc = 1, and left-hemisphere dominance is indicated. Of course, the probability of error in this instance is quite high, since this score may have been adversely influenced by random method variance.

Remaining within the framework of Baysean theory, altering the cutting point of Rc - Lc to a negative value such as -10 will change the frequency estimates of left- and right-hemisphere dominance in the aforementioned hypothetical sample of 100 right-handers. Table 5 illustrates these changes in the row totals and the resulting modifications in the cell values of the 4-pair dichotic listening test. It can be readily seen that while this alteration increases the probability of correctly predicting left-hemisphere dominance, the improvement remains minimal (p = .004). Moreover, the probability of correctly predicting right-hemisphere dominance is still quite unsatisfactory. This proposed strategy fails to substantially improve the predictive validity of this test.

There are two other areas of importance that have not yet received adequate discussion in this investigation: (a) the hemispheric competition tests, and (b) the scoring methods of the four tests.

It may be worthwhile to first delineate the wholly unexpected findings concerning the competition tests. It may be recalled that Kinsbourne (1978) and others have published research that generally substantiates the validity of the competition procedure as a clinical measure of cerebral dominance. The data from the principal investigation, however, fail to support this procedure's validity. Table 1, it can be remembered, illustrated that the two competition
Table 5
Baysean frequency table for the 4-pair dichotic listening test, with the altered cutting score.

<table>
<thead>
<tr>
<th></th>
<th>ACTUAL</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LH</td>
<td>RH</td>
<td>Totals</td>
</tr>
<tr>
<td>LH</td>
<td>86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>RH</td>
<td>9</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>Totals</td>
<td>95</td>
<td>5</td>
<td>100&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> \( p(LH) = \frac{86}{90} = .955 \)

<sup>b</sup> \( p(RH) = \frac{1}{10} = .10 \)

<sup>c</sup> \( p(Total) = \frac{87}{100} = .87 \)
tests severely underestimated the expected percentage of left-hemisphere dominance in the sample. Moreover, Table 2 revealed that the verbal fluency test failed to correlate significantly with the paragraph reading test.

An examination of the data of this study reveals a finding that may explain these results. Kinsbourne (1978), writing about his interhemispheric competition model, observed that the introduction of a verbal task to a finger tapping task would invariably cause performance in the latter to be compromised only in the hand contralateral to the dominant hemisphere. The hand ipsalateral to the dominant hemisphere would not be affected. Table 6 shows the mean finger tapping rates (right and left hand) of the baseline and dual task conditions for both competition tests. The results of a correlated t-test analysis between each set of mean rates indicate that a bilateral decrease in the rate of finger tapping consistently occurred with the introduction of a verbal task. The resultant t values are shown in Table 6 for each of the statistical comparisons. Analysis of right vs. left hand decrements yields statistically insignificant differences for the verbal fluency (t = .904, p > .10) and paragraph reading (t = .707, p > .10) tests. These findings very significantly fail to support Kinsbourne's (1978) hypothesis, i.e., rather than a single rate decrement in the hand contralateral to the dominant hemisphere, these results reveal equivalent bilateral decreases in both tests.

These findings are in general agreement with Briggs (1975) and Lomas and Kimura (1976), who also discovered varying degrees of
Table 6

The mean finger tapping rates of the baseline and dual task conditions for both hemispheric competition tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Hand</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Fluency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>84.20</td>
<td>89.23</td>
</tr>
<tr>
<td>Dual Task</td>
<td></td>
<td>80.50</td>
<td>84.56</td>
</tr>
<tr>
<td>t</td>
<td></td>
<td>5.89*</td>
<td>4.67*</td>
</tr>
<tr>
<td>Paragraph Reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>84.24</td>
<td>89.76</td>
</tr>
<tr>
<td>Dual Task</td>
<td></td>
<td>79.79</td>
<td>84.65</td>
</tr>
<tr>
<td>t</td>
<td></td>
<td>5.37*</td>
<td>6.34*</td>
</tr>
</tbody>
</table>

* = p < .01
bilateral reduction in tapping rates with the introduction of a verbal task. Since both competition tests estimated that approximately 50% of the sample was left-hemisphere dominant, perhaps random method variance was responsible for the percentage underestimates. This may explain why the two tests disagreed in 14 instances regarding the direction of cerebral dominance in the sample, and why the two tests failed to correlate significantly with each other.

The data concerning the scoring methods of the laterality procedures can be examined in two ways. On one hand, Jacksonian theorists have generally viewed cerebral dominance on a continuum. To these theorists it is clear that brain function is dynamic in nature and that cerebral dominance is relative rather than absolute (Zangwill, 1960). Accordingly, it is believed that language dominance can be measured only on a ratio scale. The adoption of one scoring method over another is considered to have important empirical consequences which can lead to quite different hypotheses about the nature of a subject's cerebral dominance (Krashen and Harshman, 1972; Marshall, 1973).

Conversely, traditional theorists have emphasized the need for a straightforward index of laterality, not a ratio measure of underlying brain asymmetry. Their belief is that the neuropsychologist is typically involved in a decision-making process, and that he is interested only in ascertaining the direction of a patient's cerebral dominance (i.e., right or left). Ironically, choosing the proper scoring method is as important to these theorists as it is.
to the Jacksonians, despite the polar differences in their respective attitudes toward cerebral dominance.

It should be recalled from Table 1 that the obtained percentages of left-hemisphere dominance within each test were constant. A particular test's set of scoring methods never had differential effects on the selection process of that test. In other words, the direction of a subject's determined cerebral dominance did not vary according to the scoring methods used in that test. Moreover, the matrix shown in Table 2 illustrates that the scoring methods within each test correlated highly with each other in a linear manner. These results suggest that the assumption that some scoring methods are superior to others is arbitrary in nature, and therefore fails to increase the understanding of the clinical measurement of cerebral dominance.

Certainly the findings of this study make it clear that more intensive research is required before laterality tests can have a place in neuropsychological assessment. The possibilities of future research are clearly evident. For instance, this investigation has shown that predicting the infrequent event (i.e., right-hemisphere dominance) is both clinically and statistically difficult. It can be recalled that the probability of correctly predicting right-hemisphere dominance with the 4-pair dichotic listening test was .055. Ironically, studies of the nature of right-hemisphere dominance are relatively rare in the literature. Perhaps concentrated study of this area should be seriously entertained by future researchers.
An example of such a study can be found in a recent unpublished paper by Carter, Hohenegger, and Satz (1980). In this paper the authors attempt to revise the antecedent base rates of cerebral dominance suggested by Satz (1977). One of their reasons for doing so is that they discovered that there is a slightly higher probability that an individual will receive a lesion in the right hemisphere \((p = .52)\) than in the left hemisphere \((p = .48)\). Satz (1977) had assumed that these probabilities were equivalent. Consequently, the authors modify Satz's (1977) theoretical model to include the possibility of bilateral dominance in right-handers, a characteristic traditionally considered unique to left-handers. (Interestingly, the authors confirm Satz's earlier base rates as still having more clinical relevance to neuropsychological assessment at this time.)

In conclusion, it is clear that this present investigation has presented some very equivocal finding regarding laterality testing. From a technical viewpoint, it is not unreasonable to therefore conclude that one of the most powerful laterality procedures remains the Wada sodium amytal test.
QUESTIONNAIRE

If you would like to participate in this study, please answer the following questions:

Which hand do you usually use:

1. To write? L R
2. To throw a ball? L R
3. To hold a tennis or badminton racket? L R
4. To strike a match? L R
5. To cut with a pair of scissors? L R
6. To guide a thread through the eye of a needle? L R
7. At the top of a broom while sweeping? L R
8. At the top of a shovel when moving snow or sand? L R
9. To deal playing cards? L R
10. To hammer a nail? L R
11. To hold a toothbrush while cleaning your teeth? L R
12. To unscrew the lid of a jar? L R

Is your father left-handed or right-handed? L R

Is your mother left-handed or right-handed? L R

Do you have an uncorrected or corrected hearing problem? Y N

Are you currently being treated for a neurological disorder? Y N

Have you ever been given an EEG? Y N

All information will be kept confidential and will not be used in any unethical manner. All questionnaires will be destroyed at the termination of the study.

Thank you for your assistance.
It was pet day at the fair. The children were waiting for the parade of animals to begin. They had trained their pets to do many different tricks. Among them was a tall boy whose goat made trouble for him. It kicked and tried hard to get away. When it heard the band it became quiet. During the parade it danced so well that it won a prize.
Airplane pilots have many important jobs. They fly passengers, freight, and mail from one city to another. Sometimes they make dangerous rescues in land and sea accidents, and drop food where people or herds are starving. They bring strange animals to our zoos. They also serve as traffic police and spot speeding cars on highways.
Hundreds of years ago, most of Europe was a very poor region. But China, a large country in eastern Asia, had many of the comforts of a rich civilized nation. Only a few people from Europe had visited this distant region. One was the famous Marco Polo. He learned some of the languages that were spoken in China and served its great ruler for many years.
The eager spectators who had cheered the plucky Warriors through eight hard-fought innings were silent. Only a run was required to defeat the much feared Champions, who had previously defeated all opponents. The spectators had earlier criticized the umpire severely. Now their faces were tense with excitement as the players took their positions.
Anna Thompson of South Boston, employed as a scrub woman in an office building, reported at the City Hall Station that she had been held up on State Street the night before and robbed of fifteen dollars. She had four little children, the rent was due, and they had not eaten in two days. The officers, touched by the woman's story, made up a purse for her.
The American liner New York struck a mine near Liverpool Monday evening. In spite of a blinding snowstorm and darkness the sixty passengers, including eighteen women, were all rescued, though the boats were tossed about like corks in a heavy sea. They were brought into port the next day by British steamer.
### SCORE SHEET FOR DICHOTIC LISTENING TEST

#### 3 pairs

<table>
<thead>
<tr>
<th>Right Channel Ear</th>
<th>Left Channel Ear</th>
</tr>
</thead>
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<td>1. 1 18 4</td>
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<td>2. 5 1 14</td>
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<td>3. 1 12 15</td>
<td>3. 4 5 13</td>
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<tr>
<td>4. 13 10 5</td>
<td>4. 18 1 12</td>
</tr>
<tr>
<td>5. 8 9 4</td>
<td>5. 3 2 1</td>
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<tr>
<td>6. 8 18 1</td>
<td>6. 2 15 10</td>
</tr>
<tr>
<td>7. 12 13 1</td>
<td>7. 2 18 8</td>
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<td>8. 10 12 14</td>
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<td>9. 12 1 13</td>
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**Total**

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**SCORE SHEET FOR DICHOTIC LISTENING TEST**

4 pairs

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Total | Total

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