THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

DIFFERENTIAL CEREBRAL HEMISPHERIC INFORMATION PROCESSING IN GESTURAL-COMMUNICATING DEAF SUBJECTS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

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Norman, Oklahoma

1977

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APPROVED BY

DISSERTATION COMMITTEE

This dissertation is dedicated to three native Oklahomans. To Glenn Carmer Couch and Ida Marguerite LeCrone of Helena and later of Norman, Oklahoma, who taught me the value of an education and passed on to me an appreciation of the importance and the strength of my Oklahoma heritage. And to Valerie Katherine Gill also of Norman, Oklahoma, who by having decided to share her life with me has touched my life in a deeper and more profound way than anyone I have ever known.

ACKNOWLEDGEMENTS

I would like to thank the members of my disseration committee, N. Jack Kanak, William B. Lemmon, John R. Morris, and W. Alan Nicewander, whose knowledge and support have aided in the completion of this manuscript. A special acknowledgement is due to the chairperson, Roger S. Fouts, whose confidence in me coupled with a willingness to explore new ideas has provided the impetus for this study.

I gratefully thank Mary Z. Mays for her willingness to help in any way at any time; Dick Rubrecht for constructing a sturdy and dependable apparatus; Al Smith and Ann Musgrave for their excellence in serving as sign language interpreters; all the members of the Oklahoma City Association of the Deaf for their cooperation in the conducting of this experiment and for the warmth and hospitality they extended to the experimenters involved in this study; and Gregory L. Hanna whose assistance throughout this study has proved invaluable.

A very special thanks must be given to three people. To Daniel Gill Couch for waiting to be born until after most of the subjects in this study had been tested. To Marla Frick whose extraordinary patience, knowledge, and eagerness to help has been appreciated more than she will ever know. And finally, to Dick Reynolds for his friendship and counsel over the years which has served in large measure to keep me on an even keel.

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Abstract

Nonspeaking, gestural-communicating, right-handed deaf male subjects with a mean age of 22 years were administered a letter classification task. Subjects were required to make a response of either "same" or "different", based on a criterion of either verbal name matching or visual identity matching, to letter pairs presented tachistoscopically to each cerebral hemisphere via the visual half fields. Both response latencies and errors in responding were recorded. The results showed that the left visual field (right hemisphere) tended to be more efficient at processing verbal stimuli (statistically significant only for responses of "different" under the verbal name matching condition) as well as visual stimuli. The data was interpreted as supporting a developmental hypothesis of differential hemispheric specialization with regard to language functioning.

DIFFERENTIAL CEREBRAL HEMISPHERIC INFORMATION PROCESSING IN GESTURAL-COMMUNICATING DEAF SUBJECTS

Early research in the area of differential cerebral hemispheric functioning led researchers like Weinsenberg & McBride (1935) to posit that "there is nothing to show that the right brain has any specific language function..." However, further experimentation during the last two decades has provided considerable evidence to the contrary. In a recent extensive review of the literature, Krashen (1976) cites numerous studies which support the position that both hemispheres are capable, at least to some degree, of both linguistic and nonlinguistic functions (e.g., Kimura, 1961; Serafatinides & Falconer, 1963; Smith, 1966; Bogen, 1969 a,b; DeRenzi, Scotti, & Spinler, 1969; Carmon & Nachshon, 1971; Zurif & Mendelsohn, 1972; Fromkin, Krashen, Curtiss, Rigler, & Rigler, 1974; Papcun, Krashen, Terbeek, Remington, & Harshman, 1974). This evidence has resulted in a change from the more traditional cerebral hemispheric differentiation in functioning of verbal (left hemisphere)/ visuospatial (right hemisphere) to what appears to be a more accurate analytic (left hemisphere)/holistic (right hemisphere) distinction (Cohen, 1973; Bogen, 1975; Patterson & Bradshaw, 1975).

An even greater departure from the traditional verbal/ visuospatial dichotomy in cerebral hemispheric functioning is found in more recent studies. Brown & Jaffee (1975) posit that "...cerebral dominance is not a state but a process, and one that continues through life" (p. 108). The authors further state that "The notion of cerebral dominance must be qualified to mean, 'dominance for what function at what age under what conditions of testing?' Thus it might be argued that the right hemisphere is dominant during the prelinguistic period, and that presumably nascent left hemisphere skills are progressively brought into play as speech develops" (p. 107). Making the distinction between the cerebral hemispheres even more flexible, Bradshaw, Gates, & Nettleton (1977) conclude that cerebral asymmetry is of a quantitative rather than a qualitative nature. Further, in regard to the concept of analytic vs. holistic functioning of the cerebral hemispheres they state that "...no one hemisphere is exclusively specialized for the performance of any such function. Both cooperate and their differences are differences of degree and of strategic approach, rather than of rigid functional specialization" (p. 285).

These new hypotheses clearly have implications for cerebral hemispheric capacities in language functioning and strongly suggest that the linguistic properties of the right hemisphere have not yet been established. One factor which has influenced the research involving language functioning in the right hemisphere has been the subject population employed. Krashen (1976) has stated, in regard to the linguistic capacity of the right hemisphere, that "Undoubtedly, some of the differences in degree of ability... are related to the subject population employed, although it is not yet clear what the relationship is. It is, in addition, difficult to make serious claims when studies are based on such small samples (a handful of split-brain subjects, one 'isolated child', three aphasics, two left hemispherectomies)" (p. 180). One population which would eliminate many of these difficulties is the nonspeaking, gestural-communicating deaf.

Recently, a few studies have been conducted utilizing deaf subjects, but the results, although interesting, have not always been clear. Ling (1971) attempted to estimate speech laterality in 19 hearing and 19 oral, deaf children using monaural and dichotic digit tasks. The monaural test produced no ear advantage in either group, with hearing subjects displaying a significant right-ear advantage on the dichotic tests. The deaf children demonstrated a nonsignificant right-ear tendency on the dichotic tests. However, analysis of individual performance revealed that the deaf children tended to show either a marked right- or left-ear advantage. More recently, Neville (1976) presented line drawings of common objects to the right and left visual fields of both hearing and congenitally deaf children 9 to 13 years of age. The visual evoked potentials (EPs) from each hemisphere were recorded. The results showed that the hearing children demonstrated strong and consistent asymmetries. The right hemisphere EP peaks occurred earlier and were larger than those of the left hemisphere. Taken as a whole, the deaf subjects did not evidence any cerebral asymmetry. However, when divided into those who signed at home with their parents and those who did not, an interesting pattern emerged. The signing deaf children showed consistent asymmetries on three of the amplitude measures taken in favor of the left hemisphere, an asymmetry in the opposite direction from that of the hearing children. The author stated that one explanation for such findings was that "... perhaps the Signers have developed a right hemisphere specialization for their sign language..., leaving the left hemisphere specialized for other nonlanguage tasks" (p. 14 of published pre-conference summary).

Lubert (1975) tested both hearing and deaf adult subjects. All subjects were given tachistoscopic tests of sign language photograph and manual letter photograph recognition, printed letter recognition and dot enumeration. The results showed that while sign language photographs were more accurately recognized by the right hemisphere in both deaf and hearing subjects, no cerebral asymmetry was found for recognition of photographs of manual letters, printed letter recognition and dot enumeration. Of interest, however, was the data from the 24 right-handed deaf males employed in the experiment. These subjects showed a tendency, although statistically nonsignificant,for right hemisphere superiority on sign language photograph recognition and printed letter recognition tasks, but a tendency toward a left hemisphere superiority for dot enumeration. These studies suggest that the right hemispheres of deaf subjects who use sign language may well be involved in language functioning. It should be noted here that although Leischner (1943) and Lenneberg (1967) have found that left-hemisphere-lesioned deaf signers exhibit manual signing deficits, in only one of these cases is it clear that the person was congenitally deaf which would rule out the confound on language lateralization of some early speech acquisition. There is ample evidence (Kimura, 1976) that the left hemisphere controls certain motor activities of the upper limbs and so the evidence of manual signing deficits in left-hemisphere-lesioned deaf persons is not surprising. However, this evidence would at best pertain only to language production and not to language receptivity.

The hypothesis that the right hemisphere in gestural-communicating deaf persons may be superior to the left with regard to language function has theoretical support from several existing hypotheses concerning cerebral hemispheric specialization. Krashen (1976) has stated that language might possibly be "overlaid on mental abilities also utilized in nonlinguistic ways" (p. 172). This concept would certainly be consistent with the notion that the right hemisphere could, under certain circumstances, become specialized for language functions; and is clearly compatible with the notion of Bradshaw et al. (1977) of a quantitative rather than a qualitative difference in the two hemispheres. Although Krashen goes on to state that it is the left hemisphere which is specialized for the mental abilities used in language functioning, it is conceivable that the left hemisphere specialization on which language is overlaid is speech rather than more general "mental abilities". Similarly, Kimura (1976) has stated that researchers should "pay attention to the motor functions of the left hemisphere" and that "brain regions considered to be important for symbolic language processes might better be conceived as important for the production of motor sequences which happen to lend themselves readily to communication" (Pp. 145-146). Although Kimura has been criticized for over emphasizing the sequential motor behavior aspects of language (Poeck & Huber, 1977), it is interesting to note the high positive correlation between cerebral hemispheric lateralization of the motor functions involved in speech and the cerebral hemispheric lateralization of language in hearing, speech-communicating subjects.

Indeed, there is evidence that a left-lateralized speech-specific mechanism does exist. In a series of experiments (Sussman, 1971; Sussman, MacNeilage, & Lumbley, 1974; Sussman & MacNeilage, 1975 a,b) subjects were found to exhibit a left hemisphere superiority for dichotic pursuit auditory tasks requiring tone matching when the cursor tone (to be matched with the first tone) was controlled by the tongue and jaw. These results led the experimenters to conclude that "... the right ear effects for tasks involving the speech articulators were due to the presence in the left hemisphere of a special speech-related auditory sensorimotor integration mechanism" (Sussman & MacNeilage, 1975a). Krashen (1976) observes, according to Sussman & MacNeilage (1975b), "that the failure to obtain significant differences when the cursor is controlled by the hand indicates that the laterality effect is not the result of any abstract mental ability in the left hemisphere but is instead directly connected to the utilization of the speech apparatus" (p. 172).

If in fact it is a speech-specific mechanism located in the left hemisphere that "draws" language to that side of the brain, then it is conceivable that in nonspeaking, gestural-communicating deaf persons cerebral hemispheric functioning may be altered from that of speech-communicating, hearing persons with regard to language. There is evidence that the right hemisphere may be dominant prelinguistically (Knox & Kimura, 1970; Carmon, Harishanu, Lowinger, & Lavy, 1972; Crowell, Jones, Kopunial & Nakagawa, 1973). Therefore, in those persons who do not use speech but have acquired language (i.e. nonspeaking, gestural-communicating deaf persons), it is possible that the right hemisphere developed the language functions normally conducted by the left hemisphere in speech-communicating, hearing persons. In order to test this hypothesis the following experiment was conducted with nonspeaking, gestural-communicating deaf subjects using a letter classification task previously used (Cohen, 1972; Geffen, Bradshaw, & Nettleton, 1972; Davis & Schmit, 1973) to detect asymmetries in cerebral hemispheric functioning of speech-communicating, hearing subjects.

Method

Subjects

Seven right-handed, deaf males served as the subjects for this experiment. Each subject had become deaf by age 4 years or younger and had no uncorrected visual defects. Handedness was determined through the administration of a modified form of the Edinburg Handedness Inventory (see Figure 1). Sign language was the major form of communication for each subject, with little or no oral speech evidenced. Subjects ranged in age from 18-32 years with a mean age of 22 years.

With the exception of one subject who had left school in the twelfth grade, all subjects had received a high school degree. All subjects were paid for their services. Five of the seven subjects employed were members of the Oklahoma City Association of the Deaf, Oklahoma City, Oklahoma. The remaining two subjects resided in the greater Oklahoma City area.

Apparatus

The apparatus employed was a Lafayette U-1 constant illumination tachistoscope. The viewing chamber consisted of GE F 475-CU stimulus lamps with a 0.1 msec. rise/fall time. The usable target size was 12 cm. W x 9.5 cm H with an eye image distance of 37.5 cm. and an elevation adjustment of 0- 7.5 cm. The control unit had a line voltage of 105/125 V AC, 50/60 Hz with a power consumption of 60 watts. The fuse was 3/4 amp and timing range settings available were 1-30 msec. or 30-900 msec.

Two response buttons were placed on either side of the tachistoscope so that the subject was able to easily press either button while comfortably looking through the viewfinder. The stimulus letters were placed on the stimulus cards so that they subtended a visual angle of 4.19°.

Procedure

The type of letter classification task used in the experiment was first introduced by Posner & Mitchell (1967) and later utilized by Cohen (1972), Geffen, Bradshaw, & Nettleton (1972) and Davis & Schmit (1973). The letter pair combinations (constructed from the letters A, B, a, b) of Davis & Schmit (1973) were used with letter pairs divided into those which could be judged "same" or "different" on the basis of visual identity matching or verbal name matching (see Figure 2). For example, the letter pair aA was classified as "different" under the visual identity matching criterion; whereas the same letter pair aA was classified as "same" under the verbal name matching criterion. The letter pairs were typed on white stimulus cards which measured 12.5 cm. W x 10.1 cm. H and were presented vertically rather than horizontally so as to eliminate any horizontal scanning effects (Cohen, 1972).

Each condition (visual identity matching or verbal name matching) consisted of 8 possible letter pairs. Each letter pair was repeated 8 times (four presentations to each cerebral hemisphere via the visual half fields). The letter pair presentations were randomized through the use of a random numbers table with the limitation that no letter pair occurred twice in succession. Hand to response button (left, right hand vs. same, different response button) and order of presentation of conditions (visual identity matching vs. verbal name matching) as well as the order of presentation within each condition (forwards vs. backwards) were counterbalanced.

Each subject was given 128 letter pair presentations for each of the two conditions (64 possible pairs presented in forward order, followed by a brief rest period, then backward order or vice versa) with a 5 minute break between conditions. Prior to the testing session for each condition, each subject was informed of the criterion to be used in responding followed by a practice session which consisted of 32 letter pair presentations. The subject was alerted to the upcoming letter pair presentation by the experimenter tapping on the desk at which the subject was seated and on which the response buttons were placed. When the subject felt the tapping, he was instructed to fixate on a centrally-illuminated asterisk. This ensured that the angle of presentation of the letter pairs was accurate and constant. Each letter pair presentation was automatically set for a 150 msec. duration. No interpresentation interval exceeded 10 sec.

Both the number of errors and latencies in responding were recorded. If on any letter pair presentation there was an error in responding or a response latency exceeding 1 sec., that letter pair was recycled and presented again to the subject. The recycling and representation occurred after each 10th trial and included all errors and unacceptable latencies that occurred in the previous 10 trials.

Results

The dependent measure recorded in this experiment was the response latency between onset of the stimulus and the subject's response. The response latencies for each condition (visual identity matching and verbal name matching) were then divided into two groups, responses "same" (64 response latencies) and responses "different" (64 response latencies). These two groups of response latencies were then subdivided into those which had been presented to the left visual field (32 response latencies) and those which had been presented to the right visual field (32 response latencies). The mean response latency was then computed for each of these subdivisions. This resulted in four mean response latencies for each of the two conditions of visual identity matching and verbal name matching (left visual field "same" responses, right visual field "same" responses; left visual field "different" responses, right visual field "different" responses). This dependent measure (mean response latency) was arranged in a 2 x 2 x 2 factorial where the factors were left vs. right visual field, "same" vs. "different" response, and visual identity matching vs. verbal name matching condition.

A completely within analysis of variance was performed on this data. The main effect for left vs. right visual field was not significant, $\underline{F}$ (1,6) = 2.85, $\underline{p}$ = .14. Both of the main effects for "same" vs. "different" response and visual identity matching vs. verbal name matching condition were significant, $\underline{F}$ (1,6) = 64.33, $\underline{p}$ < .001, and $\underline{F}$ (1,6) = 12.91, $\underline{p}$ = .01, respectively; replicating with a deaf population the findings previously reported with speech-communicating, hearing subjects by Cohen (1972), Geffen, Bradshaw & Nettleton (1972), and Davis & Schmit (1973). None of the interactions reached acceptable levels of significance (all $\underline{p}$s > .33).

However, it is clear from Figure 3 that the data reveals a trend toward a left visual field (right hemisphere) superiority under the verbal name matching condition, a finding in the opposite direction from that of Geffen et al. (1972) who utilized hearing subjects. Therefore, two individual comparisons from the three-way interaction were performed; one comparing the left vs. right visual field on the "different" responses under the verbal name matching condition and one comparing the left vs. right visual field on the "same" responses under the verbal name matching condition. These individual comparisons were done utilizing a Dunn-Bonferoni test where the predicted differences of -.030 msec. ("different" response) and -.023 msec. ("same" response) obtained from the data of Geffen et al. (1972) were employed (rather than assuming the differences to be equal to zero). The test for the "different" responses was significant, $\underline{t}$ (5) = 4.048, p < .025 indicating that the left visual field (right hemisphere) was superior at processing verbal information requiring a response of "different". This is a clear reversal from the processing of the right hemisphere, under similar verbal conditions, in speech-communicating, hearing subjects. The test for the "same" responses, while not significant, showed the same trend, $\underline{t}$ (5) = 2.673, $\underline{p}$ > .025.

An identical analysis of variance was conducted for errors in responding and neither the main effects nor any of the interactions were found to be significant.

Discussion

The results showed that two of the main effects (verbal name matching vs. visual identity matching; "same" vs. "different" response) to be highly significant, replicating the results of previously reported experiments (Cohen, 1972; Geffen, Bradshaw, & Nettleton, 1972; Davis & Schmit, 1973) utilizing speech-communicating, hearing subjects. It is interesting also to note the high similarity between the mean response latencies of Geffen et al. (1972) and those of the present experiment (see Table 1). The third main effect (left visual field vs. right visual field) was not significant. Although none of the interactions were significant, the results of the two individual comparisons performed from the three-way interaction revealed a significant left visual field superiority for responses "different" under the verbal name matching condition and, though nonsignificant, a clear trend in the same direction for responses "same" also under the verbal name matching condition. In view of the existing evidence that "different" responses require analytic processing (Bradshaw, Gates, & Nettleton, 1977) the results of the present experiment suggest that in nonspeaking, gestural-communicating deaf persons the right hemisphere may have developed the analytic properties usually ascribed to the left hemisphere in speech-communicating, hearing persons. Further, the finding that these deaf subjects process verbal stimuli more efficiently in the right hemisphere supports the hypothesis that nonspeaking, gestural-communicating deaf persons utilize the right hemisphere for language functions.

Although contrary to the findings reported by Neville (1976) which demonstrated a greater left hemisphere involvement in the processing of visual stimuli in nonspeaking, gestural-communicating deaf children, the results of this experiment did coincide with the findings reported by Fromkin, Krashen, Curtiss, Rigler, & Rigler (1974) and Curtiss, Fromkin, Krashen, Rigler, & Rigler (1974). These studies dealt with the differential cerebral hemispheric functioning of a young girl, "Genie", who had been kept in a condition of environmental deprivation (including being punished for making any noise at all) for eleven and one half years until she was 13 years, 8 months old. Dichotic listening tests performed by the experimenters revealed that some three years after her release she was learning or perhaps relearning language via her mature right hemisphere. The results of these tests showed a rather normal right hemisphere superiority for the processing of nonverbal stimuli but a marked right hemisphere superiority for the processing of verbal stimuli (although her overall linguistic ability was naturally quite depressed). Theoretical support for such findings are found in developmental hypotheses concerning cerebral hemispheric dominance (Brown & Jaffe, 1975), develop earlier, the development of the human brain appears to "favor the elaboration of language" (Sperry, 1974), with language lateralization occurring as early as 3-5 years according to Ingram (1975). It would therefore seem reasonable to postulate that persons who had become deaf by age 3-5 years or earlier and did not acquire speech but instead used a gestural form of communication (such as sign language with its visuospatial characteristics) might well develop language functioning in the right hemisphere. The lack of stimulation from speech production and reception in these persons could also be an important factor in the lack of development of language functions in the left hemisphere as it apparently was in the case of "Genie".

This line of reasoning would predict, as the results of Neville (1976) showed, that the left hemisphere might well become superior in the processing of visual stimuli in nonspeaking, gestural-communicating deaf persons. The fact that the results of the present experiment did not support that prediction may well be due to the use of letters (which clearly have verbal qualities) in constructing the stimuli used in the visual identity matching condition. Certainly other interpretations can be placed on the data from this experiment, but the results clearly indicate that the capacity of the right hemisphere for language functioning has previously been underestimated and has not yet been fully determined.

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TABLE 1

MEAN RESPONSE LATENCIES (MSEC.)

	GEFFEN, BRADSHAW, & NETTLETON (1972)		PRESENT STUDY	
	Visual Condition			
Response	LVF	RVF	LVF	RVF
same	535	547	541	552
different	601	613	607	613
	Verbal Condition			
	LVF	RVF	LVF	RVF
same	680	657	632	644
different	717	687	701	724

LVF = Left Visual Field (Right Hemisphere)

RVF = Right Visual Field (Left Hemisphere)

Figure Captions

Figure 1. Modified Edinburg Handedness Inventory administered to all subjects in this experiment.

Figure 2. Letter pair stimuli of both visual identity matching and verbal name matching conditions subdivided into "same" and "different" responses (Davis & Schmit, 1973).

Figure 3. Bar graph depicting the mean response latencies in msecs. for responses "same" and "different" by visual field under each matching condition.

Name:________________

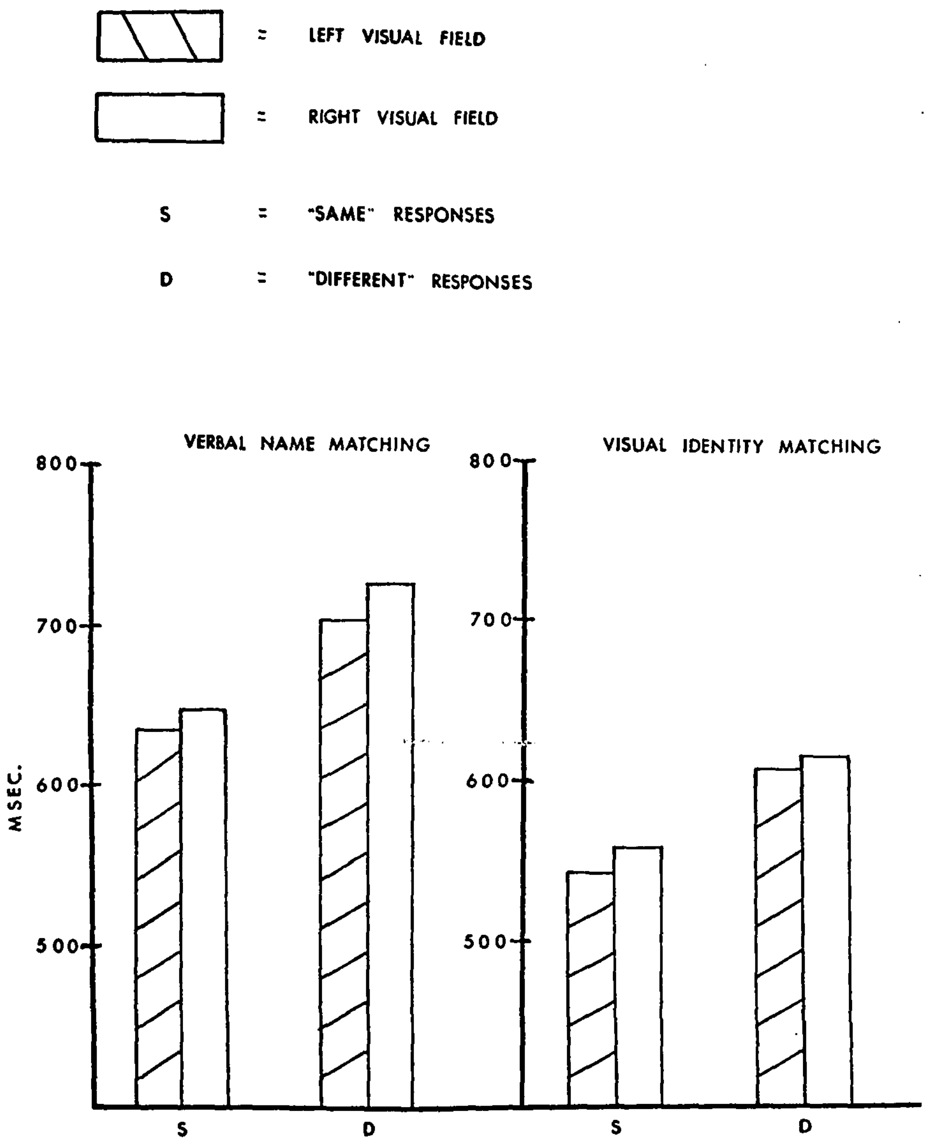
Age:_________________

This is a survey to discover which hand you use in the following manual tasks. Circle L if you perform the task with your left hand; circle R if you perform the task with your right hand; circle B if you perform the task equally well with both hands. Assume that your hands are empty, except as indicated, before attempting each task. If you have no experience with a given task, do not mark a preference.

With which hand do you:

1.	draw?	L R B
2.	write?	L R B
3.	remove the top card of a deck of cards (i.e., dealing?)	L R B
4.	use a bottle opener?	L R B
5.	throw a baseball to hit a target?	L R B
6.	use a hammer?	L R B
7.	use a toothbrush?	L R B
8.	use a screwdriver?	L R B
9.	use an eraser on paper?	L R B
10.	use a tennis racket?	L R B
11.	use scissors?	L R B
12.	hold a match when striking it?	L R B
13.	stir a liquid?	L R B
14.	on which shoulder do you rest a bat before swinging?	L R B
15.	with which food do you kick a ball for distance?	L R B
16.	carry your books or book bag?	L R B
17.	which foot do you put a shoe on first?	L R B
18.	Is at least one of your parents or siblings left-handed? In answering this, assume that a left-handed person would prefer using his or her left hand on 12 or more of the tasks listed above.	Yes No
19.	Do you have any severe uncorrected visual defects?	Yes No
20.	Is sign language your major form of communication?	Yes No
21.	Do you use any oral communication?	Yes No
22.	At what age did you become deaf?	______
23.	Can you hear any speech?	______
24.	How old were you when you began to use sign language?	______

VISUAL IDENTITY MATCHING		VERBAL NAME MATCHING	
Same	Different	Same	Different
aa	aA	aA	aB
bb	bB	bB	bA
AA	Aa	Aa	Ab
BB	Bb	Bb	Ba


= LEFT VISUAL FIELD
= RIGHT VISUAL FIELD
S = "SAME" RESPONSES
D = "DIFFERENT" RESPONSES
VERBAL NAME MATCHING
VISUAL IDENTITY MATCHING
MSEC.
800
700
600
500
S
D

APPENDIX A

Statistical Table

Summary Table for Analysis of Variance on Response Latencies

Source	MS	df	F	p
A (Visual Fields)	.0025	1	2.85	.14
error	.0009	6		
B (Response Type)	.0670	1	64.33	.0005
error	.0010	6		
C (Condition)	.1326	1	12.91	.0116
error	.0103	6		
A x B	.0000	1	.033	.85
error	.0010	6		
A x C	.0003	1	1.13	.33
error	.0003	6		
B x C	.0004	1	.60	.53
error	.0007	6		
A x B x C	.0002	1	.33	.60
error	.0006	6		

APPENDIX B

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