A Continuum of Cerebral Dominance for Speech Perception?*

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ABSTRACT

A group of 22 unselected adults and a group of 30 right-handed male adults were tested on a series of handedness measures and on a dichotic CV-syllable test. Multiple regression methods were used to determine a correlation coefficient between handedness measures and dichotic ear advantages of .69 (p < .05) for the first group and of .54 (p < .01) for the second group. Implications of these findings for the concept of cerebral dominance are discussed.

Cerebral dominance for language is commonly treated as a discrete two-, or at most three-, valued variable. This is largely due to the nature of the observations that support the concept and its operational definition. For as Semmes (1968:11) has remarked, "...the concept is little more than a label, a restatement of the findings that lesions of one hemisphere produce deficits that lesions of the other hemisphere do not." Nonetheless, the suspicion that individuals may vary in their degree of hemispheric asymmetry has been repeatedly expressed in the literature (e.g., Zangwill, 1960; Hecaen and Ajuriaguerra, 1964). Often the suspicion arises in discussion of left-handed individuals in whom the severity and duration of aphasia tends to be reduced. For such cases "greater hemispheric equipotentiality" may be hypothesized (Subirana, 1958) and the intra-carotid sodium amytal test has provided direct evidence of this: some left-handers display disturbance of speech upon injection of either hemisphere (Milner, Branch, and Rasmussen, 1966). Luria (1966) has extended the hypothesis to include right-handed individuals. From observations of some 800 patients he concludes that individual differences in degree of aphasic disturbance "cannot be entirely explained by the severity of the lesion....The degree of dominance of one hemisphere in relation to lateralized processes such as speech varies considerably from case to case" (p. 89).

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While there may be no reason to doubt the generality of Luria's conclusions, they were necessarily reached by relatively coarse, ordinal measurement of aphasic disturbance in an arduously accumulated population of patients. The advent and refinement of the dichotic technique developed by Kimura (1961a, 1961b) have made it possible to test Luria's hypothesis on normal subjects. As known, subjects asked to recognize dichotically presented speech sounds tend to perform better on sounds presented to their right ears. Kimura (1961a, 1961b, 1967) has hypothesized that this right-ear advantage reflects the greater efficiency of the contralateral pathway, under conditions of dichotic competition, and dominance of the left hemisphere for language functions. Her own and others' work have by now amply supported this interpretation.

However, one aspect of the ear advantages deserves more experimental attention: individuals differ quite widely in the size and direction of their ear advantages. Variations in direction (left ear/right ear) are almost certainly associated with variations in the language dominant hemisphere. Kimura (1961b) found that patients, known by sodium amytal test to have speech represented in the left hemisphere, were more accurate in reporting dichotic speech sounds presented to their right ears, while patients known to have right hemisphere speech representation were more accurate on those presented to their left ears. Furthermore, groups of left-handed subjects [among whom there is likely to be a fair number of individuals having speech represented in the right hemisphere (Milner, Branch, and Rasmussen, 1966)] show reduced mean right-ear advantages or mean left-ear advantages (Bryden, 1965, 1970; Curry, 1967; Satz, Achenbach, Pattishall, and Fennel, 1965; Zurif and Bryden, 1969).

But variations in the size of the ear advantage within homogeneous handedness groups are more puzzling. As was earlier remarked, two conditions are presumed necessary for an ear advantage to occur in dichotic studies: greater efficiency of the contralateral pathway and cerebral dominance for language. To which of these sources is the variability in ear advantages to be attributed? To both? To neither?

Here two facts may serve us in good stead. First is the known relation between handedness and cerebral dominance for language. Second is the fact that handedness may be measured reliably along a continuum (Benton, Myers, and Polder, 1962; Benton, 1965; Satz, Achenbach, and Fennel, 1967; Annett, 1970). For if some portion of the variability in ear advantage is, indeed, due to variations in the degree of cerebral dominance, we should expect to find a significant correlation between ear advantages and continuous measures of handedness. A significant association between these variables has, in fact, been reported by Satz and his colleagues (Satz, Achenbach, and Fennel, 1967). They showed that the association increased if handedness measures were used to reclassify self-classified left- and, to some extent, right-handers. Our approach, in contrast, is to scrap the categories, to treat both handedness and dichotic ear advantage as continuous variables, and to measure the correlation between them.

For children this correlation has already been demonstrated. Orlando (1971) used a dichotic consonants test (of the type used in the present study) on 4th and 6th grade boys. He found a significant correlation between ear advantages and scores on a battery of dexterity tests, for both right- and left-handed groups. However, the subjects of these experiments were children for
whom both dominance and handedness may still have been in the process of development. The present report is a preliminary account of a study extending the method to adults for whom dominance and handedness may be presumed stable.

METHOD

Subjects

Results are reported here for two groups of subjects screened for normal hearing by audiometry. Group 1 consists of 22 unselected adults, including 4 right-handed and 1 left-handed female, 14 right-handed and 3 left-handed males. Group 2 consists of the 14 right-handed males of Group 1 together with 16 other right-handed males, added later to make a total of 30. Handedness classification is here based on answers to the six "primary questions" of Annett (1970): with which hand do you write, throw a ball, swing a racket, strike a match, hammer a nail, brush your teeth? A subject was classified as right- or left-handed only if he answered all six questions consistently.

Subjects were run in a dozen or so one-hour sessions distributed over roughly two weeks. They were tested individually in a series of handedness tasks on the first and last days. On the intervening days they were tested in groups of 4 on a series of dichotic listening tasks. They were paid for their work.

Handedness Tasks

Subjects were asked to perform on seven handedness tests, assessing three aspects of handedness (speed, strength, dexterity) that may or may not be related. They performed each task once on the first day and once on the last day. The order of the first six tasks was different for each subject and was reversed on the second run. The seventh task (strength of grip) was taken last on each day by all subjects. Hand order was counterbalanced within a subject beginning with the preferred hand. A list and brief description of the tasks for each hand on a single day follows:

1. Scissors. Time in seconds to cut a complex shape accurately (see Figure 1).
2. Tracing. Time in seconds to trace accurately a complex pattern between parallel lines 1 mm apart (see Figure 2).
3. Crawford Screws [a subtest of the Small Parts Dexterity Test (Crawford and Crawford, 1956)]. Number of small screws inserted by one hand, with support from the other, in 2 min.
4. Crawford Pegs (a subtest of the Small Parts Dexterity Test). Number of pegs inserted and washers mounted by one hand, with tweezers, in 2 min.
5. Tapping. Number of taps with metal stylus on metal plate, counted electrically over six 15-sec trials.
6. Purdue Pegboard. Number of pegs placed in a row over two 30-sec trials.
7. Stoelting Dynamometer. Total kilograms of pull on three trials.

The test-retest reliabilities of the last two tasks were less than .30 for the first group. Accordingly, only the first five (Scissors, Tracing, Crawford Pegs, Crawford Screws, and Tapping) were used for later analysis.
SCISSORS PATTERN
(Measure: time in seconds to complete)
TRACING PATTERN
(Measure: time in seconds to complete)

Fig. 2
**Dichotic Task**

Nine different dichotic tests were run, but data are reported here for only one: the consonant-vowel (CV) syllable stop consonant test. Six syllables, formed from the six English stops, /b, d, g, p, t, k/, followed by the vowel /æ/, were synthesized on the Haskins Laboratories parallel resonant synthesizer. A fully balanced, 60-item dichotic tape was then prepared. Each subject took this test twice in one day, with earphones reversed on the second run to distribute channel effects equally over the ears, and twice in a second day. This yielded a total of 240 trials per ear per subject.

**Scoring**

An adjusted difference score, right minus left (R-L), was computed for each subject, totaled over all runs on each task. For the handedness tasks, all scores, whether in seconds, number of completed items or kilograms of pull, were treated as frequency data. Using the normal distribution as an approximation to the binomial, the right hand score was expressed as a deviation from the expected mean, to yield a standard score \( Z = \frac{R-L}{\sqrt{R+L}} \).

For the dichotic test, the phi-coefficient of correlation between performance and ear of presentation was computed. Kuhn (1972) has shown that this index compensates for variations in observed laterality effects due to variations in overall performance. Equivalent to \( R-L/R+L \) at 50% performance (where the possible ear difference is at a maximum), the coefficient systematically and symmetrically increases the weight attached to a given ear difference, as performance departs from this level, and so permits comparison among laterality effects independent of their associated levels of performance. It is therefore peculiarly apt for use in a study of individual differences.

**RESULTS**

We begin with results for the 22 unselected adults. Figure 3 (left side) presents histograms of individual scores on two handedness tests: tracing and scissors. Both tests yield a significant mean right-hand advantage, but the scatter of scores is wide, especially for the scissors task, and the distributions are negatively skewed. Other handedness tests showed a similar pattern.

\[
Z = \frac{R - (R+L)}{2} = \frac{2R - (R+L)}{\sqrt{(R+L)/4}} = \frac{R-L}{\sqrt{R+L}}
\]
Figure 3: Distribution of laterality indices on tracing and scissors tasks for unselected adults (left) and 30 right-handed male adults (right).
On the dichotic consonants test (Figure 4 top) the distribution is more or less symmetrical around a mean right-ear advantage, as measured by the phi-coefficient, of .06. Test-retest reliabilities for lateral differences on the several tasks are moderately high (see Table 1), ranging from .69 for Crawford Screws to .93 for the scissors test. Table 2 displays intercorrelations among the tests. The lower four lines show values of the product moment correlation coefficient among the handedness tests: all are statistically significant and form, for this group of subjects, a relatively tight cluster. The top line shows values of the coefficient for the dichotic consonants test and each of the handedness tests: none of them reaches significance at the .05 level.

However, a composite index predicts the perceptual asymmetry considerably better than the single measures. Figure 5 plots normal deviates of the obtained ear advantage against normal deviates of the handedness tasks, weighted and combined according to the regression equation displayed on the figure. Four of the five handedness tasks—all except tapping—enter the equation and contribute significantly, at the .05 level or better, to the prediction. The multiple correlation coefficient is .69. The increase in the multiple coefficient over the simple coefficients suggests that the several handedness tasks measure distinct additive components of handedness.

The data reported so far are perhaps open to the objection that the group of unselected adults included several left-handers for whom some relation between handedness and degree of cerebral dominance might be expected. A more telling test of the relation is provided by the results for the homogeneous group of 30 right-handed males.

Figure 3 (right side) displays their performance on the scissors and tracing tasks: the means for the right-handers are shifted to the right relative to those for the unselected subjects, and the variability, though still striking, has been reduced. Figure 4 (bottom) displays the distribution of ear advantages: the mean has again shifted to the right, but the standard deviation is unchanged. Table 3 displays the test-retest reliabilities for lateral differences: they range from .38 for the Crawford Pegs to .70 for the dichotic consonants (a value identical to that for the unselected group). These are surprisingly low, and it seems likely that more extensive testing is necessary for a relatively homogeneous group such as this if adequate reliabilities are to be reached. This conclusion is supported by the intercorrelations of Table 4. There we see that only one pair of handedness tasks (Crawford Pegs and Crawford Screws) shows any significant correlation. On the other hand, two tasks (Scissors, Tracing) show moderate, but significant correlations with the dichotic scores.

Finally, Figure 6 plots the multiple regression equation. Here, only two of the handedness tasks (Scissors, Tracing) contribute significantly, at the .05 level or better, to prediction of the ear advantage. As might be expected on statistical grounds, the reduced handedness range yields a lower correlation coefficient than was found for the unselected group of adults: .54 instead of .69. However, since the sample size was larger, the coefficient is significant at a higher level.
Figure 4: Distribution of laterality indices on dichotic consonants test for 22 unselected adults (top) and 30 right-handed male adults (bottom).
Figure 5: Normal deviates of the obtained ear advantages as a function of normal deviates of four handedness tasks, weighted and combined according to the regression equation of 22 unselected adults.

\[ Z_1 = 0.8576 Z_2 + 0.6972 Z_3 \]

\[ Z_1 = -0.0900 Z_4 - 1.3026 Z_5 \]

- \( Z \) = dextrality index
- \( Z_1 \) = dichotic consonants
- \( Z_2 \) = Crawford Pegs
- \( Z_3 \) = tracing
- \( Z_4 \) = Crawford Screws
- \( Z_5 \) = scissors

UNSELECTED ADULTS

\( N = 22 \)

\( R = 0.69 \)

\( (p < 0.05) \)
Figure 6: Normal deviates of the obtained ear advantages as a function of normal deviates of two handedness tasks, weighted and combined according to the regression equation for 30 right-handed male adults.
TABLE 1

Test-retest reliabilities for unselected adults (N = 22)

<table>
<thead>
<tr>
<th>Test</th>
<th>Pearson r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotic (consonant)</td>
<td>.70</td>
</tr>
<tr>
<td>Tapping</td>
<td>.80</td>
</tr>
<tr>
<td>Scissors</td>
<td>.93</td>
</tr>
<tr>
<td>Tracing</td>
<td>.80</td>
</tr>
<tr>
<td>Crawford Pegs</td>
<td>.78</td>
</tr>
<tr>
<td>Crawford Screws</td>
<td>.69</td>
</tr>
</tbody>
</table>
**TABLE 2**

**INTERCORRELATIONS (PEARSON r) FOR PHI-COEFFICIENT OF DICHOTIC CONSONANT TEST AND Z-SCORES OF HANDEDNESS TESTS FOR UNSELECTED ADULTS (N = 22)**

<table>
<thead>
<tr>
<th></th>
<th>TAPPING</th>
<th>SCISSORS</th>
<th>TRACING</th>
<th>CR. PEGS</th>
<th>CR. SCREWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotic</td>
<td>-.05</td>
<td>-.14</td>
<td>.21</td>
<td>.21</td>
<td>.26</td>
</tr>
<tr>
<td>Tapping</td>
<td>.73***</td>
<td>.66***</td>
<td>.66***</td>
<td>.60**</td>
<td>.53*</td>
</tr>
<tr>
<td>Scissors</td>
<td></td>
<td>.76***</td>
<td>.81***</td>
<td>.69***</td>
<td></td>
</tr>
<tr>
<td>Tracing</td>
<td></td>
<td></td>
<td>.66***</td>
<td>.69***</td>
<td>.66***</td>
</tr>
<tr>
<td>Crawford Pegs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* P < .05
** P < .01
*** P < .001
### TABLE 3

**Test-retest reliabilities for right-handed male adults (N = 30)**

<table>
<thead>
<tr>
<th>Test</th>
<th>Pearson R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotic (consonant)</td>
<td>.70</td>
</tr>
<tr>
<td>Tapping</td>
<td>.44</td>
</tr>
<tr>
<td>Scissors</td>
<td>.44</td>
</tr>
<tr>
<td>Tracing</td>
<td>.68</td>
</tr>
<tr>
<td>Crawford Pegs</td>
<td>.38</td>
</tr>
<tr>
<td>Crawford Screws</td>
<td>.44</td>
</tr>
</tbody>
</table>
TABLE 4

INTERCORRELATIONS (PEARSON r) FOR PHI-COEFFICIENT OF DICHOTIC CONSONANT TEST AND Z-SCORES OF HANDEDNESS TESTS FOR RIGHT-HANDED MALE ADULTS (N = 30)

<table>
<thead>
<tr>
<th></th>
<th>TAPPING</th>
<th>SCISSORS</th>
<th>TRACING</th>
<th>CR. PEGS</th>
<th>CR. SCREWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dichotic</td>
<td>- .17</td>
<td>.40*</td>
<td>.36*</td>
<td>.03</td>
<td>-.14</td>
</tr>
<tr>
<td>Tapping</td>
<td>-.01</td>
<td>.05</td>
<td>-.03</td>
<td>-.03</td>
<td>-.13</td>
</tr>
<tr>
<td>Scissors</td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
<td>-.10</td>
</tr>
<tr>
<td>Tracing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crawford Pegs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.35*</td>
</tr>
</tbody>
</table>

* P < .05
DISCUSSION

The results are consistent with the findings of Orlando (1971). Individual differences in the size of the ear advantage covary significantly with differences in the degree of measured handedness. Taken together, the two studies provide substantial support for the hypothesis that cerebral dominance for speech perception should be viewed as a continuum across individuals. The studies are, of course, restricted to a single type of perceptual process; phonetic recognition of English stop consonants. However, we may be justified in speculating on the implications of such findings, should they be confirmed and extended, for a model of the mechanism of cerebral dominance.

A main implication is that the concept of dominance, whether for language or handedness, must be expanded. As it stands, the concept is merely a summary restatement of the effects of unilateral lesions. Obviously, this cannot account for variations over more than three values: left, right, and center. If we take any group for whom this value is fixed for both language and handedness—say, a group of right-handers with left hemisphere specialized for the major language functions—we must now account for two facts. First, the scores of individuals within this group vary continuously on measures of both handedness and language function. Second, these two forms of continuous variation are correlated; that is to say, a significant proportion of the variance on both types of test has a common source.

The traditional concept of cerebral dominance (or hemispheric specialization) could, at best, account only for an association between handedness and speech. For example, if it could be shown that both speech and manual skills have a common source in, say, neural specialization for rapid, sequential behavior and, further, that there were good reasons why this capacity was concentrated in a single cerebral hemisphere, we would not be obliged to extend the concept of dominance beyond its present anatomical content. Just such an argument has, in fact, been made by Semmes (1968). From an extensive study of brain-injured war veterans she argues that "the phylogenetic trend toward increased localization of function" (cf. Geschwind, 1971; Geschwind and Levitsky, 1968) has issued in focal organization of the left hemisphere and its consequent specialization for "behaviors which demand fine, sensori-motor control, such as manual skills and speech" (p. 11).

However, the first fact—if it be one—namely, that lateralization for certain functions varies continuously across individuals [and, incidentally, perhaps within individuals across functions (cf. Day and Vigorito, 1972; Cutting, 1972)] cannot be accounted for without extending our concept of lateralization to include a dynamic, variable component. It seems, in fact, that we should be viewing lateralization not simply as a fixed anatomical characteristic, but rather as a process or function governing the relations between hemispheres, and open to variation within and across individuals. Just how to characterize this process we have, as yet, little knowledge to suggest.

Finally, we should stress that the data of the present study are no more than preliminary, both methodologically and substantively. Methodologically, future work will have to concentrate on selecting and refining the measures of both handedness and language dominance to achieve a fuller sampling of skills and higher test-retest reliabilities. Substantively, the study has examined
but one aspect of a single language function. Dichotic methods are necessarily restricted to the study of perceptual and short-term memorial processes. But within these limits, the technique has already been adapted to the study of a wide range of linguistic functions, from prosody to syntax and meaning.

Ultimately dichotic testing may even play a valuable clinical role, answering, in some measure, the need expressed by Luria when he wrote: "It is easy to see that our lack of knowledge concerning the degree of dominance of the hemisphere in different persons and with respect to different functions is a great handicap in the clinical investigation of patients with local brain lesions" (1966:90).

REFERENCES


