RELATIONS AMONG HANDEDNESS, HEMISPHERE LOCALIZATION, AND PERCEPTUAL SKILLS OF THE RIGHT HEMISPHERE

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ABSTRACT

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AND PERCEPTUAL SKILLS OF THE RIGHT HEMISPHERE

By

Christopher Gilbert

Left-handedness has been linked with increased variability of cerebral localization for speech. This condition in turn has been associated with deficits in some perceptual skills thought to be mediated by the right hemisphere. To test these relationships, four handedness groups of 16 members each were formed: strongly right-handed, strongly left-handed, weakly right-handed, and weakly left-handed. The designation of "weak" indicated decreased lateral asymmetry and was based on both a manual dexterity test and a hand-usage questionnaire. Subjects were tested on three perceptual measures (Block Design, Object Assembly, and facial recognition) intended to assess primarily right-hemisphere abilities, and two reaction-time (RT) tasks designed to detect lateral asymmetry in speed of information-processing. The first RT measure presented letter-pairs by tachistoscope in the left or right visual fields. An identification of letter-pairs which were physically dissimilar but symbolically identical (Aa) was considered more language-dependent than identification of letter-pairs which were physically identical (AA). It was predicted that RTs to right-field presentation of "symbolic" pairs would be faster, reflecting the more direct (non-commissural) sensory transmission pathways between the right visual field and the

left hemisphere. Physically-identical pairs were expected to yield a left-field superiority. There was little support for either prediction; the groups did not differ significantly in their visual field biases, nor was there any consistent bias across groups, so letter RTs were not useful for determining speech lateralization.

The second RT measure was a face-discrimination task in which single faces were presented tachistoscopically for identification (4-face memory set). This measure revealed an overall left-field bias (RT faster to left visual field, ave. 12.5 msec., $p < .01$), which was expected because of right-hemisphere specialization for face processing. No differences were found among the four handedness groups; the face-processing bias was unaffected by the handedness classification. This unexpected result suggested that right-hemisphere perceptual specializations are more firmly located in the right hemisphere than speech is in the left hemisphere.

When analyzed with multivariate analysis of variance, the four handedness groups did not differ significantly in their performance on the other three perceptual tests. Since the variables of handedness had very low correlations with each other, each variable was then examined separately: the effects of writing hand, asymmetry of manual dexterity, and consistency of hand-usage produced no significant differences in either the perceptual measures of the reaction-time measures. Sex was a significant effect for facial recognition, with females superior. The presence of left-handedness in the subject's family produced significantly worse performance on the facial recognition test ($p < .0001$) regardless of the subject's own handedness. This result is congruent with other evidence that familial left-handedness is associated with decreased hemisphere specialization for speech, since the partial presence of speech function in the right hemisphere (inferred from handedness data) has been associated with a drop in non-verbal perceptual abilities. J. Levy's "interference" theory of neurological incompatibility of verbal and non-verbal functions was discussed in light of this finding.

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By

David

Christopher Gilbert

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INTRODUCTION

In spite of the lack of strong morphological differences between the two hemispheres of the human brain, there appear to be large functional differences in the way they process information. Most of our early knowledge of hemisphere differences came from observing results of brain damage and from electrical stimulation of the living cortex. But the recent appearance of medically-created split-brain subjects (persons with severed cerebral commissures) has allowed the first practical testing of each hemisphere in functional isolation, since stimuli presented to one hand or one visual field of such persons are received principally in the contralateral hemisphere. Split-brain research as a whole has revealed the cerebral hemispheres as fairly specialized for specific perceptual cognitive functions. Localization of speech production in the left hemisphere seems to be the most basic lateral asymmetry; the most notable recent general discovery is that much non-verbal perception, both visual and auditory, is similarly localized in the right hemisphere (see Benton, 1972, for a review).

Several authors (Bogen, 1969; Bakan, 1971; Ornstein, 1972) have characterized the left hemisphere's abilities as analytic and symbol-manipulating, while the non-dominant hemisphere is diffuse and "Gestalt-like" in function. Levy (1969) proposed a reason for the physical separation of symbolic and non-symbolic functions in the cerebrum:

possibly because of dissimilar neural organizations, analytic processing may be incompatible with the more diffuse non-symbolic processing. Semmes (1968) has suggested an overall difference between the two hemispheres, based on neuroanatomical research finding that the dominant ("speech") hemisphere is organized more discretely, corresponding point-to-point to sensory receptors, while the non-dominant hemisphere's sensory and motor connections are more diffuse and interconnected. This would seem to make the right hemisphere more suited for Gestalt-like perception, while organization of the dominant hemisphere would be more appropriate for discrete symbol manipulation. Semmes' evidence was derived from mapping of the human cortex, and fits well with other evidence of functional differences.

These broad generalizations to characterize an entire hemisphere's perceptual and motor functions may seem excessive, but they represent the first crude attempts to classify the emerging specializations of each half-brain under a single label. The situation is probably not that simple. But at present, the basic differentiation between symbol manipulation and Gestalt-like comprehension, whether mutually antagonistic neurologically or not, seems to be the best general dichotomy available.

Most of our recent knowledge of individual hemisphere function has come from studying split-brain patients (Sperry, 1964; Gazzaniga, 1967, 1970; Milner, 1968). In the intact human being, one would assume that the cerebral commissures equalize differences between the hemispheres, as far as input and output are concerned. It would be awkward for humans to exist in a state in which only the left hand could recognize objects tactually, or in which one must look at the left of a word to comprehend it, or to the right of a face to recognize it. These restrictions do, however, hold true for split-brain persons; such people are living illustrations of how we would all function perceptually without our cerebral commissures. The overall effect of the commissures seems to be making the human being's sensory capacities more symmetrical, compensating for a degree of asymmetry of function greater than any other animal, and upon which our present intellectual capacities may depend.

From recent evidence it seems that this commissural "compensation", and thus the symmetry of our perceptual world, is not perfect. To a certain extent we are all "split-brain" persons, though the effects are normally unnoticeable in daily life. Careful testing of human perceptual capacities has revealed definite asymmetries parallel to those produced when the commissures are severed. Already a large number of studies have extrapolated from split-brain discoveries and have found evidence of the same hemisphere differences in intact human subjects, though much reduced. These "perceptual asymmetry" studies use both visual and auditory modalities. I will review the most important of these and then discuss the relations of handedness and visuo-spatial abilities to the topic of sensory asymmetry.

Audition

Results of dichotic listening experiments have been used to demonstrate hemisphere specialization in auditory information processing. The anatomical connections are not nearly as clear-cut for audition as they are for vision; each ear has afferent connections to both hemispheres, and unlike vision there is no way to separate the ipsilateral and contralateral channels. To explain asymmetries in auditory perception, experimenters have assumed that the contralateral channel is somehow more "primary," similar to the greater discrimination contralaterally for kinesthesis. There is some evidence that the contralateral auditory channel actually is more efficient(Rosenzweig, 1951) but the question does not seem entirely settled yet.

The classic dichotic listening paradigm has been to use two simultaneous channels for presenting stimuli. Typically, two different strings of letters or digits are delivered, one to each ear, at a rate of one to three per second. The recordings to the two ears are matched for sound-pressure level, usually close to threshold. Sometimes a white-noise background is used. Periodically the tape is stopped and the subject is asked to recall every letter or digit he heard. Under these circumstances, most persons report more of the stimuli delivered to the right ear than to the left. Some typical early studies reporting this effect are by Milner (1962) and Kimura (1967).

Most studies of dichotic listening have tested left-hemisphere specialization only, probably because numbers and digits are easy stimuli to work with. But several studies have shown that the expected right-hemisphere (left ear) superiority for its specialties exists too: for melodies (Kimura, 1964; Shankweiler, 1966) and for non-verbal environmental sounds (Curry, 1967; Knox & Kimura, 1970; Bakker, 1970). Examples of the "environmental sounds"used are recordings of trucks, airplane noises, and flushing toilets. Left-ear superiority has also been found for sequences of dots and dashes. Perception of temporal patterns, although verbally encodable, is considered from other research to be right-hemisphere-mediated.

The dichotic listening effect has proved compatible with developmental data on cognitive development; for example, the auditory asymmetry usually develops in children around age five, and it usually appears earlier in girls than in boys, coinciding with their earlier verbal development (Knox & Kimura, 1970). Also, Geffner & Hochberg (1971), acting on earlier evidence that socio-economic level influences the onset of auditory asymmetry, tested large numbers of children at different ages from "normal" and "depressed" environments. The children from the depressed environment developed auditory asymmetry two to three years later, on the average. Presumably this reflected delayed speech lateralization, and delayed speech lateralization in turn has been linked with reading retardation, much more common in the depressed environment.

It should be noted that dichotic listening studies actually measure the subject's perceptual bias for stimuli delivered in one ear over the other ear, rather than measuring absolute discrimination ability. When the ears are tested separately by unilateral presentation, the asymmetry generally disappears (Calearo and Antonelli, 1963; Palmer, 1964). The hemisphere-dominance explanation, therefore (stated most clearly by Kimura, 1967) has stressed the interaction of contralateral and ipsi-lateral neural transmission; competition between the two auditory chan-nels is thought to result in contralateral dominance. So the dichotic listening experiments do no more than determine which of two rival sets of stimuli seem to dominate the subject's conscious attention. This is very different from the asymmetries discovered for detection of stimuli in the right and left visual fields, which are discussed next.

Vision

Taking advantage of the clear contralateral relationship between the visual fields and the hemispheres, early experimenters sought a superiority for letter detection in the right visual field. The standard procedure is to present single letters or digits tachistoscopically for less than 200 milliseconds in one visual field at a time, using a pre-exposure central fixation point to ensure that the stimulus goes to the desired hemisphere. Sometimes words are used instead as stimuli, presented either horizontally or vertically.

The usual result, generalizing from a number of similar studies, is that letters, digits, and words in the right visual field can be identified more accurately (Kimura, 1966; Hines & Satz, 1971; McKeever & Huling, 1971). The most-used explanation for this phenomenon is that since visual input from the right visual field (RVF) goes directly to the left hemisphere, which dominates for digit and letter recognition, this perceptual "route" is shorter and perceptually clearer than the LVF-right-hemisphere route. This assumes that material appearing in the LVF must be transferred right-to-left across the corpus callosum for letter identification; somewhere in this longer pathway between stimulus and response there is a loss of information. Fedio & Buchsbaum (1971) have demonstrated such a degradation of the evoked potential after being transferred across the commissures.

There have been objections to this explanation (see White, 1969, for a review). One consistent finding has been that simultaneous bilateral presentation of letters and digits usually results in a left-field superiority for detection (Kimura, 1966). This LVF superiority was thought to reflect the left-to-right reading habits which could lead subjects, when confronted with two letters, to report the left one, even though a pre-exposure central fixation point and short exposure time are used. The left-field bias could have been based on attention or on order of report even in the absence of eye movements.

The most recent development in this controversy has been the research of McKeever & Huling (1971, 1972) and Hines (1972). It was found that requiring subjects to report a small digit appearing at the central fixation point abolished the LVF superiority which usually resulted from bilateral presentation. Subjects now recognized words better in the right visual field. The authors argue that with bilateral presentation, extra control of fixation is necessary to counteract the left-to-right scanning and reporting habits which could lead subjects to unintentionally fixate slightly to the left.

One would also expect the left visual field to be superior for recognition of abstract shapes and faces, since split-brain research has revealed this right-hemisphere specialization. The only notable successes so far for recognition accuracy have been with dot patterns (Kimura, 1966, 1969; McKeever & Huling, 1970) and with judgments of three-dimensional depth (Durnford & Kimura, 1971). Geometric shapes have been found to be equally recognizable in either visual field, but they can be easily encoded verbally, while irregular patterns of dots cannot.

Reaction time asymmetry

Measurement of choice reaction times to stimuli directed to only one hemisphere is a new technique which has supported and extended the results for early detection studies. The experimental arrangement is generally to have a subject memorize a set of letters or digits. Stimuli are then presented with a tachistoscope to the left or right visual fields; the subject discriminates between the two sets of stimuli (on the basis of the memory set) and responds as fast as possible. Instead of proportion of correct detections, the average response time is used as the index. The expectation is that the symbolic stimuli projected to the right hemisphere will be identified more slowly than will stimuli projected to the left hemisphere, because letters and digits must be processed in the left hemisphere. This extra crossing time should result in slightly longer reaction times.

Filbey & Gazzaniga (1969) were the first modern researchers to use this technique, although it had been found and then forgotten in the 1920's. Filbey & Gazzaniga found a RVF superiority for both letters and digits. Bradshaw & Perriment (1970) and Klatzky (1970), besides verifying Filbey & Gazzaniga's results, investigated the variable of which hand is responding, in case this was a possible complication. Their general finding was that there is no difference between ipsilateral and contralateral hand-response times unless individual finger control for separate responses is required. Rizzolatti, Umilta and Berlucchi (1971) and Geffen, Bradshaw and Wallace (1971) found faster reaction times to letters in the RVF and a faster reaction time to faces in the LVF.

In all these studies, subjects were only required to identify a single letter, and this produced reliable RVF superiority on the order of 15 to 20 milliseconds. However, Klatzky & Atkinson (1971) presented evidence that simple identification of letters could be done as well by the right as by the left hemisphere, because the letters were being stored and processed as spatial configurations only. These experimenters found RVF superiority only when subjects were faced with a more complicated task requiring them to match letters to the names of pictures, which was more clearly a verbal task. Their study raised important questions about the real difference between visual symbols and visuo-spatial configurations, and when their results were supported by the research discussed in the next paragraph, it became apparent that letters could not be simply considered as verbal stimuli, but that the designation depended on the discrimination required of the observer.

An effective technique for examining hemisphere differences for letter processing is an adaptation of a same-different judgment task originated by Posner & Mitchell (1967). Pairs of letters are prepared for two experimental conditions. In both conditions the subject must decide whether or not two letters simultaneously appearing in the same visual field are "the same"--but this can either mean the same symbolically, or the same physically (and also symbolically). Thus in the symbolic (name-identity) condition the subject must discriminate between "Aa and "Ae", while in the physical-identity condition the subject must discriminate between "AA" and "AE." The second discrimination is thought to be less dependent on left-hemisphere verbal specialization, while the first discrimination requires a learned knowledge that "A" and "a" are symbolically equivalent. Three studies (Geffen, Bradshaw and Nettleton, 1972; Cohen, 1972; Ledlow, Swanson and Carter, 1972) have demonstrated a right-field superiority for the name-identity condition and in some cases a left-field superiority for the physical-identity condition.

Left-handedness

A common practice in both visual-field and dichotic-listening studies has been to use all right-handed subjects. This practice maximizes the chances of obtaining the predicted results, for the assumption that verbal function is in the left hemisphere is only probabilistic when applied to an individual. The most accurate information on this matter now available is derived from the procedure of anesthetization of one hemisphere at a time and observing the degree of aphasia resulting (Branch, Milner and Rasmussen, 1964). On a sample of 48 right- and 44 left-handers, 90% of the right-handers were found to have major speech centers in the left hemisphere, and 10% in the right hemisphere. Of the left-handers, 64% seemed to have major speech centers on the left, 20% on the right, and 16% had bilateral representation. Therefore at least 20% of left-handers seem to have "reversed" brains, according to this test. The authors also observed that for left-handers generally, speech seemed more evenly distributed between the hemispheres, or less "lateralized." So excluding left-handers in perceptual asymmetry studies amounts to excluding the only known variations from the standard hemisphere-dominance pattern. This seems unwise when the experimenter has no other real assurance that hemispheric specialization is being tested at all.

Hecaen and Sauguet (1971) provided the most comprehensive recent analysis of correlations between handedness and brain-damage effects. After surveying hundreds of cases of localized brain damage, they concluded that speech impairment occurs fairly often following right-hemisphere damage to the brains of left-handers; this result is rare in right-handers. In a smaller sample, they examined the variables of strength of handedness and left-handedness in the subject's family.

H. L. Dee (1971) also studied the variables of handedness in relation to dichotic listening performance, and his conclusions closely match those of Hecaen & Sauguet's: 1) A strongly left-handed person is most likely to have the normal speech-on-the-left cerebral organization. 2) Persons who are less strongly left-handed (showing less strong lateral motor specialization) are the ones most likely to have reversed or less lateralized cortical function, at least for speech. In addition, Hecaen & Sauguet found from their data that "weak" left-handers are also more likely to have left-handedness in their immediate families.

So instead of grouping all left-handers together as most studies have done (if left-handers are included at all) it now seems best to separate them into strongly and weakly left-handed, and to pay close attention to the presence of familial left-handedness. The placement into "strong" and "weak" groups can be done both with hand-usage questionnaires and with dexterity tests. H. L. Dee found with such testing that only 30% of left-handers he sampled could be called strong left-handers. The rest were "weak"--exhibiting less lateral dominance than the average right-hander does.

Besides Dee's study, several others have included the handedness variable with perceptual-asymmetry testing, although the sample size in these studies is usually small. First, Kimura (1961) tested left-handers with speech located definitely in the right hemisphere (as determined by hemisphere anesthetization) with a dichotic listening procedure, and found reversed laterality, as expected: the left ear dominated for letter and digit recognition. This single study, incidentally, added immense validity to the whole dichotic-listening paradigm.

Zurif & Bryden (1969) found a strong difference between familial and non-familial left-handers with the dichotic listening test and also with a letter-recognition test. Familial left-handers had decreased or reversed ear and visual-field differences. Satz, Achenbach and Fennel (1967) and Satz, Fennel and Jones (1969) found a positive relationship between strong left-handedness and deviations from the normal right-ear superiority on dichotic listening tests. Bakker (1970) assessed the degree of laterality development--"sidedness" as well as handedness--in a large number of school children and found that inconsistent or retarded laterality development was reflected in a dichotic listening task: such children had either weaker asymmetry or none at all.

Ledlow et al. (1972) tested a group of 10 left-handers (simple self-report was the only criterion) in the previously-described physical vs. symbolic letter-pair matching. They found little difference in reaction times between left-field and right-field scores, as expected, while right-handed subjects showed a RVF superiority for name-matching. Hines & Satz (1971) found similar results in a group of left-handers, using accuracy of detection of letters as the index. They also reported that in their sample, right-handers with left-handedness in their families showed less right-field bias for digit detection, supporting the speculation that handedness has a genetic component.

To summarize the present state of knowledge on this matter, the three most important components of handedness seem to be:

1) Strength of handedness as measured by usage questionnaires (hand usage for various common manual activities)
2) Asymmetric dexterity (difference between hands) as measured by manual skill tests
3) Familial handedness: the presence of left-handedness in the

immediate family.

The first two components may measure the same thing in different ways; no report of correlations has appeared in the literature yet. Some studies in the past have concentrated on the familial left-handedness variable, ignoring dexterity and usage. Others have carefully focused on finding "pure" left-handers either by actual testing or by questionnaire, leaving the familial variable unmentioned.

Visuo-spatial deficits

Levy (1969) was the first to report that a sample of left-handers had performed significantly lower than a matched group of right-handers on the performance scale of the Wechsler Adult Intelligence Scale(WAIS) with no difference in their verbal scale scores. This finding was predicted; Levy reasoned that left-handers, having more variable localization of speech function, may for this reason be impaired in non-verbal tasks because the language function of the brain interferes with normal right-hemisphere functions.

Levy's study has since been verified with a different IQ test (Miller, 1971) although Ledlow et al. (1972) did not obtain such results. Other research with actual right-hemisphere-damaged persons on WAIS performance (Lansdell, 1970, Vega, 1971) has shown that although the "performance" scales as a whole measure right-hemisphere abilities more than left, the greatest right-hemisphere involvement seems to be on the Block Design and Object Assembly subtests.

Robert Nebes (1971) published results of his Arc-Circle test, developed to test Gestalt-closure ability in split-brain subjects. The test requires subjects to choose visually from several complete circles the one which best matches a circle segment examined out of sight with the fingers. The validity of this test for assessing right-hemisphere functions rests on Nebes' reported testing of many split-brain subjects; the left-hemisphere-right-hand "team" performed very poorly, usually at chance level, while the opposite combination did as well as normal subjects. Nebes also tested left-handed and right-handed normal (intact) persons and found left-handers to be deficient, performing significantly worse than the right-handers. Because of the intact commissures, it did not matter which hand was used. The left-handers in these tests, again, were undifferentiated; familial, non-familial, "strong" and more ambidextrous were all pooled. So although the studies are useful for demonstrating the involvement of laterality in the tasks, they are less useful for studying handedness itself.

To summarize: there are at least two established perceptual deficiencies already shown for left-handers as an undifferentiated group: deficit in non-verbal parts of intelligence tests, and lower performance on the Arc-Circle test. In addition, dichotic listening tests show much less ear asymmetry, if any, for left-handers, and visual-field testing shows less visual-field bias for left-handers. The two latter tests indicate less complete lateralization of function, and this in turn serves as support for the theory of brain evolution proposed by Levy: that the human's recently developed verbal-symbolic function is incompatible with Gestalt-like spatial function because of some fundamental difference in neural organization. When verbal activity intrudes into the non-dominant hemisphere the latter's functions are impaired, although for some reason verbal function is not correspondingly enhanced.

Facial recognition

Facial recognition is the most strongly established right-hemisphere specialization, judging from the agreement of brain-damage studies (De Renzi & Spinnler, 1966; Warrington & James, 1967; Milner, 1968). Damage in particular to the temporal lobes of the right hemisphere commonly impairs the person's ability to recognize faces, while this impairment is rare with left-hemisphere damage alone.

From Levy's research finding a deficit for left-handers in non-verbal skills, it seems logical to generalize the finding to facial recognition ability, since this is also a non-verbal discrimination. Here, in reference to Dee's and Hecaen & Sauguet's recent research, it is most likely that more ambidextrous left-handers would be the most impaired on this skill, because of their more variable and decreased asymmetry of speech function. This result was obtained (Gilbert, 1973) in a sample of left-handers divided into strongly and weakly left-handed. Compared to a group of right-handers, the weakly left-handed group performed significantly lower in a facial recognition test, while the strongly left-handed subjects did not differ from the control group.

Lateral face bias

One important component of facial recognition is the lateral one; that is, perception of a face in left or right visual fields. The two studies already cited showing a faster reaction time to faces in the left visual field suggest that a right-hemisphere specialization for face processing exists in intact subjects. A unique study by Levy, Trevarthen and Sperry (1972) used very dissimilar faces joined together at the midline to make a chimeric whole face. These were presented, centered in a tachistoscope, to split-brain subjects, thereby putting each half-face into the contralateral hemisphere. When the subjects were asked to choose between the two versions of the face just viewed, they usually chose the complete face whose half was represented in the left visual field. When they were asked to describe verbally what they saw, however, they described the face represented in the right visual field, since the left hemisphere controlled the speech mechanism. When no verbalization was required, the right-hemisphere-left-field link was generally dominant. This study showed a very strong right-hemisphere superiority for face-processing, presumably because of the lack of commissural transfer.

The same LVF bias seems to exist in intact subjects, though much reduced (Gilbert & Bakan, 1973). Subjects were found to consider material from the left side of a photographed face more "similar" to their impression of the entire face. This was tested by offering two half-face composites for comparison with the whole face. The bias, small but consistent, is not due to specific properties of the right side of the face, but seems to depend only on position of the stimulus material relative to the rest of the face. A group of left-handers showed no bias for the left visual field; this was interpreted as a consequence of their less consistent lateralization.

Research plan

The present study was undertaken to test the idea that decreased cerebral lateralization is associated with slight impairment of right-hemisphere abilities. From the preceding review it is clear that many methods can be used to investigate perceptual asymmetry (and presumably cortical lateralization) so some choice had to be made among these methods. The Arc-Circle test was discarded because a pilot study with 60 subjects failed to replicate Nebes' published results. Unfortunately, the most valid method for determining functional lateralization--temporary anesthetization of each hemisphere--was not feasible. Handedness is probably the next best predictor of where the primary speech centers are located, but handedness only predicts proportions among groups. If the assumptions behind visual-field reaction-time testing are true, then this measure should indicate functional lateralization in individual cases. So reaction-time testing was chosen as a second measure of lateralization.

A compromise was necessary between obtaining a reliable measure of reaction time (ideally, several hours of testing per subject) and using enough subjects in each handedness group to make the laterality predictions meaningful. The spatial-ability tests also required a fair sample size. The final plan called for around three hours of testing per subject, in two separate sessions. All testing was to be done individually except for facial recognition. Handedness was the reasonable independent variable because most other laterality tests are correlated with handedness instead of with each other. Reaction-time asymmetry along with the half-face bias both served as less certain concurrent measures of lateralization.

It was predicted that reaction times for left and right hemispheres would be more similar in the weakly left- and right-handed subjects, and would show more lateral asymmetry for the strongly right- and left-handed subjects. Specifically, reaction time was expected to be faster in the left visual field for faces and for the physical-identity letter discrimination, and faster in the right visual field for the name-identity letter discrimination. The Block Design and Object Assembly subtests and the facial recognition test served as measures of right-hemisphere function; all were predicted to be more difficult for the weakly lateralized subjects, and for those with left-handedness in the family.

METHOD

Apparatus for Reaction-time Testing

Stimulus materials for the reaction time experiments were presented on a Scientific Prototype model 800 2-field tachistoscope with binocular viewing. Exposure duration was kept constant at 150 milliseconds. Illumination was .20 log foot-lamberts at both the pre-exposre field (containing the fixation point) and the stimulus field. Eye movements were not monitored, since there is adequate evidence that subjects in similar experiments do fixate properly (Geffen et al., 1972, Cohen, 1972). A switch controlled by the experimenter simultaneously exposed the stimulus field and activated a Hunter Clockounter millisecond timer. The subject's response switch consisted of a lever which stopped the timer when moved either forward or backward. For half of the subjects, a forward movement of the lever signified a discrimination of "same" for the letter pairs; for the other half the direction was reversed. Subjects were instructed to use their whole arm for moving the switch, and to keep their wrist and fingers stiff. This was done to minimize individual finger movements, which might have introduced an unwanted contralateral-hemisphere advantage.

Face stimuli. Stimuli for the face discrimination task consisted of four small black-and-white portraits, two male and two female. In a pilot study, six portraits were used, with subjects moving the response lever one way for three of the faces and the opposite way for the other three. This proved difficult for most of the subjects to learn quickly. Rather than change to faces more easily discriminated, the size of the set was reduced to four. Each picture was 2.5 x 3.0 cm. in size, mounted on a white card so that the inner edge was 15 mm. either right or left of the central fixation point (1.1°) and the outer edge was 40 mm. (3°) from fixation.

Letter stimuli. For the letter discrimination task, letter-pairs 5 mm. high were drawn with India ink on white cards, using a Leroy lettering guide and #2 pen size. The closest edge of the closest letter to the central fixation point was 16 mm. to the left or right (1.22° of visual angle) and the outer edge of the outer letter was 28 mm. (2.14°) from the center. The letters A, E, G, and R were used; these were chosen because of the differences between their upper and lower-case forms, making a discrimination of symbolic identity maximally different from a discrimination of physical identity.

Figure 1 shows the letter-pairs used and their class membership; each pair was presented in both visual fields, making a total of 64 stimulus cards.

SAME		DIFFERENT	
Name identity	Physical identity		
Aa	AA	AE	Ae
aA	aa	ae	eA
Ee	EE	EA	aE
eE	ee	ea	Ea
Gg	GG	GR	Gr
gG	gg	gr	rG
Rr	RR	RG	gR
rR	rr	rg	Rg

Figure 1. Letter-pair stimuli for letter-discrimination task.

Procedure

Subjects were familiarized with the same-different discrimination for letters with approximately fifty practice trials. The 64 stimulus cards were then shuffled and presented in random order twice, once through for each hand. Half of the subjects began with the right hand and half with the left. The experimenter gave a verbal "ready" signal approximately one second before the onset of the stimulus.

For the face discrimination, subjects studied a card containing duplicates of the four stimulus faces to learn the stimulus-response relationships; two of the faces called for a forward response of the lever and two for a backward one. Subjects underwent fifty practice trials, more if their learning was obviously slow. The cards were then shuffled and presented in random order both with respect to stimulus and to visual field. Sixty-four observations were collected from each subject, 32 for each visual field, with the responding hand switched halfway through.

Errors. For both the letter and face reaction times, errors were treated by informing the subject of the error, recording where the error occurred, and re-inserting the card at a randomly selected position in the remaining cards. Times for errors were not recorded.

Half-face Bias

Full details of the preparation of these stimuli are in an earlier report (Gilbert & Bakan, 1973). Thirty sets of prepared faces were used. Each set consisted of a normal portrait of a face, 4" x 5", and its two related half-face composites. Each composite contained two prints of either the left or the right side of the whole face, with one print reversed and joined to the other at the midline. This gave the superficial appearance of a normal face, but each composite was perfectly symmetrical and contained material from only one half of the face. Thus a "left composite" consisted of only the left side of a face (adjacent to the photographed person's left hand), and a "right composite" consisted of only the right side of a face. The composites were the same size as the originals; all three prints of each set were mounted on cardboard and trimmed to give the same clearance on each side between the face and the print's edge (see Figure 2).

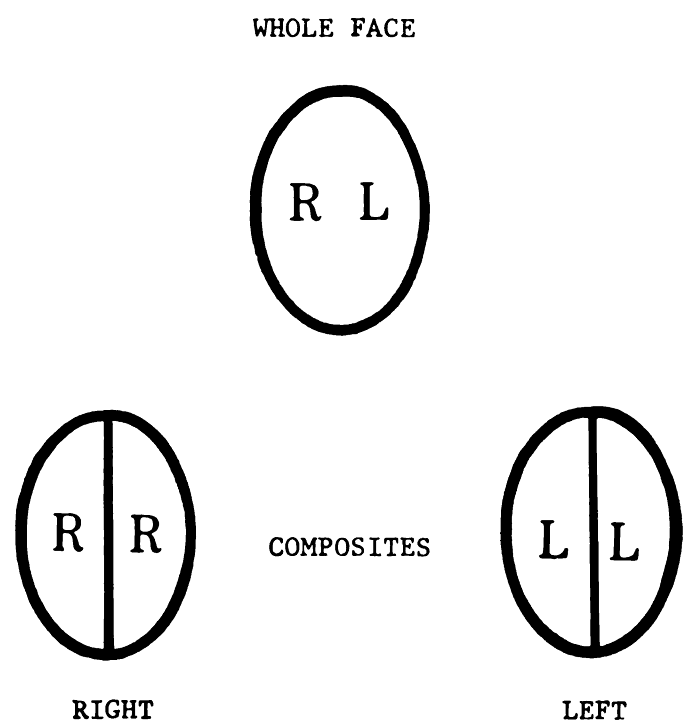

Figure 2. Schematic illustration of stimuli used for half-face bias test.

For each set, the subject's task was to decide which of the two composites looked more like the whole face. The major difference from the original method of presentation lay in not allowing the subject to view the whole face and the composites simultaneously. Whereas the original results were obtained by allowing the subject to look back and forth among the prints for comparison, this time the whole face was presented directly in front of the subject for five seconds, and then covered with the two composites. This was done to determine whether the 60% left-field bias would extend from an "immediate perception" condition (being allowed to compare both composites with the original) to a new situation calling for accurate memory of the whole face. To respond, the subject was asked to point to the composite which he thought more closely resembled his memory of the covered face. Very few subjects, when questioned later, had figured out how the composites were made.

Picture-sets were always presented in the same order, with the left-right position of the two composites randomly varied to minimize any position biases which the subjects possessed. Each subject's final score was the number of choices of the left-field composites; i.e., from the left side of the whole-face photograph. Half of the whole faces were "original" photographs, depicting the persons as they appeared in life; the other half were "reversed," or mirror images, although the previous study established that this is not a confounding variable.

Block Design

This subtest of the Wechsler Adult Intelligence Scale was administered as described in the WAIS manual. The test consists of nine blocks, each identically colored, which are used to duplicate increasingly complex geometrical desings. Scores depend on the elapsed time for correct construction of a design, and were assigned according to the WAIS norms. Total possible score for the ten designs was 48.

Object Assembly

This was another subtest of the WAIS in which the subject assembles four simple cardboard puzzles of common objects such as a hand and a human profile. Following the standard procedure, the pieces for each puzzle were laid out in the prescribed orientation behind a shield. The subject was instructed to assemble the pieces so that they made a recognizable picture. Scores again depended on the elapsed time for correct assembly, with points deducted for errors. The total possible score was 44, with scores assigned from the WAIS norms.

Handedness

The initial classification of handedness was made according to the subject's writing hand. Within that classification, each subject's degree of left- or right-handedness was assessed in two ways: by the difference between the hands for manual dexterity, and by the score on a standard hand-usage questionnaire. The questionnaire (Crovitz & Zener, 1962) consists of a list of 14 common activities such as using scissors, holding a hammer, and throwing; responses are made on a 5-point scale graded from "left hand always" to "right hand always." The range of scores is from 14 to 70, with 14 representing complete left-handedness for every activity listed and 70 representing complete right-handedness (see Appendix for a copy of the distribution of scores and a copy of the questionnaire). Examination of the score distribution for left-handers suggested a score of 30 as a reasonable dividing point for separating left-handers into "weak" and "strong;" 30 is approximately at the median. A corresponding dividing point of 54 was used for the right-handed group.

The dexterity test was the second definer of strength of handedness. As in an earlier study (Gilbert, 1973) the test was improvised, modelled after the principles of the Crawford Small Parts Dexterity Test, since both tests measure fine eye-hand motor coordination. Subjects were directed to quickly place twelve small metal washers on twelve straight pins which protruded from a styrofoam ball, using tweezers, and then to remove them one by one. The elapsed time for this sequence constituted the first score for that hand. In all cases the dominant (writing) hand was tested first, then the non-dominant. Usually two trials for each hand sufficed, alternating hands; if results were unclear a third and fourth trial were run. If the non-dominant hand completed the task consistently faster or if there were no clear differences between the hands (less than five seconds) then the person was classified as weakly left- or right-handed.

It is not clear whether a greater variability of reported hand usage on the questionnaire or a smaller difference in tested dexterity should be the better definer of "weak" handedness. Therefore, if a subject was classified "weak" on either the questionnaire or the dexterity test, that became his final classification. All other persons were designated either strongly right-handed or strongly left-handed.

Facial Recognition

The stimuli for this test were the same as those for the earlier study, and presentation was identical except for more closely controlled lighting conditions, which increased the contrast of the slide-projected stimuli and raised the average score slightly. From old university yearbooks, groups of faces were selected and combined to make four arrays of 40 faces each, two all male and two all female. All clothing was blacked out, and prominent earrings, unusual hairdos, and obvious identifying characteristics were causes for rejection of a picture. From each array eight faces were individually photographed and enlarged. These sets were re-photographed onto slide film, as were the 40-face arrays, for group presentation.

Subjects were tested in small groups of five or six, mixed with respect to handedness category. After instructions, the first set of eight test faces was projected onto a screen for 25 seconds at a distance of approximately 20 feet from the subjects. Immediately afterward, the corresponding 40-face array was projected. On answer sheets subjects identified the faces they recognized from the first group, with no time limit. This procedure was repeated for the other three sets, always in the same order. The final score was the total correct identifications for the four sets.

Subjects

In order to fill the four handedness categories, several methods were used to recruit subjects. The study was initially advertised as a "Facial recognition" study, sometimes specifying left-handers. Subjects received only class credit for participation. Later subjects were recruited with an offer of $5.00 for participation, with no stipulations about their handedness. The weakly-right-handed category, however, was the most difficult to fill. Some subjects were recruited by describing the desired characteristics to large introductory psychology classes ("...if you write right-handed but do a few things better left-handed, or if you feel equally dextrous with both hands..."). Class credit was offered and payment was not mentioned directly, but subjects who passed the initial screening (handedness questionnaire and dexterity test) received $5.00 payment.

RESULTS

First, the results of the reaction-time tests were analyzed to determine if they could reasonably be used as measures of lateralization in individuals. To attain equal cell sizes, four subjects were removed at random from the strongly left-handed group and one was drawn from the weakly left-handed group, resulting in 16 persons for each handedness group. Some extremely long reaction times were considered to be due to extraneous factors, so the following cut-off rules were used for eliminating such times: reaction times longer than 1200 msec. were discarded, and for a given subject and stimulus class, if any single reaction time was isolated by more than 200 msec. from any other in its class it was regarded as spurious and discarded. This follows the general practice of the other studies of this type, although the cut-off point varies. The number of discarded times averaged less than 2% for all groups.

Reaction Times to Faces

A 2 x 4 analysis of variance with repeated measures on the visual fields was done on the means of all correct responses for each visual field and subject group. Table 1 shows the mean reaction times for each group, for each visual field. In this and in subsequent tables, standard errors are given beside each mean.

Table 1. Means of reaction times (in milliseconds) to faces in left and right visual fields.

Handedness group	LVF (s.e.m.)	RVF (s.e.m.)
SRH	708 (20.2)	715 (18.1)
SLH	702 (19.9)	716 (17.9)
WLH	710 (16.0)	725 (17.7)
WRH	688 (21.2)	702 (24.6)

Only the main effect of visual field was significant ($F_{1, 60}$ = 9.42, $p < .01$). The lack of interaction between visual field and handedness indicates that all four groups had a similar left visual field superiority.

The average difference between the LVF and RVF mean times regardless of sign was calculated for each group, to check the possibility that the average absolute difference might be smaller in the two "weak" groups, reflecting less hemisphere asymmetry. With this calculation, no assumptions were made as to the location of facial-recognition function. Table 2 contains these differences and also the proportion of subjects in each group having a faster mean time for the left visual field.

Table 2. Average absolute visual-field difference for face reaction times and number of subjects in each group with LVF bias.

SRH	SLH	WLH	WRH
25.7	24.7	28.1	23.3
11/16	11/16	11/16	12/16

The equivalence of LVF biases for the four groups is supported by the equivalence of absolute differences and by the number in each group showing a LVF bias.

Reaction Times to Letters

Two separate conditions of discrimination were present in this segment: Physical Identity (PI) and Name Identity (NI). The subject means were analyzed using a 2 x 2 x 4 analysis of variance with repeated measures on visual fields and identity condition. Table 3 shows the means for each condition, for all "same" responses.

Table 3. Mean reaction times to letters under PI and NI conditions.

	Physical Identity (AA)				Name Identity (Aa)			
	LVF	s.e.m.	RVF	s.e.m.	LVF	s.e.m.	RVF	s.e.m.
SRH	627	(13.2)	617	(12.5)	747	(20.2)	725	(14.6)
SLH	623	(22.1)	619	(17.5)	759	(29.6)	764	(28.3)
WLH	619	(24.1)	623	(25.3)	713	(29.8)	734	(23.6)
WRH	620	(19.6)	615	(24.7)	730	(28.4)	728	(26.9)

The main effects of groups and visual fields were not significant, and no interaction was significant. The PI condition was significantly faster overall than the NI condition ($F_{1,60} = 396$, $p < .001$).

Another way to analyze these reaction times is to compare the differences within each hemisphere between the PI and NI conditions. Cohen (1972) used this method, reasoning that if the PI condition favors the right hemisphere and the NI condition favors the left hemisphere (although the PI discrimination is nearly always faster than the NI regardless of hemisphere) then the difference between the two conditions should be larger in the right than in the left hemisphere. Following Cohen's example, a Wilcoxon signed-rank test was performed on the within-hemisphere differences for all 64 subjects. This is a non-parametric test which takes account of both the direction and degree of difference. There was no support for Cohen's prediction; the two hemispheres did not differ significantly in their degree of PI-NI difference. Cohen's data did, however, show significant differences between hemispheres using conventional analysis of variance, and her Wilcoxon analysis supported that analysis. In the present study a separate Wilcoxon analysis was done on the strongly right-handed subjects only, but results for this group alone were also non-significant.

Table 4 shows the proportion of subjects in each handedness group who exhibited a right-field bias in either condition.

Table 4. Proportion of subjects showing a RVF bias under PI and NI conditions.

	SRH	SLH	WLH	WRH
PI	7/16	7/16	9/16	9/16
NI	11/16	7/16	4/16	9/16

Again, the average absolute differences were computed for each handedness group for PI and NI conditions (Table 5). No strong pattern was apparent except that the NI condition produced consistently larger mean differences.

Table 5. Average absolute visual-field differences for NI and PI conditions.

	SRH	SLH	WLH	WRH
PI	33	27	24	36
NI	48	38	43	45

Multivariate analyses

To test for the presence of group differences on the remaining measures, a multivariate analysis of variance was carried out. Table 6 gives the group means for each dependent variable, standard errors of the means, and the univariate F-ratios. The cell entries for the first three variables are mean test scores; for the half-face variable, any number above 15.0 indicates a left-field bias; the reaction-time entries are in milliseconds. There were no significant effects due to handedness group. The multivariate F-ratio was 1.10, which was insignificant.

Table 6. Multivariate analysis based on handedness groups.

	SRH	SLH	WLH	WRH	F-ratio	p less than:
Facial Recognition	20.56 (.68)	21.12 (.74)	20.19 (.64)	18.75 (.87)	1.87	.14
Block Design	40.81 (1.46)	38.00 (1.80)	41.56 (1.28)	36.37 (2.22)	1.99	.12
Object Assembly	35.50 (1.39)	35.12 (1.38)	33.87 (1.58)	32.75 (1.87)	.64	.59
Half-face Bias	15.94 (.73)	14.12 (1.01)	15.62 (1.05)	16.25 (.71)	1.11	.35
RT to Faces*	+6.75 (8.51)	+13.81 (6.92)	+14.87 (9.36)	+14.19 (7.48)	.20	.89
RT to PI Letters	-10.29 (10.8)	-4.50 (8.1)	+4.37 (7.6)	-5.24 (11.8)	.55	.65
RT to NI Letters	+21.69 (14.3)	-4.94 (13.6)	-21.34 (11.1)	+2.31 (13.9)	1.80	.16

* For the reaction-time measures, negative numbers indicate a right-field bias for the fifth and sixth variables and a left-field bias for the last variable. In each case, therefore, a negative number denotes a mean contrary to prediction.

The initial classification of persons into handedness groups based on the dexterity test and hand-usage questionnaire showed no promise for demonstrating differences in right-hemisphere performance. Therefore the next logical step was to examine each component of handedness separately in case one were masking the effects of another. The components examined were dexterity asymmetry, hand-usage questionnaire, writing hand, and presence of left-handedness in the family. Sex of subject was also examined as a possible variable.

Dexterity

Subjects were classified into two groups: one group contained those whose writing hand was superior on the dexterity test, and the other group contained those whose hands were equal or whose writing hand performed more poorly. The mean scores on the seven dependent variables are shown in Table 7. No differences were significant at the .05 level.

Table 7. Means for subjects separated on the basis of asymmetrical dexterity.

	FR	BD	OA	Half-face	Face RT	PI RT	NI RT
Writing Hand Superior (N = 42)	20.55 (.43)	40.04 (1.07)	34.88 (.84)	15.17 (.55)	+10.19 (4.36)	-11.08 (5.80)	-.53 (8.24)
Writing Hand Inferior or Equal (N = 22)	19.41 (.52)	37.54 (1.06)	33.23 (1.1)	16.09 (.55)	+15.23 (5.87)	+7.04 (5.81)	-.30 (8.73)
F-ratio	2.08	1.85	1.02	.96	.36	3.30	.00
p-value less than:	.15	.18	.32	.33	.55	.07	.99

Multivariate F: 1.20, $p < .32$

Handedness Questionnaire

Subjects were divided next into two groups based on the weak-strong distinction: one group contained those whose questionnaire scores were either between 14 and 30 or 54 and 70. These ranges defined a strong, consistent lateral preference for manual activities in contrast to those in the second group, whose scores were between 30 and 54 (see Table 8). No differences were significant at the .05 level.

Table 8. Means for subjects separated on the basis of hand-usage questionnaire

	FR	BD	OA	Half-face	Face RT	PI RT	NI RT
"Strong" (N = 43)	20.35	38.05	34.40	15.12	+9.86	-7.21	+5.98
	(.48)	(1.06)	(.98)	(.53)	(4.70)	(5.8)	(8 .9)
"Weak" (N = 21)	19.76	41.52	34.14	16.24	+16.14	.00	-13.58
	(.59)	(1.47)	(1.27)	(.82)	(7.46)	(8.7)	(9.0)
F-ratio	.53	3.59	.02	1.40	.54	.49	1.86
p-value less than:	.47	.06	.88	.24	.54	.49	.18

Multivariate F-ratio: 1.50, $p < .19$

Writing Hand

Table 9 shows the mean scores for subjects divided into two groups based on their writing hand alone. No differences were significant at the .05 level.

Table 9. Means for subjects separated on the basis of writing hand.

	FR	BD	OA	Half-face	Face RT	PI RT	NI RT
Right-handed (N = 32)	19.66 (.57)	38.60 (1.35)	34.12 (1.17)	16.09 (.50)	+10.47 (5.6)	-9.63 (7.9)	+12.25 (9.9)
Left-handed (N = 32)	20.60 (.49)	39.78 (1.15)	34.50 (1.06)	14.87 (.73)	+13.37 (5.7)	-.07 (5.5)	-13.13 (8.8)
F-ratio	1.77	.45	.06	1.88	.13	.98	3.64
p less than:	.18	.50	.81	.17	.72	.33	.06

Multivariate F-ratio: 1.55, $p < .17$

Familial Left-handedness

Regardless of their own handedness, subjects were divided on the basis of whether or not at least one parent or full sibling was left-handed. The analysis revealed a strong difference in facial recognition ability between the groups; persons with left-handedness in the family had significantly lower scores ($F_{1,62} = 17.8$, $p < .0001$). No other differences were significant (see Table 10).

Table 10. Means for subjects divided by presence of left-handedness in the family.

	FR	BD	OA	Half-face	face RT	PI RT	NI RT
No familial left-handedness (N = 27)	21.81	40.07	35.44	15.44	+13.00	-12.34	+6.92
	(.46)	(1.26)	(1.0)	(.66)	(6.7)	(6.5)	(11.9)
Familial left-handedness (N = 37)	18.94	38.54	33.49	15.51	+11.13	+.62	-5.81
	(.47)	(1.21)	(1.1)	(.61)	(4.9)	(6.8)	(7.9)
F-ratio	17.78	.74	1.56	.00	.05	1.78	.86
p less than:	.0001	.39	.22	.94	.81	.19	.36

The multivariate F-ratio was 2.71, $p < .01$.

Sex of Subject

When subjects were separated on the basis of sex (see Table 11), females were found to show superior performance on the facial recognition test ($F_{1,62} = 7.14$, $p < .01$). No other differences were significant at the .05 level.

Table 11. Group means for males and females.

	FR	BD	OA	Half-face	Face RT	PI RT	NI RT
Males (N = 29)	19.10	40.55	33.00	15.44	+12.21	-1.42	+6.55
	(.60)	(1.35)	(1.16)	(.55)	(4.8)	(6.4)	(9.0)
Females (N = 35)	21.03	38.06	35.40	15.69	+11.68	-7.69	-6.23
	(.43)	(1.13)	(1.02)	(.69)	(6.2)	(7.0)	(9.8)
F-ratio	7.04	2.03	2.41	.24	.00	.41	.87
p less than:	.01	.16	.12	.62	.95	.52	.35

Multivariate F-ratio: 2.44, $p < .03$.

Correlations

Many relationships revealed by the correlation analysis were already obtained from the multivariate analyses. Also, some of the correlations are not very meaningful; for example, the correlation between handedness group and dexterity is .71 because dexterity is one of the definers of the handedness groups. Yet several other new relationships emerged. For 64 subjects, a correlation of .24 is significant at the .05 level, and a correlation of .31 is significant at the .01 level. Table 12 presents the entire correlation matrix. Table 13 shows the correlations with three "combined" handedness variables, which were examined to test the possibility that a combination such as equal dexterity and familial left-handedness contributes a unique effect.

Table 12. Correlation matrix.

		1	2	3	4	5	6	7	8	9	10	11	12	13	
Hand group	1	--	0	-4	10	-24	-16	-17	8	9	9	-15	71	49	1=SRH, 2=SLH, 3=WLH, 4=WRH
Writing hand	2	0	--	16	-9	17	9	3	-17	5	12	-24	-13	30	1 = right, 2 = left
Sex	3	4	16	--	-21	32	-18	19	6	-1	-8	-12	6	3	1 = male, 2 = female
Fam. l.h.	4	10	-9	-21	--	-47	-11	-16	1	-3	17	-12	2	6	1 = no, 2 = yes
FR	5	-24	17	32	-47	--	14	26	16	-8	-11	15	-18	-9	
BD	6	-16	9	-18	-11	14	--	42	04	-8	-9	14	-17	23	
OA	7	-17	3	19	-16	26	42	--	-13	3	-13	9	-13	-2	
Half-face	8	8	-17	6	1	16	4	-13	--	7	-8	9	12	15	high = LVF bias
Face RT	9	9	5	-1	-3	-8	-8	3	7	--	0	5	8	9	high = LVF bias
PI RT	10	9	12	-8	17	-11	-9	-13	-8	0	--	-23	22	9	high = LVF bias
NI RT	11	-15	-24	-12	-12	15	14	9	9	5	-23	--	0	-7	high = RVF bias
Dexterity	12	71	-13	6	2	-18	-17	-13	12	8	22	0	--	26	1 = unequal, 2 = equal
Quest.	13	49	30	-3	6	-9	23	-2	15	9	9	-7	26	--	1 = strong, 2 = weak

a correlation of .24 is significant at the .05 level; .31 is significant at the .01 level. N = 64. Decimal points are eliminated.

Table 13. Correlations of combined "weak" variables.*

		14	15	16	
Hand group	1	31	50	36	1=SRH, 2=SLH, 3=WLH, 4=WRH
Writing hand	2	21	-12	19	1 = right, 2 = left
Sex	3	8	-9	-16	1 = male, 2 = female
Fam. l.h.	4	-3	43	43	1 = no, 2 = yes
FR	5	-4	-40	-19	
BD	6	12	-17	12	
OA	7	3	-28	-11	
Half-face	8	17	12	11	high = LVF bias
Face RT	9	10	-8	-1	high = LVF bias
PI RT	10	25	27	8	high = LVF bias
NI RT	11	1	-1	-7	high = RVF bias
Dexterity	12	63	70	13	1 = unequal, 2 = equal
Quest.	13	65	14	72	1 = strong, 2 = weak
Dex. & Quest.	14	--	39	39	1 = no, 2 = yes
Dex. & fam. l.h.	15	39	--	32	1 = no, 2 = yes
Fam. l.h. & Quest.	16	39	32	--	1 = no, 2 = yes

* #14: persons who were classified "weak" on both the dexterity test and the handedness questionnaire (N = 11)

#15: persons classified "weak" on the dexterity test who also had left-handedness in the family (N = 13)

#16: persons classified "weak" on the handedness questionnaire who also had left-handedness in the family (N = 12)

Variable #5, facial recognition, showed the strongest overall relationship with the handedness variables:

FR x handedness group: r = -.24. This indicates that persons in the WLH and WRH groups perform more poorly at facial recognition.

FR x sex: r = .32. This indicates that females were better at facial recognition.

FR x familial left-handedness: r = -.47. This shows that that the presence of left-handedness in the subject's family is strongly associated with a decrement in facial-recognition performance.

FR x Object Assembly: r = .26. This suggests either that Object Assembly and the facial recognition test tap somewhat the same abilities, or that they are both correlated with a third undefined factor.

FR x the combination of equal dexterity and familial left-handedness: r = -.40.

Reaction-time Asymmetries

On the whole, reaction time to faces shows lower correlations than any other variable with the handedness variables. Under the PI condition, a LVF reaction-time bias for the letter-pairs correlated .25 and .27 with two combined "weak" variables: #14 (equal dexterity and "weak" questionnaire) and #15 (equal dexterity and familial left-handedness. Thus the expected left-field superiority for the PI condition appeared most often in those persons who had other signs of being less lateralized. For the NI condition, the highest correlations were with writing hand (-.24) showing that right-handers more often show the expected right-field superiority, and with the PI condition (-.23) showing that persons with a left-field bias for the PI discrimination are less likely to show a right-field bias for the NI condition.

Of the two spatial tests, Block Design and Object Assembly, only Object Assembly seemed related to the variables of handedness, with a -.28 correlation with the combined variable #15, familial left-handedness and equal dexterity. The two spatial tests correlated .42 with each other.

Inter-correlations of variables of handedness

To clarify the relationships among the handedness variables, Table 14 contains only the variables directly concerned with handedness:

Table 14. Correlations of handedness variables.

	Writing Hand	Familial l.h.	Equal Dex.	"Weak" Quest.	
Writing hand	--	-9	-13	30	1=right, 2=left
Familial left-handedness	-9	--	2	-6	1=no, 2=yes
Equal Dexterity	-13	2	--	26	1=unequal, 2=equal
Handedness Questionnaire	30	-6	26	--	1=strong, 2=weak

Since familial left-handedness had such a strong relationship with facial recognition, the average absolute differences in reaction times between visual fields were calculated and are shown in Table 15.

Table 15. Average absolute VF differences in RT for subjects divided on the basis of familial left-handedness (in milliseconds).

	Faces	Letters PI (s.e.m.)	Letters NI (s.e.m.)
Without familial left-handedness (N = 27)	27.1	28.2 (4.3)	52.7 (5.8)
With familial left-handedness (N = 37)	25.0	30.6 (4.4)	35.9 (5.1)

A 2 x 2 analysis of variance performed on the two letter conditions only confirmed that the mean difference score found in persons without familial left-handedness (under NI condition) was significantly greater than the other means ($F_{1,62} = 5.8$, $p < .03$). This direct measure of degree of hemisphere difference revealed a more pronounced asymmetry for the first group, as predicted.

DISCUSSION

Reaction-time testing

With subjects divided into the four initial handedness groups, the results of the two letter-discrimination tasks showed no significant signs of the expected relationships. For the NI condition the largest right-field bias (22 msec.) was found in the SRH group, as expected, but it could not be rejected as due to chance. The PI condition produced no visual-field differences greater than 10 msec.; this lack of differences agrees with the results of Ledlow et al. (1972) and with Gazzaniga (1970) but not with Geffen et al.(1972), who reported a definite right-hemisphere superiority for the PI condition.

The analysis of PI-NI differences within hemispheres did not discriminate among the handedness groups, nor did examination of the size of the absolute differences between the hemispheres. The absolute-difference analysis was useful in examination of the familial handedness variable, and will be discussed later. The only other real difference shown by the letter reaction-time testing was between the PI and NI conditions disregarding visual-field: PI discriminations were on the average 118 msec. faster. Posner & Mitchell (1967) found a corresponding difference of 70 msec. and Geffen et al. (1972) reported a difference of 110 msec.

One conclusion from the letter reaction-time testing is that a larger number of observations is necessary for accurately assessing reaction-time biases, in view of the great response variability. Although it was important to have a large number of subjects in the study for the other measures, the size of the sample plus the necessary hand recording of the data made more extensive reaction-time testing impractical. Each subject had to be trained in the letter-discrimination and the face discrimination tasks, with an adequate amount of practice, and then make nearly 200 recorded discriminations, all in one session. For the letter discrimination, since only the "same" responses were analyzable, the 64 response times per subject were divided into PI-NI conditions and also into the two visual-field conditions.

<u>Reaction times to faces</u>

Because the face-discrimination task had no PI-NI distinction, more observations per subject were available. The significantly faster LVF reaction time, averaging 13 msec., supports the earlier findings of Rizzolatti et al. (15 msec.), of Geffen et al. (25 msec.) and of Moscovitch & Catlin (5 msec.). The surprising result is that all four handedness groups had the same bias, of approximately the same magnitude. If this right-hemisphere superiority is truly due to right-hemisphere specialization for face processing, then the only logical conclusion is that localization of this function is unaffected by handedness. This conclusion is reinforced by the consistently low correlations between face reaction times and all other handedness variables (Table 12); none is higher than .09. Since there is abundant evidence that handedness is associated with shifts in speech localization, theorists in this area have often assumed that when speech dominates in the right hemisphere, the left hemisphere would naturally become dominant for nonverbal functions. Yet this assumption has never been rigorously tested or even seriously questioned, and it should be, judging from the sparse evidence available so far.

H. L. Dee's dichotic-listening study (1971) found a large difference in apparent cerebral lateralization between weakly and strongly lateralized subjects on a verbal dichotic-listening task. But for these same subjects, strength and side of handedness did not affect performance on a non-verbal dichotic-listening test composed of melodies. Melody recognition has been fairly well verified as a right-hemisphere function (Kimura, 1964; Milner, 1962; Shankweiler, 1966), yet in Dee's sample all handedness groups had a right-hemisphere superiority for discriminating melodies, regardless of their performance on the verbal dichotic test.

Another bit of evidence along this line was provided by Levy, Trevarthen and Sperry (1972) in their chimeric-face study with split-brain patients. They located one split-brain patient with language definitely in the right hemisphere, and his hemispheric bias for non-verbal perception resembled that of split-brain persons having speech in the left hemisphere: this subject's perception of faces and recognition of objects both showed a LVF bias, indicating right-hemisphere specialization for non-verbal as well as for verbal function.

If right-hemisphere functions eventually prove to be less "movable," this would give new weight to the idea that non-verbal perception is impaired when speech function is not confined to the left hemisphere. If the two functions simply changed places, no interference would logically be expected, but if facial recognition and other visuo-spatial abilities are firmly embedded in the right hemisphere, then the presence of speech in that same hemisphere could interfere with the established neural organization.

There is some conflicting evidence, however; the matter was examined recently by McGloning & Davidson (1973), who correlated localization of speech function (as determined by a dichotic listening test) with ability to estimate the number of dots in the left visual field--supposedly a right-hemisphere function. The results did not show a decrement in LVF dot-enumeration ability in subjects who showed a left-ear superiority for digits. Also, Curry (1967) reported from a dichotic listening test that there was a "tendency," though non-significant, for the left hemisphere to be superior for non-verbal environmental sound discrimination (normally the right hemisphere excels) when the right hemisphere was superior for speech discrimination.

The faster left-field reaction times to faces in the present study may, of course, have nothing to do with right-hemisphere specialization, but no other explanation is immediately obvious. If some unevenness of lighting existed in the tachistoscope, it should have affected the letter-discrimination task in the same way. If a left-to-right post-exposural scanning effect existed, as White (1971) has suggested to explain visual asymmetries for letter detection, then again there is no obvious reason why letter reaction times would not be similarly affected. So from the entire reaction-time testing this left-field bias is the most significant and the most interesting finding, precisely because it is unrelated to handedness.

Multivariate analyses

The initial division of subjects into the four handedness groups revealed no significant differences on any of the dependent variables. It should be noted that for all three of the right-hemisphere tests

(Block Design, Object Assembly, and facial recognition) the mean for the two "weak" groups combined was lower than the mean for the two "strong" groups combined; but this is meager support for the prediction and can only be called a non-significant trend. Facial recognition is the only variable tested before in this manner; the only difference from the details of the earlier study (Gilbert, 1973) was in the less restrictive dividing point between "weak" and "strong" on the handedness questionnaire: 30 in the present study and 40 in the previous one. The change admitted a few more strongly lateralized left-handers into the "weak" category.

These results are not in strong agreement with Levy's 1969 study. There are three important differences to consider: 1) The present sample size is three times as large as Levy's sample. 2) Levy's sample was made up of Cal Tech graduate students, while the present subjects were college freshmen and sophomores. 3) Levy used the entire WAIS Performance scale for assessment of non-verbal ability, while the present study used only Object Assembly and Block Design subtests. Of the several Performance scale subtests, these two have the strongest likelihood of tapping right-hemisphere abilities exclusively, judging from the performance decrements in persons with right-hemisphere damage. However, Levy does not report which subtests contributed the most to the left-handed deficit; part of it could be due to the Digit Symbol subtest for reasons having nothing to do with hemisphere dominance. Bonier & Hanley (1961) found that performance on this test is impaired when the writing hand obscures the symbols which have just been written, which is what happens with most left-handers. In their study, rearranging the response sheet layout erased the difference between left-handers and right-handers.

Since the handedness-group subject differentiation based on dexterity and questionnaire performance yielded few strong dependent-variable differences, the subjects were re-ordered in other ways to examine the separate components of handedness. Dividing subjects into "weak" and "strong" on the basis of the dexterity test alone produced no significant differences. As with the handedness-group classification, the three right-hemisphere tests all produced lower means for the less lateralized group than for the strongly lateralized group, but the differences did not reach the necessary significance level. The same insignificant results occurred for the ordering of subjects on the basis of the handedness questionnaire and of the subject's writing hand. So the failure of the more general handedness-group classification to discriminate performance on any of these variables was not due to one handedness component masking another; none of the three components showed much relationship with the perceptual skills tested.

Dividing subjects on the basis of sex did reveal a female superiority for facial recognition. This result has appeared before (Howells, 1938; Witryol & Kaess, 1957; Goldstein & Chance, 1970; Cross, Cross and Daly, 1971) and has often been attributed to greater social interests on the part of the females. One more thorough recent study (Kent, 1972) showed that although females recognize females better, males recognize males better. In the present study, however, this interaction was not examined since females had an overall superiority.

Familial left-handedness

A strong right-hemisphere deficit appeared only when a variable more remotely connected with the subject's handedness was examined.

When subjects were divided on the basis of familial left-handedness, a large difference in facial recognition scores appeared. Oddly enough, the handedness of the subjects themselves did not seem to matter; the correlation between writing hand and facial recognition score was .17, with left-handers having slightly higher scores.

The association of familial left-handedness with decreased cerebral lateralization has considerable experimental support. Hecaen & Sauguet's previously cited survey of components of aphasia following brain damage showed clearly that familial left-handedness is associated with cerebral ambilaterality: in "familial" left-handers, disturbances of oral language and of reading occurred equally often following either right or left-hemisphere damage. Left-handers with no left-handedness in the family showed almost no disturbances of language following right-hemisphere damage. The study did not include right-handers, unfortunately.

Two other studies are relevant to this issue. Hines & Satz (1971), using a letter-detection test, noticed that right-handers with familial left-handedness had much less visual-field asymmetry. Zurif & Bryden (1969) used both auditory and visual testing to examine the perceptual asymmetries of a group of left-handers and right-handers. Right-handers with familial left-handedness were not included, but the left-handers were divided into familial and non-familial groups. Zurif & Bryden's strongest finding was the diminished asymmetry of the familial left-handed group relative to the other two groups on both the dichotic listening and the tachistoscope letter-detection tasks, while non-familial left-handers performed like the non-familial right-handers; both groups showed right-ear and right visual field dominance for verbal stimuli.

These results, taken together, suggest a genetic component to lateralization, especially considering that the handedness of the subject himself does not seem more important than the presence of left-handedness in the family. Annett (1964) has proposed such a model which includes explanations for ambilaterality, strong vs. weak left-handedness, and reversal of hemisphere function with dominant and recessive alleles. The model is discussed further in Satz, Fennel and Jones (1969); the predictions do not lead to the results reported here, however, and Miller (1971) also found that his results which supported Levy's "interference" theory were contrary to Annett's predictions.

The present study offers more support for the hypothesis that familial left-handedness is associated with decreased lateralization: from the analysis of absolute reaction time differences in the NI letter-discrimination task, persons without familial left-handedness had significantly greater differences between their two visual-field scores. This measure is assumed to reflect greater lateralization of speech function, and the direct relationship neatly supports the connection between familial left-handedness and facial recognition ability, adding to the likelihood that lateralization, rather than some other unspecifiable factor, is the variable responsible for the drop in facial-recognition ability among the familial left-handedness group.

Half-face bias

Throughout these subject-classification manipulations, the half-face test scores remained firmly centered near the mean of 15, indicating no bias for one side of the face over the other. Considering the consistent 60% bias obtained in previous samples (60% would be a score of 18 on this test) the lack of bias this time is very likely due to the face that subjects were not allowed to compare the composites to the whole-face portrait, but only to their memory of it. The explanation for the half-face bias has been as follows: Subjects are somewhat subliminally aware of lateral asymmetries in the whole face, and because of the more direct visual transmission between the left visual field and right hemisphere, the components of the left side of the face (as seen in the photograph) are more "salient." This leads to a more frequent choice of the composite from that side. When subjects cannot simultaneously compare all three photographs the bias apparently disappears, and this is probably because the subtle differences between the two sides of the whole face are lost in the memory, and so the choice of composite is made on some other basis. Previous studies showing the left-field bias (McCurdy, 1949; Lindzey, 1952) always allowed simultaneous comparison of the whole face and the composites.

A brief unpublished study was carried out last year: the whole face was presented tachistoscopically with a fixation point in the center of the face, followed by presentation of the two composites in free view. This method was used in an attempt to restrict the subject's fixation point to the center of the face, but subjects as a result had no opportunity to compare the three pictures simultaneously. In this brief experiment no bias was found. The short exposure of the whole face (200 msec.) was assumed to be the reason, but the present results suggest that lack of opportunity for simultaneous comparison could be responsible as well.

Levy et al.'s study using chimeric faces with split-brain subjects must be mentioned again. Apart from the drastic difference in the subjects, the only other difference from the conditions of the study just described was in the asymmetry of the whole faces shown in the tachistoscope: theirs were constructed from two very dissimilar half-faces, with glasses on one side, beard on the other side, etc. The strong left-field bias obtained in that study was undoubtedly due principally to the severed communication between the subject's hemispheres, but the increased asymmetry in the stimulus faces may have been a factor too.

To test that possibility, new stimuli are being constructed now from portraits of persons who were instructed to introduce asymmetry into their faces by smiling crookedly, arching one eyebrow, etc. The new set will be tried with both presentation conditions; if the left-field bias exists in the no-comparison condition, then the increased asymmetry will be assumed responsible.

Correlations

From the correlation matrix, the facial recognition test emerged as the most closely related to handedness variables. This is reasonable, since perception of faces has been more thoroughly verified as right-hemisphere-dependent than either the Block Design or Object Assembly subtests. The presence of familial left-handedness in the subject's family had the strongest relationship to facial recognition ability (-.47) followed by the combination of familial left-handedness and equal dexterity (-.40), then by sex (.32, females superior), Object Assembly performance (.26) and membership in the weak-handedness group (-.24).

Therefore it could be said that the highest scores for facial recognition tests should be obtained on the average by females with a strong lateral manual preference, who have no left-handedness in the family and who do well on the Object Assembly test.

One important variable not measured in this experiment is general intelligence, and there is evidence (especially Berman, 1971) that decreased lateral asymmetry, measured by a battery of motor skill tests, has a high correlation with more general intelligence, at least in the 8-14 year age range which Berman tested. In the present study, the two WAIS subtests which are used for assessment of intelligence, Block Design and Object Assembly, have correlations of -.17 and -.13 with the equal-dexterity variable. Object Assembly showed more signs of relationship to the handedness variables than Block Design did, with its correlation of -.28 with the combined variable of familial left-handedness and equal dexterity. This is similar to the -.40 correlation between the same combined variable and the facial recognition test.

The present results of the reaction-time testing are somewhat in line with other studies, but the effects are weak. The tradition of collecting hundreds of observations for each condition is a tedious but necessary one. For studies which set out to measure large numbers of subjects, perhaps either a visual-field letter-detection measure or the dichotic-listening test would produce the needed information more efficiently. For the PI condition, three correlations here point to the conclusion that the right hemisphere does not dominate for this discrimination: the expected left-field bias occurred most often in those persons possessing characteristics of less lateralization (combined variables #14 and #15) and a strong LVF bias for the PI condition correlated -.23 with a strong RVF bias for the NI condition. These are all low correlations, but the total impression does seem meaningful.

Last of all comes the matter of the remarkably low correlations among the components of handedness (Table 14). The highest meaningful correlation is only .26, between equal dexterity and "weak" categorization from the handedness questionnaire. The warnings of other writers on handedness are verified again here: self-report is a poor indicator of overall lateralization, and even more careful testing shows little consistency among the components of handedness. This leads to the commonly-observed situation of a subject reporting that he does many things left-handed and many other things right-handed, yet one hand performs consistently twice as well as the other on the dexterity test. The opposite of this happens also: a right-handers may answer that he uses his right hand for every item on the hand-usage questionnaire, but then he shows absolutely equal dexterity with either hand, trial after trial. Either the concept of "weak" and "strong" handedness is not very general but applicable only to a specific activity, or else accepted methods of measuring lateralization are inadequate.

In the present sample, familial left-handedness correlated -.09, .02, and -.06 with writing hand, dexterity, and the hand-usage questionnaire, respectively. If this non-relationship holds in larger populations, then it seems trivial to continue collecting a battery of handedness data for sensory-asymmetry studies, since familial left-handedness by itself seems to be a more useful indicator of speech lateralization.

This contradicts more extensive studies of cerebral speech lateralization in relation to handedness, however, so the more conservative conclusion should be that the situation is very complex. It could be that the overt expressions of handedness are much more peripheral and variable than some central genetic factor. This factor could determine the lability of both speech localization and lateral motor specialization; these are in a way the same thing, since the language dominance seems to apply to speech production more than to comprehension, and speech production, like skilled manual activity, is ultimately a motor act. (Kimura's recent research showing a relationship between the speech hemisphere and the gestures of the contralateral hand during speech [Kimura, 1973] is a step toward clarifying the relationship between speech production and skilled motor activity).

At any rate, the results of the present study imply that familial left-handedness seems to be the most unjustly neglected of all the facets of handedness. This variable's involvement with facial recognition deficit and with diminished reaction time asymmetry is not an isolated result, and the possibility of a more general genetic factor in determining lateralization, perceptual asymmetries, and right-hemisphere deficits should soon produce new research based on the genealogy of handedness.

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APPENDICES

APPENDIX A: HAND-USAGE QUESTIONNAIRE

This is a questionnaire about your handedness. Please think carefully and decide which hand you use for each activity listed. It is often helpful to act out the ones you're not sure about. Answer according to the following key:

RA	= right hand always	[5]
RM	= right hand mostly	[4]
E	= both hands equally	[3]
LM	= left mostly	[2]
LA	= left always	[1]
?	= no idea	

Which hand do you use to--

____1. write with
____2. hold a nail when hammering
____3. throw with
____4. hold a jar when removing the lid
____5. cut with scissors
____6. hold a needle when threading it
____7. draw with
____8. hold a glass when drinking
____9. hold a knife when cutting meat
____10. hold a potato when peeling it
____11. hold a ptcher when pouring out of it
____12. hold a toothbrush
____13. hold a dish when wiping it
____14. hold a tennis racket

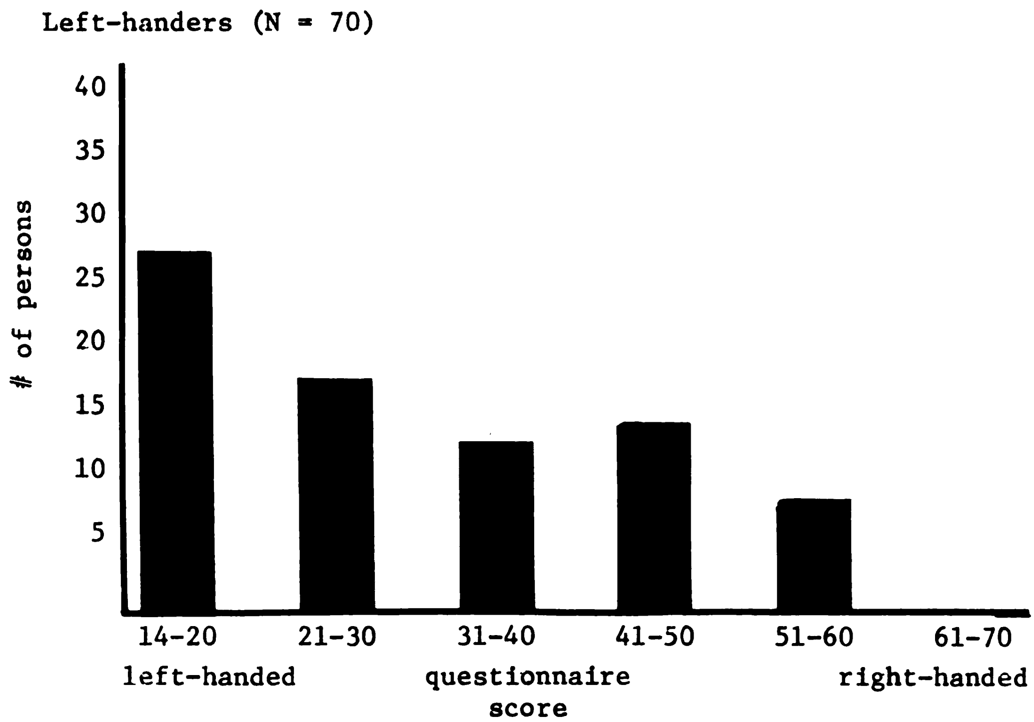
Also, indicate whether the persons listed below are right-handed or left-handed generally. This is for full relatives only; do not include step-parents, half-sisters, etc.

Mother____________ Father____________
Sister
Sister____________, ____________, ____________

Brother____________, ____________, ____________

(Scoring note: The numbers in brackets above indicate each response's score value. Items #2, 4, 6, 10, and 13 are reversed, since they ask for the non-dominant hand. These notes did not appear on the questionnaire.)

APPENDIX B: DISTRIBUTION OF HAND-USAGE QUESTIONNAIRE SCORES



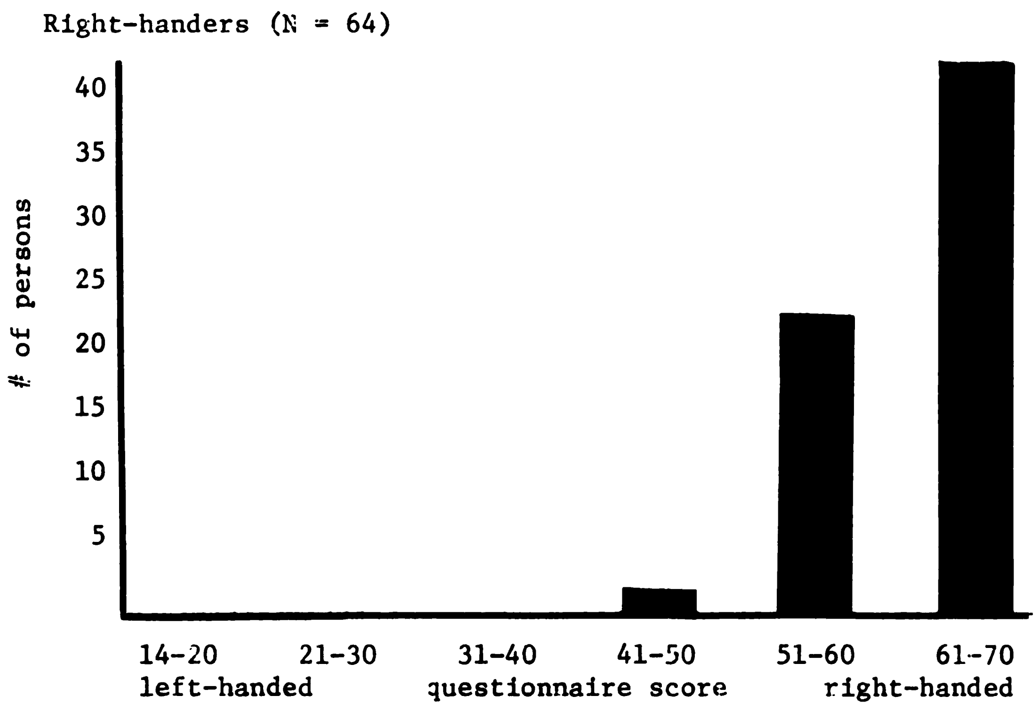


Figure 3. Distributions of handedness-questionnaire scores for left-handers and right-handers classified initially by writing hand. Data includes persons from earlier studies.

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