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A Continuum of Lateralization for Speech Perception?[1]

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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.

However great the temptation to regard the left cerebral hemisphere as the exclusive organ of language, Hughlings Jackson (1874) cautioned long ago that its dominance cannot be absolute. Indeed, the dominant hemisphere is not, in every case, the left. Almost as early as the idea of left hemisphere speech representation won acceptance, individual variations were noted. Apparent reversals in the relations between the hemispheres with respect to speech processes occur in about one third of the left-handed population (Milner, Branch & Rasmussen, 1966; Zangwill, 1967). Reversals of dominance, however, are more rarely met than less extreme variations in cerebral asymmetry, and the suspicion that individuals may vary in their *degree* of hemispheric asymmetry has been repeatedly expressed in the literature (e.g., Zangwill, 1960; Hecaen & Ajuriaguerra, 1964).

The suspicion first arises in discussion of aphasia among left-handed individuals in whom the severity and duration of language disturbances tends to be reduced. For such cases "greater hemispheric equipotentiality" may be hypothesized (Subirana, 1958) and the intracarotid

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sodium amytal test has provided direct evidence of this: Some left-handed patients display disturbance of speech upon injection of either hemisphere (Milner *et al.*, 1966). Luria (1966) has extended the hypothesis to include right-handed individuals. From observations of a large number of aphasic 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)."

While there may be no reason to doubt the generality of Luria's conclusions, they were necessarily reached by relatively coarse evaluation of aphasic disturbance. Even without the question of the unidimensional or multidimensional character of aphasic impairment, measurement of its severity poses formidable problems. Fortunately, 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. Our experience with dichotic rivalry experiments has shown that individuals differ quite widely in the direction and degree of their ear advantages. Kimura (1961b) discovered that variations in direction (whether right or left ear is superior) are associated, at least on a statistical basis, with differences in hemispheric lateralization. She found that patients, known by intracarotid 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 show reduced mean right-ear advantages or mean left-ear advantages, consistent with more nearly equipotential hemispheric relations, or with reversal in the usual direction of asymmetry (Bryden, 1965, 1970; Curry, 1967; Satz, Achenbach & Fennell, 1965; Zurif and Bryden, 1969).

However, variations in the *degree* of ear advantage within homogeneous handedness groups are more puzzling. Two conditions are presumed necessary for an ear advantage to occur in dichotic speech studies: greater efficiency of the contralateral pathways, under conditions of dichotic competition, and hemispheric specialization for language. To which of these sources is the variability in ear advantages to be attributed? To both? To neither? Our purpose was to frame a symtematic approach to these questions.

Here two facts may serve us in good stead. First is the known relation between handedness and cerebral lateralization for language. Second is the fact that handedness is not simply a two-valued variable, but may be measured along a continuum (Benton, Meyers & Polder, 1962; Benton, 1965; Satz *et al.*, 1967; Annett, 1970). If some portion of the variability in ear advantage is due to variations in the degree of cerebral lateralization, we might expect to find a significant correlation between ear advantages and measures of handedness. A significant dichotomous association between these variables has, in fact, been reported by Satz and his colleagues (Satz *et al.*, 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 ignore the categories, to treat both handedness and dichotic ear advantage as continuous variables, and to measure the correlation between them. If the degree of lateral asymmetry of manual praxis correlates significantly with the degree of perceptual asymmetry on an appropriate auditory rivalry test, the hypothesis is supported that each is an expression of the same underlying principle of hemispheric specialization (cf. Semmes, 1968; Kimura, in press) and that this principle admits of continuous variations in degree across individuals.

For children the correlation has already been demonstrated. Orlando (1971) used a dichotic consonants test (of the type used in the present study) on schoolboys 8–10 years of age. He found a significant correlation between ear advantages and asymmetry scores on a battery of manual dexterity tests, for both right- and left-handed groups. However, the subjects of these experiments were children for whom both speech lateralization and handedness may still have been in the process of development. The present study extends this method to adults for whom speech lateralization 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 young 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 1-hr sessions distributed over roughly 2 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.
2. Tracing. Time in seconds to trace accurately a complex pattern between parallel lines 1 mm apart.
3. Crawford Screws [a subtest of the Small Parts Dexterity Test (Crawford & 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.

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 ($z = R - L/\sqrt{R + L}$).[2]

For the dichotic test, the phi-coefficient of correlation between performance and ear of presentation was computed. Kuhn (1973) 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 1 (left side) presents histograms of individual scores on two handedness tests: tracing

[2] $z = R - (R + L)/2/((1/2)^2 N)^{1/2}$, where R = right-hand score, L = left-hand score, $N = R + L$. Then, $z = R - (R + L)/2/((R + L)/4)^{1/2} = 2\ R - (R + L)/(R + L)^{1/2} = R - L/(R + L)^{1/2}$.

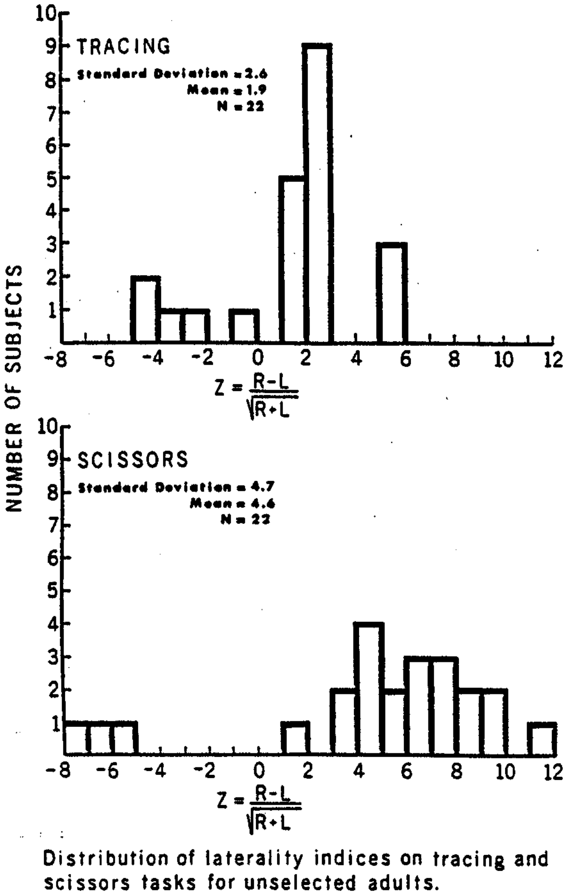
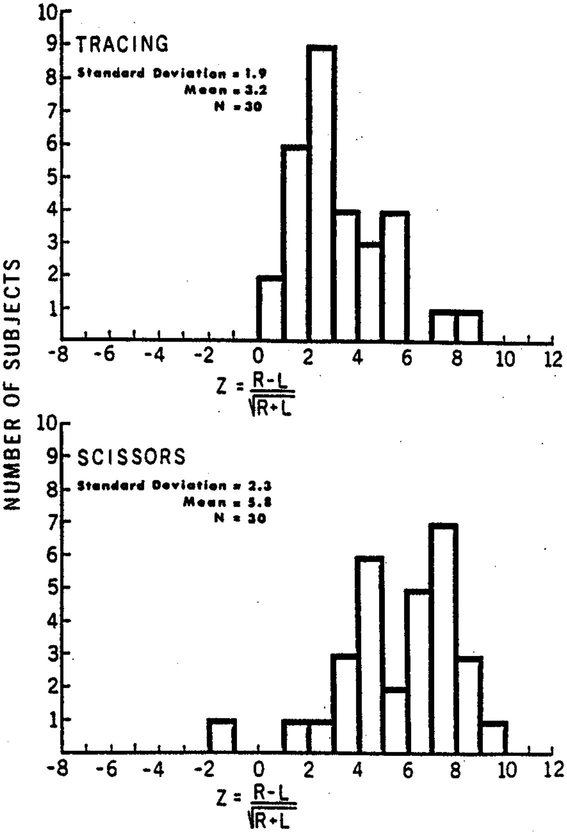


FIG. 1. Distribution of laterality indices on tracing and scissors tasks for 22 unselected adults (left) and 30 right-handed male adults (right).

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. On the dichotic consonants test (Fig. 2, 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. At the same time the correlations are not so



Distribution of laterality indices on tracing and scissors tasks for right-handed male adults.

FIG. 1 (cont.)

TABLE 1
TEST–RETEST RELIABILITIES FOR UNSELECTED ADULTS (N = 22)

Test	Pearson R
Dichotic (consonant)	.70
Tapping	.80
Scissors	.93
Tracing	.80
Crawford Pegs	.78
Crawford Screws	.69

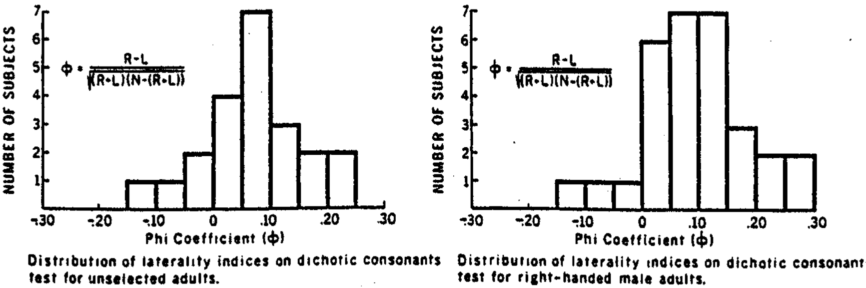


FIG. 2. Distribution of laterality indices on dichotic consonants test for (top) 22 unselected adults—SD = .10. Mean = .06. $N = 22$—and (bottom) 30 right-handed male adults—SD = .10. Mean = .10. $N = 30$.

high as to suggest complete redundancy among the various measures of handedness.

The top line of Table 2 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 3 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 the cerebral asymmetry underlying handedness.

TABLE 2

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

	Tapping	Scissors	Tracing	Crawford Pegs	Crawford Screws
Dichotic	−.05	−.14	.21	.21	.26
Tapping		.73***	.66***	.66***	.60**
Scissors			.76***	.81***	.53*
Tracing				.66***	.69***
Crawford Pegs					.66***

* $p < .05$.
** $p < .01$.
*** $p < .001$.

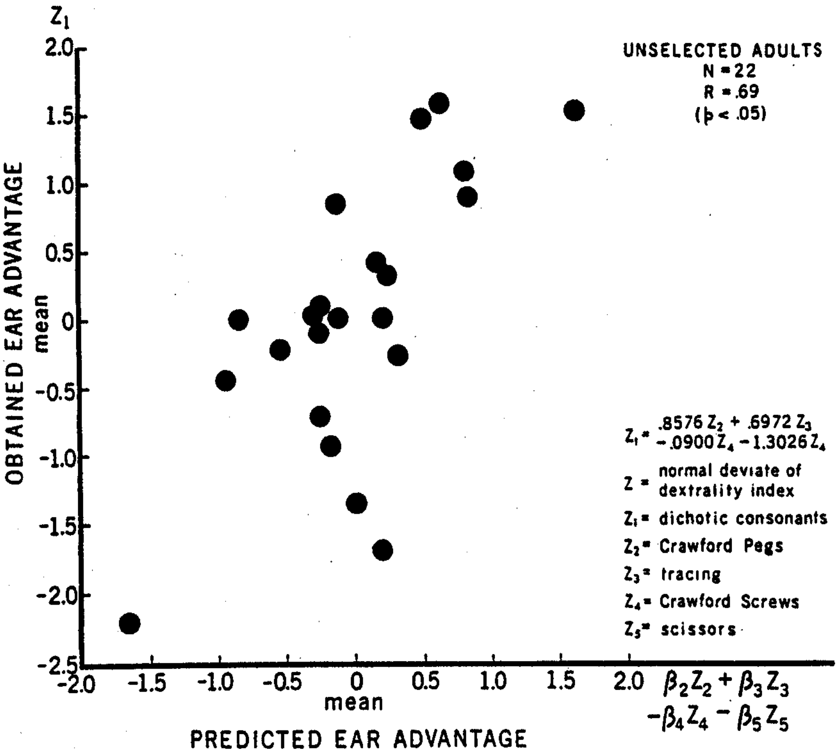


FIG. 3. Normal deviates of the obtained ear advantages as a function of normal deviates of four handedness tasks, weighted and combined according to the regression equation for 22 unselected adults.

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 lateralization of speech might be expected, whether or not the hypothesis of a continuum of cerebral dominance can be supported. A more telling test of the relation between manual and speech lateralization is provided by the results for the homogeneous group of 30 right-handed males.

Figure 1 (right side) displays their performance on the Scissors and Tracing tasks: the means for the group of right-handers are shifted to the right relative to the means for the unselected subjects. Although, as is to be expected, the variability is reduced, it is still striking. Figure 2 (above) displays the distribution of ear advantages: The mean is again shifted to the right, but the standard deviation is unchanged. Table 3 displays the test-retest reliabilities for differences in performance level between the sides. All are positively correlated, but the reliabilities of the hand difference scores are markedly lower, on the whole, for the

TABLE 3
TEST–RETEST RELIABILITIES FOR RIGHT-HANDED MALE ADULTS ($N = 30$)

Test	Pearson R
Dichotic (consonant)	.70
Tapping	.44
Scissors	.44
Tracing	.68
Crawford Pegs	.38
Crawford Screws	.44

homogeneous than for the unselected group. And, in Table 4, we note that inter-test correlations among handedness scores for the homogeneous group are also low: Only one pair of handedness tasks (Crawford Pegs and Crawford Screws) shows significant correlation. At the same time, two tasks (Scissors, Tracing) show moderate, but significant correlations with the dichotic scores.

Finally, Fig. 4 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.

DISCUSSION

The results are consistent with the findings of Orlando (1971): Individual differences in the degree of ear advantage covaried significantly with differences in the degree of measured handedness. Taken together, the two studies support the hypothesis that cerebral lateralization for

TABLE 4
INTERCORRELATIONS (PEARSON R) FOR PHI-COEFFICIENT OF DICHOTIC CONSONANT TEST AND z-SCORES OF HANDEDNESS TESTS FOR RIGHT-HANDED MALE ADULTS ($N = 30$)

	Tapping	Scissors	Tracing	Crawford Pegs	Crawford Screws
Dichotic	−.17	.40*	.36*	.03	−.14
Tapping		−.01	.05	.15	−.01
Scissors			−.03	.03	−.13
Tracing				.01	−.10
Crawford Pegs					.35*

* $p < .05$.

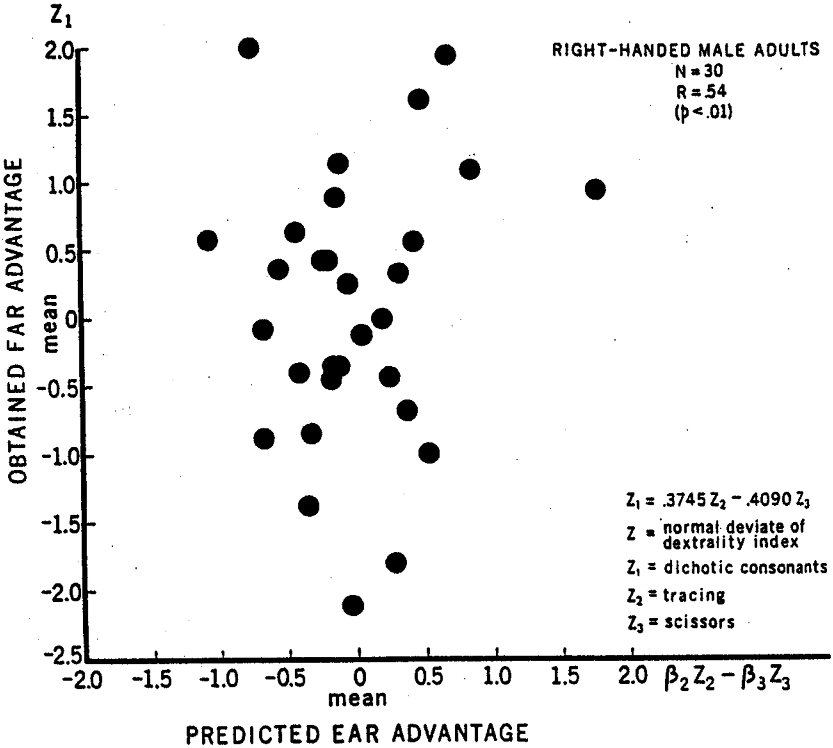


FIG. 4. Normal deviates of the obtained ear advantages as a function of normal deviates of two handedness tasks, weighted and combined according to the regression equation for 30 right-handed male adults.

speech perception and for manual praxis should be viewed as gradients. Furthermore, since these two forms of continuous variation across individuals are correlated, we may suppose that both gradients derive, in part, from a common source. The studies are, of course, restricted to a specific language process: phonetic recognition of English stop consonants. However, we may be justified in speculating on their implications, should the findings be confirmed and extended.[3]

A main implication is that the concept of hemispheric specialization must be elaborated to take account of the link between speech perception and manual praxis. The traditional concept, though it acknowledges a connection between speech and handedness, provides no rationale for understanding its nature. Semmes (1968), Geschwind (1971) and Ki-

[3] Since this research was completed, Studdert-Kennedy and Foard (in preparation) have replicated the findings on a sample of 32 right-handed male adults. They determined a significant multiple correlation coefficient of 0.51 between dichotic ear advantages on a CV syllable test and two handedness tasks.

mura (in press) have recognized that the link is fundamental to an understanding of cerebral specialization and of language itself. If it could be shown that both speech and manual skills have a common source in neural specialization for rapid, sequentially organized, rule-governed behavior and, further, that there were good reasons why this capacity was concentrated in a single cerebral hemisphere, the concept of cerebral dominance would cease to be a mere summary statement and become a hypothesis capable of generating new questions. Just such an argument has, in fact, been made by Semmes (1968). She argues that "the phylogenetic trend toward increased localization of function" (cf. Geschwind, 1971; Geschwind & Levitsky, 1968) issued in focal organization of the left hemisphere and its consequent specialization for "behaviors which demand fine, sensorimotor control, such as manual skills and speech (p. 11)."

The hypothesis of overlapping cerebral control of speech and manual skills is supported by the long-known frequent association of disorders of skilled movement (the apraxias) with disease of the left hemisphere. The nature of apraxic disorder has recently been clarified by the work of Kimura and her colleagues (Kimura, in press). They have shown that, in addition to impairment on traditional apraxia tests of practiced skills, patients with left hemisphere lesions show deficits in reproduction of meaningless movement sequences, but not in copying static hand postures. Two further findings are also relevant. First, the discovery by Kinsbourne and Cook (1971) and its confirmation by Hicks (in press) that motor decrement in normal subjects is produced on the right hand by concurrent speaking, but not on the left. Second, an asymmetry recently discovered by Kimura (1973): the free hand movements that frequently accompany speaking are highly lateralized to the hand contralateral to the speech-dominant hemisphere. Each of these results suggests a link between the neural organization of speech and temporally-patterned motor behavior of the upper extremities. The present study specifically implicates speech *perception* with lateralization of manual function. In sum, there is a number of indications that certain manual skills and speech mechanisms have a common source.

However, the fact that lateralization for these functions varies continuously across individuals cannot be accounted for without further extending the 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 (although current research finds congenitally-based anatomical differences between the hemispheres (cf. Geschwind & Levitsky, 1968; Wada, 1974)), but rather as a process or function governing the relations between hemispheres, and open to variation among individuals. Just how to characterize this process we have, as yet, little knowledge to suggest.

We might hypothesize, with Gazzaniga (1970), that whatever genetic and ontogenetic factors predispose an individual to rely, more or less, on his left hemisphere for speech, predispose him to rely on that hemisphere to a like degree in the guidance of certain actions of the leading right hand. Both hemispheres then participate in speech perception to a degree that may be gauged by the degree of lateralization of skilled hand use. Ambilaterality in manual performance thus implies bilateral representation of speech. However, the obtained relation between the two asymmetries is far from perfect: the correlation accounts for no more than one-quarter to one-half of the variation in the two sets of scores. Whether the correlation is limited by other unshared sources of variation in perceptual and manual asymmetries, or by deficiencies in the tests, we cannot at present determine.

Certainly from a psychometric point of view, the data of this study are hardly satisfactory. Particularly unsettling might seem to be the low reliabilities of the lateral difference scores on hand performance for the group of right-handers. However, the fact that the unselected group of subjects displayed acceptably high reliabilities suggests that the problem is not intrinsic to the tests or to the procedures for administering them, but is a function of the groups themselves. And, in fact, it is not truly paradoxical that the more homogeneous group should yield the lower reliabilities. Provins and Cunliffe (1972) also obtained low reliabilities of left–right differences in performance of manual tasks among subjects matched for degree of hand preference. They point out that, on a well-practiced task such as handwriting, these individuals give difference scores that are consistent in *direction* from one performance sample to the next, and perform consistently from time to time for each hand taken separately, but that such left and right variations as occur tend to be out of phase, so that correlations between difference scores are low.

In this connection it is worth noting that tracing and cutting with scissors, both practiced tasks generally performed with the writing hand, were the only significant predictors of the ear advantage in the group of right-handers. Tracing was also the best predictor for the unselected group. A practical conclusion to be drawn, and one supported by other students of handedness (Oldfield, 1971; Provins & Cunliffe, 1972), is that well-practiced tasks, which are nearly always carried out with the same hand, should be used for measurement of manual laterality. This would insure that differential experience in use of the hands, otherwise a potent uncontrolled variable, does not contribute to the variance. We thus homogenize performance among subjects on their preferred hand and permit individual differences in performance with the nonpreferred hand to exert a maximal effect on the lateral difference score. If the goal of the investigation is to assess relations between lateral differences in manual skill and cerebral organization, the most appropriate measures are of individual differences in degree of transfer of a unimanual motor pattern to the unpracticed side.

In conclusion, we should stress that the data of the present study are preliminary, both methodologically and substantively. Methodologically, future work will have to concentrate on selecting and refining the measures of both handedness and cerebral representation of language processes. And if multiple-regression analysis is to be used, much larger samples than those of this study will be necessary. 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 (Zurif, 1974).

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, p. 90).

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