HEMISPHERE DIFFERENCES AND INTERHEMISPHERIC RELATIONS WITH SPECIAL REFERENCE TO THE FUNCTIONS OF THE CORPUS CALLOSUM

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by

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Abstract

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Ph.D. Thesis by Don McQuoid Reynolds

This thesis contains reports of behavioural investigations carried out on an acallosal girl and her brain-damaged sister. These patients were compared on tasks involving tactile, auditory, and visual perception with a group of control Subjects matched for sex, I.Q. and age, as well as with normal Subjects of the same sex and age. The general aim of the experiments was (a) to investigate and compare the functions of the cerebral hemispheres and (b) to study interhemispheric relationships. Using normal Subjects as well as the acallosal patient special attention was directed towards furthering our understanding of the functions of the corpus callosum. Our results were compared with previous findings in an effort to resolve conflicting findings in the agenesis literature and to explain differences between the previously reported acallosal and surgical-bisected patients' behaviour.

The acallosal was found to perform less efficiently than control Subjects on some bimanual and unimanual motor coordination tasks. This finding is consistent with earlier reports on agenesis Subjects. Some evidence was found to indicate that acallosals do not efficiently transfer learning of a tactile formboard task from one hand to the other. The acallosal patient did not show an anomia of the left hand as do surgical-bisected patients. There is, however, an inefficiency in tactile cross-localization of light touch stimuli.

Dichotic listening experiments used verbal stimuli to test the hypothesis that the acallosal girl would demonstrate equipotentiality of language processes in both hemispheres. Tonal patterns were similarly

presented dichotically. The acallosal Subject exhibited a greater right-ear advantage than the controls on the recall of digits.

Studies of reaction time to a simple visual stimulus replicated findings of greater pathway differences for acallosals than for normals. Another visual perception study supported the finding that acallosals do not show interocular transfer of movement aftereffects.

Tachistoscopic recognition tasks of alphabetical and facial stimuli were used on the acallosal, her sister, and normal controls. A developmental study of normals was also carried out. Thirteen year old normals and adults were found to have a left-hemisphere superiority for letters and right-hemisphere for faces. The seven and eight year olds did not show significant lateralization of either faces or letters. The acallosal showed a left visual field superiority for letters, a finding opposite to that for normals. These findings suggest that processes involved in recognition of letters and faces develop with increasing age in childhood. The acallosal Subject appears to have bilateral representation of language processes across sensory modalities in opposite hemispheres, presumably the result of compensatory development arising from lack of a corpus callosum.

Certificate

I hereby certify that Don McQuoid Reynolds has completed nine terms of research work under my supervision, has fulfilled the conditions of the Resolution of the University Court, 1967, No. 1, and that she is qualified to submit the accompanying thesis in application for the Degree of Doctor of Philosophy.

Research Supervisor

31 March 1975

DECLARATION

I hereby declare that this thesis has been composed by myself, that the work of which it is a record has been done by myself and that it has not been accepted in any previous application for a higher degree in the University of St Andrews or elsewhere.

Signed:

Don McQuoid Reynolds

31 March 1975

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CONTENTS

CHAPTER ONE

AGENESIS OF THE CORPUS CALLOSUM: INTRODUCTION

We began this study of a case of agenesis of the corpus callosum originally with the hope of examining a number of cases intensively. We intended to make a comparison with the agenesis reports already in the literature and also, a comparison with the extensive literature on surgically-bisected patients. We felt, in 1971 when we began this study, that there was a lack of coordination for comparative purposes between existing studies. There was a lack of experimental data reported; the reports tended to be anecdotal.

In practice, it was only possible to study one acallosal Subject suitable for our purposes, the others (located through hospital records) being either dead or excluded because of extensive extra-callosal brain damage. However, our one acallosal Subject appears to have no extra-callosal damage and has been very cooperative over the period of three years that we tested her.

There is not at this point a great deal of behavioural data in the relatively small body of literature in which attempts have been made to explore the functions of the corpus callosum by studying patients who were born without this structure. The lack of data is due, in part, to the difficulty in obtaining congenital acallosal patients to study (agenesis being a rather uncommon phenomenon which is itself clinically asymptomatic and unlikely to be diagnosed unless other problems of a neurological nature are present, e.g., epilepsy).

There may be instances in research where a very few Subjects tested were enough to arrive at trustworthy conclusions;

however, in this case, because it is difficult to obtain Subjects known to lack extra-callosal damage, or who have extra-callosal damage specifically and correctly identified, or who can even be correctly identified as having no corpus callosum at all, it seems necessary to accumulate data on these patients whenever possible. Eventually, in spite of individual variation, a pattern of behaviour attributable to the lack of the corpus callosum in human Subjects born without it should clearly emerge.

Interest in studying the functions of the corpus callosum has been centred in the literature much more on Subjects who have had their brains bisected surgically than in Ss born without the corpus callosum, but to some extent this direction of the research has a similar difficulty. There is inevitably an unknown amount of extra-callosal damage due to the operation itself or to lesions of varying age connected with the intractable epilepsy which was the reason for the surgery. This continues to be a problem in interpreting results of testing.

We have studied our acallosal patient within a broad context concerning cerebral dominance and functional asymmetry of the brain. Acallosals and surgically bisected patients are particularly appropriate for investigation within this context.

The study of surgically-bisected patients has been the more fruitful approach to identifying the functions of the corpus callosum, particularly in terms of the development of new testing procedures. The early results of the 1960s obtained by Sperry and Gazzaniga on these surgically-bisected patients and by Geschwind and Kaplan on their deconnection patient conflicted considerably with the kinds of data obtained by Akelaitis in the early 1940s on surgically-bisectioned patients, and also with the kind of data being obtained on agenesis Ss (Jeeves, 1964, 1965; Saul and Sperry, 1968; Russell and Reitan, 1955; and others). The conflict may be identified as being between all-or-none, pass/fail type data obtained for surgically-bisectioned patients (the first patients of Sperry and Gazzaniga, and Geschwind), and the quantitative impairments found by Jeeves.

We hope to contribute to a resolution of the conflict between the agenesis data and the surgical-bisection data. Originally we had envisaged this resolution taking the form of exploring the development of the functioning of the corpus callosum in behavioural terms by looking at the effect of age on acallosal Ss' performance on a variety of tasks compared to normal Ss matched for age and mental age and neurological deficits. The suggestion we are making is that the difference found previously between surgically-bisectioned patients and individuals with congenital agenesis are presumably due to the greater ability of the brain to develop compensation in early development than in adulthood. This greater ability of the acallosal brain to compensate could be examined to some extent by looking at age differences in performance of the acallosals.

This was our original intention, but our inability to locate suitable acallosals excluded this developmental approach. We then decided to pursue the issue of development of cerebral lateralization generally, using normal Ss. This had not been done previously, and could conceivably tell us from a different angle something about the functions of the corpus callosum. This we proceeded to do, and this study of the development of cerebral lateralization forms the second part of our thesis, the first part of our thesis reporting our investigation of agenesis.

We wished, also, to take a good look at differences in experimental procedure which were possibly contributing to some of the conflicting findings.

SPECIFIC PROPOSED AREAS OF EXPLORATION.

We would like to follow along the line that Jeeves (1965) took in suggesting that "what we should look for is not dramatic impairment of function but the relative efficiency of function as compared with normals", because this approach has been useful in his own studies and, more often than not, in other agenesis studies, depending on the specific task involved. Furthermore, the more recent surgical-bisection literature is leaning in this direction also.

I. BIMANUAL MOTOR COORDINATION

Jeeves reported in 1965, in a study on three congenital acallosal patients, deficiencies on certain bimanual motor tasks. His acallosal Ss were less efficient (in terms of time) than normals on these tasks: bimanually fitting 16 cubes in a box, buttoning up, winding string around a pencil, and placing pegs (with the preferred hand, non-preferred hand, and both hands). They were less efficient than normals at a task which scored the number of beads strung in two minutes. In addition, his older acallosal patient obtained considerably different scores from the younger acallosals, suggesting age-related differences.

Sperry reported in 1968 (paper on plasticity of neural maturation) on an acallosal S of college age that some perceptuo-motor deficits were found compared to Normals on tasks like stringing beads, putting pegs in holes, and matching jigsaw pieces using right and left hands together, but no quantitative data were reported.

Data comparable to the data published for acallosals on bimanual tasks have not been reported for surgically-bisectioned patients, but researchers have commented on the kinds of performance exhibited on motor tasks.

Quoting from Ettlinger and Blakemore in Contributions to Clinical Neuropsychology (1969): "Surveying motor functions broadly, it appears that only in special circumstances is there severe deficit in the commissure-sectioned patient (e.g., in the intermanual transfer of skills, and in the change from contralateral to ipsilateral eye-hand pairs with visual pattern discriminations); and even then, such deficit is subtotal or impermanent".

We wanted to see whether the differences in performance that have previously been reported on the several acallosal Ss compared to Normal Ss would be replicated by our acallosal girl compared to Ss matched for Intelligence and Age and Sex.

Our review of the literature is divided into two parts. In the following section is the early review from which we generated our view of each area we wanted to investigate. The specific experiments we planned are divided into the areas of Tactile, Auditory, and Visual Perception. Although the tasks themselves may not be primarily about perception, this is a convenient way of organizing our investigations. After these early reviews and a discussion of agenesis of the corpus callosum and surgical bisection literature, we present the case histories of our Subjects. Then our empirical work is reported, prefaced in each case by such further review as is necessary.

II TACTILE LEARNING AND TRANSFER OF TRAINING, AND CROSS-LOCALIZATION

Tactile Tasks: Russell and Reitan (1955), Sperry (1968), Solursh et al. (1970) and Jeeves (1965) have all found a deficit in bilateral transfer in the tactual modality and attribute these deficits to the role of the corpus callosum.

A. Maze Learning.

Maze learning is a type of perceptual-motor learning using, when the S is blindfolded, tactual-kinesthetic guidance. It has been used to some extent in studies designed to assess brain damage.

In the agenesis literature, Lehmann and Lampe (1970) in a report of nine patients with agenesis (of whom three had total agenesis) found that the acallosals did not significantly transfer learning of the maze from the preferred hand to the non-preferred hand, while both their Normal Controls and Epileptic Controls did quite significantly exhibit savings.

Geschwind and Kaplan (1962) attempted to test their deconnection patient on a transfer of learning maze task. Their right-handed patient learned the maze with his left hand but was "totally incapable of running the maze with the right hand". This failure was attributed to a grasping reflex which caused the S's finger to stick in the maze or jerk out of it.

Gazzaniga, Bogen, and Sperry (1962) reported on a surgically-bisectioned patient that learning did transfer (though no figures were given) from either hand to the other in the same S (on learning a stylus maze). In a 1963 report they suggested that this could be attributed to "in part at least to the nature and size of the maze and the consequent shoulder movement and trunk adjustments (not confined to one side) involved in its performance".

B. Form Board Discrimination

Solursh et al. (1965) tested a 14-year-old, right-handed acallosal male of normal intelligence on a number of learning tasks.

On the form board task the patient was required, while blindfolded, to place objects lying on the table into their position on the board with the dominant hand first, then the non-dominant hand, and then both hands together. He also tested a group of ten Ss matched by age for comparison with the acallosal.

Solursh et al.'s results:

	Dominant Hand		Non-dominant		Savings	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Agenesis S	15 min.		9.5 min.		5.5 min.	
Control Ss	6.7 min.	2.54	3.9 min.	1.27	2.20 min.	1.81

An alternate form board was used with reverse order of presentation, the non-dominant hand preceding the dominant:

	Non-dominant		Dominant		Savings	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Agenesis S	3.1 min.		4.8 min.		-1.7 min.	
Control Ss	3.36 min.	1.12	2.25 min.	0.93	1.10 min.	0.77

Solursh reports that both savings scores of the agenesis Subject are inferior to Controls. It is noteworthy that in going from the non-dominant hand to the dominant hand the Subject showed no transfer of training whereas he did on the dominant to non-dominant switch.

Jeeves, reported (1965) on a somaesthetic training and transfer task using a three-hole formboard on a six-year-old, blindfolded male acallosal, and tested first the preferred hand and then the non-preferred hand. He obtained no savings whereas his Normal Controls did show a savings. This is in contrast to Solursh's finding on the dominant to nondominant transfer.

Russell and Reitan (1955) administered a modified version of the Seguin-Goddard Formboard. Using first the dominant hand and then the non-dominant hand, and then both hands, the acallosal S they tested gave different results from Normals. The results indicated that no bilateral transfer occurred.

The results from these three acallosal studies give conflicting results. A further experiment may contribute to a resolution of these differences.

C. Tactile Cross-localization and Identification of Objects.

Jeeves (1965) found no evidence of a deficit in tactile cross-localization on body surface in the one acallosal he reported on.

Gazzaniga, Bogen, and Sperry (1963) found that the surgically bisected man studied and reported on in this paper was not able to cross-identify objects.

Saul and Sperry (1968) reported on an agenesis S̲ that she was able to cross-identify objects with no difficulty.

Ettlinger et al. (1972) found that a deficit in cross-localization of tactile stimuli was definitely present in their agenesis patients.

We tested our acallosal patient and her Sibling as well as a group of normal controls and a group of Mental Match S̲s for comparative purposes.

III. AUDITORY PERCEPTION PERFORMANCE (VERBAL VERSUS NON-VERBAL).

One of the hypotheses put forward to explain how the brain 'compensates' for the congenital absence of the corpus callosum is that language, including speech mechanisms, is laid down bilaterally in the brain in congenital acallosals rather than unilaterally as seems to be the case in normals, with left cerebral dominance of language generally found in right-handed individuals (Sperry, 1968). Milner et al. (1964) found that seven out of forty-four left-handed epileptic patients who were injected with sodium amytal in the carotid artery (the Wada Test) had bilateral speech representation and language comprehension. Sperry suggests that if there are these Ss with callosum intact who have bilateral speech representation, it is even more likely that bilateral speech representation would be found in congenital acallosals.

Gazzaniga has also suggested bilateral language representation, but reported (1970) an opposite finding in one agenesis patient of B. Milner who was injected with sodium amytal. This acallosal patient demonstrated unilateral language processes only.

A way in which we may examine the question of bilateral speech representation and functional asymmetry of the brain involves use of the dichotic listening procedure first devised by Broadbent (1954) and adapted by Kimura (1967) who reported in a summary of previous experiments the (by then) well-established right-ear superiority of right-handed normal Ss for verbal material. Kimura had found (1963) the right-ear-advantage to be generally established by four or five years of age, indicating that "speech functions were already predominantly represented in the left hemisphere as early as age four years".

Kimura has also explored the functional differentiation of the hemispheres by adapting the dichotic listening recall technique to a multiple-choice recognition technique using non-verbal material, i.e., melodic patterns (1964). For melodic pattern recognition, she established a left-ear superiority interpreted as right-hemisphere dominance for normal Ss.

The dichotic listening procedure has been useful in looking at cerebral dominance and the functional asymmetry of the brain in normal individuals. It has also been used similarly on brain-damaged patients with various sites and types of lesions. Of particular relevance are the studies of Sparks and Geschwind (1968) and Milner, Taylor, and Sperry (1968) on surgically-bisected patients.

Regarding verbal dichotic listening procedures used on congenital acallosal Ss, Bryden and Zurif (1970) reported on one 15 year old acallosal boy, and Ettlinger et al. (1971) report a study including two total agenesis patients. Both Bryden and Zurif's S and Ettlinger et al.'s two total agenesis Ss showed left-ear superiorities for report of digits.

If there is in fact a left-ear superiority in agenesis of the corpus callosum patients, and we do not think this is yet firmly established, considering the limited number of acallosals tested and confounded as the results have been with handedness, then what is the significance of this finding as considered with the left-ear extinction results found with surgically-bisected patients, and the right-ear superiority of normals?

Along with the questions arising from the dichotic listening task using verbal material which are not yet resolved it might be useful to explore the question of functional asymmetry with non-verbal material, such as musical patterns, which have been found in normals to exhibit an opposite ear superiority from that of verbal material. This, as far as we have been able to determine, has not been explored with agenesis patients. This type of experiment, using both verbal and non-verbal material presented dichotically to the acallosal S and her Sibling, and Ss matched for age, sex, and intelligence with the acallosal, as well as normals matched for age and sex, may help us to resolve the questions of ear superiority, functional asymmetry, and/or the possibility of bilateral speech perception in the brain of the acallosal.

IV. VISUAL PERCEPTION: COMPARISONS OF INTERHEMISPHERIC TRANSMISSION TIMES

Motor responses to visual stimulation.

Kinsbourne and Fisher (1971) reported a study using a sixteen year old male callosal agenesis on a task which measured speed of reaction to visual stimulation. They found no significant difference in reaction time between interhemispheric and uncrossed transmission times. As they pointed out in their report, this finding conflicted with that of Jeeves (1969), who reported a difference in Reaction Time such that the contralateral transmission time was significantly longer than for the shorter (ipsilateral) pathway. Kinsbourne and Fisher suggest that the difference may be due to a difference in procedure. Jeeves' Ss were required to respond with both hands to a light stimulus falling on the nasal or temporal retina, while Kinsbourne's S was to respond with one hand to a visual stimulus. There are other possible explanations for the difference in results which could also be resolved by testing the same acallosal with both procedures to see whether the difference in performance is due to differences in procedure or to individual variation in the Ss.

With regard to the surgical-bisection data, Gazzaniga, Bogen, and Sperry (1965) reported on their second patient in the study that they found "no difference between ipsilateral and contralateral combinations in reaction time to a simple flash of light in either half-field". No directly comparative results are reported for their first patient, but an examination showed that "when visual stimuli entered one hemisphere, manual responses utilizing the arm governed primarily from the same hemisphere went off appropriately while responses with the other limb were absent in the early months (after surgery) and never became as good as those of the primary arm".

Gazzaniga et al. reported no data on either patient, but there does seem to be some conflict with the acallosal data, and it might be worthwhile to look at further acallosal data.

V. VISUAL PERCEPTION PERFORMANCE: OPPOSITE SUPERIORITIES OF RIGHT AND LEFT HEMISPHERES FOR ALPHABETICAL AND PHYSIOGNOMICAL MATERIAL

A recently published experiment by Rizzolatti et al. (1971) suggests another way in which the question of whether congenital acallosals have bilateral language representation might be investigated. The results of Rizzolatti et al. indicate that in Normal Subjects there is a left hemisphere superiority in response to letters and a right hemisphere in speed of response to faces. If language is bilaterally represented in congenital acallosals, neither left nor right field superiority in speed of response to letters would be found.

We tested both our acallosal patient and her Sibling on a replication of the Rizzolatti et al. experiments, and also a group of Normals matched for age and sex for comparative purposes.

VI. VISUAL PERCEPTION: INTEROCULAR TRANSFER OF MOVEMENT AFTEREFFECTS

Jeeves and Dixon (1972) reported that agenesis Ss showed an inability to transfer movement aftereffects interocularly. Such transfer would not seem a priori to depend on the presence of the corpus callosum. It was therefore of interest to test whether Jeeves' findings could be repeated.

We propose to test the acallosal and her Sibling on this procedure, as well as a group of Normal Subjects and a group of Mental Match Ss with the expectation that the acallosal will not exhibit interocular transfer of the movement aftereffects.

A BRIEF REVIEW OF THE CLINICAL LITERATURE

Agenesis of the Corpus Callosum.

The Corpus Callosum is the largest bundle of commissural fibers in the brain. Its 200 million fibers constitutes the main cross-connection between both hemispheres of the brain, connecting reciprocal points in the neocortex on the two sides.

Total absence of the corpus callosum can be established fairly reliably while the Subject is alive. It cannot always be ascertained whether the anterior and hippocampal commissures are absent also, but they often are missing also (Slager, Kelly and Wagner, 1957).

Absence of the corpus callosum occurs because of some developmental defect in the human foetus. Normally, the entire corpus callosum is evident by the beginning of the fifth month, but the first evidence occurs in the third month as a thickening on the lamina terminalis just dorsal to the anterior commissure (Hyndman and Penfield, 1937). The anterior part of the corpus callosum develops first and then the posterior, which is directly associated with the development of the septum pellucidum and hippocampal commissure. If the developmental arrest occurs before the fourth month, the anterior commissure, corpus callosum, septum pellucidum and hippocampal commisure will be absent. If toward the end of the fourth month the developmental arrest occurs, the anterior commissure is likely to be present along with the anterior part of the corpus callosum, but the posterior part of the corpus callosum will be arrested to a degree depending on the timing of the arrest. During the fourth month, if arrest occurs, the anterior commissure will be present without the corpus callosum.

Total agenesis of the corpus callosum does not produce in itself any obvious motor disturbances or cognitive disturbances or any other functional disturbances. There are a number of cases on record (Slager et al., 1957) where no dysfunctions were observed and the absence of the corpus callosum was only discovered on autopsy. The cases which are discovered while the patient is alive are where the patient has or is suspected of having some other dysfunction or brain damage, such as epilepsy (particularly), or mental retardation, or associated malformations of the brain.

One of the problems encountered in using agenesis patients for looking at cerebral lateralization and interhemispheric relationships is that they often have extra-callosal damage. The best way to deal with this problem is to use neurological Ss as Controls, trying to match for known extra-callosal damage (as Ettlinger et al., 1972, 1974, and other have done).

Usually agenesis patients have been found to be of less than normal (90-110 I.Q.) intelligence. One way to deal with this is to use Subjects as controls who are matched for intelligence level (as Jeeves, 1965, among others) has done.

Agenesis of the corpus callosum may be identified in life from pneumoencephalographs. The classic picture is one identified by Davidoff and Dyke (1934) in three patients which they compared:

"1. Marked separation of the lateral ventricles;

2. The angular dorsal margins of the lateral ventricles.

3. The concave mesial borders of the lateral ventricles.

4. The dilatation of the caudal portions of the lateral ventricles.

5. The elongation of the interventricular foramina.

6. The dorsal extension and dilatation of the third ventricle.

7. The radial arrangement of the mesial cerebral sulci around the roof of the 3rd ventricle and this extension through the zone usually occupied by the corpus callosum."

Koch and Doyle (1957) reported on eight cases of agenesis of the corpus callosum in children and found, as have others, no definite clinical syndrome. They found five of their eight cases had enlarged heads. Agenesis cases often have mental retardation, cerebral palsy, seizures, and other related anomalies.

Cases of agenesis have sometimes been reported among siblings. Naimon and Fraser (1955) reported two cases in sisters who had presented to hospital for investigation of mental retardation and physical underdevelopment at the ages of seven years and four years. They both had small heads and were left-handed. One of the sisters had had seizures. Naimon and Fraser have said that the occurrence of agenesis in the siblings suggests that the cause of agenesis is genetic.

Edwards (1963) and Norman (1965) have reported evidence of the agenesis of the corpus callosum in association with chromosomal anomalies which has to do with the amount of chromatin in the cells examined.

Shapira and Cohen (1973) reported two cases of agenesis in sisters. The clinical symptoms were different for the sisters. The sister, aged seven on presentation, had seizures, no physical or neurological abnormalities at examination, abnormal EEG, mild mental retardation. The other sister presented at six months of age with failure to thrive, generalized hypotonia and no seizure, and EEG within normal limits1

Four other families with familial agenesis of the corpus callosum have been reported in the literature (Zellweger, 1952; Ziegler, 1958; Menkes, Philipport, and Clark, 1964; Dogan, Dogan and Lovrenci, 1967).

Of 210 cases of agenesis of the corpus callosum reported up to 1965, 138 were diagnosed by post-mortem autopsy and 72 by pneumoencephalography only (Harcourt-Webster and Rack, 1965). It is an interesting consideration that 25 of the 210 reported cases were neurologically asymptomatic during life and the defect was an accidental finding at autopsy.

Surgical Bisected Patients

Much of the experimental work with the surgically bisected _S_s has been in the area of visual perception. There are, so it seems, two visual perceptual systems in the brain, one within each cerebral hemisphere. Each hemisphere receives stimulation directly from the contralateral visual field. Sperry (1968) proposed that each hemisphere of the callosally sectioned patient possessed its own visual world separate from the opposite hemisphere.

Dr. Bogen, who suggested the surgery and who has been involved in much of the testing of surgically-bisected patients, in a lecture at Edinburgh University in 1974, reviewed the surgically-bisected findings. He reported that cerebral commissurotomy is still being carried out, and to date the behaviour has been studied of sixteen patients who have had a complete cerebral commissurotomy and four patients who did not have the splenium cut. He reported categorically that the one finding which has not altered over the years is that anomia in the left hand does not go away or improve, and that this has been the case in <u>every</u> patient.

Bogen suggested that the reason people who have agenesis of the corpus callosum do not show the same performance differences that surgically bisectioned patients do is that agenesis patients usually have a relatively large anterior commissure which performs the functions of the corpus callosum.

Bogen also pointed out that over sixty papers have now been published on the performance of these surgically bisected patients. He feels that one issue which can now be regarded as settled as a result of these studies is that high level (intelligent) processes can be carried on without language.

Explanations of Agenesis Versus Surgically Bisected Patients' Behaviour.

Sperry (1968) summarized a number of explanations for the apparent lack of deficit of the subject with agenesis of the corpus callosum he has observed.

Sperry points out that we can forget about the possibility of growth of callosal fibers through other routes, as autopsy in asymptomatic cases of agenesis hasn't suggested this occurs, nor does there appear to be a growth of new cross-connecting systems.

1. Some of the deficit potentially created by the congenital absence of a corpus callosum may be taken up by the anterior commissure, which though often absent in agenesis of the corpus callosum, may sometimes be enlarged (Reeves and Courville, 1938) even up to one and one-half times its normal size. However, an increase in size of anterior commissure would not make up for more than one-two per cent of the absent Corpus callosum fibres system.

2. There may also be changes in the axonal and dendritic

network within the cortex.

3. The compensatory changes might also be involving chemical changes within existing networks of fibres.

4. Sperry suggests that a development of bilateral language would explain a lot of the lack of deficit of agenesis patients.

5. Further, an increased bilateralization of the functional representations of the hands, feet, and body at the cortical level would help account for functional compensation of the acallosal person. This would mean, particularly, increased use of ipsilateral pathways.

It is reasonable to suppose that nerve fibres denervated by the absence of endings from callosal fibres would be more responsive to the remaining neural associations such as the ipsilateral ones.

CHAPTER TWO

AGENESIS OF THE CORPUS CALLOSUM: CASE HISTORIES

Case histories of acallosal patient and her sister:

We have tested the acallosal patient and her sister on all our experiments in order to make a comparison between the two girls, the prediction being that if the Sibling performed like the Acallosal Subject, she is probably acallosal also. We had thought that Air studies might be carried out on the Sibling, but this now seems inappropriate as there is no medical reason for doing so, though there may be such reason at a later date at which time we can verify our conclusions.

CASE HISTORY: AGENESIS OF THE CORPUS CALLOSUM: PATIENT K.C., age 11 to 14 years during period of observation.

The patient, K.C., a right-handed female (date of birth: 11 May 1960), was admitted to the Neurological Surgery Unit of the Dundee Royal Infirmary in July, 1970 on the mother's observation of a progressive intellectual decline and intermittent headache, in order to investigate the possibility of an intracranial dermoid cyst. K.C. is the youngest in a family (father, brother, sister) who have had combined frontal and nasal dermoid cysts.

At the time of admission to the Neurological Surgery Unit, she was found to have no external abnormalities of nose or forehead, and, except for a small head (51.5 cm.) and slight mental retardation, no neurological abnormality was found.

Subsequent neurological tests revealed as follows (quoting from the D.R.I. Radiologist's report):

<u>Bilateral carotid angiogram</u>: "On both sides there is some posterior

displacement of the anterior cerebral artery and on the left side some depression of the pericallosal artery. Some elevation of the internal cerebral vein is also shown. No shift is shown". (see photocopies of the X-rays: Figures II, A, B, and C).

Air encephalogram: "Air filled the ventricular system without difficulty. There is enlargement of the entire ventricular system particularly posterior horns of the lateral ventricle. The anterior horns are less markedly affected, but there is separation from the midline. The third ventricle is elevated". "The appearances considered with those of the cerebral angiograms are suggestive of agenesis of the corpus callosum". (See photocopies of the X-rays: Figures I.A, B, C, D, and E).

A further independent evaluation of the air studies and angiograms was made by a Consultant Radiologist from Edinburgh. He commented: "The air study shows the characteristic hydrocephalus and high position of the third ventricle, which is associated with agenesis of the corpus callosum". This report further states that "the appearances on the angiogram where the anterior cerebral artery appears to be displaced backwards are secondary to the absence of the corpus callosum and I do not think that they represent the presence of any frontal mass. -- I feel fairly certain that the question of dermoid cyst does not arise here".

The neurosurgeon in charge of this case has stated in a personal communication that the arteriograms "are classical of agenesis of the corpus callosum," and the air studies "too are absolutely classical of the condition". He has further stated that we cannot tell whether this patient has an intact or partial, or larger than normal, anterior commissure because it doesn't show on

FIGURES I AND II: These are described by Mr. I. Jacobson, Neurosurgeon, Dundee Royal Infirmary, as being absolutely pathognomic of agenesis of the corpus callosum.

Figure I.A,B,C,D, and E. Pneumoencephalograms. Descriptions with relation to agenesis of the corpus callosum.

I.A. Supine lateral view. This is not a good reproduction.On the X-Ray film it is possible to more clearly see the shadows of the third and lateral ventricles in the characteristic picture of agenesis of the corpus callosum with the upward extension of the third ventricle.

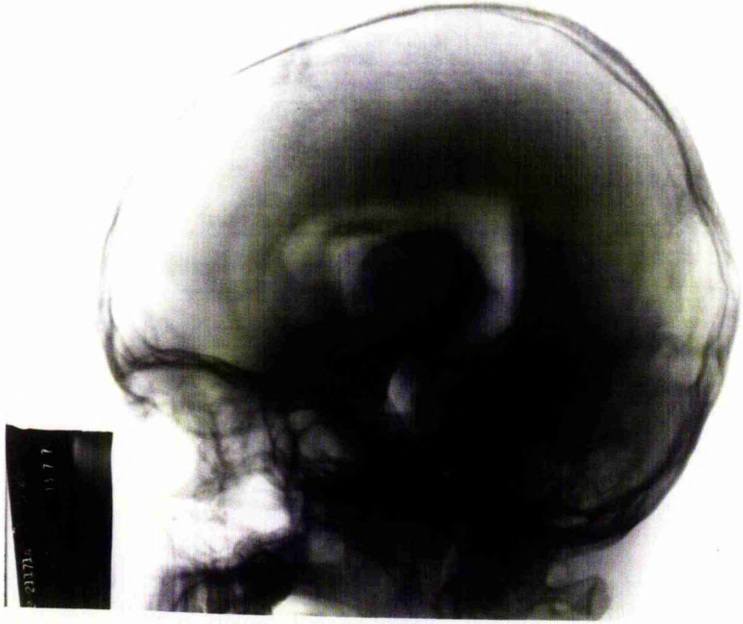
I.B Dilatation of lateral ventricles and of the third ventricle.

I.C. Anterior-Posterior view. Marked separation of lateral ventricles.Raised enlargement of third ventricle.

I.D. Posterior-Anterior view. On this figure we can see the dilatation of the caudal portions of the lateral ventricles.

I.E. Anterior-Posterior view. Here we can see the marked separation of the lateral ventricles; the angular dorsal margins of the lateral ventricles; and the concave mesial borders of the lateral ventricles characteristic of agenesis.

IA



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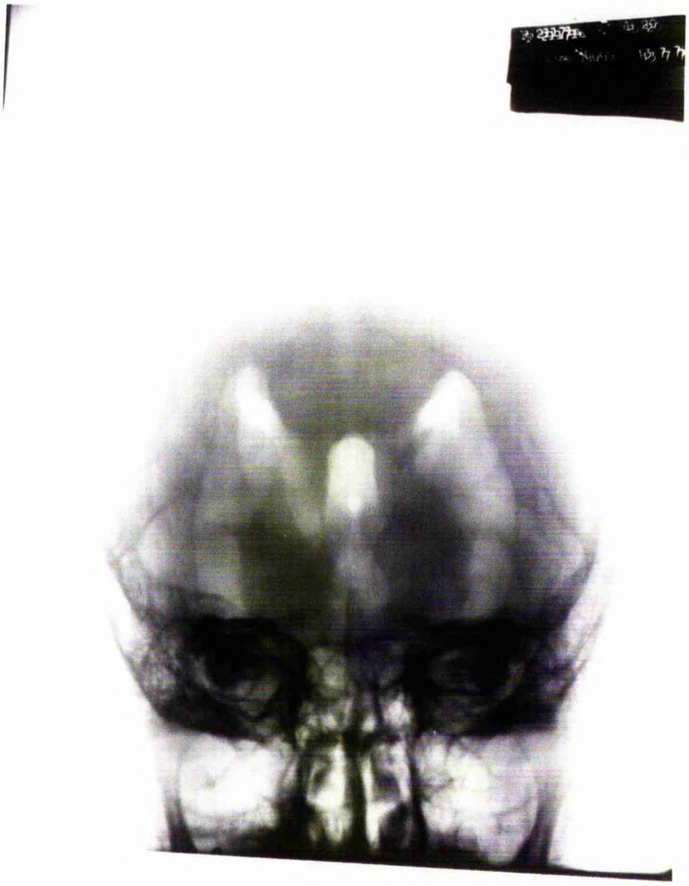
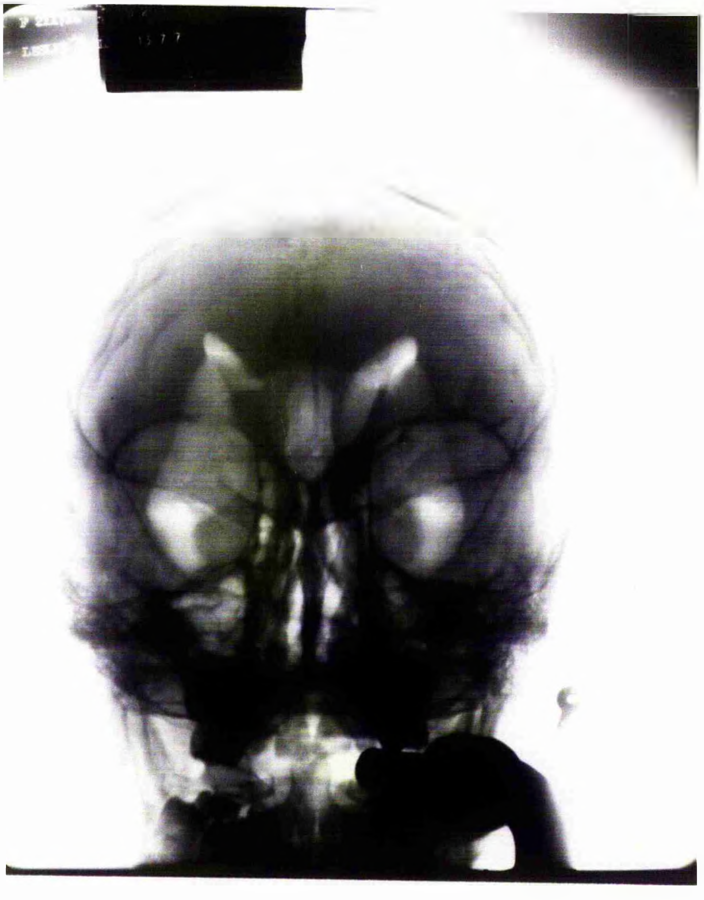


I C

I D



[redacted]

I E

Figure II.A,B, and C. Description of Arteriograms with relation to agenesis of the corpus callosum.

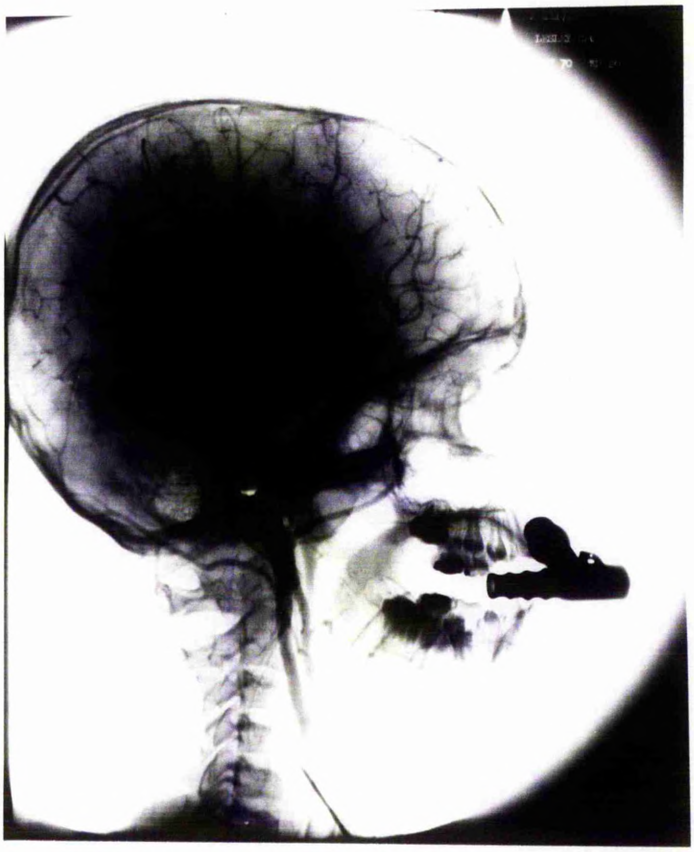
II.A. Anterior-Posterior view. Not a good reproduction of the X-Ray, but can see the anterior cerebral artery in position characteristic of agenesis on X-Ray film.

II.B. Lateral view. The pericallosal artery is seen to wander in the characteristic fashion indicative of agenesis of the corpus callosum. This is the most clear evidence in the arteriograms.

II.C. Lateral view. Not a good reproduction, but X-Ray film shows the characteristic wandering anterior cerebral artery.

II A

II B



II C

these air studies.

A psychological evaluation carried out by the hospital psychologist, not the present author, and made during the hospital admission when the neurological studies were carried out, reported a WISC Full Scale I.Q. = 78; Verbal Scale = 75; Performance Scale = 87. Psychomotor retardation was not present; her manual motor response speed was very good. In relation to her I.Q. level, verbal and non-verbal abstract thinking, abstract reasoning by analogy, and concept formation were reported as unimpaired. A minor degree of visual memory impairment and significant impairment of short-term auditory memory were reported, sufficient to account for K.C.'s poor performance in school.

The patient was the product of a normal delivery at Term plus 1/12. There was no neonatal illness; no jaundice.

There was no evidence from any of the tests to confirm the parent's impression that K.C. was deteriorating. The neurosurgeon in charge of the case concluded that the girl "was born with a congenital malformation of the corpus callosum but there is no certainty of a tumour . . . in view of the absence of tumour shadow as seen with her on the angiograms or on the air pictures."

K.C. at the time of participating in the experiments reported here was aged eleven at the outset and fourteen years when we terminated our studies.

We tested her on the full form of the Stanford-Binet Intelligence Scale when she was twelve years zero months old and found she obtained a mental age of eight years six months, an I.Q. of 73.

We further tested her on the Raven Coloured Matrices and found a normal performance for her age.

Her social behaviour is generally appropriate, except that she is sometimes quite shy. She is cheerful, good-humoured, and was always quite cooperative as a Subject.

Family history: Father epileptic and had intracranial dermoid cyst removed as did the elder sister and brother. Mother is normal.

CASE HISTORY: POSSIBLE AGENESIS OF THE CORPUS CALLOSUM: THE SIBLING, L.C.

The patient, L.C., a right-handed female, was born 11 Sept. 1957. A bifrontal craniotomy was performed on her to remove a midline interfrontal dermoid cyst extending through the cribriform plate. This procedure was carried out on 22 January 1970 when she was aged twelve. Post-operative recovery was uneventful. The details of this patient are described by Plewes and Jacobson (1971).

The Sibling was tested by the same hospital psychologist as tested the acallosal, and this about five months after surgery. She was tested on the abbreviated Wechsler Intelligence Scale for Children, and obtained a Full Scale I.Q. of 71, comprised of a Verbal Scale I.Q. of 67 and a Performance I.Q. of 81. The Psychologist felt that the Performance Scale I.Q. of 81 should be taken as the more realistic index of her intellectual capacity.

The Sibling's abstract conceptual thinking was unimpaired relative to her overall level of intellectual functioning.

The Psychologist found no clinically significant abnormality in visual perception, and her sense of gross position in space and body image is not disturbed. He found a significant deficit in visual short-term memory. He also found a "quite clear impairment of short-term auditory memory. L.C. has considerable difficulty in retaining information for periods longer than about 6-12 seconds when the information to be remembered is new or unfamiliar".

Her handwiritng shows no primary writing difficulty, "although her letters are not well formed (immature)." No abnormality was detected in speech or language.

L.C.'s hand-eye coordination is "very fast but very inaccurate. This reflects an impulsive, uninhibited and poorly controlled motor strategy that is consistent with, and commonly associated with, frontal pathology (Luria 1962). In L.C.'s case, the difficulty is minimal."

"There is no impairment of the ability to attend to one stimulus whilst ignoring the other".

We tested L.C. further on the Raven Coloured Matrices and found that she performed below normal (while the acallosal had performed normally).

The neurosurgeon involved with this patient has stated in a personal communication that he believes this child has a similar problem to the acallosal. Air studies have not been performed on this patient, however.

The hospital psychologist compared both sisters and felt that K.C. presented a very similar picture of cognitive dysfunction to L.C., including the "presence of an impulsive response strategy and minor motor inhibition and co-ordination difficulties that would be consistent with frontal lobe pathology. However, in all points K.C.'s "difficulties are less marked in degree in absolute terms and certainly less in relation to her age and development,"

Our observation is that her social behaviour is appropriate generally. She is shy in unfamiliar situations. She tends to perseverate in her conversational ideas and is often "moody". As a Subject she has always cooperated well and enjoyed the special attention the testing situation provided.

CHAPTER THREE

AGENESIS OF THE CORPUS CALLOSUM: OUR EMPIRICAL EVIDENCE

TACTILE PERCEPTION: BIMANUAL MOTOR COORDINATION: TACTILE LEARNING AND TRANSFER OF TRAINING: CROSS-LOCALIZATION: AND CROSS-IDENTIFICATION OF OBJECTS

INTRODUCTION

Jeeves (1965) reported a number of simple tests studying the Bimanual Motor Coordination, Tactile Learning and Transfer of Training and Cross-localization of agenesis Subjects compared with Control Groups. He found, generally, evidence of a less efficient performance in the acallosals compared to Normals.

Other researchers have found, testing one or other aspect of Tactile perception or performance, some evidence supporting Jeeves' findings and some which fails to support his findings. The details are reported at the beginning of each experiment. Generally, we tested our acallosal and Sibling and compared them with 'Mental Match' Subjects and Normal Subjects of the same age and sex. Our expectation was that we would find a 'less efficient' type of response from our Acallosal and Sibling as compared to the Normals and Mental Match Ss. Specifically, our statistical prediction is that the Acallosal and Sibling will perform 'different from' the Normals and Mental Match Ss.

We also did a Tactile Cross-localization task and obtained data on our Subjects. Jeeves (1965) reported no quantitative data, but stated that he did not find deficits with the one of his acallosals tested.

Solursh et al. (1965) found that their acallosal made no errors in localizing touch on various parts of his body (fingers, cheeks, arms, legs). Reaction time was rapid. Solursh et al. does not say that this was a cross-localization task. However, on a tapping test, where the S was tapped on one hand and required to tap an equivalent number of times with the opposite hand the S made 90% errors on numbers exceeding eight. The Control group made 10% errors on numbers exceeding fourteen.

Ettlinger et al. (1972) did find some differences in Cross-localization with their agenesis Ss. They subsequently (1974) carried out other kinds of intermanual tactile matching tasks to test the ability of the agenesis patient to cross-communicate information and found "no marked differences in matching performance" among their three groups of Subjects.

Saul and Sperry (1968) report that an acallosal had no difficulty in cross-localization of mirror points on the hands and fingers, in contrast to surgically bisectioned patients who were severely impaired on this task.

The ability to perform Tactile cross-identification of objects was tested by Gazzaniga, Bogen, and Sperry (1963) in the surgically-bisectioned patients, and deficits found. Solursh et al., testing an acallosal, found that the S was able to identify correctly common objects handled by either hand, and by writing the identification with either hand, such that no deficit was observed.

More details from the literature have already been given in the Introduction to the Agenesis section of this thesis.

Normal Subjects: We have used 6 or 12 Normal female Subjects of approximately the same age as the Acallosal.

Mental Match Subjects: These Subjects are used in most of our experiments for purposes of comparison with the Acallosal and the Sibling. They were selected for use rather than neurological controls because, while the acallosal has no known extra-callosal damage (such as epilepsy or other lesions) and therefore neurological controls would not be the most appropriate control (because there is nothing to control for), she is slightly retarded. We selected therefore, what we are calling 'Mental Match Ss', that is a group of eight or nine female Ss of the same approximate age and in the same sort of remedial class at school, and of approximately similar I.Q. None of these girls has defined (known) damage to the brain. The mean I.Q. (from most recent I.Q. tests) is I.Q. = 77. The I.Q. range is from 71 to 88.

EXPERIMENT I: HANDEDNESS

Our acallosal and Sibling are self-reported right-handers. Sperry (1968) points out that the agenesis S Saul and Sperry investigated (1968) was "left-handed and somewhat ambidextrous" and that this is a common finding among agenesis patients.

We wanted to determine handedness by other than self-report, though all of our Control Ss are right-handed.

Method and Results: Ss were selected on the basis of a self-report of right-handedness. They were administered an inventory of 19 items (in the case of the acallosal and Sibling plus 12 Normals), or a shortened version of 11 items (the 9 Mental Match Ss). The Ss were required to show the E by miming or actually doing the activity given, such as "Show me how you comb your hair", "wave goodbye", "Bounce the ball", "knock on the door", etc. Almost every S did every item with her right hand. The acallosal and several other Ss performed one or two items with the left hand. We felt this was a function of the social situation (e.g., facing the E while trying to open the door) rather than an indication of handedness.

EXPERIMENT II: BIMANUAL MOTOR COORDINATION

We repeated Jeeves (1965) study of bimanual motor coordination in two or three acallosals on our Acallosal and Sibling and also on a group of Normal Ss, and a group of Mental Match Ss. Jeeves had found evidence for a reduced efficiency in bimanual motor coordination tasks. His data are included for purposes of comparison.

Sperry (1968) reports that his 20 year old agenesis girl S obtained perceptuomotor test results below normal in tasks like stringing beads or putting pegs in holes or matching jigsaw pieces using left and right hands together. This is in contrast to the lack of deficit found in surgical patients, according to Ettlinger (1972).

Method and Results:

See table of results which includes the previously published data of Jeeves' three acallosal Ss for comparison.

The method for fitting cubes in a box: The Kohs Blocks were removed from the box and placed on the table beside the box. The S was timed whilst replacing the blocks in the box using both hands.

The method for stringing beads was to demonstrate to the S how to put the beads on the string (subtest from Merrill-Palmer Scale) and then to see how many she could string in two minutes.

The method for winding string around pencil was to ask S to wind the string as fast as possible, not bothering to be neat and tidy, and to measure the time this took.

The Pegboard used was the Minnesota Pegboard. The pegs were in one side of the board and the S was asked to move them all with the Preferred hand as fast as possible. The same procedure was then done with the non-preferred hand and then both hands, each condition being timed.

With reference to Table I (Summary of Bimanual Motor Coordination Tasks), there is not much evidence that our acallosal is less efficient at the bimanual motor tasks than the Normal Subjects or Mental Match Subjects. She is well within the range of normal and Mental Match Ss on Fitting Cubes in a Box, and Stringing Beads. The acallosal is, however, slower at winding string around a pencil than almost all other Normal and Mental Match Subjects.

The Sibling performed the same as the acallosal when fitting cubes in a box, but was slower than the acallosal when stringing beads, and also below the range of all the Mental Match and Normal Subjects. She was well within the range of responses when winding string around a pencil.

Our acallosal was faster on everything than Jeeves' acallosals except for fitting cubes in a box, where one of Jeeves' patients was faster than she was.

No pattern seems to emerge from these three tests to strongly distinguish our acallosal from the Normals and Mental Match Subjects.

The Pegboard results (see Table II, for summary of data), indicate that both our acallosal and Sibling tend to be slower on the pegboard task than the Normal Ss and the Mental Match Ss. Here the acallosal and Sibling are distinguishable from the Normal and Mental Match Ss. Our Ss cannot be directly compared with Jeeves' Ss as the task was somewhat different, but Jeeves' acallosals in

Table I: The Data Summary of Bimanual Motor Coordination Tasks: including Fitting Cubes in a Box, Stringing Beads, and Winding String around a Pencil.

	Fitting Cubes	Stringing Beads	Winding String
Jeeves' (1965) S A Age 6, I.Q. 75	45 seconds	15 beads	60 seconds
Controls for A	N=19; 32 sec. ± 1.5	N=8; 21 ± 0.87	N=6; $\bar{x}$ =43 range 20-56 sec.
S B Age 41, I.Q. 91	20 seconds	28 beads	47 seconds
Controls for B	N=5; $\bar{x}$=11; range 9-15 secs.	N=5; $\bar{x}$=46; range 41-51	N=5; $\bar{x}$=15; range 12-17 secs.
S C Age 5.6, I.Q. 80	68 seconds	10 beads	132 seconds
Controls for C	N=6; $\bar{x}$=28; range 20-46 secs.	N=6; $\bar{x}$=23; range 18-30	N=6; $\bar{x}$=74; range 45-180
Acallosal (K.C.)	21 seconds	32 beads	39 seconds
Sibling (L.C.)	21 seconds	23 beads	21 seconds
'Mental Match' Controls			
Control S1	20 seconds	38 beads	29.8 seconds
S2	20 seconds	30 beads	25.5 seconds
S3	19.5	35	15.5
S4	19.5	41	21
S5	15	34	17
S6	24.5	35	14
S7	14	31	15
S8	13.5	37	29.5
S9	13.5	40	29
Normal Controls Same Age and Sex			
S1	21	33	23
S2	32.5	32	27.5
S3	22.5	38	13.5
S4	22.5	31	20
S5	19.5	35	29
S6	27	28	44
Total Mean			
For 9 Mental Match Cs.	17.72 seconds	35.67 beads	21.81 secs.
For 6 Normal Cs.	24.17	32.83	26.17

Table II. A Comparison of Acallosals, Sibling, and Normal Ss and 'Mental Match' Ss on a Pegboard Task

*Jeeves' Pegboard data not directly comparable to our data.

	Dominant Hand	Non-dominant Hand	Both Hands
*Jeeves' S A	45 Seconds	42 Seconds	
Controls	N=6; $\bar{x}$=29; range 19-35	N=6; $\bar{x}$=28; range 22-35	
S B	20 seconds	24 seconds	16 seconds
Controls	N=5; $\bar{x}$=17 range 15=20	N=5; $\bar{x}$=19; range 17-22	N=5; $\bar{X}$=13; range 11-16
S C	47 seconds	56 seconds	40 seconds
Controls	N=6; $\bar{x}$=26 range 24-30	N=6; $\bar{x}$=28; range 24-31	N=6; $\bar{x}$=23; range 18-25
Acallosal (K.C.)	1 min. 19 secs.	1 min. 32 secs.	0 min. 48 secs.
Sibling (L.C.)	1 min. 29 secs.	1 min. 25 secs.	1 min. 00 secs.
Mental Match Controls			
S 1	1:02	1:12	0:41
S 2	1:15	1:16.5	0:48.5
S 3	1:29	1:26	0:54.5
S 4	1:05.5	1:10	0:38.5
S 5	1:09	1:13.5	0:47.5
S 6	1:11	1:19	0:42.5
S 7	1:04.5	1:17	0:42.5
S 8	0:57.5	1:15	0:41
S 9	1:07.5	1:05.5	0:39.5
Normal Controls Same Age & Sex			
S 1	0:59	1:09	0:44
S 2	1:21	1:19	0:48
S 3	1:07	1:05	0:39
S 4	1:07	1:14	0:45
S 5	1:04	1:11	0:39
S 6	1:23	1:21	0:41
Total Mean			
For 9 M.M.Cs.	1:9.1	1:14.9	0:43.9
For 6 Normal Cs.	1:10.2	1:13.2	0:42.7

comparison to his normal controls are pretty consistently slower on this task also.

On the Pegboard task, the sister, L.C., does not perform much faster with two hands than one hand, in contrast to all of our other Ss including the acallosal.

EXPERIMENT III A: TRANSFER OF TRAINING: FORMBOARD TASK.

Jeeves (1965) reported no savings on a Formboard test of a six-year-old, blindfolded, acallosal from Dominant to Non-dominant Hand, whereas his normal controls did show a savings.

Solursh et al. (1965) tested a 14-year-old and found a savings from Dominant to Non-dominant hand, but not as great a savings as for their control Ss (In going from Non-dominant to Dominant hand, they found no savings for the agenesis S.).

Russell and Reitan (1955) found no transfer in an agenesis S from dominant to non-dominant hand, while they did find a savings in transfer for Normals.

Method: Using the same sort of 3-hole formboard that Jeeves (1965) used on his acallosal and Normal Control Ss, we tested our Ss similarly. The Subject is seated before a screen with her hands through the screen at the bottom such that she cannot see her hands or the objects on the table behind the screen and formboard. The S is tactually guided using her dominant hand to the boundaries of the formboard, where the three holes are, and where the three forms are. She is then timed for five trials on the dominant hand placing the forms in the holes and then timed on the non-dominant hand for five trials and then once on the dominant hand again. The measure of savings is the difference between the Means of the five trials on each hand. The prediction is that the acallosal and Sibling will not show as much savings as the Normals and Mental Matches.

Results: Table III contains a summary of the data for our acallosal and Sibling as well as Normals and Mental Match Controls. For the Normal Ss the Mean Dominant Hand response was 13.03 seconds, the Mean Non-dominant transfer response was 12.03 seconds. The range of responses on the Dominant hand was 4-53 seconds, on the Non-dominant transfer hand, 4-48 seconds. The acallosal's Mean responses fall outside these ranges, but the Sibling does not. Even if we were to disregard the Acallosal's unusual second trial of both Dominant and Non-dominant Conditions, we would still find she is slower on this task than Normals and does not transfer from one hand to the other. The Mean for the Dominant Hand (Mental Match and Normal data combined) is 12.57 secs., and for the Non-dominant Hand, 10.19 secs. This results in a total savings score of 2.38 secs. Four of the fifteen Mental Match and Normal Ss did not show any transfer savings at all.

EXPERIMENT III B: TRANSFER OF TRAINING: MAZE-LEARNING

We have used a maze-learning procedure to look at perceptual-motor learning in a tactual-kinesthetic task to see whether our acallosal and Sibling have deficits in this task compared to Normals, and compared to the findings already in the literature.

Akelaitis and colleagues (1941, 1943, 1944; Akelaitis et al. 1942; Smith and Akelaitis, 1942; Bridgman and Smith, 1945) generally failed to find any behavioural deficits in their surgical patients, mostly because they did not make refined observations. However, they were found to have an impaired efficiency in the transfer of a learned maze task from one hand (hemisphere) to the other hand (contra-lateral hemisphere).

Table III: Transfer of Training: A Comparison of Acallosal and Sibling with a Group of 'Mental Match' Ss and a Group of Normals and other Neurological Ss from the Literature on a Formboard Task.

	Dominant Hand	Non-Dominant Hand	Savings	Dominant Hand Again
Acallosal (K.C.)	*X = 57.8 sec.	*X = 58.2 secs	-0.4	15 secs.
*Of 5 trials, 2nd trial took almost 3 mins.				
Sibling (L.C.)	X = 20.4 secs.	X = 20.4 secs.	0	31 secs.
Mental Match Controls				
S 1	X = 23.4 secs.	X = 8.9 secs.	+14.5	8.5 secs.
S 2	13.1	12.9	+ 0.2	5.5
S 3	14.1	7.7	+ 6.4	6
S 4	5.9	5.8	+ 0.1	4
S 5	10.7	5.3	+ 5.4	3.5
S 6	13.9	11.4	+ 2.5	5.5
S 7	8.1	8.9	- 0.8	5.5
S 8	10.8	10.9	- 0.1	7
S 9	10.4	8.9	+ 1.5	6
Total M.M. Mean	12.27	8.97	+ 3.30	
Normal Controls				
S 1	X = 24 secs.	X = 23.2 secs.	+ 0.8	6 secs.
S 2	8.2	9.8	- 1.6	10
S 3	9.6	5.8	+ 3.8	5
S 4	12.2	7.8	+ 4.4	9
S 5	8.2	6.8	+ 1.4	6
S 6	16	18.8	- 2.8	8
Total Normal Mean	13.03	12.03	+ 1.0	
Jeeves' Agenesis S.	68 secs.	75 secs.		
Controls	X = 53±7	X = 36±8		
Myers' S (Adult with Lipoma)	3 min.24 secs.	1 min.14 secs.		
8 yr old agenesis	4 min.32 secs.	2 min.10 secs.		
Russell and Reitan (1955) 19 yr old agenesis	16.3 min.	20.1 min.	Both hands: 8.3 mins.	
Solursh et al. (1965) 14 yr old acallosal	15 min.	9.5 min.		
Controls, N=10	X = 6.7 min. S.D.=2.59	X = 3.9 min. S.D.=1.27		

Lehmann and Lampe (1970) found that acallosals did not significantly transfer learning of the maze from the dominant to the non-dominant hand.

Geschwind and Kaplan (1962) attempted to test their deconnection patient on transfer of a maze learning task, but extra-callosal damage made this an impossible task for the S.

Gazzaniga, Bogen and Sperry (1962) found a surgically-bisected patient could transfer from either hand to the other. In 1963 they attributed this success to nature and size of the maze, and the consequent shoulder movement and other gross body movements involved in its performance, thus communicating from one side to the other by extra-callosal means.

Method: First a small pencil maze was used (AIM Bio-sciences, Ltd.) on the acallosal, but she was unable to learn it, so transfer could not be tested. Then a larger maze was used, the Lafayette Stylus maze. This maze, produced by Lafayette Instrument Company, was used by Corkin (1965), who found that patients with right cerebral lesions were inferior in tactually-guided maze learning to patients with left-sided lesions (who performed normally).

The Lafayette Maze is aluminium, and measures 12 3/4 in. X 10 inches.

Corkin's experiment was a simple learning task with the preferred hand, not a transfer of learning test.

Because the acallosal had found the first maze too difficult to learn, we adopted the procedure on the second maze of reversing the maze in front of the S and allowing her to trace the maze once through with the right hand and then once with the left hand; then the maze was placed behind a screen such that the S could not view it, and turned to the standard position. The preferred right hand was then used to learn the maze, and then the left hand. The method we used was different from that of Corkin whose Ss had higher I.Q.s, with mean I.Q.s being about 100. We did, after the maze was placed in correct position behind the screen, allow the S to feel the perimeters of the apparatus with both hands. Then her preferred hand was guided to the starting point, to the finish, and back again to the starting point, in order to provide a general orientation to the maze. The instruction to the S was to find the correct path from start to finish without going into any blind alleys. In Corkin's experiment, a bell was rung whenever a blind alley was entered, and this was the signal to start again. We allowed the S to retrace and continue to the end of the maze and there was no warning bell. Corkin used a fifty trial limit.

Both the time taken per trial and the number of errors per trial were recorded in our test.

Results: The Acallosal took thirty trials to learn the maze and ten trials to achieve zero errors on the transfer of learning to the left hand. A total of 141 Errors were made on the initial learning, and 21 errors on the transfer test. The Total time with the Right Hand was 47 minutes and on transfer was 3.9 minutes.

TABLE Showing Results on First Five Trials and Last Three Trials on Right Hand, Then Left Hand. Acallosal S.

	Trial 1	2	3	4	5	Last Three Trials			totals
Right Hand Errors	8	9	10	6	8	1	2	0	141 errors
Right Hand Time	4:21	5:21	4:44	2:01	1:25	1:16	1:27	1:10	47 mins.
Left Hand Errors	2	4	2	2	1	2	4	0	21 errors
Left Hand Time	1:01	0:56	1:05	054	1:32	1:06	1:21	1:04	3.9 mins.

The Sibling did not reach criterion (an error-free trial) on the large maze. The test was discontinued after about one hour and forty-five minutes. The actual time of all trials alone totalled one hour and twenty-two minutes. We did not score for errors.

In terms of time taken to reach criterion, the acallosal shows a large savings in transfer from preferred hand to non-preferred hand. A large savings in terms of number of errors was also found.

Two Normal Ss of the same age were tested; one became very upset and testing was discontinued. The other S completed the maze learning in 16 trials on the right hand and in two trials with the left hand. Total errors with the right hand were 79 and total errors with the left hand were 3. Total time to criterion was 26 minutes with the right hand and one minute thirty-two seconds with the left hand. No further controls were run because the Subjects found this test distressing and the source of our Subjects supply had been assured that "nothing we do is upsetting to the Subject".

A comparison with Corkin's Normal Ss which is an older group and which was run somewhat differently as described in the Methods section, illustrates that the task is difficult to learn, the mean error score being about 90 errors and about 20% of Normal Ss did not reach criterion in 50 trials. This suggests that our S is within the normal range on the learning of the maze with the right hand, but there are no comparative data for transfer of training.

It looks, in summary, as though the Acallosal shows good transfer of training in this maze task.

It is interesting that she was not able to learn the small maze, but was able to learn the large maze.

They were equally difficult in the sense that both had ten "choice" points. Perhaps there were more cues to her memory from shoulder and arm positions on the larger maze.

EXPERIMENT IV: TACTILE CROSS-IDENTIFICATION OF OBJECTS.

Gazzaniga, Bogen, and Sperry (1963) report the case of a 48 year old man who underwent complete section of the corpus callosum, anterior and hippocampal commissures. They found that "tactile discriminations limited to palpation of objects with the fingers showed no intermanual transfer".

Bogen (1974) stated that of the 16 completely commissurotomized patients studied to date the one deficit which has been found in every patient and has remained stable, is anomia in relation to the left hand; that is, an object held in the left hand (out of view) is not nameable by the patient, though the conclusion cannot be escaped that the object is "known" to the patient because the object can be correctly manipulated.

Saul and Sperry (1968) report that a 20 year old female college student with agenesis of the corpus callosum had no difficulty in crossed tactual retrieval for stimuli presented to the visual half fields or verbal description of objects in the subordinate hand in contrast to surgical bisectioned patients who were severely impaired.

Geschwind and Kaplan (1962) found that a patient who had a callosal lesion (infarction) was able, if an object was placed in the right hand (but out of sight) to name the object correctly, but if placed in the left hand, he could not name the object correctly. He also could not select from a group of objects with his right hand, an object previously held by his left hand, but he could, using his left hand, select the object from a group which was previously held in his left hand.

Milner and Taylor (1972) tested a group of seven commissurotomized patients in retrieving tactile nonsense shapes with the left hand, cross-matching, and with the right hand, and introduced delays also. These patients were compared with a group of neurological controls (the neurological controls were cases of unilateral cortical excisions but also included a partial agenesis patient) and it was found that the commissurotomized patients could not crossmatch, and also they performed better with the left hand (right hemisphere) than with the right hand.

We decided to test our agenesis patient to see whether she would support Saul and Sperry's (1968) finding that their agenesis patient had no difficulty in cross-identification of objects.

Method: An object is placed in the left hand of the S (non-preferred hand) for brief palpation while the Ss hand is behind a screen such that the S can not see the object. Then the object is mixed with four other objects behind the screen and the S asked to retrieve it with the same hand, and then asked to name it, and then mixed in again and asked to retrieve it with the other hand (Right hand, preferred hand). The objects used are fairly common objects such as a button, 2-pence piece, spool of thread, a ring, eraser, yarn, orange, and so on. Fifteen different trials were used.

A list of items and the form used is included in the appendix.

Six Normal Ss were tested.

Results: Neither the acallosal nor the Sibling had any difficulty with this task at all. Both were able to identify objects very quickly, finding them, and then naming them.

None of the Normal Ss had any difficulty in cross-identification.

EXPERIMENT V: TACTILE CROSS-LOCALIZATION

Introduction

Gazzaniga (1970) suggested that if cross-cueing strategies were eliminated, the behaviour of the agenesis of the corpus callosum Subject would be more similar to the adult surgically split-brain patient. He reports the testing of one agenesis patient on tactile cross-localization, as an example of a situation where no cross-cueing occurs, at least from verbal or visual input, and his finding that the agenesis S was unable to cross-localize. No data are given. Gazzaniga compared this agenesis patient to surgically-bisected patients on a test of cross-localization and found the same results in both cases. The surgically-bisected patients had not been able with "the left thumb to find a corresponding point of stimulation on the right hand", nor vice versa. Furthermore, these findings with regard to the surgically-bisected patients have "held up and endured through six years of testing on the brain-bisected patients". No specific data are reported.

Of the ten cases which Gazzaniga reports as having undergone midline sectioning of the corpus callosum and anterior commissure, three (ages 48, 30 and 12 at time of surgery) are described in Gazzaniga's The Bisected Brain (1970). Shortly after surgery, all patients performed poorly on cross-localization testing, and have remained unable to perform intermanual localization tasks.

The suggestion was made that agenesis does not result in a "fundamental reorganization of the hemispheric commissure data-exchange system", but "it is conceivable that the remaining systems take on an increased load, but it would be viewed more as a quantitative increase in activity, than as a qualitative one".

Ettlinger, Blakemore, Milner, and Wilson (1972) investigated the performance of a group of four total agenesis of the corpus callosum patients, four partial agenesis Ss, and four neurological Controls on a number of perceptuomotor tasks, among them tactile cross-localization. Three of the four total agenesis patients showed "poor" performance; the fourth S (T4) was not tested (declined to cooperate). Of the four partial agenesis cases, one performed "excellently", one's performance was "good", and the other two were not tested (reason not given). Of the four Controls, one performed "excellently" and two performed "good" and the other was "not tested adequately due to some relevant impairment". Subject T1 (total agenesis) scored "about 75% correct on the test of cross-localization, irrespective of the hand making the response, her errors being largely confined to responses with the middle and ring fingers." Subject T2 was 80% correct when the left hand responded, 50% correct when right hand responded; "errors were made in finding the middle and ring finger, and once in finding the index finger". Subject T3 "performed overall at 80% correct", "with best performance when the left hand was responding to right-hand stimulation. Most errors were made with the middle and ring fingers, but there were occasional errors, especially with right hand responses, with the index and little fingers".

The Control Subject, C3, was 90% correct, the "errors relating to middle or ring fingers". The cross-localization performance of Ettlinger's neurological control patients was significantly better than that of the total agenesis Subjects. Ettlinger et al. had administered a number of perceptuomotor tasks and concluded that the "only task tending to differentiate these groups was probably cross-localization". Ettlinger et al. suggested the possibility that in the agenesis patients there is an increased use of ipsilateral motor or sensory pathways, but that "it seems improbable that a globally increased usage of ipsilateral sensory projections takes place, given the difficulties experienced with cross-localization".

Lehmann and Lampe (1970) reported on a sample of nine patients with agenesis or partial agenesis whom they had studied. They found some differences between the agenesis group and a group of normal controls on a bimanual weight judgement task which involved interhemispheric transmission of information. They also compared a group of epileptic controls with the acallosal group (only one of whom was a total agenesis case) and found the epileptic group also performed better, but not significantly so (the difference between normal controls and acallosals was significant).

On a bimanual matching of rod-length test, the acallosals performed more poorly than the two control groups, but not significantly more poorly than the epileptic group.

Both of these experiments involve tactile and kinaesthetic identifications and interhemispheric transfer of information and are in that sense relevant to the present experiment. Lehmann and Lampe concluded that the "slight impairments of perceptuomotor transmission are specific effects and due to the lack of the corpus callosum".

We decided to test our acallosal girl to see whether the findings of Ettlinger et al. and Gazzaniga would be supported, and to provide more systematic results (Gazzaniga completely ignores the usual research requirements for data, relying on anecdotal summaries to convince us). Further, we wanted to provide support for our hypothesis that the Acallosal's Sibling is also acallosal, and it appears from the Ettlinger et al. data that the tactile cross-localization test may be capable of discriminating between total agenesis and partial agenesis as well as other neurological defects.

Subjects

One Acallosal girl, aged 13, her Sibling, aged 16, and a group of 7 female Mental Match Ss (of approximately same age as the acallosal girl and taken from similar remedial class and of approximately same I.Q.) were used.

Method

The method used was that described by Ettlinger et al. (1972): "The test described by Gazzaniga (1970, p.139) was used; after preliminary stages of within hand localization of a touched finger by the thumb, the finger of one hand was touched and the thumb of the other hand required to indicate the finger on that hand corresponding to the finger that had been touched on the other hand". The Subject was blindfolded and his hands were also placed under a partition and out of what would normally be the view.

Five trials on each finger (index, middle, ring, and little finger) of each hand were administered; a total of 40 trials for each S. The order of administration of trials was randomized, but was the same for all Ss.

Results

The results are tabulated in Table IV. A Mann-Whitney U Test on the hypothesis that the Acallosal S and the Sibling will make more errors than the Control group gives a Probability = .028.

In further description of the results, we note that the

TABLE IV: Cross-Localization, Data Summary

Left Hand Stimulated by E,S Required to Locate on Right Hand

	L1=Index**	L2=Middle	L3=Ring	L4=Little	Totals
S 1	+++++	+++++	+++++	+++++	0
S 2	+++++	+++++	+++++	+++0+	1
S 3	+++++	+++++	+++0+	+++++	1
S 4	+0+++	+++++	+++++	+++++	1
S 5	+++++	+++++	+++0+	+++++	1
S 6	0+0++	+++++	+++++	+++++	2
S 7	+++++	00+++	0++0+	+++++	4
Sibling	+++0+	+++++	0000+	+0+++	6
Acallosal	+++0+	0++++	0++00	0+0++	7

Right Hand Stimulated by E, S Required to Locate on Left Hand

S 1	+++++	+++++	+++++	+++++	0
S 2	+++++	+++++	+++++	+++++	0
S 3	+++++	+++++	+++++	+++++	0
S 4	+++++	+++++	+++++	+++++	0
S 5	+++++	+++++	+0+++	+++++	1
S 6	++0+0	+++++	++0++	+++++	3
S 7	+++++	+++0+	+++++	+++++	1
Sibling	+++++	++++0	000++	+0++0	6
Acallosal	+0+++	0++++	0++++	+++++	3

Total Errors Right Hand + Left Hand per S

S 1	S 2	S 3	S 4	S 5	S 6	S 7	Sibling	Acallosal
0	1	1	1	2	5	5	12	10

Total Errors per Finger

	L1	L2	L3	L4	Total Errors
Ss1-7	3	2	4	1	10
Acallosal + Sibling	2	1	7	3	13
	R1	R2	R3	R4	
Ss1-7	2	1	2	0	5
Acallosal + Sibling	1	2	4	2	9

** + =correct localization

0 =incorrect localization

Acallosal girl made 10 errors out of 40 trials (75% correct). The Acallosal girl made more errors when required to locate the stimulus on her Right Hand (Left Hand stimulated) than when required to locate on the Left Hand (7 errors out of 20 trials vs. 3 errors out of 20 trials). The Control group also made more errors when required to locate the stimulus on the Right Hand.

The Acallosal girl made more errors on the Ring finger of the Right Hand (stimulus to left hand, location on right hand). The Control group made more errors also on the Ring finger of the Right Hand as did the Sibling.

Discussion and Conclusions

Our Acallosal scored about 75% as did Ettlinger et al.'s Case T1, but T1 showed no difference between hands responding, whereas our Acallosal was 65% correct on right hand responding, 85% correct on left hand responding, or more like Case T3. Ettlinger et al.'s Total Agenesis Ss made more errors on middle and ring fingers, our Acallosal made more errors on ring fingers only.

The similar performance of the Acallosal girl and the Sibling supports the hypothesis that the Sibling is also acallosal, especially in view of the difference found by Ettlinger et al. (1972) between their total agenesis patients and partial agenesis and neurological control patients.

The fact that the Acallosal seems able to perform cross-localization at a higher level than the surgically-bisected patients (though we don't know precisely how the surgically-bisected patients perform, we don't see in the agenesis case the "dramatic inability" with which Gazzaniga describes the surgically-bisected patients), leads us to suspect an alternative interhemispheric route, or increased reliance on ipsilateral pathways as Ettlinger et al. suggest.

Ettlinger et al. did further studies of apparently related cross-localization tests (1974) such as spatial localization and size cross-matching and found no differences of note between their agenesis, partial agenesis, and neurological Controls on these tests.

DISCUSSION OF ALL FIVE EXPERIMENTS IN TACTILE PERCEPTION.

We find that there is some evidence of deficit in crossed tactile perception and visuomotor coordination in the agenesis case. However, she does not always show a deficit.

Our strongest evidence, statistically tested, is the deficit in cross-localization of light touch stimuli. Also, neither the Acallosal nor the Sibling show a savings in transfer of training on a formboard task (neither did the Normal Controls). However, the acallosal does show savings on a maze-learning task. The Sibling did not reach criterion on the Maze task.

As regards motor coordination, the Acallosal tended to be less efficient than the normals and Mental Match Ss on the Pegboard task, whether using both hands or one hand. She also tended to be slower at the string-winding task than the Normals and Mental Match Ss.

The Sibling was less efficient than the Normals and Mental Match Ss on the Pegboard task, also on stringing beads, but not fitting cubes, or string-winding.

The Sibling also tended to be slower than Normals and Mental Match Ss on the Formboard transfer of training task.

The Sibling performed more poorly than Normals and Mental Match Ss on the cross-localization of light touch stimuli as did the acallosal. However, she had no difficulty with the cross-identification of familiar objects.

We think the Sibling tends to perform like the acallosal, but has a greater memory deficit as witnessed by failure to learn the maze initially.

We conclude that our observations tend to support Jeeves'

1965 report of agenesis behaviour deficits. One exception is that we found a deficit in cross-localization of light touch, whereas Jeeves did not.

Our evidence may be compared with that of Persson (1970) who reported on a 28 year old total agenesis male patient and two partial agenesis patients. The total acallosal was reported to have an I.Q. of 115 on the Swedish modification of the Wechsler-Bellevue Scale. He had some personality disturbance which expressed itself in a tendency to be socially isolated, rigid, depressed and anxious. This patient may be compared with ours who has no personality disturbance.

The EEG for this patient showed a light episodic unspecific abnormality which was not asymmetrical or asynchronous. The encephalographic studies showed the classic features which are evidence of total agenesis of the corpus callosum. Because of the total acallosal's mental disturbance, he was not able to cooperate on all the tests. Persson's cases 2 and 3 were able to cooperate fully. Persson's agenesis cases were compared with psychiatric patients or normal Ss.

On a tactile localization task, which involved cross-localization of 32 points on each side of the body, with the E first touching the point, and then the S tried to touch the same point, the distances between the points touched by E and S were measured. Persson's hypothesis was that if there is a transmission defect due to absence or partial absence of the corpus callosum, the error distances with the ipsilateral hand must be less than with the contralateral hand. No significant differences were found for his acallosals. They were not compared with other Ss however. This test is not directly comparable to our experiment in that our Ss were localizing points on the fingers, not body parts. Persson did not find a deficit, while we did, as did Ettlinger, et al.

The total acallosal S was also tested (as were the two partial acallosal Ss) on a bimanual transfer task. This task involved judging the size of six cubes while blindfolded by selecting the largest. The exact procedure used is not clear to us; as to what makes this a bimanual task, or a transfer one. The Ss were compared with 6 psychiatric controls. The measures were the time taken to select a specified cube and the number of errors made. The hypothesis was that if there exists a transmission defect, it would evidence itself in the agenesis cases taking more time than the control group. For the agenesis group, the average time was 7.7 seconds and average errors were 16.7%. The control group gave an average time of 4.0 seconds and 5% errors. Persson concluded that there exist differences between the groups. but there is also a large overlap. He points out that the differences could be due to a transmission defect or equally to a sensory deficit or general retardation of motor control in agenesis. The task involved is not directly comparable to any of our bimanual tasks which do not require difficult judgements of size, as well as motor control, but are simple motor tasks. Both Jeeves (1965) and our own studies, however, also show bimanual transfer deficits.

More directly comparable is a formboard task using the Seguin Formboard. Persson's Ss were to select with the right hand the ten forms lying to the right of the formboard and this was repeated with the left hand. The hypothesis was that if there was a transmission defect, it would take more time to do the task with the left hand than with the right. Case 1, the total agenesis case, took more time with the right hand, but cases 2 and 3 did not. Persson suggested that while cases 2 and 3 appeared to show a transmission defect, the results could also be interpreted as an inability to perform the task. Our own acallosal did not show a transfer, but then neither did our normals.

A task comparable to our cross-identification of objects was performed on Cases 2 and 3. They both performed the task with ease as did our acallosal.

Persson also studied the two partial agenesis cases on several experiments involving tactile recognition of forms and letters and also naming of figures and letters presented in the right or left hemifield as well as words.

Persson concluded that, as with Jeeves' Ss, cases 1 and 2 showed some deficit in motor coordination, but case 3 did not. He further concluded that no transmission defect could be proved by his experiments, because even if there was an apparent defect, there were other possible interpretations of the results.

CHAPTER FOUR

AUDITORY PERCEPTION: DICHOTIC LISTENING EXPERIMENTS

The dichotic listening procedure can be used to investigate cerebral hemisphere lateralization of various kinds of auditory perceptual functions.

Kimura (1961) adapted Broadbent's (1954) technique of 'dichotic listening' to investigate the lateralization of cerebral mechanisms for speech perception. She reported a right-ear superiority in accuracy for the report of digits which had been presented in pairs simultaneously to the right and left ears (a presumed left-hemisphere superiority).

Kimura (1961b) suggested this right-ear superiority effect was due to the functional prepotency of the contralateral pathway (from right ear to the left cerebral hemisphere) compared to the ipsilateral pathway. This included the assumption that the left cerebral hemisphere is dominant for language. The anatomical basis for a lateralization of auditory function lies in the evidence that the crossed pathways dominated the uncrossed pathways. Bocca, Calearo, Cassinari, and Migliavacca (1955) had previously contributed evidence for stronger contralateral pathways than ipsilateral pathways. Milner, Taylor, and Sperry (1968) and Sparks and Geschwind (1968) contributed to this hypothesis also when they found an inhibition of the ipsilateral signal during dichotic presentation, using surgically brain-bisected patients. Kimura (1961b) had also found that there was a right hemisphere (left ear) advantage in Ss who were right cerebral dominant for language.

Bryden (1965) did not find a significant ear difference for a group of left-handed Ss, in contrast to Kimura (1961b) finding a significant ear difference for left-handers. Four of Bryden's twenty Subjects had shown a left-ear superiority, and these were also the only familial left-handers in the study. This is in agreement with evidence that familial left-handers are more likely to have right-hemisphere dominance for language than non-familial left-handers (Weinstein and Saul, 1961).

Kimura had found (1963) the right-ear phenomenon to be generally established by four or five years of age, indicating that "speech functions were already predominantly represented in the left hemisphere as early as age four". She did report a sex difference with five year-old males lagging behind females in this lateralization.

Sparks and Geschwind tested a 52-year-old commissurotomized male with verbal material presented dichotically (animal names and digits). They obtained results of 100% left ear extinction, while right ear performance yielded perfect scores. The explanation that Sparks and Geschwind offered was that the callosal pathway, which had been sectioned in this patient, always plays a role in left-ear performance in dichotic listening tasks.

Milner et al. found essentially the same left-ear extinction in a study of seven surgically sectioned patients presented with digits in the dichotic procedure. Her conclusion was that "the suppression of ipsilateral input in the presence of a competing stimulus from the contralateral ear provides clear behavioural evidence of the dominance of the contralateral auditory projection system in man".

Another test was administered to Milner's Ss which gave results favouring the left ear over the right ear. Milner presented verbal instructions dichotically which the S was to carry out with his left hand. That is, the S was to retrieve with his left hand the named objects in any order. After retrieval the S was to name the object picked up in his left hand, and commonly misnamed the objects using the names that had been presented to his right ear. This test was described as a nonverbal test by Milner et al., but since words were presented dichotically, and the S was asked to name the object retrieved, it seems misleading to call this a nonverbal task. The task is not directly comparable to that of presenting nonverbal material, such as melodic patterns, dichotically, which results also in left-ear superiority (in normals).

The right ear/left hemisphere superiority for what Buffery (1972) calls EV stimuli ("easy to verbalize"; including among other things, single letters or spoken numbers) has been confirmed by other experimenters.

Other explanations for the left hemisphere superiority in reporting numbers which have been offered solely in terms of memory, attention, or response factors have not been adequate. These have been reviewed by Bryden (1967) and Satz (1968).

Regarding verbal dichotic listening procedures used on congenital acallosal Ss, Bryden and Zurif (1970) reported on one 15 year-old Acallosal boy, and Ettlinger et al. (1972) report a study including two total agenesis patients.

Bryden and Zurif's experiment used three basic conditions: free recall, where the S was requested to report as many of the numbers as he could remember in any order; Pre-ordered recall, where S was told which ear to report first before hearing the numbers; and Post-ordered recall, where the S was told after hearing the material which ear to report first. Three different list lengths were administered in each condition: 3 pairs, 4 pairs, and 5 pairs of digits. In addition, in the free-recall condition, 3 different rates of presentation were used: 2 pairs of digits per second, 1 pair per second, and 1 pair per two seconds.

In terms of over-all accuracy, the Acallosal S did not appear to differ from the Normal Controls. Bryden and Zurif report, however, that their S who was right-handed, and who would be expected to be left-hemisphere dominant, was more accurate on the left-ear than on the right in all tasks, while most of the control Ss showed a right-ear superiority on the free-recall and pre-ordered recall tests. It is interesting to note that the Acallosal S showed a smaller laterality effect than the control average in most conditions, a phenomenon supportive of a bilateral speech representation hypothesis.

The examination of the post-ordered results showed that the Normal Controls, who were otherwise right-ear superior, were not significantly better on the right ear and three of the twelve Ss were more accurate on the left ear. The Acallosal S on this condition showed a large left-ear laterality effect. What is there about the post-ordered condition that accentuates the left ear for both types of Ss? This may somehow be the effect of delayed response or interference of instructions after stimulus presentation and before responding.

Another difference in performance was found where the acallosal S became less accurate as the rate of presentation slowed down wherease the Normals improved in accuracy; Bryden and Zurif attribute this failure on the part of the Acallosal to a failure to switch to a temporal order of recall strategy at the slow rate. The Acallosal S was also more accurate than the Normals at the fast and intermediate speeds. Perhaps the Acallosal was more accurate than the Normals at the faster rate because of a lack of competition due to the absence of the corpus callosum; that is, the messages went straight along the contralateral lines to the temporal lobes and, because speech is bilaterally represented, straight to the response area without having to cross through a callosal pathway for language analysis where competition of messages might arise. Bryden and Zurif suggest that if the Acallosal analyzes right-ear material in the left hemisphere and left ear material in the right hemisphere, this might account for the Ss "failure to switch to the temporal order of report at the slow rate of presentation; lack of a corpus callosum may make it difficult to integrate complex verbal information presented to the two ears simultaneously". It may be that the corpus callosum is ordinarily involved in memory storage processes and that these are interfered with if one lacks a corpus callosum.

Bryden and Zurif also state that the Acallosal's performance could be accounted for by the hypothesis of a subcortical occlusion mechanism if their patient has bilateral speech representation, but not if he has unilateral speech representation. The subcortical occlusion mechanism Bryden and Zurif refer to was postulated by Kimura (1967). Kimura suggested that auditory inputs arriving along the ipsilateral pathway are suppressed at a subcortical level by the contralateral inputs to such an extent that very little of the information from the ipsilateral ear ever reaches the auditory cortex by the ipsilateral pathway.

Ettlinger et al. (1972), included in their investigation of agenesis of the corpus callosum a study on verbal dichotic listening performance which utilized two cases, both left-handed, of agenesis diagnosed as having total agenesis of the corpus callosum. The method reported consisted of presenting 3 pairs of digits at the rate of two per second with the S requested to report first the right or left ear and then the other ear. The two total agenesis Ss recalled digits presented to the left ear more accurately than digits presented to the right ear. Three out of four of their group of partial agenesis S̲s showed a right-ear superiority, and their control groups of three S̲s all showed right-ear superiority. Ettlinger et al. (1972) stated, however, that because their findings were confounded by differences in handedness, i.e., two out of three left-handed S̲s showed right-ear superiority, their experiment did not give differential findings. Since this task was similar to the preordered recall task of Bryden and Zurif, the ear-superiority findings are consistent with Bryden and Zurif's findings.

What are the mechanisms involved in producing the laterality effect in dichotic listening? Bryden and Zurif (1970) cite Milner et al. (1968) and Kimura (1967) as suggesting the general view that the input arriving from the contralateral ear competes with and suppresses the input from the ipsilateral ear. Supposing that there is in fact a left-ear superiority in patients with agenesis of the corpus callosum, then we want to consider the significance of this finding as considered with the left-ear extinction results found with surgically-bisectioned patients, and the right-ear superiority of Normals. We do not believe that the left ear-superiority in acallosals is established yet, considering the limited number of patients with agenesis of the corpus callosum who have been tested and confounded as the results have been with handedness.

Along with the questions arising from the dichotic listening task using verbal material which are not yet resolved, it might be useful to explore the question of functional asymmetry with non-verbal material, such as musical patterns, which have been found in Normals to exhibit an opposite ear superiority from that of verbal material. This has not been seriously explored with agenesis patients.

Kimura has also explored the functional differentiation of the hemispheres by adapting the dichotic listening recall technique to a multiple-choice recognition technique using non-verbal material, i.e., melodic patterns (1964). For melodic pattern recognition, she established a left-ear superiority interpreted as right-hemisphere dominance for Normal _Ss_.

As the question arose whether Kimura's opposite ear superiority for melodic patterns might be attributable to the difference in technique, that is, a recognition technique as opposed to the recall technique used with verbal material, Broadbent and Gregory (1964) performed an experiment using the recognition technique with verbal material, and again confirmed the right-ear superiority for verbal material in normal _Ss_.

Aside from Kimura's (1964) finding of a left-ear/right hemisphere superiority for melodies, other non-verbal stimuli, such as sonar signals and environmental noises have been found to elicit a left ear superiority (Chaney and Webster, 1965; Curry, 1967).

We decided to test our acallosal _S_ and her Sibling as well as a group of Mental Match Subjects and Normal Subjects for comparative purposes on two techniques (free recall, and recognition) for dichotically presented digits, and also the recognition technique for tonal patterns.

EXPERIMENT I. RECALL OF DICHOTIC DIGITS, ACALLOSAL VERSUS SIBLING VERSUS NORMALS VERSUS MENTAL MATCH Ss.

The expectation is that the Normals and 'Mental Match' Ss will show a right-ear superiority, while the Acallosal and Sibling will show no difference between ears.

Method:

The Acallosal and Sibling were tested on a series of Dichotic Listening tasks using a Recall Technique.

The Subject was first given the Digit Span test from the WISC.

Then a pre-test was given to adjust the volume control which involved playing digits from a tape-recorder in one ear until the S indicated she could hear them clearly and comfortably, then in the other ear for the same purpose, and then playing the digits dichotically until the S indicated the numbers sounded "like they are in the middle of your head, the centre of your head and not to one side or the other". Broadbent used this method of subjective equivalence.

We then had a practice section with four digits sounded in either the right or the left ear (for six trials). After the S heard the four digits, she was to repeat them back to the E. Then there was further practice with six digits for 12 trials. Following this there were two pairs of digits presented dichotically, that is a total of four digits, but two digits are sounded in one ear at the same time two different digits are sounded in the other ear. After hearing the two pairs of digits, the S was to repeat out loud what she had heard, and if not sure, to guess. The S was further instructed to report as many of the numbers as could be remembered, in any order the S chose.

A. On the Main Test (Free Recall), the S was presented with three pairs of digits presented at the "fast" rate of one pair per second, and was to report as many of the digits as possible in any order she chose.

B. Free Recall: on this section, the three pairs of digits were presented at the slow rate of one pair per two seconds.

C. Pre-ordered Recall: Now the S was presented with three pairs of digits at the fast rate of one pair per second, but just prior to the beginning of each trial the S was told to report first one ear and then the other and told which ear to report first. For example, the S was told "Report left ear first".

D. Pre-ordered Recall: The same condition as 'C', but presented at the slow rate of one pair per two seconds.

E. Post-ordered recall: After hearing the digits presented at the fast rate, the S was told verbally which ear to report first.

F. Post-ordered Recall: Same condition as 'E', but presented at the slow rate.

The Acallosal and the Sibling were run on these six Conditions of twelve trials each in one testing session, and then one week later the whole was replicated with the earphones switched on (on a different series of digits, however). (Bryden found significant results using ten trials per Condition.)

It was found that this experiment, coupled with the two other dichotic experiments, was too time-consuming to have the Control Ss (school children) perform it all. Therefore the two groups of Control Ss, a group of 12 Normal 11/12 year-old girls from a local school, and a group of 8 <u>Ss</u> matched roughly for intelligence and also sex and age were tested on only Condition A repeated (Free Recall, fast rate of one pair per second)(plus the practice trials).

<u>Results</u>: We include a Table of Results for the Acallosal and Sibling for the <u>Recall Technique</u>.

Table I: Recall Technique Summary for All Conditions (Total Correct) for Acallosal and Sibling.

Condition	A	B	C	D	E	F
	Fast	Slow	Fast	Slow	Fast	Slow
	R-ear/L-ear	R-ear/L-ear	R-ear/L-ear	R/L	R/L	R/L
Acallosal:						
Week 1:	*33/17	29/24	19/19	19/27	12/8	15/12
Week 2:	25/22	26/27	24/19	24/19	13/10	20/15
Week 1 + 2:	58/39	55/51	43/38	43/46	25/18	35/27
*Out of 36 possible correct					Total R/L 259/219	
Sibling:						
Week 1:	30/7	24/27	31/17	22/15	25/15	21/14
Week 2:	28/2	25/9	24/3	33/3	29/3	24/4
Week 1 + 2:	58/9	49/36	55/20	55/18	54/18	45/18
					Total R/L 316/119	
Total R+L-ear	A	B	C	D	E	F
Acallosal	97	106	81	89	43	62
Sibling	67	85	75	73	72	63

The Acallosal performs best on "Report in any order" Condition, next best on Pre-ordered Condition, worst on Post-ordered Condition. Instructions to report one ear or the other first are probably confusing to the Subject, and on the post-ordered Condition, the time-delay probably contributes to the poorer performance as well.

The Acallosal is right-ear dominant in all conditions except the slow, pre-ordered condition where she was slightly left-eared.

The Acallosal was better on the slow conditions than on the fast conditions (and this improvement in performance is reflected primarily in the left ear).

The Sibling shows an even greater right-ear superiority, in fact she seems more like what we expect of surgically-bisected patients.

The Sibling performs best on the Free-Recall condition, next best on pre-ordered condition, and worst on the post-ordered condition, just as the Acallosal.

The Sibling does not tend to perform as well on the slow conditions as on the fast; this is probably due to a memory deficit such as the Hospital Psychologist found in her performance.

Comparison with Normal Subjects.

Table II: A Table of Comparison with Normal Ss on Free Recall (fast) Condition

	Free Recall (12 trial)	Repeat	Total R.-ear	Tot.L-E	Diff.
S 1	34R/34L-ear	34R/33L	68	67	+1
S 2	34R/32L	36R/26L	70	58	+12
S 3	33R/36L	35R/35L	68	71	-3
S 4	36R/34L	33R/35L	69	69	0
S 5	35R/35L	34R/36L	69	71	-2
S 6	35R/33L	33R/36L	68	69	-1
S 7	32R/32L	35R/29L	67	61	+6
S 8	33R/35L	35R/35L	68	70	-2
S 9	34R/34L	35R/35L	69	69	0
S 10	36R/35L	36R/36L	72	71	+1
S 11	36R/34L	34R/36L	70	70	0
S 12	36R/35L	35R/34L	71	69	+2
Acallosal	33R/17L	25R/22L	58	39	+19
Sibling	30R/7L	28R/2L	58	9	+49

This group of Normal Ss shows a Mean right-ear superiority of +1.2 digits. This is not significant (Wilcoxon Matched-Pairs Signed-Ranks Test), as four of the twelve Subjects go in the opposite direction and three Ss show no difference.

The Acallosal and Sibling, far from giving support to our hypothesis that they may show bilateral language representation, show a quite strong lateralization to the left hemisphere for short-term memory for digits presented dichotically. In fact, they seem to perform more like surgically-bisectioned patients than like Normals.

One further comment about the performance of the Normal Controls is that they seem to demonstrate a ceiling effect. The average number of correct digits recalled was 69 out of a possible 72 for the right ear; 68 out of 72 on the left ear. This ceiling effect may account for the lack of a significant difference between ears for the normal controls.

Comparison with 'Mental Match' Subjects

Table III: A Table of Comparison with Mental Match Ss: Free Recall (Fast) Condition.

	Free Recall (12 trials)	Repeat	Total R-ear	Total L-ear	Diff.
S 1	36R-31L	33R/30L	69	61	+8
S 2	31R/35L	26R/33L	57	68	-11
S 3	35R/26L	34R/28L	69	54	+15
S 4	30R/27L	34R/22L	64	49	+15
S 5	32R/26L	28R/27L	60	53	+7
S 6	35R/35L	34R/34L	69	69	0
S 7	27R/24L	31R/26L	58	50	+8
S 8 No data - S unavailable for testing					
S 9	34R/33L	34R/33L	68	66	+2
Acallosal	33R/17L	25R/22L	58	39	+19
Sibling	30R/7L	28R/2L	58	9	+49

The Acallosal and the Sibling both show a larger ear difference than the entire range of both normal controls and Mental Match Ss.

The 'Mental Match' Subjects show a Mean ear difference of 8 points (disregarding sign), while the Normals show a Mean ear difference of 2.5 correct digits.

A test comparing the combined Mental Match and Normal S ear difference data, with the Acallosal and Sibling, shows that the Acallosal and Sibling are significantly ($< .05$) different from the other combined groups.

We conclude that the Acallosal and Sibling are different from the Normal and 'Mental Match' Ss on the Free Recall Technique of Dichotic Listening.

EXPERIMENT II. RECOGNITION OF DIGITS: ACALLOSAL VERSUS SIBLING VERSUS NORMALS VERSUS MENTAL MATCH Ss.

The expectation is that the Normals and the 'Mental Match' Subjects will show a right-ear superiority, while the Acallosal and Sibling will show no difference between ears.

Method:

The instructions for the Main Test were that the Subject would hear three digits in each ear, that is, a total of six digits. One digit would sound in one ear at the same time another digit would sound in the other ear. The numbers were presented at the rate of one per second:

Like this: (Play three pairs)

for example, 1 6 5
2 3 6 then a three-second pause, and the
four groups of three digits each would be heard, one group after
another.

As, dichotically, the pairs 1 6 5 (presented binaurally)
2 3 6 then (1 6 5 1 6 3 2 1 6 2 3 6).

After the Subject heard all four groups presented binaurally, that is in both ears, he was to say which two of the four groups he heard before when different numbers were played in each ear. Say, Groups One and Four, in the example.

There was an eight second break between trials (or longer if necessary for the S to respond) and the next trial was signalled by the sound of a tap.

Twenty-four trials were presented and earphones were reversed half-way through.

This method was modelled on Broadbent and Gregory's (1964) use of the Recognition Technique, except that they used shorter time periods (their three pairs of digits presented at the rate of one pair per half-second, then one second pause, then the four groups of digits presented at rate of one digit per half-second with a half-second gap between each group). Of the four binaural triads presented for recognition, one triad corresponded to the digits previously given to the right ear and one triad to the left ear. The S had to respond by saying which two of the four triads he had heard before.

The point of doing this experiment was to be able to make a direct comparison with the third experiment, using the recognition technique on tonal patterns.

The Acallosal and Sibling were tested on this Condition, as well as a group of twelve Normals and Nine 'Mental Match' Ss who were in both Control groups girls, right-handed, and of the same age, as the Acallosal.

The Condition was doubled in terms of the number of trials for Acallosal and Sibling because the test was repeated the following week with earphones switched again. It was repeated to try to get a more reliable estimate of ear lateralization.

Results:

A comparison of the Acallosal and Sibling data (see Table following) shows that for the Acallosal there is no over-all difference between Right Ear and Left Ear for the number of digits recognized. The Sibling showed an overall Right Ear superiority, as she had done on the Recall Technique.

Table IV: A Table of Comparison of Acallosal and Sibling on Recognition Technique (Digits).

No. of Triads correct	Week 1 (24 trials)	Week 2 (repeat)	Totals	Ear Diffs.
Acallosal	15R/10L	13R/18L	28R/28L	0
Sibling	16R/6L	13R/13L	29R/19L	+10

The Normal Ss show an overall right ear advantage (as with the Recall Technique); the Mean difference between ears being 1.7 triads. This is probably not a significant difference as only seven out of the twelve Ss show this directional difference, with three Subjects showing a difference in the opposite direction, and two showing no difference. The results are summarized in the following Table.

The Mean difference for Normals between ears is 3.1 triads (without regard to sign). The Acallosal in comparison shows no difference, and the Sibling shows five triads difference which is not outside the range of the Normals.

Table V: A Comparison of Normals with Acallosal and Sibling on Recognition Technique (Digits).

Totals (24 triads possible for each ear)

	Right Ear	Left Ear	Difference
S 1	13	14	- 1
S 2	16	12	+ 4
S 3	16	13	+ 3
S 4	14	15	- 1
S 5	17	17	0
S 6	16	14	+ 2
S 7	19	11	+ 8
S 8	16	8	+ 8
S 9	14	13	+ 1
S 10	13	19	- 6
S 11	15	15	0
S 12	16	13	+ 3
	185/12	164/12	
	=X = 15.4 R	=X= 13.7 L	Diff.=+1.7
Acallosal	X= 14 R	X= 14 L	= 0
Sibling	X= 14.5 R	X= 9.5 L	= +5

Table VI. A Comparison of Mental Match Ss with Acallosal and Sibling (Acallosal and Sibling data above).

	Right Ear	Left Ear	Difference
S 1	15	9	+6
S 2	15	13	+ 2
S 3	12	12	0
S 4	9	14	- 5
S 5	15	18	- 3
S 6	15	7	+ 8
S 7	13	18	- 5
S 8	12	12	0
S 9	20	13	+ 7
	126/9	116/9	
	=X= 14.0 R	=X= 12.9 L	Diff.= +1.1

The Normal Ss show a mean number of correct triads equal to 14.5 (out of a possible 24 triads). This 60% correct figure indicates the level of difficulty of this recognition task.

A comparison of 'Mental Match' Subjects with the Acallosal and Sibling (see summary Table on previous page) shows that the mean difference for Mental Match Ss between ears is 4.0 triads (without regard to sign). However, four of the nine Ss showed the expected right ear superiority, while three showed the opposite superiority and two showed no difference. While the over-all Mean difference is in the right-ear direction for these Mental Matches, as for the Normals, this difference is not significant. The Acallosal and Sibling are not significantly different on this Recognition Task Technique from the Normals and the Mental Match Subjects.

EXPERIMENT III. RECOGNITION OF TONAL PATTERNS: ACALLOSAL VERSUS SIBLING VERSUS NORMALS VERSUS MENTAL MATCH SUBJECTS.

The expectation is that the Normal Ss and the 'Mental Match' Ss will show a left-ear superiority for recognition of tonal patterns. The Acallosal and Sibling will show no difference between ears or else they will show a greater left-ear advantage than the Normals and Mental Matches. That is, one hypothesis we have about patients who have an agenesis of the corpus callosum is that they develop language mechanisms or processes in both hemispheres so that the hemispheres would have an equipotential for language, and this would be reflected in the dichotic digits task by a finding of no difference between the ears. We can make the same hypothesis about recognition of tonal patterns. Another hypothesis is that they do not have language in both hemispheres and the lack of a functional corpus callosum would be reflected in a greater right-ear advantage for dichotic digits compared to normals, similar to the performance of surgically-bisectioned patients. In other words, we could expect the acallosal to perform as if surgically bisectioned. In the case of tonal patterns we hypothesize that surgically-bisectioned patients would be left ear superior, and if acallosals do not have a hemisphere equipotentiality for tonal patterns, they may perform as though surgically bisected. The statistical prediction we will test is that Acallosal and Sibling will perform differently from the Mental Match Ss and the Normals Ss.

Kimura's (1964) recognition technique is used here for dichotically presented tonal patterns. Kimura had used individual melodies which were excerpts from solo passages in concertos by Mozart, Telemann, Vivaldi, Bach, and Antonini. In Kimura's experiment most of the music was played by woodwinds, but some was recorded from violin, viola, and cello. Eighty melodic passages were tape-recorded from commercial records and subsequently classified into twenty sets of four.

Within each set of four melodies, the same instrument was used, and an effort was made to have the tempo and the pitch range very similar, so that the main clue to recognition was the melodic pattern. The melodies were of four seconds duration.

For each trial, two of the four melodies were first played simultaneously on the two separate channels, so that one melody was heard in one ear at the same time another melody was heard in the other ear. A four-second silence ensued and then the four melodies were played in succession in normal binaural manner. There was a three-second interval between melodies. Subjects responded by saying which two of the four melodies they had heard dichotically: "They were the second, third", or "first and fourth". The score for each ear was the number of correct identifications for that ear. The first two sets were used for practice, and the other 18 sets comprised the main part of the test. Kimura found a left-ear advantage for melodic patterns.

Broadbent and Gregory (1964) used the same recognition technique using digits and the material was prepared so that in each trial the two triads presented dichotically "had one digit in common which was not in the same serial position,"

"The two binaural triads which were not identical with either of the dichotic triads had, however, two items in common with one of them and one with the other."

"In each trial, one of the correct triads was in the first two alternatives of the recognition, and one was in the second pair. Each of the four possible arrangements of the two correct triads occurred with equal frequency, and the first correct alternative was in equal numbers of cases that from the right ear and from the left."

The S was instructed to write down which two of the four groups for recognition corresponded to the triads he had heard separately on the two ears.

We used Broadbent's above described method of composing triads of digits for recognition also for our Experiment II as previously described, except that our time pattern was different, and the Ss were asked to say aloud which two of the four triads he had heard before.

We then used exactly the same technique on tonal patterns to make the two experiments strictly comparable.

Method:

The method for preparing the tonal patterns was the same as for the Experiment II, using Broadbent's restrictions mentioned above for both Experiment II and III. Beginning the tonal scale from Middle-C and assigning numbers:

1	2	3	4	5	6	8	9
C	D	E	F	G	A	B	C

(Number '7' hadn't been used in dichotic digits because it is bisyllabic). We then transformed the same digit patterns we had used into the tonal scale, such that triad 1-6-5 became triad C-A-G, etc.

These tonal patterns were recorded from the piano and played at the same speed as the digits, i.e., one pair per second, then a three-second pause, then the triad at one tone per second, and a two-second pause between triads. The S̲ was to say which two of the four patterns he had heard before.

There were twenty-four trials and the earphones were switched half-way through the test.

Results:

The results for the Acallosal and Sibling are given below. The first set of 24 trials was repeated one week later with headphones switched again.

Table VII: A Comparison of Acallosal and Sibling on Recognition Technique (Tonal Patterns)

	Totals (24 trials, week 1)	Week 2	Total R-ear	T.L-ear	Diff.
Acallosal	14R/14L	14R/14L	28 R	28 L	0
Sibling	13R/13L	10R/19L	23 R	32 L	-9

The Acallosal shows no difference between ears for tonal patterns. The Sibling shows a left ear superiority.

The Twelve Normal Ss data summary is presented on the following page for comparison. Only four of the twelve Normal Ss show the expected left ear advantage, six Ss show right ear advantage, and two show no difference between ears. The Mean difference between ears, disregarding sign, is 2.3 triads. There is not a significant ear difference demonstrated for the Normal Ss. Both Acallosal and Sibling fall within the range of the Normals' scores.

Comparing the Acallosal and Sibling with the Mental Match Ss we find only four of the nine 'Mental Match' Ss show a left ear superiority; three show a right ear superiority, and two show no difference at all. There is overall a 0.3 triad superiority for left ear; not very impressive, and obviously not significant. The Acallosal and Sibling are not significantly different from this group of Ss either, their scores falling within the range of scores for the Mental Match Ss as well as the Normals.

Table VIII: A Comparison of Normal Ss with Acallosal and Sibling on Recognition Technique (Tonal Patterns).

	Totals (24 possible triads on each ear)		
	Right Ear	Left Ear	Difference
S 1	14	14	0
S 2	14	16	-2
S 3	13	13	0
S 4	16	15	+1
S 5	11	9	+2
S 6	12	14	-2
S 7	14	10	+4
S 8	9	13	-4
S 9	18	12	+6
S 10	14	12	+2
S 11	11	15	-4
S 12	15	14	+1
Acallosal	X = 14	X = 14	0
Sibling	X = 11.5	X = 16	-4.5

Table IX: A Comparison of Mental Match Ss with Acallosal and Sibling (Acallosal and Sibling data above).

	Right Ear	Left Ear	Difference
S 1	9	15	-6
S 2	14	13	+1
S 3	13	13	0
S 4	14	15	-1
S 5	12	16	-4
S 6	13	10	+3
S 7	11	12	-1
S 8	16	11	+5
S 9	14	14	0

EXPERIMENT IV. REPLICATION OF RECOGNITION TASK (TONAL PATTERNS) ON 25 ADULT SUBJECTS

Because we have not found a significant left-ear superiority for our group of twelve Normal girls on this tonal pattern recognition task (Experiment III), where Kimura had found significant differences, we decided to replicate the experiment on a larger group of University students, before trying to draw any further conclusions about it.

Method:

This is a replication of Experiment III but on 25 male and female University students. They were presented 24 trials of the initial tonal patterns recognition task in a laboratory practical, and after an intervening task and a break, they were retested on the same 24 trials with the earphones reversed.

The tests were scored in two ways; first, on the basis of number of correctly recognized triads (as in Experiments II and III), and then on the basis of which ear reported first, to see whether one scoring method might show a superiority over the other.

Results:

The Means for all 25 Ss are found in the following Table. The results indicate, if any difference, a right ear, not a left ear, superiority for tonal patterns. Ten of the twenty-five Ss show a left ear superiority, twelve show a right-ear advantage, and three Ss demonstrate no difference between the ears.

It seems clear that this recognition technique fails to show a left ear superiority as reported by Kimura. It is not clear what could account for this. It is not that the task is too

Table X: Summary of data for 25 Adult Ss on Recognition Task (Tonal Patterns)

	Test I (24 trials)			Repeat Test			Totals	
	Left-ear	Right-ear	total	L-ear	R-ear	Tot.	Tot.-L	Tot.-R
N=25	334 total	335	709	361	371	732	695	746
	13.36 =mean=	15.00	=28.36	=14.44	=14.84	=29.28	13.9	14.9
% of total possible:	53.44%	60.0%	56.72%	57.76%	59.36%		55.6%	59.7%

difficult; the Subjects perform above chance level. The dichotic tape is satisfactory; everything that one would anticipate counterbalancing is counterbalanced. The length of time of a trial is comparable to that of Kimura's experiment. The S is asked to respond verbally which presumably involves the left hemisphere and could wipe out the difference between hemispheres, yet Kimura used the same kind of verbal response and still found a right hemisphere advantage.

It may be that our experiment is in a sense better controlled than Kimura's, in that tonal patterns is all we claim to be investigating, while Kimura's tonal patterns, i.e., melodies, included some tempo, and pitch range, though she "had made an attempt" at controlling them. Possibly we are tapping something different from what Kimura was tapping.

A further point is that, while we obtained a right ear advantage for the digits using the recognition technique, such as Broadbent had used, this is not a significant difference between ears. This may be due to the longer time presentation involved in our Experiment II. Broadbent had presented a pair of digits every one-half second; then only a two-second interval, and the other intervals were a half-second, while our rate of presentation of digits was one per second, with a three-second pause, then again one per second, with two-second intervals between the four groups of triads. This appears to be the only difference between the two experiments, and may mean something about the role of memory storage in hemisphere lateralization.

In summary, we can say that the Acallosal and Sibling are significantly different from Normals and Mental Match Ss on the Free Recall of Digits Condition. They perform more like surgically-bisectioned patients. Their performance does not support the hypothesis of bilaterality of speech mechanisms.

The Acallosal and Sibling are not significantly different from Normals and Mental Match Ss on either of the Dichotic Recognition Technique Tasks. The fact that Normals are not significantly right-hemisphere lateralized for Tonal Patterns makes it impossible to say anything about the bilateralization hypothesis for the Acallosal on these two Recognition Experiments.

CHAPTER FIVE

VISUAL PERCEPTION COMPARISONS OF INTERHEMISPHERIC TRANSMISSION TIMES: STUDIES OF CROSSED AND UNCROSSED PATHWAY RESPONDING IN CALLOSAL AGENESIS

Introduction

Jeeves (1969) reported on a comparison of "interhemispheric" transmission times in Acallosals and Normals. His findings were that his two Acallosal patients had lengthened interhemispheric transmission times over those reported for Normal (male, 18-21 years old) Subjects. (See Table II)

Smith, K. (1947) found in split-brain patients that the contralateral pathway was longer than the ipsilateral.

Bradshaw, Geffen, and Nettleton (1972) found that in using a point source of light as the stimulus to either the right or left Visual Field, the reaction time was faster when the visual field of the stimulus and the responding hand were both on the same side. They suggest that if they are on opposite sides, the signal may have to be relayed across the corpus callosum (a difference in pathways of about 20 msecs.). Alternatively, they suggest, ipsilateral pathways may be functioning.

The direct- or short-pathway is defined as the one where the hemisphere receiving the stimulus initially and the hemisphere controlling the hand responding are presumed the same. For example, the stimulus falling on the nasal part of the retina of the right eye will stimulate the visual cortex of the left hemisphere directly, and when this stimulus is responded to with the right hand, no crossing from one hemisphere to the other is necessary. The indirect- or long-pathway in this case would be if this stimulus were responded to by the left hand, requiring a presumed crossing of information to the right hemisphere after initial arrival of the stimulus in the left hemisphere. In the case of stimulation of the nasal retina, responding with the hand ipsilateral to the side of stimulus would constitute the short-pathway; responding with the hand contralateral to the stimulus would constitute long-pathway.

In the case of temporal stimulation of the retina, the hand contralateral to the side of stimulus constitutes the short-pathway (for example, right temporal retina stimulated/left hand responding), and the hand ipsilateral to the stimulus side constitutes the long-pathway.

SUMMARY TABLE OF PATHWAYS FOR NASAL AND TEMPORAL STIMULATION CONDITIONS

	Short Pathway	Long Pathway
Nasal Stimulation (angle 70 to midline)	Right Side/R-Hand; LS/LH	RS/LH; LS/RH
Temporal Stimulation (lights embedded in spectacle frames)	Left Side/R-Hand; RS/LH	LS/LH; RS/RH

In a 1970 paper, Jeeves and Dixon reported on hemisphere differences in response rates to unstructured visual stimuli (a point source of light) and found a right hemisphere superiority in Reaction Times where the visual stimulus went initially to the right hemisphere as compared to the initial reception of the point of light in the left hemisphere. Jeeves (1972) confirmed this finding on a sample of Normal, right-handed children also.

Rizzolatti, et al. (1971) did not find visual field (hemisphere) differences in responses to unstructured light stimuli.

Dimond (1970a) did not find hemisphere differences either. Dimond and Beaumont (1974), suggest that the extreme brevity of Jeeves' stimulus accounts for his results.

Goodglass (personal communication to Dimond and Beaumont, 1974) "reported a lower threshold for visual stimuli at the right hemisphere and suggests that in perceptual terms this hemisphere is less coarsely grained than the left".

Bradshaw et al. (1972) also found that lights flashed in the left visual field were responded to faster than lights presented in the right visual field (to the left hemisphere).

Bradshaw and Perriment (1970) found a crossed versus uncrossed pathway difference of approximately + 20 msecs. The task was a forced-choice reaction time task which would presumably require longer latencies than the simple reaction time task, due to the difficulty of the task.

Kinsbourne and Fisher (1971) provide further evidence about the performance of Acallosal patients on tasks requiring the interhemispheric transfer of information. Their studies, which report interhemispheric transmission times for an Acallosal boy of 12.4 msecs. and 13.1 msecs., in two different experiments, are held to support the view that such latencies are within the minor differential found in Normal Subjects. However, since the latency difference between response to uncrossed and crossed stimulation in highly practiced Normals is usually found to be of the order of 1-4 msecs. (Moskatova, 1965; Poffenberger, 1912; Efron, 1963; Jeeves, 1969, 1972), this conclusion calls for comment.

Since statistical treatment of their results failed to produce differences reliable at the 5% level (on a two-tailed test), it is a defensible conclusion on the basis of their own experiments. However, Kinsbourne and Fisher obtained a total number of responses by their Acallosal patient of only 100 (50 for each hand) trials in one experiment and in the other, 90 responses. Jeeves (1969, 1972, 1970) has found that the variability of responses in simple reaction time tasks is such that where differences of the order of 3 msecs. are being investigated, many more than 50 responses per hand are required to generate sufficiently reliable data. In Jeeves' earlier studies (1969, 1972), comparisons of crossed and uncrossed response times were based upon 300 responses per hand under each condition. This same criticism, i.e., too few trials, may be made of the Ettlinger et al. (1972) experiment (see Table II) in a situation where they themselves noted "extremely high within Subject variance".

Kinsbourne and Fisher suggested that Jeeves' earlier results may have been produced by the nature of the responses required from the Subjects. They noted that Jeeves' Subjects were required to have both hands on response keys. From this correct observation they made the incorrect inference that "in the uncrossed condition, the instruction was to respond on the same side as the stimulus; in the crossed condition, to respond to the opposite side". They point out further that such a procedure produces a situation where "the former condition is highly compatible the latter an example of gross stimulus-response incompatibility". However, reference to Jeeves' own published paper to which they refer makes it clear that what in fact happened was, to quote from Jeeves' paper, "<u>S</u>s were told that when a warning buzzer sounded they should press down two morse keys and ensure that they were fixating a central point on a grey screen 2 m. to their front. Immediately after a stimulus appeared they were to release both keys as quickly as possible". Thus it is clear that, first, Jeeves' <u>S</u>s responded in the two-handed responding experiment with <u>both</u> hands on <u>all</u> trials irrespective of which side the stimulus appeared. They did not, as as Kinsbourne and Fisher suggest, respond only on the same side as the stimulus in the uncrossed condition and only on the opposite side to the stimulus in the crossed condition. Rather, Jeeves' Ss responded to every stimulus irrespective of which side it appears with both hands. This meant that with the balanced design used, there were equal numbers of right-handed responses with the stimuli appearing on the left, and with the stimuli appearing on the right. Likewise with the left-handed responses. Thus, any tendency such as that which Kinsbourne and Fisher suggest is fully counter-balanced in the experimental design. Second, Jeeves did carry out and report at the same time an experiment in which only one hand was used in any given session, and the stimulus appeared randomly on either side. Under that condition, as his published results show, the picture which emerged was substantially the same as under the two-handed condition.

We decided to collect further data on the crossed versus uncrossed response latencies under both two-handed and single-handed response conditions on our Acallosal girl and her older sister, as part of our study exploring the possibility of behavioural results predicting whether the Sibling is also Acallosal. The Sibling is tested under the same Conditions as the Acallosal girl.

The single-handed response condition was the same as that used by Kinsbourne and Fisher in their Experiment I and would thus provide comparable data, the only difference being that whereas their data was based on 50 trials per hand, collected at one session, ours was based on 300 trials per hand collected over ten sessions. Our reason for this procedure was that data from such experiments shows considerable variance and also that by collecting data over ten sessions, we avoided our Ss becoming fatigued during any one session and thus hopefully reduced the likelihood of another uncontrolled source of variance entering into the data. We also used a time accurate to 1 msec.; Kinsbourne and Fisher's use of a less accurate device would seem undesirable when dealing with differences of the order of 10-20 msecs.

Our prediction is that the Acallosal would demonstrate a faster Direct Pathway than Indirect Pathway, and this difference between the two pathways would be greater on both the two-handed Nasal Stimulation Condition, and the Two-handed Temporal Stimulation Condition, than for the Normal Ss previously tested by Jeeves (1969), and the same would apply to the single-handed, Nasal Stimulation Condition.

Further, we intend to look at the effect of Side of Stimulation by the point source of light (Visual Field Difference). We would not expect the Acallosal or Sibling to show a Visual Field Difference, if they are not hemisphere lateralized; that is, if they are bilateralized for simple visual perception and responses to the simple visual stimuli. A pilot study reported by Jeeves (1965) on two Acallosals indicates a right hemisphere superiority for responses to a point source of light (of 104 msecs. in one case and 11 msecs. in the other).

We report four Experiments, two with the Acallosal and then two replications on the Sibling. The first experiment (Experiment I) involves two experimental conditions; two-handed responding to a Nasal stimulus; and two-handed responding to a Temporal stimulus by the Acallosal. Experiment II involves single-handed responding to a Nasal Stimulus by the Acallosal. Experiment III: the same as Experiment I, but on the Acallosal's Sibling. Experiment IV: The same as Experiment II, using the Sibling. Our hypothesis is that if the Sibling performs similarly to the Acallosal in having larger than normal pathway difference, we may infer that she is likely to be acallosal also.

EXPERIMENT I. ACALLOSAL: TWO-HANDED RESPONDING

Procedure and Apparatus: The apparatus used was the same as reported in Jeeves' previous publications (1969, 1970, 1972). The procedure for both the nasal and temporal retinal stimulating conditions differed in no essentials from that perviously reported by Jeeves, except that in this experiment the control and recording equipment and E were in the same room as the S, and the S wore headphones in order to control background noise and reduce auditory cues, if any, as much as possible. The stimulus was a point source of light. On the Nasal Stimulation Condition, the two keys and the two lights were counterbalanced to control for any differences. In the Temporal Stimulation Condition the lights were embedded in spectacle frames and could not be moved, consequently only the keys were switched in a balanced manner in this part of the experiment.

The Acallosal S made 60 two-handed responses which provided 120 RT observations at each session. She was tested for 5 consecutive days under the Nasal Condition and then 5 consecutive days under the Temporal Condition. The S was tested at the same time each day and each session began with a short practice period (five trials). A total of 600 RTS was obtained under the Nasal Condition and the same total under the Temporal Condition.

The Acallosal girl was 12 years old at the time of this testing procedure.

Results

The Mean response times for the direct- or short-pathway, and indirect- or long-pathway, under each of the two stimulation conditions -- Nasal and Temporal -- is given in Table I.

Table I: Mean RTs for Acallosal S (Experiment I)

	Mean RT/Short Path	Mean RT/Long Path	Mean RT Difference
Nasal Stimulation, Two-handed responding	347.68	361.39	+13.71
Temporal Stimulation, Two-handed responding	314.66	326.81	+12.15

These Mean RT differences fall well outside the range of those for the 20 Normal Ss (see Table II for mean RTs for Jeeves' Normal Ss) studied in an earlier experiment (Jeeves, 1969). The likelihood of this happening by chance is less than .05 (Fisher exact probability test). The range of Mean differences for the 20 Normal Ss was from -2.9 msecs. to +4.45 msecs. (Nasal Stimulation Condition) and from -0.56 to +4.35 msecs. (Temporal Stimulation Condition). The Mean RT differences between the pathways is thus significantly greater for this acallosal girl than for the Normal adults.

Data obtained from 20 Normal boys, aged nine years, six months to eleven years, five months (Jeeves, 1972) gave RT differences between crossed and uncrossed pathway responding of the same order as for the Normal adults. When the data from the Acallosal girl were compared with the Children's data, it was again found that her Mean RT differences were significantly longer ($p < .05$ on the Fisher exact probability test) than the Normal children.

In order to examine the experimental procedure more closely, a three-way Analysis of Variance was computed on the observations gathered on the Acallosal for the separate experimental Conditions, Nasal Stimulation, and Temporal Stimulation (Two-handed responding in each Condition). The predictions were that the indirect pathway (LP) was significantly longer than the direct pathway (SP) (a directional hypothesis), and that none of the other conditions or interactions would be significant.

Tables III and IV contain summaries of these Analyses of Variance with a summary table of the raw data totals included. The results show on the Nasal, two-handed Response Experiment that the difference between the pathways fails to reach the specified .05 level of significance on the t-test. In addition, a Hand X Key interaction was found to be significant. The hands and keys were counterbalanced, and all four conditions of Hand X Key were tested under each pathway Condition. Examination of the Interaction Graph (Figure 1, Part A) will illustrate that the Hand X Key interaction does not affect the RT difference between the indirect and direct pathways, where all four Hand X Key Means are lower (faster) under level A1 (direct path) than the four corresponding Means under level A2 (indirect pathway).

In the analysis of the temporal retina-stimulated experiment, the one-tailed t test on the difference between the pathways was significant at $< .05$. There was also a main effect significant difference between the keys, and further, a significant Path X Hand Interaction.

The plots of both Hand X Key Interactions are given in Figure IA and Figure IB for comparison. The significant Hand X Key Interaction under the Nasal Retina, Two-handed Responding Condition

Table II. Mean Interhemispheric Transmission Times of Normals and Acallosals in Response to Visual Stimulation.

-- Condition	Numbdr of Subjects	short Pathway	Long Pathway	Difference	Significance
Expt. I. Nasal Stimulation, Two-handed responding.	1 acallosal girl, Age 12	347.68	361.39	+ 13.71 msec.	p=.085 (one-tailed test)
Expt. I. Temporal Stimulation, Two-handed responding.	"	314.66	326.81	+ 12.15	p < .05 (one-tailed test)
Expt. II. Nasal Stimulation, Single-hand responding.	"	330.00	360.36	+ 30.36	p < .001 (one-tailed test)
Jeeves (1969): Nasal Stimulation, Two-handed responding.	10 Normal Adults	271.09	272.89	+ 1.80	p < .001 Wilcoxon matched-pairs signed-ranks test on all 30 Ss.
"	10 Left-handed Adults	243.85	245.50	+ 1.65	
" Single-handed responding.	10 Normal Adults	234.99	237.55	+ 2.56	
" Temporal Stimulation, Two-handed responding.	10 Normal Adults	256.16	257.72	+ 1.56	p < .005 Wilcoxon matched-pairs signed-ranks test on all 30 S_s.
"	10 Left-handed Adults	233.24	234.54	+ 1.30	
" Single-handed responding.	10 Normal Adults	218.89	221.98	+ 3.09	
" Nasal Stimulation, Two-handed responding.	1 acallosal boy, Age 14	346.5	365.0	+ 18.5	p=.27 (One-tailed)
" Temporal Stimulation, Two-handed responding.	"	286.0	300.5	+ 14.5	p= .28 (One-tailed)
" Nasal Stimulation, Two-handed responding.	1 acallosal man, Age 46 Left-handed, except for writing	251.52	312.85	+ 61.33	p=.005 (one-tailed)

Table II. Continued. Mean Interhemispheric Transmission Times.

Condition	Number of Subjects	Short Pathway	Long Pathway	Difference	Significance
Jeeves (1972): Nasal Stimulation, Two-handed responding.	10 Normal Children	314.57	316.00	+ 1.43	Wilcoxon test $p < .005$
" " "	10 Left-handed Children	307.07	308.36	+ 1.29	
" Temporal Stimulation, Two-handed responding.	10 Normal Children	303.03	304.25	+ 1.22	Wilcoxon test $p < .005$
" " "	10 Left-handed Children	297.13	297.91	+ 0.79	
Kinsbourne and Fisher: Nasal and Temporal Stimulation, Single-handed responding.	1 Acallosal boy, Age 16	233.0	245.4	+12.4	$p > .05$; $p < .10$ F=2.24;df3,96
" " 3 Stm. Positions.	"	240.1	253.2	+ 13.1	F= 0.69; df5,84
Ettlinger et al.: Nasal and Temporal Stim., Single-handed responding.	3 Total acallosals 3 Partial acallosals 4 Neurological Controls aged 3.3 to 23.5 right and left-handers male and female	497.48	497.83	+ .35 (1)	$F < 1$

(1) difference score reported - 1.03

Table II. Continued. Mean Interhemispheric Transmission Times.

Condition	Number of Subjects	Short Pathway	Long Pathway	Difference	Significance
Poffenberger:Single-handed responding, Nasal and Temporal data, Visual ∠ = 30 degrees.	1 male, right-handed adult	203.5	208.0	+ 4.5	P.E. =.92
Visual ∠ = 10 degrees	"	193.2	199.4	+ 6.2	P.E. = 1.05
Visual ∠ = 3 degrees	"	188.2	194.4	+ 6.2	P.E. = .92
Visual ∠ = 30 degrees	1 male,left-handed adult	184.7	191.7	+ 7.0	P.E. = .96
Visual ∠ = 10 degrees	"	183.4	187.5	+ 4.1	P.E. = 1.09
Visual ∠ = 3 degrees	"	187.2	193.6	+ 6.4	P.E. = 0.67
Bradshaw and Perriment: Nasal Stimulation, Single-handed responding. ++	12 Male and female Ss +	424 (approx)*	444 (approx.)	+ 20 (approx.)	p <.0005 (one-tailed test)

+ text does not state whether right or left-handed.

++ choice of digit 2 or 3

* claculation based on authors' graphs since precise times not given.

Table III. 3-Way Analysis of Variance - Nasal Stim. - 2 Handed Responding K.C.

Source of Variation	Ss	df	MS	F
A(Long path/Short path)	.0282	p-1=1	.0282	1.9583 A
B(Hand Resp)	.0168	q-1=1	.0168	1.1667
C(Keys)	.0186	r-1=1	.0186	1.2917
AB(Path XHand)	.0083	(p-1)(q-1)=1	.0083	.5764
AC(Path X Key)	n..0018	(p-1)(r-1)=1	.0018	.1250
BC(Hand X Key)	.1125	(q-1)(r-1)=1	.1125	7.8125 *
ABC	.0002	(p-1)(q-1)=1	.0002	.0139
Within cell (Exper. Evor)	8.5498	pqr(n-1)=592	.0144	
Total	8.7362	pqrn-1=599		

^{A}(Path) $F = 1.9583 = t^2$

$t = \sqrt{1.9583} = 1.3964$ significant at .08 level

ABC Summary Table

Nasal Stim. 2-handed Responding

	C1 Key A		C2 Key B		
	B1 RH	B2 LH	B1 RH	B2 LH	Totals
A1 short-path	RS/RH 25.923	RS/LH 25.135	RS/RH 24.876	LS/LH 28.369	104.303
A2 Long-path	LS/RH 27.683	RS/LH 25.948	LS/RH 26.292	RS/LH 28.493	108.416
	53.606	51.083	51.168	56.862	212.719

Table IV. 3-Way Analysis of Variance - Temp. Stim. - 2 Handed Responding K.C.

Source of Variation	Ss	df	MS	F
A (Pathway)	.0221	1	.0221	3.2985 A
B (Hand Resp)	.0096	1	.0096	1.4328
C (Keys)	.0671	1	.0671	10.0149 *
AB (Path X Hand)	.0582	1	.0582	8.6866 *
AC (Path X Key)	.0103	1	.0103	1.5373
BC (Hand X Key)	.0145	1	.0145	2.1642
ABC	.0181	1	.0181	2.7015
Within cell (Exper. Error)	3.9428	592	.0067	
Total	4.1427	599		

A $\sqrt{3.2985} = \sqrt{F} = t = 1.8162$ * sign. at ∠ .05 one-tailed test

ABC Summary Table

2 Handed respording Temporal Stim.

	C1 Key A		C2 Key B		
	B1 RH	B2 LH	B1 RH	B2 LH	Totals
A_2 Indirect Path	RS/RH 23.800	LS/LH 23.014	RS/RH 26.097	LS/LH 25.132	98.043
A_1 Direct Path	LS/RH 22.859	RS/LH 23.375	LS/RH 22.263	RS/LH 25.902	94.399
	46.659	46.389	48.360	51.034	192.442

might be interpreted as follows: Examining the Key X Hand Interaction on both levels of A (Pathway), it is seen that the pattern of the Hand X Key Interaction is the same. Assuming that Key B is in fact slower to release than Key A, then when the left-hand, which is the non-preferred hand, operates Key B, this will obtain the slowest RT. We would expect then, Key A to be faster than Key B when either is released by the left hand. Because Key B is slower to release, it may be that the right hand more easily compensates for the difference between the keys, and in fact, overcompensates in effort when releasing Key B, thereby obtaining a faster RT on Key B with the right hand than on Key A.

A further Analysis of Variance looking at whether there is a difference between the Visual Fields, gives a significant difference between Right and Left Side of Stimulation on the Temporal Condition of F which is significant at $< .01$. This favours the left hemisphere by a Mean 19.7 msecs.

On the Nasal Stimulation, Two-handed Responding Condition the Right Side of Stimulation (left hemisphere initially receives stimuli) was favoured by 7.5 msecs., but this was not significant.

This trend is opposite that found for Normals by Jeeves (1972) and Jeeves and Dixon (1970) (who found a right hemisphere superiority).

Fig.I.A. Nasal Stimulation, Two-handed responding: Hand X Key Interaction. (Significant).

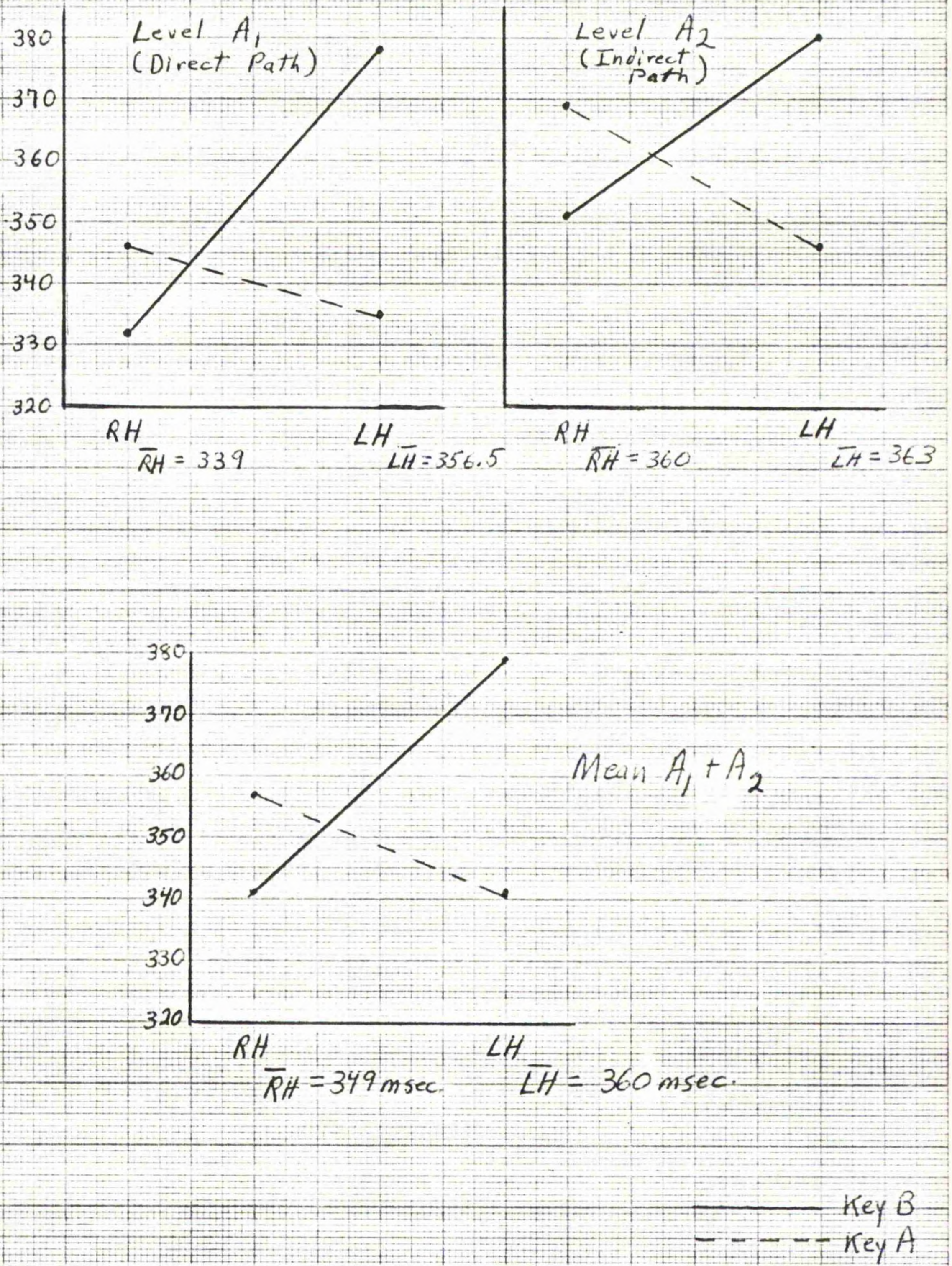
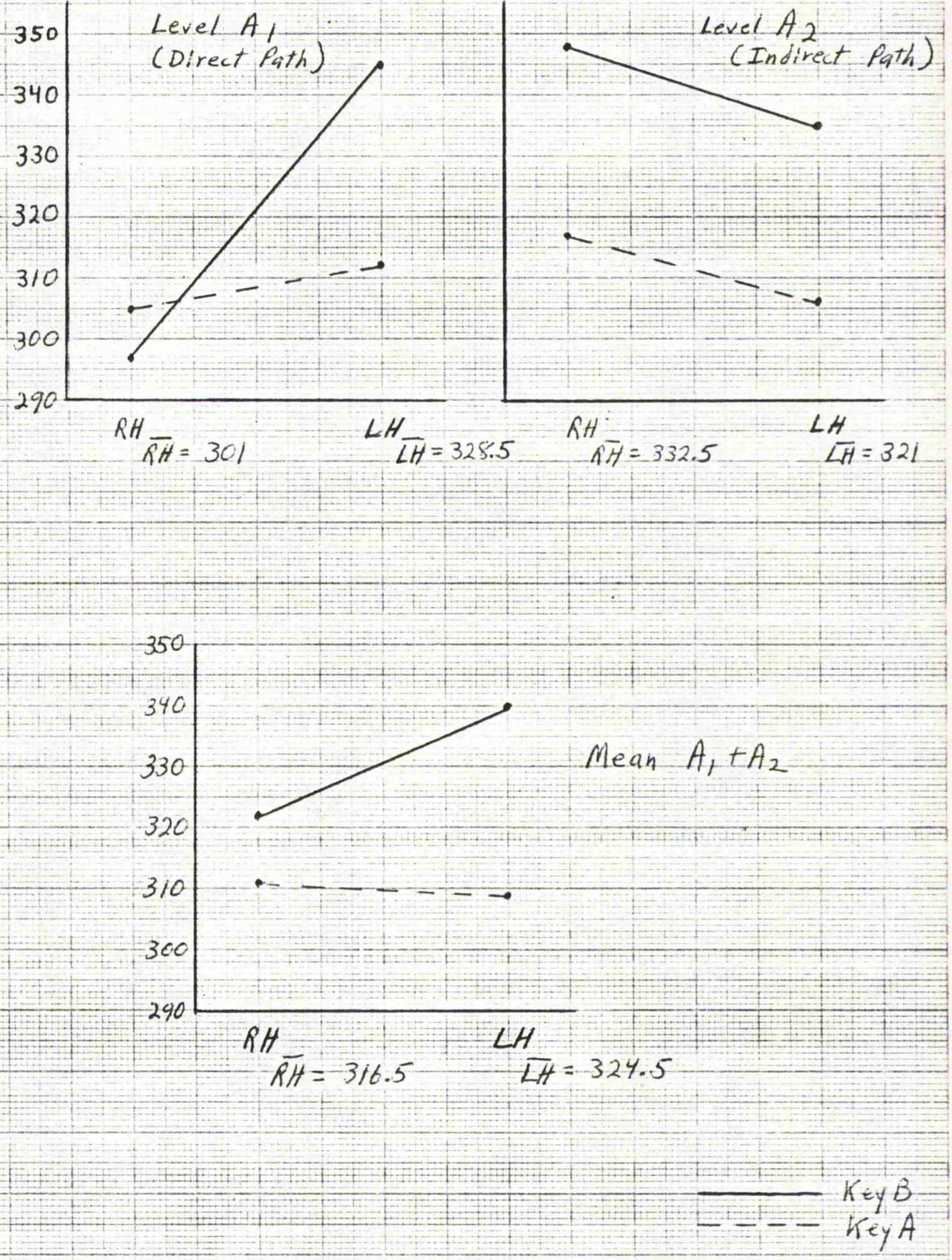


Fig.I.B. Temporal Stimulation,Two-handed responding:Hand X Key Interaction. Non-significant.



EXPERIMENT II. ACALLOSAL: SINGLE-HANDED RESPONDING.

Procedure and Apparatus: The apparatus was the same as in Experiment I. The S was stimulated on the Nasal Retina of either eye randomly and was asked to respond with one hand. The hands were alternated within daily sessions, obtaining 30 responses with one hand and then thirty with the other, totalling 60 responses at a session. The keys and lights were counterbalanced. 300 responses with each hand were obtained, for a total of 600 RT observations.

Results:

The Mean Reaction Times for the short-pathway and long-pathway under the Nasal Stimulated, single-handed responding Condition are 330 msecs., and 360 msecs. respectively. The Mean difference between the two pathways is 30 msecs.

A Three-Factor Analysis of Variance (Table V) gives a highly significant ($p < .001$) value of t (one-tailed test) for the difference between the pathways. The only other significant variable was the Hand X Key Interaction (Table V; Figure 2).

On a further Analysis of Variance, the Side of Stimulation, that is, the hemisphere which initially receives the stimulus, was not found to be significant on the Nasal Stimulation, Single-handed responding Condition.

Discussion of Experiments I and II

The results of the present experiments may be compared with those of Jeeves and of Kinsbourne and Fisher by tabulating the main findings as in Table II.

The trend there presented indicates that the response

Fig. 2. Nasal Stimulation, Single-handed responding: Hand X Key Interaction. Significant.

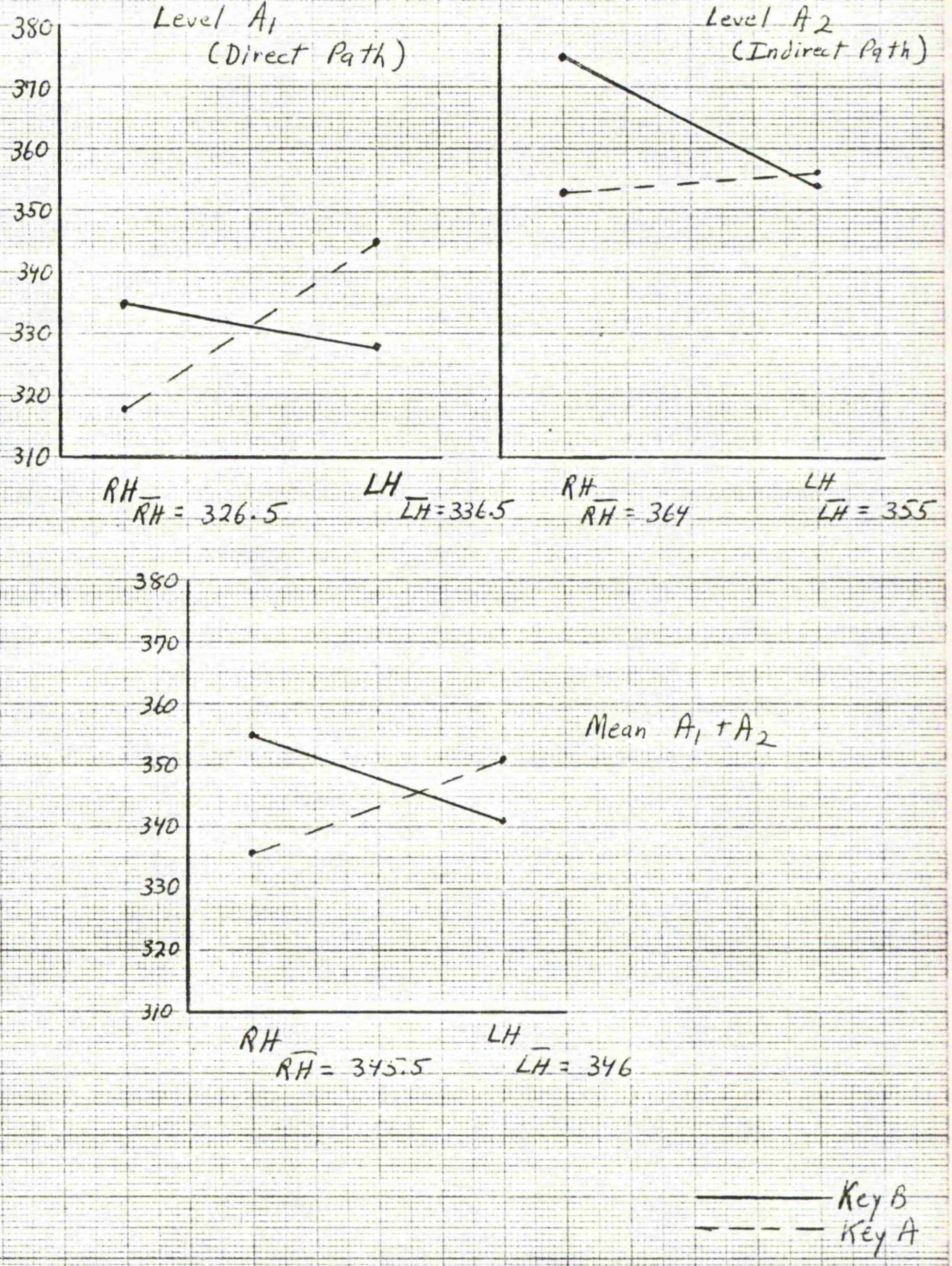


Table V: 3-Way Analysis of Variance. Nasal Stim.-Single-handed responding, K.C.

Source of Var.	SS	df	MS	F	
A (Pathway)	.1208	p-1=1	.1208	20.1333*	t< .001
B (Hand Resp.)	.0001	q-1=1	.0001	.0167	
C (Keys)	.0039	r-1=1	.0039	.6500	
AB(Path X Hand)	.0130	(p-1)(q-1)=1	.0130	2.1667	
AC (Path X Key)	.0034	(p-1)(r-1)=1	.0034	.5667	
BC (Hand X Key)	.0315	(q-1)(r-1)=1	.0315	5.2500*	p .05
ABC	.0012	(p-1)(q-1)(r-1)=1	.0012	.2000	
Within cell (Exper.Error)	3.5512	pqr(n-1)=592	.0060		
Total	3.7251	pqrn-1=599			

ABC Summary Table

An. of Var.
Nasal Stim. single-handed resp.

	C1 Key A		C2 Key B		
	B1 RH	B2 RH	B1 RH	B2 LH	Totals
A1 short-path	RS/RH 23.825	LS/LH 25.864	RS/RH 25.144	LS/LH 24.597	99.430
A2 long-path	LS/RH 26.501	RS/LH 26.732	LS/RH 28.123	RS/LH 26.587	107.493
	50.326	52.596	53.267	51.184	207.373

latency of crossed responding is longer than uncrossed responding. Our Experiment I and II results (in 2 out of 3 analyses) reach the 5% level of significance, and the magnitude of the difference between crossed and uncrossed latencies is similar in Kinsbourne and Fisher's and our studies. We note that the F reported by Kinsbourne and Fisher is significant at the 5% level on a one-tailed test. However, not enough information is given as to what their F represents to make an unambiguous interpretation of this significance. As they stated that they did a two-way analysis of variance and that df was 3 and 96, their reported F=2.24 presumably refers to a pooling of the two main effects (Hand Responding and Visual Field) and their interaction.

In the present experiments, it is noteworthy that whereas in Experiment II, we followed Kinsbourne and Fisher's suggestion that a single-handed responding technique is more reliable, under such a condition we find an even greater, and highly significant, difference ($p < .001$) of 30.36 msecs. Since, as we pointed out above, the kind of gross stimulus-response incompatability suggested by Kinsbourne and Fisher did not occur in our two-handed condition, it is not surprising that the results of Experiment I are consistent with those of Experiment II and with Jeeves' earlier studies.

Since Kinsbourne and Fisher have raised the possibility that such incompatibilities were a major factor in producing Jeeves' earlier results of lengthened crossed as compared with uncrossed latencies, it may be helpful to point out in fact that such evidence as there is goes contrary to their expectations. Table II provides data for making direct comparisons between crossed versus uncrossed latencies under conditions of single-handed and two-handed responding. As the right-hand column indicates, the difference in Normals between crossed and uncrossed response latencies for right-handed

Ss with two-handed responding is 1.80 (Nasal Stimulation), 1.56 (Temporal Stimulation) msecs., and with single-handed responding 2.56 (Nasal Stimulation) and 3.09 (Temporal Stimulation) msecs. Comparable data are not available for the left-handed Normal adults tested since they were only tested on the two-handed condition.

The most important point we want to make about Experiments I and II is not that the acallosal shows a significant difference between pathways within herself (since even normals show this effect), but that she is significantly different from the normals.

Thus while our findings confirm and strengthen Jeeves' earlier findings that there are significant increased latencies in crossed pathway responding in Acallosals as compared with Normals, nevertheless, we agree with Kinsbourne and Fisher that the assumption of functional ipsilateral corticospinal projections in Acallosals is quite as plausible an alternative neural arrangement as that of a hypothetical circuitous route through the brain stem. However, Acallosal patients can experience apparent movement when stimulated with point sources of light on either side of the vertical meridian (Ettlinger et al., 1972). In order to explain this it would seem necessary to postulate the efficient operation of commissural fibers (e.g., between the superior colliculi), which could also be operating in crossed visual reactions.

EXPERIMENT III. SIBLING TESTED

Procedure and apparatus: The apparatus used was the same as described in Experiment I. The procedure was likewise the same.

Results: The Mean response times for the direct- or short-pathway and indirect- or long-pathway, under each of the two Stimulation Conditions -- Nasal and Temporal -- are given in Table VI.

The Mean RT differences for Nasal Stimulation is well outside the range of those for the 20 Normal Ss studied in Jeeves' 1969 experiment. The likelihood of this happening by chance is less than .05 (Fisher exact probability test). The Mean RT difference between the pathways is significantly greater for the Sibling than for the Normal Adults. The Sibling's performance is in this regard similar to the Acallosal's performance.

Table VI. Mean RTs for Sibling (Experiment III)

	Mean RT/Short Path	Long Path	Mean RT Difference
Nasal Stimulation, Two-handed responding	317.8 msecs.	333.0	+15.3
Temporal Stimulation, Two-handed responding	298.9 msecs.	306.8	+7.9

The Mean RT difference for Temporal Stimulation is 7.9 msecs. and is also outside the range of those for the 20 Normal Ss studied in Jeeves' 1969 Experiment. The likelihood of this happening by chance is less than .05 (Fisher exact probability test). On a comparison with Jeeves (1972) children's data, the Sibling and Acallosal both were significantly different in having longer Pathway differences than the 20 children (Mann-Whitney U=0 is significant at P=.05; one-tailed test). The range of difference between pathways for the children was from -2.73 msecs. to +4.34 msecs.

In order to look at the experimental procedure more closely, a Four-Way Analysis of Variance was computed on the Sibling data for each of the experimental conditions, Nasal Stimulation and Temporal Stimulation (Two-handed responding in each condition). The predictions were that the indirect pathway (LP) would be significantly longer than the direct pathway (SP), and that none of the other variables would be significant.

Tables VII and VIII contain summaries of these analyses of variance. The summary table shows that on the Nasal Stimulation, two-handed responding condition, the difference between the Short Pathway and the Long Pathway is significant at $p < .05$ (one-tailed t test). The obtained difference of 15 msecs. is similar to that obtained for the acallosal (whose nasal stimulation data did not quite reach significance: t at .08 level of significance). The Sibling was faster over-all in Mean RTs than the Acallosal.

There is a significant ($p < .05$) Hand difference for the Sibling with the Left Hand faster than the Right Hand by a Mean 21.7 msecs. This is different from the Acallosal who did not show a significant hand difference.

There is also a significant Hand X Key Interaction for the Sibling, as for the Acallosal. But the specific interaction is different, except that the Left Hand shows a larger Key difference for both Subjects.

There is also a significant keys difference with responses on Key A being faster than responses on Key B (+20.6 msecs. difference).

There is a significant DAYS difference in overall RT

TABLE VII. Four-Way Analysis of Variance: SIBLING; Two-Handed Responding. Interhemispheric Transmission Times. Nasal Stimulation.

Source of Variance	Sum of Squares	df	Mean Squares	F	*(sig.)
A (Hands)	70633.500	1	70633.500	6.9999	* .05
B (Pathway; SP/LP)	34899.627	1	34899.627	3.4586	not sig.
AB	10533.660	1	10533.660	1.0439	not sig.
C (Keys)	63695.207	1	63695.207	6.3123	* .05
AC (Hand X Key)	60000.000	1	60000.000	5.9461	* .05
BC (Pathway X Key)	17216.327	1	17216.327	1.7062	not sig.
ABC	1338.027	1	1338.027		
D (Days)	303137.543	4	75784.386	7.5103	* .05
AD	17012.350	4	4253.088		
BD	7549.157	4	1887.289		
ABD	76115.457	4	19028.864	1.8858	not sig.
CD	13973.377	4	3493.344		
ACD	79174.183	4	19793.546	1.9616	not sig.
BCD	118392.323	4	29598.081	2.9332	not sig.
ABCD	8649.023	4	2162.256		
Within Cell	204414.143	14	14601.010		
Error Between Cells	5509503.590	546	10090.666		
Total	6596237.493	599			

TABLE VIII. Temporal Stimulation. Four-Way Analysis of Variance. SIBLING: Two-Handed Responding. Interhemispheric Transmission Times.

Source of Variance	Sum of Squares	df	Mean Squares	F	*(sig.)
A (Hands)	9432.735	1	9432.735	1.8638	not sig.
B (Pathway)	9768.735	1	9768.735	1.9302	not sig.
AB	11137.042	1	11137.042	2.2005	not sig.
C (Keys)	97053.602	1	97053.602	19.1765	* .01
AC (hand X Key)	10982.482	1	10982.482	2.1700	not sig.
BC (Pathway X Key)	509.682	1	509.682		
ABC	6214.602	1	6214.602	1.2279	not sig.
D (Days)	250377.940	4	62594.485	12.3678	* .01
AD	20610.540	4	5152.635	1.0181	not sig.
BD	2585.307	4	646.327		
ABD	16792.267	4	4198.067		
CD	1309.573	4	327.393		
ACD	16644.093	4	4161.023		
BCD	36495.593	4	9123.898	1.8028	not sig.
ABCD	4946.073	4	1236.518		
Within Cell	100800.890	14	7200.064		
Error Between Cells	2763341.910	546	5061.066		
Total	3359003.065	599			

which reflects a practice effect generally. The Acallosal data was not analysed in this regard.

There are no other significant interactions in the Nasal Stimulation, two-handed responding Condition.

With regard to the Analysis of Variance for the Temporal Stimulation experiment, the Sibling's short pathway was faster than the long pathway by 7.9 msecs. which does not reach our required significance level of $< .05$ (significant at t= .08 level of significance, one-tailed test, however). The Acallosal's data did reach the .05 level. The differences for Sibling and Acallosal are both in the same direction.

For the Sibling, there was no significant Hands difference nor Hand X Key Interaction on the Temporal Stimulation Condition. There is a significant Keys difference and also a significant DAYs difference with the Sibling generally getting faster over the five days.

A further Analysis of Variance was carried out to examine whether there were significant effects in regard to which hemisphere received the stimulus first. For the Nasal Stimulation (Two-handed) Condition, the Side of Stimulation was not significant, but the trend was in favour of the left hemisphere by a Mean 8.4 msecs.

For the temporal Condition, the difference between the hemispheres was not significant, though in this case the trend favours the Right Hemisphere by a Mean 8.6 msecs.

EXPERIMENT IV. SIBLING: SINGLE-HANDED RESPONDING TO NASAL STIMULATION

Procedure and apparatus: The apparatus and the procedure were the same as in Experiment II.

Results: A Three-Factor Analysis of Variance was computed. The Pathway difference is significant at $p < .01$ ($t < .001$, one-tailed test) for this Single-handed responding to Nasal Stimulation Condition (see Table IX). The Direct Pathway (SP) is faster than the Indirect Pathway (LP) by +23.3 msecs. This result is comparable to the Acallosal in that the Acallosal was similarly significantly faster on the SP than the LP by some 30 msecs. The Mean Pathway RTs and RT differences for Nasal Stimulation, Single-handed Responding for both the Acallosal and the Sibling are given in Table X.

Table X. Mean Pathway RTs for Nasal Stimulation, Single-Hand Responding for Sibling and Acallosal.

	SP	LP	Mean Difference
Acallosal, Nasal Stim., Single-hand responding	330 msecs.	360 msecs.	+30 msecs.
Sibling, Nasal Stim., Single-hand Responding	259 msecs.	282 msecs.	+23 msecs.

The Sibling Mean Pathway difference as well as the Acallosal's Mean Pathway difference is much greater than for the Normal Ss single-handed responding which Jeeves (1969) reported.

The Sibling is faster in over-all RT than the Acallosal.

The Sibling also demonstrated a significant ($p < .05$) Hand effect in that the left hand was faster than the right hand by +10.3 msecs., but the Acallosal does not show a hand difference under

TABLE IX. Nasal Stimulation. Three-Way Analysis of Variance. SIBLING: Single-Hand Responding. Interhemispheric Transmission Times.

Source of Variance	Sum of Squares	df	Mean Square	F	*(sig.)
A (Hands)	14749.779	1	14749.779	5.2704	* .05
B (Pathway)	76004.600	1	76004.600	27.1580	* .01
AB	731.429	1	731.429		
C (Keys)	7666.400	1	7666.400	2.7394	not sig.
AC (Hand X Key)	34320.457	1	34320.457	12.2634	* .01
BC (Pathway X Key)	150.179	1	150.179		
ABC	14586.007	1	14586.007	5.2119	* .05
Within Cell	325519.171	69	4717.669		
Error Between Cells	1351725.400	483	2798.603		
Total	1825453.421	559			

this single-handed response condition.

A significant ($p < .01$) Hand X Key interaction was also found for the Sibling, as well as for the Acallosal. The Hand X Key Interaction is in the same pattern for both the Acallosal and the Sibling.

There is also a significant ($p < .05$) Hand X Path X Key Interaction for the Sibling in this Condition, but there was not for the Acallosal.

In a separate Analysis of Variance, the Visual Field effect was examined. The Sibling did not show a significant Side of Stimulation difference in the Nasal Stimulation, Single-handed responding Condition.

Jeeves and Dixon (1970) had found that with Normals, the Single-handed responding was faster than the two-handed responding. We find, comparing the two Nasal Stimulation Conditions, that this is true for our Sibling and Acallosal also.

We find, in this Condition, that the mean pathway difference for the Sibling is of the same order as that for the Acallosal, and both differ from the previously reported Normal Ss Jeeves (1969) tested on the Single-handed Condition (see Table II for Jeeves' 1969 reported means).

We have found, looking at all four Experiment, that Side of Stimulation is generally not significant (in 5 out of 6 Conditions) for the Acallosal and Sibling. This supports the notion that for the Acallosal and Sibling, the Hemisphere receiving the stimulation first does not make a difference.

Summary: We conclude that there is a likelihood that the Sibling is acallosal also in as much as all the pathway differences for the Sibling as well as the Acallosal are increased over those for the Normals. The argument would be strengthened by testing neurological controls for the Sibling with known specifiable extra-callosal damage.

CHAPTER SIX

VISUAL PERCEPTION: ALPHABETICAL STIMULI: ACALLOSAL VERSUS SIBLING VERSUS NORMALS

Introduction

A normal, right-handed person would be expected to be left-hemisphere-dominant for language mechanisms. This would be the general expectation, though there is considerable variation in the degree of language lateralization (Millikan and Darley, 1967).

Branch, Milner, and Rasmussen (1964) used the Wada Technique (Wada, 1949, 1960) to investigate the speech production of 123 patients. Subjects were required to name objects and count following the intracarotid injection of sodium amytal. In none of Branch et al.'s right-handed patients was there bilateral representation of speech; however, some of the left-handed and ambidextrous patients did exhibit bilateral representation. About one-tenth of the right-handed Subjects had speech on the right side of the brain, while the rest had speech represented on the left side of the brain.

Speech was found to be controlled by the left hemisphere for two-thirds of the left-handed and ambidextrous patients where there was no record of early left-sided brain injury. Two-thirds of the left-handed patients who had brain-damage to the left hemisphere at birth or in early life exhibited right-hemisphere speech.

Speech as well as language comprehension was found to be bilaterally represented in seven out of forty-four left-handed epileptic Ss who had been examined by the Wada Test (Milner, Branch and Rasmussen, 1964).

Since there are people with bilateral speech representation in the population whose corpora callosa are intact, it seems reasonable to suggest that in the developing brain that had no corpus callosum, bilateral speech representation would develop also. This development of bilateral speech representation would help to explain the relative lack of deficit found in cases of agenesis. Sperry (1968) has suggested that a bilateral development of language (including speech) in both hemispheres "would go a long way toward explaining the lack of many of the symptoms in the congenital condition".

It is with this consideration of the possibility of bilateral speech and language representation in mind that we decided to test our Acallosal girl using the technique Rizzolatti et al. (1971) had used to look at opposite superiorities of the right and left hemispheres with regard to physiognomical and alphabetical material. This same technique we subsequently used in a developmental study of normals.

Solursh et al. (1965) tested a 14 year old acallosal boy by (among other tests) presenting letters of the alphabet for 0.1 second to either the right or the left half of the Visual Field while the S fixated on a light in the centre of the field. He was required to identify the stimuli flashed by writing first with the right hand and then with the left hand.

This S, when writing with the left hand made more correct identifications of letters presented in the RVF (left hemisphere) than in the LVF (25% correct versus 12% correct).

When responding with the right hand, the S made more correct identifications to RVF than LVF (50% correct in RVF compared to 25% correct in LVF).

This indicates that for this acallosal there is a RVF superiority in identification of letters. Solursh et al.'s Normal Controls identified all the letters. Solursh also found that errors in identifying letters by the acallosal were often the result of perseveration, the patient having difficulty in shifting from one letter to another.

Sperry (1968) reports that the 20 year-old agenesis patient he and Saul examined had no difficulty in describing verbally "with normal facility" stimuli such as letters, numbers, words, colours, geometric shapes, irregular shapes, or pictures, which were presented to either the right or left Visual Field. This could imply a bilaterality of visual function (it contrasts with the deficits shown by surgically-bisected patients), or an inefficient experimental method for revealing lateralization in the acallosal (as opposed to the reaction time method, for example). Sperry's intent, of course, was only to demonstrate a difference from the surgical patients.

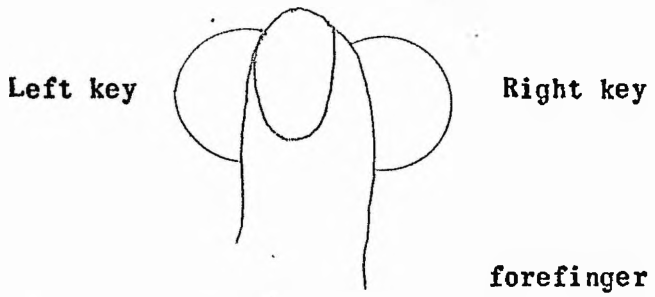
Ettlinger et al. (1972) found "no consistent evidence of laterality effects" on tachistoscopic recognition tasks which required, for example, acallosals to read short words presented to the visual half-fields. It appears from their published report, however, that only 20-30 trials were given each Subject. We would not expect this number of trials to be sufficient to give a clear result with regard to lateralization or lack of it. In a report published in 1974, Ettlinger et al. describe a further tachistoscopic word presentation task. In this case they report the data. A significant asymmetry favouring recognition of words presented to the right half-field is found for all three groups of Ss (Total agenesis Ss, Partial agenesis Ss, and Neurological Controls). The extent of asymmetry was similar for all three groups. Again, however, perhaps too few trials were presented for differences in asymmetry to emerge (only ten trials in each condition).

Our prediction is that the Normal Ss will show the RVF superiority in Reaction Time to single letters presented tachistoscopically as did Rizzolatti et al.'s Ss. Our Acallosal S will show no Visual Field differences. She will show no visual field differences because she has language bilaterally represented in her cerebral hemispheres. The Sibling will perform like the acallosal (i.e., no hemisphere differences) if she is acallosal also, or if she is not Acallosal, she will perform like the Normals.

We further intend to look at Pathway differences to see whether the Normal Ss will conform to our hypothesized rank-ordering for Pathways, which is: RVF/RH < RVF/LH < LVF/RH < LVF/LH. The rationale for this ordering of pathways is discussed in the Developmental Study (Chapter Eleven). We wish to look at how well the Acallosal and Sibling Pathway orders accord with the model for Normal Subjects.

Method: The Method for this experiment is described in detail in our Developmental Study of Cerebral Lateralization for Alphabetical and Physiognomical Material. The same test was administered to our acallosal girl and her Sibling. The group of twelve Normal females of the same age group as the acallosal S (age 13/14 years) were used as the Middle Group in the Developmental Study.

Four letters (F, R, A, and K) are presented one at a time tachistoscopically to the Subject. When the S sees either F or R he is to press down on one of two keys (the right-oriented key), and when he sees A or K he is to press the left-oriented key). The S's forefinger is resting at all times on and between the two keys like this:



The letters were presented randomly to either side of fixation with the restriction that the same letter would not appear more than twice in succession on the same side. The keys themselves were reversed in position each day so that any effect due to the lack of balance of key (i.e., whether one was harder to press than the other) would be counterbalanced. However, the S̲ always responded to a given letter in the same manner (i.e., left or right) because we could not have the S̲ relearning his task from day to day.

Each S̲ received four Conditions of Eye and Hand in each testing session, and there were four testing sessions of approximately one hour each, for each Subject. Each Condition corresponded to a tray of 36 slides containing a random sequence of 18 RVF slides and 18 LVF slides further broken down into 9 stimuli to be responded to on Key A and 9 stimuli to be responded to on Key B within each set of 18.

There were 144 trials each day, and the total number of trials was 576 for each Subject.

The order of presentation of the Conditions was according to a Latin Square design over the four days.

The letters were projected at six degrees of visual angle from the fixation point.

The Subject was positioned with head on chin-rest and restrained by side-bars. One eye was used in each Condition, while the other was covered by an eye-patch.

The response keys were positioned toward the same side as the hand being used.

The Subject heard a buzzing warning signal that told him to fixate on the central point. The letter appeared immediately the buzzer stopped. The letter was presented for 100 msecs.

Practice trials were given before the main part of each Condition. The experiment was a recognition task, not a learning task. The letters and appropriate response were learned before beginning the main part of the experiment.

This was a "go-go" choice task, not the choice go-no go task of Rizzolatti et al. (1971).

A television camera was used to monitor eye movements during one set of practice trials for all Subjects in order to satisfy ourselves that Subjects were able to fixate on being requested to do so and for as long as necessary to the experiment (letters exposed for 100 msecs.). No Subjects had any trouble fixating on being signalled to do so, including the Acallosal and Sibling.

Results

A Six-Factor Analysis of Variance was computed (Table I) comparing Acallosal and Sibling Performance in Reaction Time to single letters.

The Acallosal is significantly ($p < .01$) different from the Sibling in overall Reaction Time; the Acallosal being faster in responding than the Sibling by a Mean 184 msecs.

The over-all Visual Field difference is not significant but there is a significant ($p < .01$) Subject X Visual Field Interaction.

TABLE I. LETTERS. Six-Way Analysis of Variance Comparing Acallosal and Sibling.

Source of Variance	Sum of Squares	df	Mean Square	F	* (sig.)
A (Acallosal /Sibling)	9590740.06	1	9590740.06	311.6278	* .01
B (Visual Field)	153135.00	1	153135.00	4.9757	not sig.
C (Keys)	58.68	1	58.68		
D (Hands)	14238.28	1	14238.28		
E (Eyes)	99420.84	1	99420.84	3.2304	not sig.
F (Days)	953346.83	3	317782.28	10.3256	* .01
AB (S X VF)	538981.53	1	538981.53	17.5129	* .01
AC (S X Keys)	481017.01	1	481017.01	15.6295	* .01
BC (VF X Keys)	98901.28	1	98901.28	3.2136	not sig.
AD (S X Hands)	28980.28	1	28980.28		
BD (VF X Hands)(Pathway)	60378.13	1	60378.13	1.9618	not sig.
CD (Keys X Hands)	193805.00	1	193805.00	6.2972	* .05
AE (S X Eyes)	120009.17	1	120009.17	3.8994	not sig.
BE (VF X Eyes)	12587.56	1	12587.56		
CE (Keys X Eyes)	23962.25	1	23962.25		
DE (Hands X Eyes)	9568.06	1	9568.06		
AF (S X Days)	1297254.63	3	432418.21	14.0504	* .01
BF (VF X Days)	43148.43	3	14382.81		
CF (Keys X Days)	287679.03	3	95893.01	3.1158	not sig.
DF (Hands X Days)	135498.43	3	45166.14	1.4676	not sig.
EF (Eyes X Days)	168970.98	3	56323.66	1.8301	not sig.
DEF (Hands X Eyes X Days)	526870.79	3	175623.60	5.7065	* .05
+					
Within Cells	189463.65	8	23682.96		
Error Between Cells	31268688.35	1016	30776.27		
Total	48909965.65	1151			

+ No other Interactions are significant.

The Sibling is faster in responding to Right Visual Field, which is in the same direction as Normals. The Acallosal is faster in responding to the Left Visual Field.

Table II: Mean Reaction Times for Acallosal and Sibling to Letters.

	RVF	LVF	Mean Differences
Acallosal	594.7 msecs.	574.5	-20.2 msecs.
Sibling	733.9	800.2	+66.3

There is no significant over-all difference between Keys, but there is a significant ($p < .01$) S X Keys Interaction, which is that the Acallosal is faster on the left Key than the right Key, and the Sibling is faster on the right Key than the left Key.

There is not a significant Visual Field X Key Interaction nor triple interaction with Subjects, meaning that neither the Acallosal nor Sibling have a significant tendency to respond faster in the direction of the stimulus.

There is no significant difference between Hands. There is no significant Visual Fields X Hands Interaction, but there is an overall significant Keys X Hands Interaction ($p < .05$); this reflects the fact that the right Hand is faster on the right Key than the Left Key, and the left Hand is faster on the Left Key than the right Key.

There are no significant Eye differences.

There is an over-all significant DAYS difference, but also a significant ($p < .01$) Subject X DAYS Interaction. Reaction Times get faster over the four days of testing. The Sibling is slowest on DAY 1, and gets progressively faster, but the Acallosal is slowest on the fourth day.

There are no other significant effects or interactions.

Our conclusion from this analysis is that the Acallosal is functioning differently from the Sibling.

A Five-way Analysis of Variance was carried out on the twelve Normal Subjects (Table III).

The Visual Field difference was found to be significant ($p < .01$). The Right Visual Field is responded to more quickly than the Left Visual Field (by a Mean +13.2 msecs.). This Visual Field difference is in the predicted direction for Normal Ss. We include a Table (Table IV) of Visual Field Means for each Subject.

There is not a significant Key difference, but there is a significant Visual Field X Keys Interaction, which is that there is a tendency to respond faster in the direction of the stimulus.

There is no significant Hands difference.

The Pathways (Visual Field X Hands) are not significantly different from one another. The Pathway order is:
RVF/LH (Fastest) RVF/RH LVF/RH LVF/LH (slowest). This actual ordering is different from our hypothesized model, which is:
RVF/RH (Fastest) RVF/LH LVF/RH LVF/LH (slowest). The observed order indicates that which hemisphere the stimulus arrives in initially is more important than which hand responds.

The Eye difference is not significant.

The DAYS effect is significant, in that there is a definite practice effect, Reaction Time getting faster with practice. There is no significant Visual Field X DAYS Interaction, which indicates that the Hemisphere Superiority is a stable phenomenon, not affected by degrees of familiarity with the task.

TABLE III. LETTERS. Five-Way Analysis of Variance. Data for Twelve Normal Subjects.

Source of Variance	Sum of Squares	df	Mean Square	F	*(sig.)
A (Visual Fields)	33155.131	1	33155.131	11.5266	* .01
B (Keys)	43643.589	1	43643.589	3.0104	not sig.
C (Hands)	36.619	1	36.619		
D (Eyes)	3759.049	1	3759.049	2.3450	not sig.
E (Days)	289002.373	3	96334.124	4.4728	* .01
AB (VF X Keys)	120257.609	1	120257.609	26.6515	* .01
AC (VF X Hands) (Pathway)	982.604	1	982.604	1.0353	not sig.
BC (Keys X Hands)	14839.449	1	14839.449	4.1621	not sig.
AD (VF X Eyes)	2594.929	1	2594.929	4.7508	not sig.
BD (Keys X Eyes)	2097.809	1	2097.809	1.2347	not sig.
CD (Hands X Eyes)	2403.739	1	2403.739		
AE (VF X Days)	783.399	3	261.133		
BE (Keys X Days)	808.381	3	269.460		
CE (Hands X Days)	7836.637	3	2612.212		
DE (Eye X Days)	7033.006	3	2344.335		
ABD	4707.955	1	4707.955	6.4262	* .05
ABCDE	494.454	3	164.818		
+					
Subjects	725160.651	11	65923.696		
Total	3432585.009	767			

+ No other Interactions are significant.

The degrees of freedom are for the F ratios, 1 and 11, and 3 and 33.

Table IV. Mean RTs for Right and Left Visual Fields for Each Normal Subject and for Acallosal and Sibling.

	Right Visual Field	Left Visual Field	Difference
Acallosal	591.8 msecs.	577.3 msecs.	-14.5 msecs.
Sibling	733.9	800.2	+66.3
Normals			
S 1	511.2	515.5	+ 4.3
S 2	483.9	496.0	+12.1
S 3	479.5	484.3	+ 4.8
S 4	500.3	513.4	+13.1
S 5	522.5	526.4	+ 3.9
S 6	412.5	453.9	+41.4
S 7	539.0	566.7	+27.7
S 8	466.0	480.6	+14.6
S 9	497.8	527.8	+30.0
S 10	527.4	533.7	+ 6.3
S 11	523.5	528.0	+ 4.5
S 12	530.5	525.7	- 4.8
Mean Total(Normals)=	499.5	= 512.7	= + 13.2

The Acallosal data was analyzed separately in a Five-Factor Analysis of Variance (Table V).

We find a significant Visual Field difference ($p < .05$); the Left Visual Field is responded to faster than the Right Visual Field. This is an opposite superiority to the RVF superiority of our normal Ss. The Acallosal's superior LVF responding is, however, not in accordance with our hypothesis of bilateral language mechanisms.

There is a significant difference between keys with faster responding on the left Key (letters A and K). The Left Key responses were also faster for Normals, but not significantly so.

For the Acallosal, there is no Visual Field X Key Interaction; thus, for the Acallosal there is no significant tendency to respond in the direction of the stimulus. However, this Visual Field X Key Interaction is significant for the Normals.

Simon (1969) had found that for Normal Ss there is with the Right Hand a Reaction Time toward the source of stimuli which is shorter than RTs away from the source of stimuli. His experiment required the S to move a control handle to the Right or Left from the midline of the body depending on the ear in which they heard a tone. He was able to separate Movement Time from Reaction Time. Our method of responding requires very little movement time; it involves mostly reaction time.

Simon did not test the left hand, so we do not know from his studies if results would be the same for the left hand or whether left hand responses would give an opposite result. He also used auditory input; we do not know that results would be the same with Visual input, except that our Normals' results indicate that this is the case.

TABLE V. LETTERS. Five-Way Analysis of Variance: Acallosal Data.

Source of Variance	Sum of Squares	df	Mean Square	F	* (sig.)
A (Visual Fields)	30595.840	1	30595.840	5.7183	* .05
B (Keys)	235225.000	1	235225.000	43.9628	* .01
C (Hands)	1296.000	1	1296.000		
D (Eyes)	484.000	1	484.000		
E (Days)	43473.812	3	14491.271	2.7084	not sig.
AB (VF X Keys)	491.361	1	491.361		
AC (VF X Hands) (Pathway)	81986.778	1	81986.778	15.3231	* .01
BC (Keys X Hands)	22225.840	1	22225.840	4.1539	not sig.
AD (VF XEyes)	7453.444	1	7453.444	1.3930	not sig.
BD (Keys X Eyes)	13053.063	1	13053.063	2.4396	not sig.
CD (Hands X Eyes)	357.840	1	357.840		
AE (VF X Days)	52401.896	3	17467.299	3.2646	not sig.
BE (Keys X Days)	149974.125	3	49991.375	9.3432	* .01
CE (Hands X Days)	23677.625	3	7892.542	1.4751	not sig.
DE (Eyes X Days)	51843.681	3	17281.227	3.2298	not sig.
CDE	105108.757	3	35036.252	6.5482	* .05
ACDE	76053.396	3	25351.132	4.7380	* .05
ABCDE	6871.597	3	2290.532		
+					
Within Cell	166055.437	8	20756.930		
Error Between Cells	2696673.007	504	5350.542		
Total	3914962.437	575			

+ No other Interactions are significant.

Brown and Slater-Hammel (1949) found that right to left lateral movements of the Right Hand are faster than left to right, but they did not find that the direction of the move affected Reaction Time (as opposed to Movement Time).

We find for the Acallosal alone that she shows no Hand effect. This is the same result as for the Normals.

There is a significant Pathway effect (Visual Field X Hand Interaction). For the Acallosal, the Pathway order is:

LVF/LH (faster)	RVF/RH	LVF/RH	RVF/LH (slowest)	
566.8 msecs.	578.4	587.7	605.3	(Mean RTs)

The interesting thing about this Pathway order is that both ipsilateral uncrossed pathways are faster than both contralateral pathways, which would lead one to suggest that either hemisphere is efficient at processing letters. We are calling these pathways (LVF/LH, RVF/RH) uncrossed as they would be if there were no cerebral lateralization or as if this were the same sort of stimuli which is not lateralized. They are uncrossed in the specific sense that callosal transmission is not required to initiate a motor response. In our hypothetical model for Normals, we would consider LVF/LH to be a crossed pathway, because of the hypothesized left hemisphere lateralization for the analysis of letters.

There is no Eye effect. This is the same as for the Normals.

There is no significant DAYS effect, but there is a Key X DAYS Interaction, which is that faster responses are made on the left Key for the first three Days, and faster responses on the right Key for the fourth Day.

A comparison of the Means for Visual Fields for Acallosal, Sibling, and Normals (Table IV) shows that both the Acallosal and

Sibling have longer Mean Visual Field Reaction Times for both Right and Left Visual Fields than the Normal Ss.

An aside on the Acallosal's behaviour during testing is that while she was quite cooperative generally, she complained quite a bit about having to have one eye covered. We tried different variations of eye cover with her, none of which was satisfactory to her. None of our other Ss complained about this. We have wondered if this resistance to using only one eye is due to the necessity to have both eyes operating to 'get it together' in one hemisphere and to overcome the handicap of lack of corpus callosum to help integrate visual information. We carried out an examination of her visual fields and they were normal. She has normal vision.

The over-all error rate for the Acallosal S was 12.0%. She made more errors in the RVF (12.8% error rate) than the LVF (11.1%) (37 erros versus 32 errors). This is not a significant difference.

The overall error rate for the Normal Control Group was 10.2%. There were fewer errors in the RVF (9.5%) than in the LVF (10.9%), but this Visual Field difference was not significant.

Summary

We have concluded that the Acallosal is significantly different from the Sibling in over-all Reaction Time (the Acallosal is faster). The acallosal is also significantly different from the Sibling in terms of Visual Field differences. The Acallosal is LVF superior in the recognition of letters, while the Sibling is RVF superior, as are Normals of the same age as the acallosal (ages 13/14 years).

In this experiment, it appears that the Sibling behaves more like Normals than like the Acallosal and this data is therefore not supportive of our hypothesis that the Sibling is also an Acallosal.

The question of whether the Acallosal has bilateral representation for speech is not easily answered by this experiment, as it turns out. On the basis of our prediction about the lack of Visual Field differences we would have to conclude that our Acallosal does not have equal bilateral representation for language. Neither is she like the Normals, because she has a significant LVF superiority. However, she has a significant Pathway effect (which is larger than the Visual Field effect) and this pathway order, which is that the ipsilateral pathways are faster than the contralateral pathways (by inspection), is an indication that either hemisphere can deal equally well with the letter stimuli. Further, this finding supports Sperry's (1968) suggestion that lack of deficit in agenesis behaviour may be in part attributable to an increase in the use of and strength of ipsilateral pathways.

A possible explanation of the Acallosal's LVF superiority is that she is responding to the letters as "patterns" rather than as verbal material. She does not read very well. Perhaps this is because her language analysis may take place in the right hemisphere while the speech functions per se may reside in the left hemisphere. However, the Sibling does not read well either, but shows the usual RVF superiority for letters.

CHAPTER SEVEN

VISUAL PERCEPTION: PHYSIOGNOMICAL STIMULI: ACALLOSAL VERSUS SIBLING VERSUS NORMALS

Hecaen and Angelergues (1962) reported that inability to recognize familiar faces was found more often in patients with right hemisphere lesions than left.

Warrington and James (1967) found in patients with right hemisphere lesions a poorer recognition ability for familiar faces and for immediate memory of previously unknown faces compared to patients with left hemisphere lesions.

Solursh, et al. (1965) presented designs such as triangles and squares, for a duration of .01 seconds to either the right or left Visual Field and required their acallosal S to respond by writing first with the right hand and then with the left hand. They found that the S was able to identify designs presented to the left visual field but not to the right visual field, no matter which hand he was writing with. Their Normal controls easily identified all the designs.

When they presented colours similarly (but for 0.1 second duration),.all were identified correctly.

Solursh et al. obtained the opposite Visual Field superiority when they presented letters tachistoscopically.

Rizzolatti, Umilta, and Berlucchi (1971) found that using manual response times, faces were more quickly discriminated in the Left Visual field, than the right Visual Field (in Normal Subjects).

Geffen, Bradshaw, and Wallace (1971) found the same result, i.e., left visual field superiority in response time to faces.

Buffery (1974) tested normal Ss and found a right hemisphere superiority for Faces which were presented as made up of four cartoon features each.

Levy, Trevarthen, and Sperry (1972) tested four split-brain patients on a face recognition task which involved the tachistoscopic presentation (at 150 msecs.) of a split-stimulus such that when the patient fixated on the midline point one-half of one face went to one hemisphere and the other half of another face went to the other hemisphere. The patient was then to point to the face he had seen in a free-vision array of the three possible whole faces. The patients overwhelmingly selected the face seen in the left visual field. Double responses were only found in 2.3% of trials.

Following this test, the patients were taught names for the three faces and required to name the face seen. This time there was a right visual field superiority. There was a 15% error rate on this aspect of the experiment compared with 3% for the first experiment.

We decided to use a replication of Rizzolatti et al.'s (1971) experiment on our Normal Subjects and the Acallosal, while using a go-go design on both the Acallosal and the Sibling. Details of the Rizzolatti et al. experiment as well as further details about Faces experiments reported in the literature may be found in Chapters Nine and Ten of our Developmental Study of Normal Subjects.

Method

The Acallosal was tested under two different experimental conditions.

Experiment I.

Both the Acallosal and Sibling were tested on a "go-go" choice task directly comparable to the Letters Experiment (Chapter Six). This involved the use of two response keys. When the S recognized either of two faces she pressed one key, and when she recognized either of the other two faces she pressed the other key.

The S was presented a total of four Faces one at a time randomly, to either the Right or the Left Visual Field. She was required to respond by pressing either the right-oriented key or the left-oriented key, depending on which of the four faces she recognized.

The Faces were the same four Faces used by Rizzolatti et al (1971). A Face was presented tachistoscopically for 180 msecs.

Four conditions of Eye and Hand were tested at each session. There were four consecutive days of testing for each Subject. Each Condition consisted of 36 trials and each day's total number of trials was 144. There was, then, a total of 576 trials for each Subject.

For the Acallosal and Sibling, we were able to obtain Reaction Times to all Four Faces using the two-key condition. We expected that there would be differences in overall Reaction time to particular Faces relating to difficulty of discrimination. We also thought that there might be differences in lateralization of each Face in terms of 'easy versus difficult to discriminate' Faces.

We predicted that there would be no difference between the Acallosal and the Sibling performance.

Experiment II.

We then decided to replicate the Rizzolatti et al. (1971) experiment exactly for our Developmental Study, which is a go- no go task, for reasons which are discussed in the Chapter on the Developmental Study. As our Control Group forms part of the Developmental Study, it was necessary to retest the Acallosal girl on the choice go-no go task. This testing was done approximately eight months after the original testing of the Acallosal. The Sibling was no longer available for extensive testing as she was now employed, having left school. We therefore cannot make direct comparisons between the Sibling and the Normal Subjects, but can indirectly compare her through the Acallosal's performance on both Experiment.

We tested the Acallosal girl and twelve Normal Ss matched for age and sex on Rizzolatti et al.'s go-no go task. When the S saw either of two particular faces she was to press the key; when she saw either of the other two faces she was to refrain from key pressing.

One prediction was that the Normal Ss would be left Visual Field (right hemisphere) superior for Faces; that is, the Reaction Time to the Faces presented in the Left Visual Field would be faster than to Faces presented in the Right Visual Field.

We also predicted that the Acallosal would perform differently from the Normal Ss, in that she would show no Visual Field Differences in overall Reaction Time to Faces.

As for Experiment I, we expected that there would be differences in over-all Reaction Time to particular Faces relating to difficulty of discrimination. We also felt that there might be differences in lateralization of each face in terms of 'easy versus difficult to discriminate' Faces.

The hypothesized pathway model for normal Ss was:

LVF/LH (fastest) LVF/RH RVF/LH RVF/RH (slowest)

The rationale for this hypothesis is dealt with in the Developmental Study of Normals.

We also decided to look at error rates for the Acallosal and Normal Ss to see how they accorded with Rizzolatti et al's error rate results and with our Reaction Time Results.

Results

Experiment I.

A Five-Factor Analysis of Variance was computed comparing the Acallosal *S* and the Sibling (Table I). A highly significant over-all Reaction Time difference ($p < .01$) was found between Acallosal and Sibling (Mean over-all RTs: Acallosal = 484.4 msecs., Sibling = 1444.9 msecs.). The Sibling is three times as slow as the Acallosal on the two-key Faces experiment (responding to all four Faces).

There is no significant over-all Face difference, and the Acallosal/Sibling X Face Interaction is not significant.

There is an over-all significant ($p < .01$) Visual Field difference on the combined data; and also a significant ($p < .01$) Acallosal/Sibling X Visual Field Interaction. The Sibling responds faster to the LVF than the RVF (Mean VF difference = +211.3 msecs.); the Acallosal responds slightly faster to the RVF than the Left Visual Field (Mean VF Difference = -5.8 msecs.).

Overall, there is a significant ($p < .01$) Face X Visual Field Interaction. The Acallosal and Sibling both have the same directional trends for each face, but the Acallosal is much faster in responding.

FACE 1;	FACE 2;	FACE 3;	FACE 4
RVF slower than LVF;	LVF slower;	RVF slower;	LVF slower.

Overall, no significant Hands difference, but there is a significant ($p < .05$) Acallosal/Sibling X Hand Interaction. The Acallosal is faster with the right hand than with the left hand, while the Sibling is faster with the Left Hand than with the Right Hand.

There is no over-all significant Pathway effect (Hand X

TABLE I. Five-Way Analysis of Variance: Acallosal Compared to Sibling;Faces 1,2,3,4; Visual Fields; Two-Key Responding (Go-Go Design).

Source of Variance	Sum of Squares	df	Mean Squares	F	*(sig.)
A (Acallosal / Sibling)	265,674288	1	265674288	1267.4289	* .01
B (Faces 1,2,3,4)	1948119	3	649373	3.0979	not sig
AB (Subject X Face)	1429391	3	476464	2.2730	not sig
C (Visual Fields)	3040783	1	3040783	14.5064	* .01
AC (S X VF)	3393012	1	3393012	16.1867	* .01
BC (Faces X VF)	23231984	3	7743995	36.9436	* .01
ABC	19684784	3	6561599	31.3028	* .01
D (Hands)	512072	1	512072	2.4429	not sig
AD (S X Hands)	1068843	1	1068843	5.0990	* .05
BD (Face X Hands)	277297	3	92432		
ABD	148788	3	49596		
CD (VF X Hands) (Pathway)	173362	1	173362		not sig
ACD (S X Pathway)	179750	1	179750		not sig
BCD	435747	3	145249		
ABCD	452587	3	150862		
E (Eyes)	1680861	1	1680861	8.0187	* .05
AE (S X Eyes)	700632	1	700632	3.3424	not sig
+					
DE (Hands X Eyes)	1391	1	1391		
ABCDE	124884	3	41628		
Trials	14020624	17	824743		
Error Between Cells	224499504	1071	209617		

+ Other Interactions Not Relevant; Therefore excluded from Table.

Visual Field Interaction) and no Acallosal/Sibling X Pathway Interaction.

The overall directional trend of the Pathways is the same, however, as the model we hypothesized for normal adults:

LVF/LH (Fastest)	LVF/RH	RVF/LH	RVF/RH (slowest).

The Pathway trend for the Acallosal, however, is partially reversed:

RVF/RH (fastest)	LVF/RH	RVF/LH	LVF/LH (slowest)
(471.9 msecs.)	(478.1)	(491.1)	(496.5)

It appears that whatever Pathway differences exist for the Acallosal are more attributable to which hand is responding than which field receives the stimulus. The Pathway trend for the Sibling is the same as the hypothesized Model for Normal adults.

There is a significant Eye difference, but no significant <u>S</u> X Eye Interaction. The left eye is 'faster than' the right eye in both effects. No other significant differences were found.

We also analyzed the Acallosal Results alone on the two-key (four faces responded to experiment) "go-go" task using a four-factor Analysis of Variance (Table II). We find the Visual Field difference <u>not</u> to be significant.

For the Acallosal alone, there is a significant difference ($p < .05$) in RTs to the four faces. She is slowest on FACE 2, then

FACE 4	FACE 3	FACE 1 (fastest).

The Sibling (data analyzed separately) does not react significantly differently among the four FACES.

The FACES X Visual Field Interaction is not significant for the Acallosal. For the Sibling, this Visual Field X Faces Interaction is significant ($p < .01$). The LVF is responded to fastest on Faces 1 and 3, and the RVF is responded to fastest on Faces 2 and 4. This is different from what we expect of Normal Adults.

TABLE II. Four-Way Analysis of Variance: Acallosal; Faces 1,2,3,4; Two-Key Responding (Go-go design).

Source of Variance	Sum of Squares	df	Mean Square	F	*(sig.)
A (Faces)	299,639.44	3	99,879.81	7.0066	* .05
B (Visual Fields)	4,824.46	1	4,824.81		not sig.
AB (Face X VF)	90,339.06	3	30,113.02	2.1124	not sig.
C (Hands)	50,643.75	1	50,643.75	3.5527	not sig.
AC	31,594.35	3	10,531.45		
BC	28.89	1	28.89		
ABC	1324.27	3	441.42		
D (Eyes)	105,543.77	1	105,543.77	7.4039	* .05
AD	28,975.09	3	9,658.36		
BD	265.42	1	265.42		
ABD	15,163.16	3	5,054.39		
CD	94,274.59	1	94,274.59	6.6134	* .05
ACD	5,798.52	3	1,932.84		
BCD	20,556.39	1	20,556.39	1.4420	not sig,
ABCD	42,174.55	3	14,058.18		
Trials	1,242,267.65	17	73,074.57		
Error between Cells	7,512,465.40	527	14,255.15		
Total	9,545,878.75	575			

For the Acallosal data alone, there is no significant Hands difference, and no significant Pathway differences (Hand X Visual Field Interaction)("go-go" choice task). Similarly, for the Sibling data analyzed separately.

Both Ss show significant eye differences.

Experiment II.

Acallosal data compared to Normal 13/14 year-old's data

The Normal Control Group of twelve female Subjects aged 13-14 years obtained the expected Right Hemisphere superiority (that is, a Left Visual Field superiority (See Analysis of Variance Summary, Table IV)). This group was used as one of the groups in the Developmental Studies described in Chapter Ten, and further details may be found in that section. All twelve Subjects responded faster to the Left Visual Field presentation of faces than to the Right Visual Field.

The Mean Right Visual Field versus Left Visual Field Reaction Times for Normals compared to the Acallosals are:

	RVF Mean RT	LVF Mean RT	Difference
Normal Ss:	1053.94 msecs.	956.96 msecs.	+96.98 msecs.
Acallosal S:	796.89	716.73	+80.16

These Visual Field Results are both in the same direction (LVF superiority). The range of Mean Visual Field differences for the twelve Normal Ss was +18.26 msecs. to 206.00 msecs.

With regards to the difficulty of recognition for each Face, there is a significant Face difference for the Normals. FACE 2 was responded to faster than FACE 3, which was responded to faster than FACE 1 and then FACE 4. Half the Normal Ss responded to Faces 1

TABLE IV. Six-Way Analysis of Variance: 12 Normal Ss; Faces; Single-Key Responding (Go-No go Design). Summary of Relevant Factors and Interactions.

Source of Variance	Sum of Squares	df	Mean Squares	F	* (sig.)
Between Subjects	24846438.2	11			
A (Group)	1664404.7	1	1664404.7		
Error Between	23182033.4	10	2318203.3		
Within Subjects	79573176.1	756			
B (Faces)	272932.8	1	272932.8		
AB (Face/Groups)	14421278.2	1	14421278.2	51.7764	* .01
Error (B)	2785299.8	10	278530.0		
C (Visual Field)	1805693.8	1	1805693.8	41.9394	* .01
AC (Groups X VF)	9983.5	1	9983.5		
Error (C)	430548.8	10	43054.9		
BC	784704.9	1	784704.9	20.1492	* .01
ABC (Face Groups X VF)	55314.7	1	55314.7	1.4203	not sig.
Error (BC)	389447.9	10	38944.8		
D (Hands)	124221.5	1	124221.5	1.4425	not sig.
AD	117834.8	1	117834.8	1.3684	not sig.
Error (D)	861128.6	10	86112.9		
BD	10244.8	1	10244.8		
ABD	150981.9	1	150981.9	4.3114	not sig.
Error (BD)	350192.9	10	35019.3		
CD (Visual Field X Hands) (Pathways)	119350.8	1	119350.8	2.7542	not sig.
ACD	30381.2	1	30381.2		
Error CD)	433337.1	10	43333.7		
BCD	8276.6	1	8276.6		
ABCD	284.2	1	284.2		
Error (BCD)	201733.9	10	20173.4		
E (Eyes)	1602.6	1	1602.6		not sig.
AE	161199.5	1	161199.5	1.5867	not sig.
Error (E)	1015942.3	10	101594.2		
F (Days)	10769996.6	3	3589998.9	9.0784	* .01
Error (F)	11863281.6	30	395442.7		
CF (VF X Days)	101187.7	3	33729.2		not sig.
Error (CF)	1262892.6	30	42096.4		
ABDEF	472764.5	3	157588.2	5.5001	* .01
ABCDEF	18635.4	3	6211.8		not sig.

and 2, and half to Faces 3 and 4. As for the Acallosal, responses to Face 2 are faster than to Face 1.

	FACE 1			FACE 2		
	RVF	LVF	Diff.	RVF	LVF	Diff.
Normals (6 Ss)	1207 msec.	1022	+185	814 msec.	791	+23
Acallosal	987	820	+167	606	612	-6

For the Normals, the Visual Field differences are larger for FACE 1 than for FACE 2. It appears that the processing of FACE 1 is more lateralized than the processing of FACE 2 for both Acallosal and Normals.

For the Acallosal, there is a significant difference between RVF and LVF on FACE 1 ($< .05$, two-tailed test, Wilcoxon Matched-pairs Signed-Ranks Test). There is no significant difference between RVF and LVF on FACE 2 for the Acallosal, suggesting that there is no difference between the hemispheres in dealing with an easily recognizable face. For the Normal Ss, there were always sizeable differences between RVF and LVF for FACE 2, though not all Ss were superior in the same direction (two of the six Ss were RVF superior on FACE 2).

For the Normal Ss there were no significant Hands or Eyes differences. This is similar to the Acallosal on this experiment.

There were no significant Pathway differences for the Normal Group, but the Pathway order was as the hypothesized model (discussed in Developmental Study):
LVF/LH LVF/RH RVF/RH RVF/LH. It appears that the Visual Field receiving the stimulus, is more important than which hand is used (for the Acallosal, not much difference between RVF/RH and RVF/LH in Reaction Times was found).

Error Rates: There is a significant difference in error rate between RVF and LVF for the Normals (Wilcoxon Matched-Pairs Signed-Ranks Test: $p < .05$ level, two-tailed test). There were more errors in RVF (this is in accordance with LVF superiority in speed of response). However, three of the twelve Normal Subjects made more LVF than RVF errors. For Normal Ss there were more errors for FACE 4 than for FACE 1 than FACE 3 than FACE 2. The Acallosal made more LVF errors than RVF errors (15 LVF versus 6 RVF errors), which is surprising, considering that she was faster in responding to LVF stimuli (she made no errors on FACE 2).

A Comparison of Acallosal's Single Key Responding (Go-no go task, Exp. II) with two-key responding (Exp. I "go-go" choice task).

The Visual Field difference is significant ($p < .05$) on the single-key task (Experiment II, responding to Faces 1 and 2, not responding to Faces 3 and 4; go-no go choice task) favouring the Left Visual Field (which is the same as expected of Normal adults). In Experiment I, using the "go-go" choice design (responding to all four Faces, two Faces on one key, two on the other), we found the Visual Field difference was not significant. The Reaction Times on Experiment I (go-go task) are much faster than for the go-no go task (Experiment II).

There is a significant ($p < .01$) Faces effect (Table III) on the single-key experiment (Exp. II) where responses are recorded for Faces 1 and 2 (S does not respond to Faces 3 and 4). There were much faster responses to Face 2 than to Face 1. There was also a significant ($p < .05$), but different, Faces effect on Experiment I (Slowest responses on Face 2, rather than fastest). There is an inconsistency here which is possibly involved with the method of the

TABLE III. Four-Way Analysis of Variance:ACALLOSAL;Faces 1 and 2;
Single-Key Responding (Go-No go Design).

Source of Variance	Sum of Squares	DF	Mean Square	F	*(sig.)
Visual Field	462,641.84	1	462,641.84	4.6417	* .05
Faces	6,263,145.28	1	6,263,145.28	62.8385	* .01
VF X Face	542,274.34	1	542,274.34	5.4407	* .05
Hands	102.039.03	1	102,039.03	1.0238	not sig.
VF X Hands (Pathway)	123,049.34	1	123,049.34	1.2346	not sig.
Faces X Hands	114,840.28	1	114,840.28	1.1522	not sig.
VF X Face X Hand	1,038.92	1	1,038.92		
Eyes	24,957.50	1	24,957.50		
VF X Eyes	7,927.50	1	7,927.50		
Faces X Eyes	3,465.28	1	3,465.28		
VF X Face X Eyes	28,620.28	1	28,620.28		
Hand X Eye	607,110.17	1	607,110.17	6.0912	* .05
VF X Hands X Eyes	191,632.09	1	191,632.09	1.9227	not sig.
Faces X Hands X Eyes	323,007.03	1	323,007.03	3.2407	not sig.
ABCD	122,306.34	1	122,306.34	1.2271	not sig.
Trials	6,555,701.31	17	385,629.49		
Error between Cells	25,415,991.97	255	99,670.56		
Total	40,889,748.50	287			

experiment. There is not as much difference between Faces 1 and 2 on the "go-go" task (Exp. I) experiment as on the go-no go task (Exp. II).

The Face X Visual Field Interaction is significant on the (Single-key) Experiment II. Here there is a Visual Field difference on Face 1 in the expected direction for Normals (LVF superiority). There is almost no Visual Field difference on Face 2, and what there is, is reversed (a RVF superiority). In comparison, there is no Visual Field X Faces Interaction on (two-key) Experiment I (two faces have RVF superiority, two LVF superiorities), but the Visual Field superiorities are in the same direction for Face 1 and Face 2 in this experiment as in the other experiment.

On neither experiment is there a Hand difference.

In the Single-key Experiment (II), there is no Hand X Visual Field Interaction (Pathways), nor on the two-key experiment (I). The Pathway trends are different for the two experiments:

Single-key expt. (II) (go-no go design) LVF/LH (faster) LVF/RH RVF/RH RVF/LH

Two-key expt. (I) (go-go design): RVF/RH (faster) LVF/RH RVF/RH LVF/LH.

There is no significant Eye effect on the go-no go experiment. There is on the "go-go" experiment. Both experiments show a significant Hand X Eye interaction.

Go-no go Expt.: LH/LE faster than LH/RE
RH/RE faster than RH/LE.

Go-go Expt.: LH/LE faster than LH/RE
RH/LE faster than RH/RE (probably no difference).

There are inconsistencies between the results of the two experiments, since in one case we find a significant Visual Field difference and in the other we do not. They may be related to the differences in the experimental tasks. The sort of decisions which the S is required to make (such as to 'press the key' or 'not to press the key' in the one task, while in the other task the decision is made to 'press this key' or 'that key') could affect the results. The motor responses required could affect the results, but the use of two keys per se would not make a difference because there is no difference between the two keys. The RVF is 'faster' on both keys. The inconsistencies may indicate a greater flexibility as regards which hemisphere processes faces in the acallosal. That is, it may be that she can process faces in either hemisphere, but that something about the experimental task (other than faces) sets up a process for responding favouring one hemisphere over the other. A comparison of Normal Ss on both experiments would be necessary to give support to this hypothesis (assuming the Normals would perform similarly on both experiments).

The Sibling can not be directly compared to the Normal Group of Controls, because the experimental design was different. The Sibling does, over-all, respond faster to the faces in the LVF than the RVF as do the Normals, and as the Acallosal does in the experiment which is directly comparable to the experiment carried out on the Normals. The Sibling's Pathway order is the same as the Pathway order for the Normals, but neither is significant.

Both the Sibling and the Acallosal are slower in responding to FACE 2 than any other FACE on the two-key experiment. But the Acallosal is faster on FACE 2 than FACE 1 on the Single-key experiment, as are the Normals, so it is not possible to draw conclusions about the "ease of discriminability" on the two-key experiment. If the Acallosal had performed consistently on the two experiments, we could have made more inferences about the Sibling's performance. As she did not, it would have been desirable to retest the Sibling on the second experiment (Single-key responding), but she was not available for further extensive testing.

It is not possible to say whether the Sibling is more like the Acallosal, or more like the Normals in recognition of Faces. Over-all, they all seem to have the LVF superiority for recognition of Faces.

Conclusions: The Acallosal is not different from Normals in over-all hemisphere superiority in response to Faces. She does appear to be different from the Normals in the recognition of an 'easy' face (there did not appear to be any lateralization for the Acallosal on FACE 2, while there was for Normals).

The Pathway effect is not significant for either Normals or the Acallosal, but the order is similar.

The differences found in asymmetry of recognition of certain faces requires explanation. Levy et al. (1972) found that when half-faces were presented to left and right Visual Field, the one in the left Visual Field was recognized better, but when asked to describe the face, their commissurotomy Ss described the one in the right Visual Field. It seems clear in this case that the Subjects were perceiving the faces independently in the two hemispheres and that two different perceptual processes were going on. It may be that something of the sort was occurring with our Normals, according to the face presented. Perhaps the amount of information obtained from the face necessary to process the face (that is, to recognize it) varies, and in accordance with this variation one hemisphere or the other processes it more quickly.

COMPARISON OF ACALLOSAL AND SIBLING PERFORMANCE ON BOTH LETTERS AND FACES EXPERIMENTS

The Acallosal has a significant Left Visual Field Superiority for Reaction Time to LETTERS which is opposite to the Right Visual Field superiority characteristic of the Normal Subjects. The Acallosal is also significantly different from her Sibling who has a Right Visual Field superiority for Reaction Time to LETTERS. The Sibling, who has a similar directional superiority to that of the Normals, has a larger Mean difference between visual fields than any of the Normal Subjects. The Sibling's Reaction Times are also longer than the Mean Reaction Times of the Normals and also of the Acallosal S. The Mean Reaction Times of the Acallosal are also longer than the Mean RTs for the Normals.

In contrast to LETTERS, the FACES results for the Acallosal indicate that she is not significantly different from the Normals in terms of Visual Field superiority in Reaction Time. Both Acallosal and Normals have over-all left Visual Field superiorities for recognition of FACES on comparable experiments. The Acallosal does show significantly different Visual Field effects on the two separate FACES (a LVF superiority for FACE 1 and no Visual Field difference on FACE 2.) This is similar to Normals in that the Normal Ss also show a significant Visual Field X FACE Interaction: FACE 1 is more lateralized to the Right Hemisphere than FACE 2.

On the FACES experiment, the Acallosal has Mean Reaction Times within the Mean range of performance of the Normal Ss.

On the FACES experiment, the Sibling can not be directly compared with the Normals because she responded only in a go-go design condition compared to the go-no go design for Normals, and this difference should be borne in mind. However, the Sibling does, overall, respond faster to the faces in the LVF than in the RVF as do the Normals.

Comparing Acallosal performance on the two comparable experiments of letters and faces (both the go-go design Conditions), she responded significantly faster to LETTERS presented in the LVF (Normals responded faster to LETTERS in the RVF), but she did not show a significant Visual Field difference on the exactly comparable FACES experiment. She did show a LVF superiority on the go-no go design for FACES as did the Normals.

The Sibling, on the FACES experiment, responded significantly faster to FACES presented in the LVF as did Normals. The Sibling has the opposite superiority for LETTERS (RVF) as do the NORMALS (RVF) in Reaction Time.

It would appear from this comparison that the Sibling is not Acallosal, but neither is she exactly Normal in performance, because she is slower in Mean Reaction Time for RVF and for LVF and has a longer mean difference between VFs than the Normals. Her Visual Field superiorities are directionally like the Normal Subjects.

Concerning similarities between Pathways for LETTERS and FACES, the Acallosal Pathways are for FACES:

(not signif.) Go-no go Expt.: LVF/LH LVF/RH RVF/RH RVF/LH.

(not signif.) Go-go Expt.: RVF/RH LVF/RH RVF/LH LVF/LH.

For LETTERS:

(signif.) Go-go Expt.: LVF/LH RVF/RH LVF/RH RVF/LH.

The Pathways for Normal <u>S</u>s for FACES:

(not signif.) Go-no go Expt.: LVF/LH LVF/RH RVF/LH RVF/RH,

where the hypothesized model was borne out by the data.

For LETTERS:

(not signif.) Go-go Expt.: RVF/LH RVF/RH LVF/RH LVF/LH, where the hypothesized model was: RVF/RH RVF/LH LVF/RH LVF/LH.

The rank order of Pathways for the Acallosal are not the same as the Pathways for the Normals.

CHAPTER EIGHT

VISUAL PERCEPTION: THE INTEROCULAR TRANSFER OF MOVEMENT AFTER-EFFECTS

Introduction

Dixon and Jeeves (1970) reported on the differences in interocular transfer of movement aftereffects between acallosals and normal Subjects. They studied three male acallosals (ages 10, 14, and 47 years) and a group of 18 normal Subjects. They found a "relative lack of interocular transfer in acallosal as opposed to Normal Subjects', a difference which was statistically significant. Dixon and Jeeves pointed out in their 1970 paper that there was "no a priori reason why information received by the test eye should have to cross between the hemispheres in order to make contact with stimulus effects mediated by the other eye", since each eye projects bilaterally.

Dixon and Jeeves briefly reviewed the literature (Holland, 1965, and Wohlgemuth, 1911, and others have made more extensive reviews), contrasting the evidence in favour of a peripheral explanation of movement after-effects and the evidence for a central processing mechanism. It was with regard to these elements of contrasting evidence and opinion that they decided to look at the role of the corpus callosum in interocular transfer of movement aftereffects.

We decided to try to replicate the Dixon and Jeeves study, using our now 14 year old Acallosal girl to see whether their findings would be confirmed. Further, we tested the Acallosal girl's female Sibling, hypothesizing that if she were Acallosal also, she would perform similarly. If the Sibling were brain-damaged in some other way or only mentally retarded she would perform more like the group of "Mental Match" Subjects than like the Acallosal girl. Of course, it was expected that the Acallosal girl would perform differently from the "Mental Match" Subjects as well as from the Normals.

Several of the normal Ss in the Dixon and Jeeves (1970) study had failed to transfer the MAE (Movement After-Effect) when viewing a grey test field, and the Total Mean transfer was very weak. Pickersgill (1959) reported on the effect of using an unstructured, black disc for the test field and found that while 23 of 25 Ss saw some aftereffect, most reported difficulty in determining when the aftereffect had ceased. The total duration of MAEs for all Ss was less when viewing the black disc than when viewing the stationary spiral (which had been the rotating inducing field).

There is disagreement in the literature about whether the MAE is best observed on an unstructured or structured field; Holland (1965) briefly reviewed the results of Holland (1957), Deutsch (1956), Grindley and Wilkinson (1953), Griffith and Spitz (1959), George (1953), and Spitz (1958) in this regard. But Wohlgemuth as long ago as 1911 compared MAEs in a brightly lit objective field with distinct contours to a darker field with less distinct contours, and found more marked MAEs in the distinctly contoured field. Bakan and Mizusawa (1963) used both forms -- the inducing figure, and a white square on a grey background, and found shorter MAEs for white on grey background.

We decided to use both the unstructured test field, that is a grey matt surface as Dixon and Jeeves had used, and as another condition, the stationary stimulus disc in the expectation that the stationary disc would facilitate any MAE and make it easier for the Subject to determine when the MAE had ceased, rendering our measurements therefore more precise. Presumably the use of the stationary stimulus disc of random squares as test field rather than a matt grey surface would facilitate MAEs because the stationary pattern would provide more retinal stimulation where the movement is a function of displacement of the stimulus elements imaging on the retina (in a sense, the stationary stimulus provides a continuing stimulation for the Aftereffect to displace from).

This suggestion is similar to the case that Baker and Dixon (1967) made in regard to their hypothesis (tested by them) that MAEs would be of greater duration if the inducing field were a random field of black and white squares rather than a spiral field. They argued that "retinal contribution would be proportionately greater in the case of the random field since retinal transmission rate as a function of interface displacements within the retinal image is greater for the random field". That the MAE is due to retinal stimulation (and not eye-head movement) was determined by Anstis and Gregory (1965); they found that an MAE occurred when the eye remained stationary and the image moved across the retina, and an MAE did not occur when the eye tracked the stimulus in such a way that the image was kept stationary on the retina.

Day and Strelow (1971), investigating the effect of patterned vs. nonpatterned surrounds on the movement aftereffect, found that a patterned surround had a greater effect on the test phase than on the inducing phase and that generally a patterned surround was of more effect with regard to the MAE (increasing the duration and strength of the MAE) than the lack of pattern surround. They suggested that their findings indicated that "the MAE is essentially a relative movement phenomenon, and it can be assumed that the neural processes correlated with the aftereffect derive from stimulation by moving and stationary contours".

Method

The stimulus disc was a replica of the disc that Dixon and Jeeves (1970) had used. It consisted of a random distribution of approximately 22,000 black and white squares. Dixon and Jeeves stated in their report that previous research had found that it produced "low thresholds for visually perceived movement and strong aftereffects of long duration". The Subject was placed at a distance of one metre from the stimulus disc which was caused to rotate at a speed of 10 rpm with the Subject viewing it for 20 seconds of stimulation.

There were two main conditions. In the Condition I, the Subject was asked to look at the rotating disc for 20 seconds when it would then be covered by a grey matt card. Then he was to continue looking at the grey card until any aftereffect had ceased and he was to report when this occurred.

Condition II was the same as Condition I except that instead of the grey matt card, the Subject viewed the stationary stimulus disc.

The performance of the Acallosal Subject was compared with a group of twenty normal young adult university Subjects (both male and female), with her Sibling, and with a small group of five "Mental Match" Subjects (these were girls of approximately the same age and intelligence as the Acallosal girl and who were taken from a remedial class similar to the class the Acallosal attended). Originally seven "Mental Match" Subjects were tested, but two of these obtained no monocular aftereffect and so were not completely tested and dropped from the sample.

There were four conditions within each of the two main conditions. (1) The Subject was first stimulated in the right eye and then tested for aftereffect on the right eye (RR). (2) The Subject was stimulated on the right eye and tested on the left eye (RL). (3) The Subject was left eye stimulated and left eye tested (LL). (4) Left eye stimulated and right eye tested (LR). Two of these conditions we called monocular, meaning that the same eye is tested as was stimulated (RR and LL); the other two conditions involve interocular transfer (RL and LR). A monocular condition was alternated with an interocular transfer (IOT) condition. The four conditions were repeated in a different order and means were obtained. Prior to stimulating a single eye and at the beginning of each of the two main conditions, both eyes were stimulated and tested, to make sure the Subject understood what he was being asked to do.

Results

The Mean durations of aftereffects for Conditions I and II are shown in Tables I and II, respectively. The combined Means for both conditions are in Table III.

A Mann-Whitney U Test on the averaged means of the two main conditions of interocular transfer (Table III)(that is, where the aftereffects were mediated on the grey test card (Cond. I) and on the stationary stimulus (Cond. II)) for the Acallosal compared to the group of Normals is significant at the .05 level. The interocular transfer of the Acallosal is nil in all conditions, whereas the mean interocular transfer for each Subject (whether Normal or Mental Match) exceeded zero (refer to last column of Table III for data). This finding supports the finding of Dixon and Jeeves (1970) that the Acallosals do not exhibit interocular transfer of movement

TABLE I

Condition I (Grey Test Field) :Mean MAEs Duration in Seconds

	RR	LL	RL	LR	IOT
Acallosal	4.5	4.5	0	0	0
Sibling	3.0	4.25	0.5	1.0	0.75
Normals					
1	7.5	5.5	6.5	6.0	6.25
2	8.75	7.5	0	1.0	0.5
3	6.5	8.0	0	0	0
4	5.5	5.0	3.0	3.5	3.25
5	6.0	5.5	0	0	0
6	5.5	5.0	4.5	3.5	4.0
7	5.5	4.0	3.0	0	1.5
8	8.0	7.25	0	0	0
9	6.0	4.5	3.75	3.0	3.375
10	11.0	9.25	5.5	0	2.75
11	6.0	4.0	3.5	1.0	2.25
12	4.75	4.25	0	0	0
13	7.0	6.75	0	0	0
14	3.5	3.5	0	0	0
15	6.5	5.75	4.5	1.5	3.0
16	5.25	5.0	2.5	2.5	2.5
17	7.5	9.5	0	3.75	1.875
18	3.5	3.25	2.75	0	1.375
19	2.0	5.0	0	0	0
20	8.0	7.0	5.75	5.25	5.50
N=20 $\overline{X}$ =	6.21	= 5.78	= 2.26	=1.55	
Mental Match Ss					
1	4.0	4.75	3.0	3.25	3.125
2	4.75	4.75	5.0	4.75	4.875
3	8.75	8.25	6.25	7.25	6.75
4	4.25	6.50	0	3.0	1.50
5	5.75	2.50	0	0	0

TABLE II

Condition II (Stationary Stimulus Disc as Test Field): Mean MAEs Duration in Seconds

	RR	LL	RL	LR	IOT
Acallosal	7.75	5.0	0	0	0
Sibling	8.0	10.5	7.5	7.5	7.5
Normals					
1	19.75	19.75	15.5	14.25	14.85
2	15.25	12.75	11.0	10.50	10.75
3	21.0	19.25	19.25	20.25	19.75
4	11.5	9.5	12.75	8.0	10.375
5	13.25	14.0	12.5	11.0	11.75
6	16.25	17.5	11.75	12.75	12.25
7	20.0	17.5	15.0	12.5	13.75
8	15.0	14.5	8.0	9.5	8.75
9	8.5	8.75	5.75	5.0	5.375
10	21.0	22.0	10.0	10.5	10.25
11	10.0	7.75	0	0	0
12	17.0	16.75	11.0	9.0	10.0
13	13.75	12.75	9.0	6.25	7.625
14	13.50	16.25	11.5	4.5	8.0
15	16.25	16.0	6.25	6.25	6.25
16	14.25	15.0	10.75	10.75	10.75
17	24.0	23.0	9.0	11.5	10.25
18	17.5	16.0	11.25	11.0	11.125
19	16.0	15.0	8.0	7.0	7.5
20	17.5	16.5	14.0	14.0	14.0
N=20 $\bar{X}$ =	16.06	= 15.52	= 10.61	= 9.72	= 10.17
Mental Match Ss					
1	9.75	7.0	6.5	6.0	6.25
2	11.0	8.5	7.5	9.0	8.25
3	12.5	11.75	9.5	6.5	8.0
4	11.5	15.0	8.5	10.5	9.5
5	17.0	11.0	12.25	9.5	10.875

TABLE III

Means of Conditions I and II Combined : Mean MAEs Duration in Seconds

	RR	LL	RL	LR	IOT
Acallosal	6.125	4.75	0	0	0
Sibling	5.50	7.375	4.0	4.25	4.125
Normals					
1	13.625	12.625	11.0	10.125	10.55
2	12.0	10.125	5.5	5.75	5.625
3	13.75	13.625	9.625	10.125	9.875
4	8.5	7.25	7.875	5.75	6.8125
5	9.625	9.75	6.25	5.5	5.875
6	10.875	11,25	8.125	8.125	8.125
7	12.75	10.75	9.0	6.25	7.625
8	11.50	10.875	4.0	4.75	4.375
9	7.25	6.625	4.75	4.0	4.375
10	16.0	15.625	7.75	5.25	6.50
11	8.0	5.875	1.75	0.5	1.125
12	10.875	10.50	5.5	4.5	5.0
13	10.375	9.75	4.5	3.125	3.8125
14	8.50	9.875	5.75	2.25	4.0
15	11.375	10.875	5.375	3.875	4.625
16	9.75	10.00	6.625	6.625	6.625
17	15.75	16.25	4.5	7.625	6.0625
18	10.50	9.625	7.0	5.50	6.250
19	9.0	10.0	4.0	3.5	3.750
20	12.75	11.75	9.875	9.625	9.750
N=20 $\bar{X}$ =	11.05	= 10.59	= 6.26	= 5.43	= 6.04
Mental Match <u>Ss</u>					
1	6.875	5.875	4.75	4.625	4.6875
2	7.875	6.625	6.25	6.875	6.5625
3	10.625	10.0	7.875	6.875	7.375
4	7.875	10.75	4.25	6.750	5.50
5	11.375	6.75	6.125	4.750	5.4375

aftereffects.

Looking at the data in more detail, we can make some further comments.

Under the condition which is most comparable to that reported by Dixon and Jeeves, where the aftereffect was mediated by the grey test card (Cond. I) the monocular aftereffect (the same eye tested as stimulated) of the Acallosal girl was within the range of duration of aftereffects of normal Subjects. This was the case also with the acallosals Dixon and Jeeves studied compared with their normal sample. Dixon and Jeeves felt that therefore no claim could be made that the aftereffect per se depends on any interhemispheric interaction mediated by the corpus callosum. Condition I is possibly not a strict replication of the Dixon and Jeeves study because of differences in room lighting and lighting on the inducing stimulus and the texture of the grey matt card used as the test field. (However, Day (1957) found no variation in duration scores due to total brightness level of the stimulus object or to brightness/contrast between the display and ground, though other presumably essential factors were the same.)

Relative to the question of whether our Condition I is indeed a replication of the Dixon and Jeeves' study, a comparison of the Mean monocular (Mean of LL + RR) MAEs for Dixon and Jeeves' Normals with the present group of Normals (Condition I) gives a significant difference between the two groups of normals on the Mann-Whitney U Test (two-tailed test, significant at $<$ .02 level).

Comparing Condition I with Condition II (aftereffect mediated by stationary stimulus disc), we see that the means for the normal group are significantly higher (longer durations) in the second condition than in the first condition (Wilcoxon Matched-Pairs

Signed-Ranks Test: One tailed test on monocular MAEs Condition II $>$ Condition I significant at $< .005$ level). It is not surprising that the stationary disc would facilitate the movement aftereffect. The interocular transfer effect is so greatly enhanced that only one of twenty Normal Subjects failed to transfer (and she was something of an anomaly in that she had shown transfer in the <u>first</u> condition) (Wilcoxon Matched-Pairs Signed-Ranks Test on IOT MAEs found Condition II $>$ Condition I significant at $< .005$ level, one-tailed test). This Condition II would then seem to be a better test of movement aftereffects for comparisons between normals and acallosals. However, this Condition II reveals another difference between the Acallosal and the Normal group. This is that while the mean monocular aftereffect in Condition II for normal Subjects was about 2.6 times the aftereffect duration in Condition I, the Acallosal's mean monocular aftereffect in Condition II was only 1.4 times her mean in Condition I. On Condition II her mean durations for monocular aftereffects fall completely outside and below the range of responses for the normals. She can no longer be said to perform as a normal Subject initially. Furthermore, A Mann-Whitney U Test on the combined means of the <u>monocular</u> movement aftereffects (Table III data) is significant at the .05 level for the Acallosal compared to the group of Normals. This then suggests that perhaps the Corpus Callosum <u>is</u> involved in mediating movement aftereffects per se, contrary to the results from Condition I. It is also possible that some unknown brain abnormality is causing a generalized reduction in MAEs.

For the combined means of the Normals, the IOT MAE is approximately 56% of the monocular MAE. Normal Subjects on Condition II obtained mean IOT MAEs at 65% of their monocular MAEs. The Sibling's mean IOT is 64% of her monocular MAE. The Acallosal's baseline MAE (that is, her mean monocular MAE) is not so low that an IOT MAE could not have been calculated; assuming that her IOT would be 56% of her monocular score as in the case of normal Subjects. Holland (1957) observed transfer durations approximately 60 to 70% of non-transfer durations.

A comparison of the data for the Mental Match Subjects with the Normal Subjects on a Mann Whitney U Test gives a significant ($<$ .05 level of significance on two-tailed test) difference between the combined means for monocular MAE durations (Table III data). However, there is no significant difference between the Mental Match Ss and the Normal Ss on interocular transfer (Mann Whitney U Test on combined means - Table III data).

For most normal Subjects, where the stimulation and test field was to the same eye, the duration of the movement aftereffect was longer for the right eye than for the left eye, but this result does not reach significance on the Wilcoxon Matched-Pairs Signed-Ranks Test for either Table I data (comparable to Dixon and Jeeves' study) or Table III data which contains the combined means for Conditions I and II. In the case of Interocular Transfer, the RL condition (right eye stimulated, left eye tested) was usually of a longer duration than the LR condition. This result is not significant on Condition I, but is significant at $<$ .01 level, two-tailed test, on Wilcoxon Matched-Pairs Signed-Ranks Test for combined means for Conditions I and II (Table III data).

Sibling

A Mann-Whitney U Test on the Sibling vs. Normal Ss' Interocular Transfer Means (Table III data) is not significant. Four of the twenty Normals obtained lower Mean IOTs than the Sibling.

The Sibling obtained a Mean RR monocular MAE duration which was below the range of Normal scores. Her Mean LL MAE duration is just marginally within the lower end of the range of Normal Subject MAE duration scores. Her Mean monocular MAE is similar to her Acallosal sister's monocular MAE, but falls just within the range of Mental Match scores obtained, while the Acallosal's was below the range obtained (no importance is attached to these slight differences because the sample of Mental Match Subjects was so small and two Subjects were discarded because they didn't obtain monocular MAEs). The point to be made here is that the monocular MAEs for Acallosal, Sibling, and Mental Match Subjects appear more similar to each other than to the group of Normal Subjects.

The Sibling's Monocular MAEs are within the range of scores of the Normal Subjects. Her mean monocular MAE on Condition II is approximately 2.6 times the mean monocular MAE on Condition I -- an increase similar to that for Normal Subjects.

The Sibling's monocular MAEs were longer for LL than for RR. This result is opposite to that of the Acallosal and the Normals (RR is usually longer). The Mental Match group were variable in this regard.

If failure to transfer the MAE could be accepted as evidence for absence of Corpus Callosum, then the performance of the Sibling does not here provide evidence of Agenesis of the Corpus Callosum.

Discussion

Given that acallosals do not transfer movement after-effects, but normals do transfer, then what is the role of the corpus callosum in the interocular transfer? There is presumptively (and prior to Dixon and Jeeves' report of their three acallosals), no reason, since each eye projects bilaterally, to think that the corpus callosum is involved in interocular transfer of movement aftereffects.

Dixon and Jeeves suggested two possible explanations:

1. "the corpus callosum is involved in a storage function that only becomes necessary when the tested eye differs from the stimulated eye", or

2. "Interocular transfer depends upon inhibitory or excitatory effects between homotopically related foci in the two visual cortices". The involvement of the corpus callosum identifies the process as 'central' because the corpus callosum projects only to the two cortices.

It is possible that when testing the previously unstimulated eye of the acallosal, the effect of stimulating it with the test field is so strong that without callosal connections to 'facilitate' the MAE, no perception of an MAE is made and only the test field itself is perceived. That is, it may be that the Acallosal _S_, because of the lack of interhemispheric connections, can more easily switch attention to the 'new' stimulus (i.e., the _test field_, whether stationary disc or unstructured field), although the context of the testing situation is one where the _S_ is asked to attend to any MAE. The Acallosal is able to perceive the MAE monocularly (that is when the same eye as stimulated by the rotating disc is stimulated by the test field) because the eye having been 'fatigued' or 'in use' by the rotating stimulus is not able to respond so greatly to the stimulus of a test field (as would the unstimulated eye) that it would see only the test field. In other words, the monocular MAE situation is perhaps one where the 'attention' cannot be switched because the previously stimulated eye is still 'in use' physiologically. This explanation does not account for Ss who do not see a monocular MAE in the first place (there could be any number of explanations for that).

Brain Damage and the MAE

There is no evidence that the acallosal S is brain-damaged apart from the lack of a corpus callosum and below-average I.Q. Below-average I.Q. is not necessarily evidence of brain damage. However, the below average I.Q. and the lack of a corpus callosum in our S renders the performance of brain-damaged Ss reported in the literature relevant to our investigation. It is possible that our acallosal would perform similarly to brain-damaged Ss.

Wohlgemuth's (1911) investigation of the effects of attention/inattention on the MAE suggested the use of the spiral-induced MAE in diagnosis of brain damage. Subsequently, there have been many investigations of the possible usefulness of the MAE as a diagnostic tool (See Holland, 1965, for review).

Price and Deabler (1955) hypothesized that Ss with "cortical involvement" (organic brain disorder or disease) would either not perceive the MAE or would only perceive it "incompletely".

Gallese (1956) used normals, schizophrenics, and two classes of organics (one group of chronic or acute brain damage and the other lobectomized schizophrenics). This study tended to validate the Price and Deabler research, except that the surgically damaged patients were not significantly different from Normals and schizophrenics.

Spivack and Levine (1957) tested an adolescent brain-damaged group and a group of emotionally disturbed adolescents. They obtained significantly longer durations in the organics.

Scott, et al. (1963) reported that brain-damaged Ss have slightly less inter-ocular transfer than normals. (They tend to have slightly longer binocular effects.) However, our Mental Match Ss did not significantly differ from normals on transfer.

Instruction Bias

Mayer and Coons (1970) tested the premise that the apparent deficit in perception of the MAE in brain-damaged could be due to a failure in reporting the effect (because of anxiety) rather than failure to perceive the effect. They found this to be the case, that "reassuring" instructions result in no appreciable difference between brain-damaged and schizophrenics, but neutral or anxiety-producing instructions will result in a group difference. Other researchers (for example, London and Bryan, 1958, Becker, 1959, Harding et al., 1957, Gollin and Bradford, 1958, Goldberg and Smith, 1958, and Schein, 1960) have also found the form of the instructions a variable for concern. Our Acallosal girl generally is strongly subject to anxiety about being "different", as is her sibling (to a lesser degree), and required reassuring instructions which nevertheless did not suggest that she should or should not see an MAE ("some people do, some people don't, see anything"). In any case, the Acallosal and her Sibling had established a relationship with the Experimenter to the extent that they weren't bothered about being asked to do ridiculous things.

Fixation

The duration of the MAE has been reported by Holland (1957) to be dependent upon fixation and that it would not occur if the fixation point was randomly varied within a period of stimulation.

Movement, other than eye movement *per se*, focus, and attention, are all involved in fixation, and the inability to fixate properly has been suggested by Day (1960) as one of the variables affecting the perception of the MAE in brain-damaged Ss. Holland and Beech (1958) also suggest the importance of this variable in perception of MAE by brain-damaged Ss; that the difficulty in maintaining fixation could be a contributing factor to the lower MAEs of their brain-damaged group.

There is no evidence that the Acallosal S and her Sibling cannot voluntarily fixate. The evidence from a previous unrelated experiment where the Ss were required to fixate on a signal for a very short time duration (up to 200 msec.), but repeated for several minutes at a time, is that they are able to voluntarily fixate. However, this is not to say that we know for certain they fixate (as regards eye movements) the same as the normal subjects in this experiment. Possibly this does account for the lower monocular MAE scores, but it does not account for the failure to transfer.

Attention/Inattention as measured by Wohlgemuth (1911), involving the use of distracting tasks such as mental arithmetic, led him to conclude that the MAE is produced even if the mind does not attend to the objective movement, but is occupied by some other activity. Other authors have commented generally on the distractability of brain-damaged Ss.

There does remain the unsupported possibility that associated with agenesis of the corpus callosum could be a dysfunction of the visual system that doesn't have to do with the presence or absence of the corpus callosum per se.

Ettlinger et al. (1972) compared a group of three Total Agenesis Ss with a group of four Neurological Controls on an apparent movement perception task. This task involved having a S look at a fixation point around which were set 4 lamps into a black board in the corners of a square. The lamps could be illuminated in a selected time sequence of pairs so that clockwise, vertical, or horizontal motion could be perceived. Two of the Three Total Agenesis Ss had some difficulty in perceiving movement. Ettlinger et al. reported the conclusion that no differences appeared to result between the two groups (nor differences between vertical or horizontal movement). They concluded that the fact that some Ss were "able to report the illusion of movement in a horizontal as well as in a vertical direction, and with similar stimulus parameters" implied "that an acallosal brain can not only interrelate inputs entering its two hemispheres but can do so in a manner which takes into account fine time differences between such inputs". We are impressed with the difficulty the Total Agenesis Ss had in reporting the illusion of movement, rather than the amount of success. There is a definite deficit, but whether this is related to brain damage per se, and not the absence of the corpus callosum per se is questionable, because the Neurological Controls demonstrated a definite deficit in this regard also. Our impression of their Table V summarizing the Totals and Controls' data is that while both groups have difficulty, the acallosals have a bit more of a deficit. Both groups are presumably different from normals.

The question about what the deficit is due to does not seem to be resolved. Ettlinger et al. pointed out that the three acallosal Ss of Dixon and Jeeves (1970) had been entirely normal in their perception of the sort of apparent motion which occurs in a movement after-effect (which particularly involved monocular viewing of the stimulus and same eye tested for MAE), but that the MAEs "might have been independently generated in the two hemispheres; resulting in a composite impression of a single moving field", while in their test, "independently operating hemispheres could not possibly have given rise to apparent movement in a horizontal direction".

We have no evidence with our acallosal girl that there is any defect in her visual system (as opposed to corpus callosum) which would account for her lower monocular MAE or complete lack of IOT of MAE.

It might be that associated with agenesis of the CC are anomalies in the visual system which could account for the deficits in perception of MAEs, or for Ettlinger's deficits in apparent movement. In particular, if along with failure to develop the corpus callosum went a failure to develop binocular cells in the visual cortex, then failure to fire binocular cells could account for failure to transfer MAE, because the 'new' stimulus in the other eye would fire other cells, not binocular ones. With this possibility in mind we tested our acallosal S on several depth perception tasks. She was tested on the Pulfrich Pendulum and also Julesz-type stereograms. She had no difficulty in immediately perceiving the Pulfrich Phenomenon, being able to describe readily the direction of apparent depth, whether clockwise or anticlockwise. On the Julesz type stereograms, she was immediately able to integrate the stimuli to perceive a T-shape, a triangle, and a Mueller-Lyer Illusion figure stereogram. Obviously, there was no problem for her about binocular integration of information. Further, a test of her "range-finder" depth perception indicated no difficulties there. In addition to the depth perception tests, we looked at her colour vision, using the Ishihara Colour cards and she had no difficulty with her colour perception. Her visual fields appeared normal upon examination.

To answer the question which arose after the initial MAE Experiment about whether the Acallosal Ss' monocular MAEs might be lower than normal due to a fixation difficulty or a tendency to track the stimuli, we retested her on the MAE experiment, this time using a stimulus even more likely (because the stimulus contained more information) to result in longer MAEs than the one we used originally, and which also had a large fixation point in the middle of the disc to optimize likelihood of fixation. The disc in the experiment was rotated in different directions so as to rule out any residue effect from a previous trial. Her mean Monocular MAE was 6.0 seconds in this case and she again failed to transfer any MAE. There was no obvious difficulty in tracking observed.

The further visual tests we carried out seem to indicate that there is no malfunction of our Acallosal's visual system per se.

A test of some of the surgically bisected patients would provide a good comparison, if we can assume there is no damage to their visual systems. This could provide further evidence of the role of the Corpus Callosum in interocular transfer of movement after-effects, and would allow us to distinguish callosal from other cerebral contributions to the effect.

CONCLUSIONS REGARDING ALL EXPERIMENTS ON ACALLOSAL AND SIBLING.

We find some support for our hypothesis of bilateral speech representation in the Acallosal when comparing <u>all</u> the "verbal" experiments.

Comparing Auditory with Visual Perception, we find that the Agenesis patient is left-hemisphered (inferred from finding of Right-Ear Superiority) for recall of auditorily presented digits in a dichotic listening task, and right-hemisphered (Left-Visual Field Superior) in superiority for reaction time to visually presented Letters. This is a kind of bilaterality in different modalities. Perhaps there are different kinds of verbal representations in the two hemispheres.

We found no hemisphere differences in the Auditory task of recognition of musical patterns nor in recognition of digits presented auditorily. She has a Left-Visual Field superiority for Faces (as do Normals) in one visual task, but does not show a significant Visual Field difference on another form of the same test. While in one experiment she 'lateralized' one Face, she did not lateralize another Face (whereas Normal <u>S</u>s 'lateralized' both faces, but to differing degrees).

These findings for FACES suggest that it is something about the nature of the task other than the type of stimuli per se, which 'cues in' the process which results in apparent lateralization or bilateralization of function.

Support for Sperry's (1968) notion that use of ipsilateral pathways may account for differences between Acallosal and surgically-bisected <u>S</u>s is found in the Letters Experiment where the Acallosal's ipsilateral pathways were faster than the contralateral pathways, whereas this was not the case with the Normals.

We think the evidence for agenesis in the Sibling is not clear-cut. There is some evidence in support of agenesis and some against. Some performances are more like surgically-bisected patients as on the Auditory perception task, some performance more like Normal Ss (as on the Visual Perception tasks involving recognition of Letters and Faces).

We generally find evidence that our acallosal is 'different from' Normals and Mental Match Ss on Motor Co-ordination, Auditory Perception, Visual Perception, and Tactile Perception, although not in every specific test.

We think a patient like this Acallosal with no known extra-callosal damage contributes something to our understanding of interhemispheric relationships, if only a clear example of the complexity involved in the relationships, and a sense of the compensatory developments in her brain which result in her appearing generally so normal outside the laboratory.

The next step, it seems to us, is to look further at these relationships in the developing normal individual. For this reason, we carried out our Developmental Study.

CHAPTER NINE

A DEVELOPMENTAL STUDY OF CEREBRAL LATERALIZATION FOR ALPHABETICAL AND PHYSIOGNOMICAL MATERIAL IN NORMAL SUBJECTS: LITERATURE REVIEW

There is clinical evidence that the brains of children have less functional asymmetry than those of adults, or are not lateralized in the same way. There are many clinical reports of the recovery of children after considerable brain trauma, and the comparative lack of recovery of adults, depending on the type and extent of damage. This is a large field of literature, and one we do not intend to review here, but we do want to point out that systematic observation across age groups of brain-damaged patients has not been evident in the literature with regard to the issue of hemisphere lateralization. The difficulty in matching Ss across age groups for type and extent of damage and whether the condition is observed in the acute stage or after stabilization, fairly well precludes systematic observation, or if not the systematic observation, there is difficulty in the interpretation of the results.

The stress in the neurological literature with regard to hemisphere specialization has been on language disorders and their relation to the side of lesion. There is no doubt that disorders of speech production (articulation) and other language disturbances in adults have been related to left-sided brain lesions. Dimond (1972) cites several of the reviews of this literature. These are in articles by Piercy (1964), and Zangwill (1960,1963, 1964).

Adults can show remarkable recovery of language functions after left-hemisphere brain-injury. This is not a contradiction to the earlier statement comparing adults to children. Lenneberg (1967) has pointed out that many aphasics exhibit spontaneous recovery in three to five months. Adults with cerebral lesions do not, however, exhibit the same hemisphere equipotentiality for speech that children do. Lenneberg (1967) says that children, after the age of acquisition of language, which is between 20 and 36 months of age, who suffer cerebral trauma will subsequently repeat the stages of acquisition of language. Trauma to either cerebral hemisphere at this time will be equally recovered by the other hemisphere.

Adults do not, if they suffer cerebral trauma, lose all their language and repeat the stages of language acquisition in the manner of a child of three years of age. Rather, the speech of the adult is distorted in some specific ways, but he is still likely to have considerable linguistic capacity; that is, the language dysfunction of the adult is imposed upon a large residual language capacity. There is not the hemisphere equipotentiality of the two or three year old, but it may be that some potential remains for the adult's nondominant hemisphere to take over some of the speech mechanisms.

Basser (1962) reports evidence for the equipotentiality of the hemispheres in early childhood. Approximately half of the children in this sample (who had sustained brain lesions at under two years of age) had begun to speak at the normal developmental period, but the other half were delayed in onset of speech. The interesting thing, from our point of view, is that it did not matter which side of the brain the lesion was on. The children with right hemisphere lesions exhibited delayed onset of speech as often as those with left hemisphere lesions. This is evidence for the view that cerebral dominance is not yet established by the first two years of life. But by the time the child is not quite ten years old Basser's lesion studies give a picture of hemisphere lateralization: left-hemisphere lesions result in speech distrubances in 85% of the children and right-hemisphere lesions result in speech dysfunctions in 45% of the children. It is evident that as the child matures, speech dysfunctions become more associated with left hemisphere lesions than with right hemisphere lesions. However, speech dysfunctions are still associated with right hemisphere lesions even up to the age of about ten, in about half of the cases.

Dimond (1972), who has quoted Basser's 1962 study in his book, The Double Brain, suggests that the apparent equipotentiality of the cerebral hemispheres in early childhood is significantly related to "the stage at which the child is learning about language", while at the "later stage the child is learning to use language and it is at this time we witness the lateralization of the speech process." Dimond quite rightly makes a distinction which is relevant here between speech and linguistic cpacity: "in the early equipotential stages the linguistic capacities of each hemisphere are employed but it is only later that speech as the output system becomes localized in the left hemisphere. The development of a unilateral system for control of speech need not rob the other hemisphere of the linguistic capacities it apparently demonstrated so ably at an earlier time." Dimond thinks that the data regarding cerebral lesions which occur before the age of ten "suggests that the left hemisphere develops control of speech output, but that prior to that time both contribute in differing degrees to linguistic function until quite a late age."

Relevant also to the issue of hemisphere lateralization of speech and language processes in brain-injured children, are papers by Sugar (1952) and Boone (1965) which Dimond (1972) also refers to. Boone (1965) found that severe and lasting aphasia rarely occurred before the ages of nine or ten in cases of unilateral cerebral injury of any kind. After this age, more children with left-sided lesions develop aphasia than children with right-sided lesions. Sugar (1952) reported that left-sided injuries in children aged between five and ten years resulted in only temporary aphasia, but after age ten language dysfunctions persist.

Obrador (1964) reported that language functions can be taken over by the opposite hemisphere during early childhood, if the language centres in the dominant hemisphere are destroyed or even if the whole hemisphere is removed. But this is not possible after the age of about ten or eleven.

The work of Kimua (1967) and Annett (1970) offers evidence that left-hemisphere lateralization for language is well-established by age eight in both boys and girls.

R.W. Sperry (1968) in his article, "Plasticity of Neural Maturation", uses the comparison of a case of agenesis of the corpus callosum with the surgically bisected patients to highlight the issues involved in investigating the limits of plasticity of neural development. He points out that the mechanisms that underlie the extra functional plasticity of the still-developing brain (as particularly illustrated by the ability of the young brain to compensate for injuries) are not known.

The notion coming from the lesion literature that the right hemisphere may retain linguistic capacities from childhood on to maturity fits in with the lesion literature on adults: Adults with left-hemisphere lesions may lose part of their speech output but rarely total loss of speech. Dimond (1972) states that "linguistic capacities as distinct from the mechanism of speech output are often preserved and that their presence as part of the system for general behavioural control represents a persistent and stable feature of both right and left hemisphere function."

The lesion literature has brought us around to questions about (1) the developmental process of cerebral lateralization in normal human beings, (2) what we mean when we talk about lateralization of language processes and speech mechanisms; that is, what aspects of language function are located in the left hemisphere; what aspects of language process are localized in the right hemisphere normally; what aspects of language processes are common to both hemispheres normally? (3) How are other cognitive functions lateralized, such as in recognition of physiognomical material, if they are different from language functions?

We will try to specify what we mean by language processes in the first place. Language is sequential in nature, that is, it has a temporal structure, and it has a grammar and a syntax, and language has meaning.

Lashley, dealing with the problem of serial order in behaviour (1951), noted that while speech was serially ordered, so too are all skilled acts. This is a point worth remembering, as is the point that many other aspects of language are true also of non-verbal behaviour. It is not easy to identify a dividing line between language and non-language. This problem complicates the conclusions drawn from experimental results as well as clinical studies which indicate that language processes are located in the left hemisphere and non-verbal processes in the right hemisphere. What is the "language process" that goes on in the left hemisphere? Are we speaking only of the control of active speech output? Or do we include what the brain does with verbal input? Do we mean something about the control of sequencing of verbal material or integration of verbal material? Is it something to do with the complexity of the material we are calling verbal?: that is, if the material is 'simple' in nature to recognize or process or 'to decide about', will it be equally well-handled by one hemisphere or the other? Where does the issue of parallel processing fit into lateralization? (if language is somehow only involved with that which is 'serial', does that mean anything involving 'parallel' is unrelated to language?).

The evidence from lesion studies makes it pretty clear that the left hemisphere controls the musculature for speech articulation, though the right hemisphere can give 'voice' sometimes in simple recognitions. There is a likelihood that the input system (speech perception) is tied up with the output system and therefore also located in the left hemisphere, according to Liberman, et al. (1963), and Liberman (1957). Dimond (1972) suggests that the speech mechanisms (input and output) are located in the left hemisphere, but that the linguistic capacities, which operate through the speech mechanisms, are located in both hemispheres, though to a greater extent in the left hemisphere (in a normal, right-handed human).

If we look only at the "linguistic capacities" are we referring then only to that which is serially processed as opposed to being parallel processed? Cohen (1973) looked at serial versus parallel processing in regard to hemisphere differences in a set of three experiments which involved Reaction Times to judge a set of items 'same' or 'different' (the RTs to be related to the number of items in the set). When the items were letters, serial processing seemed to occur in the left hemisphere because RTs increased with the number of letters in the set, but parallel processing seemed to occur in the right hemisphere where there was no increase in RT for larger numbers of letters. When the material presented was unnameable shapes, both hemispheres seemed to process holistically (in parallel). "Thus a serial vs. parallel processing difference between left and right hemispheres appears to be limited to linguistic material which can be analyzed either verbally or visuospatially. If verbal analysis forces a serial procedure, while visuospatial analysis permits parallel processing, then the results can be explained in terms of the lateralization of these modes of analysis." When we look at serial processing versus parallel processing, we are trying to examine the processing mechanisms which underlie the apparent hemisphere specializations or superiorities which laterality studies have demonstrated to belong to one hemisphere or the other. It appears from Cohen's studies that the answer to the question with which we began this paragraph is that some linguistic material can be analyzed by <u>either</u> a serial process or a parallel analysis process. "Linguistic capacities" does not refer to serial processing as <u>opposed</u> to parallel processing, but may include both modes of processing.

There has been a lack of developmental studies in normal Subjects of hemisphere differences in regard to cognitive material. We had not encountered any in the literature at the time we began our study of opposite superiorities of the right and left hemispheres for physiognomical and alphabetical material based on Rizzolatti, Umilta, and Berlucchi's 1971 report of experiments on adults.

Jeeves and Dixon (1970), and Jeeves (1972) looked at hemisphere differences in response rates to "unstructured" visual stimuli in normal adults as well as normal children. They found that both children and adults respond faster to the point source of light when this stimulus goes initially to the right hemisphere than when it goes initially to the left hemisphere. However, the hemisphere differences are generally smaller for the children than for the adults.

The right-hemisphere superiority is not as consistent in the children's data as in the adults' data. The children were generally <u>slower</u> to respond than the adults, the magnitude of the overall difference being of the order of 50 msec. The children were boys aged between 9 years 6 months and 11 years 5 months. The adults were aged 20-22 years.

Jeeves' finding of a right-hemisphere superiority for "unstructured" visual stimuli requires an explanation. He observed that the stimuli had neither verbal nor spatial qualities, and there was at that time no explanation of the results in terms of development of hemisphere dominance for verbal material. Our interpretation of his results is that the point source of light is a structured, visuo-spatial stimulus.

Jeeves also looked at the ordering of the four possible pathways, which was the same for the right-handed children as for the adults: (1) fastest RTs; right-hemisphere receiving stimulus, right-hand responding, (2) right-hemisphere receiving stimulus, left-hand responding, (3) left-hemisphere receiving, right-hand responding, and (4) slowest RTs; left-hemisphere receiving, left-hand responding.

Jeeves and Dixon (1970) stated that two assumptions could explain the facts that "(1) the faster RTs of pathways 1 and 2 as compared with 3 and 4, and (2) the rank ordering from fastest to slowest of pathways 1, 2, 3, and 4, in that order. The two assumptions are (1) that the sensory receiving area in the right hemisphere processes visual information faster than the corresponding area in the left hemisphere, and (2), that the motor responding area in the left hemisphere is faster at initiating a response than the corresponding area in the right hemisphere. The second assumption is required to explain why, for example, the response to stimulation which arrives in the right hemisphere and which must cross by the long pathway to the opposite hemisphere before being responded to by the right hand is faster than that to stimulation arriving in the right hemisphere and being responded to within the same hemisphere without any necessity for passing along a transcallosal pathway."

Jeeves and Dixon (1970) found support for their hypothesis that the motor cortex of the left hemisphere is more efficient (faster) in Cernacek's (1961) report.

Berlucci, Heron, Hyman, Rizzolatti, and Umilta (1971) had found that in an experiment which involved a simple motor reaction time to a visual stimulus presented in the left or right visual field there were no visual field (hemisphere) differences, but that the response was faster when the stimulus and the hand responding were on the same side (right visual field, right hand responding, for example) than when the stimulus and responding hand were contralateral to each other. They suggested that this was because in the ipsilateral case (same side of stimulus as hand responding) both stimulus and response were directly integrated within one hemisphere, while in the contralateral situation interhemispheric communication would occur, which would lengthen response time due to the transmission time between the hemispheres.

Doreen Kimura (1963) did several studies using children and investigating the development of the functional asymmetry of the cerebral hemispheres in the auditory perception of digits using the dichotic listening technique. She found that in children of above average IQ who were members of 'professional' families, from the age of four years there was a significant right-ear (left-hemisphere) superiority. This was the case for both boys and girls.

Kimura also tested a group of boys and girls from a low- to middle-class economic area. She found a significant right ear (left hemisphere) superiority for five-year-old girls but not for five-year-old boys

There seems, from these results, to be a sex difference with regard to the development of cerebral lateralization in children.

Kimura's findings tend to show that the neural mechanisms for speech perception are lateralized in the left hemisphere by the age of four in normal children.

This would appear to conflict with the findings (previously mentioned) of neurological studies which indicate apparently complete recovery of speech processes can occur after injury to the left hemisphere much later than four or five. From the neurological studies we would conclude that speech mechanisms are not fixed until somewhat later. Kimura pointed out that her findings are not in conflict with the neurological findings, in the sense that early lateralization does not preclude greater flexibility of neural organization in the child's brain, nor the participation of the opposite hemisphere in the same speech functions.

Sex Differences in Development of Linguistic Skills.

Buffery (1970, 1971, 1972) has hypothesized that lateralization of cerebral dominance for language processes occurs earlier in the female than in the male.

Kimura found an earlier lateralization for auditory speech perception in girls than in boys (1963).

Taylor (1962) also showed a right-ear advantage for girls, but not for boys (aged seven and eleven years) in children who had reading difficulties. However, Kimura and Taylor found a right-ear superiority in older boys with reading difficulties.

Handedness.

The evidence considering developmental aspects of handedness is conflicting, partly because of the variety of criteria employed in deciding 'handedness'. According to Beaumont's review (1974), certain lateral perferences are shown from as early as the neonatal stage, but consistent hand preferences are not finally established until the child reaches six to nine years (Belmont and Birch, 1963; Bruml, 1969).

Gesell and Ames had previously described (1947) the development of hand preference as a development which exhibits reversals of preference as well as bilaterality at certain ages, until the stable adult lateralization occurs. They had concluded that children were primarily unilateral by four years of age. Johnson and Duke (1936, 1940), Johnson and Davis (1937), and Johnson and Bissell (1940), found stable hand preference frequencies from age six through high school age. Hildreth (1948) had found no changes in the frequency of right-handedness from age 2 to 4 years.

Related to the subject of hadedness, in simple reaction time studies, no difference in response times has been found between right and left hands (Rizzolatti et al., 1971; Dimond, 1970c).

Findings of Laterality Differences in Perception.

Murray White (1969) reviewed studies of laterality differences in perception in adults. His theoretical framework for the review was primarily in terms of a hypothesis that the data support a "postexposural trace-scanning" mechanism. He felt this was preferable to a left-hemisphere dominance for language mechanism because it seemed to fit more of the data from tachistoscopic studies of visual perception. However, White does concede that laterality differences derived from single element displays fit a cerebral dominance explanation quite well, and may be preferred because it is structure dependent. He was specifically reviewing the results of studies where either a line of alphabetical or numerical or other material or a single letter was tachistoscopically presented in one or the other hemifield (either right or left visual field) or across the visual fields of the Subject while the S fixates on a central fixation point. The general finding has been that when either strings of letters or a single letter was presented in one or the other hemifield, the material presented in the right visual field was recognized more accurately or more quickly than the material presented in the left visual field.

Mishkin and Forgays (1952) had tachistoscopically presented English words and Yiddish words in either the right or left visual field and found a Right Visual Field advantage for English words and a smaller Left Visual Field advantage for the Yiddish words. They interpreted their results as being related to a more effective neural organization developed in the relative hemisphere as a result of the process of training in reading the particular languages (Yiddish is read from right to left, English from left to right).

Heron (1957) presented the stimuli bilaterally (simultaneously in both left and right visual fields) rather than unilaterally (in right or left visual field) and found a left visual field (right hemisphere) advantage. Heron suggested "directional postexposural scanning" of a rapidly decaying memory trace to account for this finding. Heron's explanation is compatible with his results and with those of Mishkin and Forgay's unilateral stimulus presentation experiments as well as those of Bryden (1960), Harcum and Jones (1962); and Terrace (1959).

Following these early studies, many more experiments were done, manipulating various types of stimulus materials, in various sorts of presentations (see White's review, 1969). Some of the findings which may be relevant to our own studies:

1. Barton et al. (1965) found a Right Visual Field superiority when three-letter Yiddish words were unilaterally presented at threshold exposures in a vertical rather than horizontal position. They suggested that this result was related to left hemisphere cerebral dominance.

2. Newhort (1966) "varied the sequential redundancy of eight-letter pseudowords. When these stimuli were presented bilaterally, the degree of sequential redundancy was found to interact with laterality differences. Newhort interpreted his data in terms of sequential processing and memory decay: Stimuli, or parts of stimuli which are highly redundant are more easily "chunked" and processed before the trace decays from memory than are low-redundant stimuli." (quoting White's review).

However, Dornbush and Winnick (1965) presented varying sequentially redundant words unilaterally and found a Right Visual Field superiority.

3. Harcum (1964) examined laterality differences between bilaterally presented symmetrical letters (H, X, Y, etc.) and asymmetrical letters (B, G, K etc.) and found that asymmetrical letters were easier to recall than symmetrical letters.

4. Wyke and Ettlinger (1961) and Bryden and Rainey (1963) presented outline drawings of familiar objects (fish, face, etc.) unilaterally, and found better recall for the objects presented in the Right Visual Field. Wyke and Ettlinger also presented the objects bilaterally and still obtained a Right Visual Field superiority.

5. Differential processing strategies may be used by the <u>S</u> depending on the spatial and directional characteristics of the

stimulus display. Increasing the spacing between letters results in poorer accuracy than for closely spaced letters, but a similar effect does not seem to occur with digits (Bryden et al. 1968).

Murray White (1969) in summarizing the results from his review of 'type and arrangement of stimulus material' suggests that "when stimulus material consisting of rows of letters or digits are presented in normal sequence, the optimal processing strategy is one proceeding from left to right. When letters and words are reversed in sequence (orientation), the best processing strategy is one which proceeds from right to left". "Material which is virtually non-directional and which demands no optimal processing strategy (forms and binary elements) could be expected to realize negligible Laterality Differences".

White also points out that whether laterality differences are observed or not could also depend upon the amount of information in the stimulus display. He suggests that "a decrement in laterality differences might be related to an increase in the number of verbal or digit elements".

Further, White points out that the evidence for a directional scanning mechanism may not be relevant to single element displays, but only to multiple-element displays.

6. Whether an experiment is conducted under conditions of minimal stimulus intensity can affect laterality differences obtained. Studies which show a differential sensitivity of the eyes used threshold stimulus intensities. When stimulus exposure durations are of the order of 100 msec., no eye-differential effects are found, according to Harcum and Dyers' (1962) study.

7. The duration of stimulus exposure has been an issue in regard to the significance of eye movements. It seems to be generally

accepted now that with stimulus exposures set at less than 200 msec. the data will not be "contaminated" by eye movements. White (1969) makes the point that the "artifactual nature of eye movements per se, as an important component of Laterality Differences, must be seriously doubted".

8. The issue of pre-exposure attentional sets has also been investigated, and White concludes that "attentional sets are not of paramount importance in accounting for Laterality Differences". But if an explanation of laterality differences in terms of the neural pathway differences is to be entertained, then this depends on central fixation, such that stimulus information from a particular visual field must impinge on a particular hemiretina.

9. White (1969) in his discussion on cerebral dominance suggests that stimuli in the Right Visual Field are transmitted to the Left, dominant hemisphere for speech "whereas stimuli from the LVF (Left Visual Field) are transmitted to the nondominant speech hemisphere -- ergo -- the superior recognition or recall of verbal material presented in the Right Visual Field, and the absence of a recognition differential for nonverbal material whether presented in the RVF or in the LVF (Bryden, 1965, 1966b)." However more recent evidence suggests that the Right hemisphere is superior for handling certain types of nonverbal material (musical patterns, faces, unnameable shapes, for example).

With regard to the apparent lack of a Right hemisphere superiority for "nonverbal" material, nonsense forms and geometric forms tended to be equally well recognized whether they were presented in the Right Visual Field or the Left Visual Field (Bryden and Rainey, 1963; Heron, 1957; Terrace, 1959). Outline drawings of familiar objects tended to be better recognized when presented to the RVF (Wyke and Ettlinger, 1961). It may have been that a verbal label was put on the geometric forms thus cancelling a Right Hemisphere superiority. A verbal label might have been put on the familiar objects also. White stated quite categorically that no definite LVF superiority had been found with the presentation of either geometric or nonsense forms, but he also made clear the difficulty in ascribing with certainty what is "nonverbal".

In 1969, White felt that the relationship between cerebral dominance and visual stimulation had not been as clearly demonstrated as the relationship between cerebral dominance and auditory stimulation, and he put forth a number of points which were relative to the disparate data.

One of the particularly interesting comments he makes refers to the use of competing stimuli in auditory asymmetry studies as opposed to the noncompetitive conditions used in visual perception laterality studies. This technique has been used in some form in the studies of split-brain patients.

Another point he makes which may be relevant to our developmental study, is that the nature of the dichotic listening task defines it more as a memory test than as a perceptual recognition one. "Functional asymmetry may thus be directly related to the ability to "hold" stimulus information rather than the ability to immediately process it, though Shankweiler and Studdert-Kennedy (1967) have argued otherwise."

The points we have mentioned from White's (1969) review (though the review is in some aspects now out of date) may have particular relevance to our developmental study; this will be considered in the Discussion of our Results.

One of the issues which White brings up is just what is nonverbal; on the converse side, what is verbal? Some have criticized the use of single letters (alphabetical material) to determine "a left cerebral hemisphere dominance for language". They object to the apparent equation of "letter = language". This is a valid criticism up to a point. Of course we should be careful that we don't mistake the paw for the whole dog.

Relevant to this issue are some "dichotic listening" experiments which were used to explore the relation of speech perception to language. Sounds of speech have been used to determine whether the left hemisphere processes them or whether the right hemisphere does or whether both equally are involved in processing. Shankweiler and Studdert-Kennedy (1967); Curry (1967); Curry and Rutherford (1967); Kimura (1967); Kimura and Folb (1968); Darwin (1969); and Haggard (1969) have all used some sort of nonsense speech and found that the right ear (left hemisphere) superiority does not depend on the stimuli being meaningful.

Shankweiler and Studdert-Kennedy (1967) used components of the speech signal to try to determine which aspects of the perceptual process depend on lateralized cerebral mechanisms. They used synthetic speech in a "dichotic listening" situation and they found a right-ear (left hemisphere) superiority for the stop consonants which was statistically significant. They also obtained a small left-hemisphere (right ear) superiority for the vowels (but this was not statistically significant).

A further study by Studdert-Kennedy and Shankweiler (1970) used natural speech to test the lateralization of final consonants, initial consonants, vowels embedded in consonant-vowel-consonant syllables, and of the consonant features of voicing and place. Significant right-ear (left hemisphere) superiorities were found for initial and final stop consonants, and articulatory features of voicing and place of production in stop consonants. A right-ear (but non-significant) superiority was found for six medial vowels. Consonant features were processed equally well by both hemispheres. Studdert-Kennedy and Shankweiler concluded that the left-hemisphere dominance in speech perception is due to its possession of a "linguistic device" and not to specialized capacities for auditory analysis. They also concluded that both hemispheres are equipped to extract the auditory parameters of a speech signal, the left hemisphere is specialized for the extraction of linguistic features from those parameters.

We have raised the issue of what we mean when we accept experiments utilizing single letters as representing language functions or being involved with language mechanisms. Researchers in the past generally seemed to have accepted that faster recognition of single letters presented in the Right Visual Field means that the left hemisphere has superior linguistic capacities. As we review further the findings of studies relating to hemisphere superiorities we should keep this problem in mind.

Gibson, Filbey and Gazzaniga (1970) found that the left visual field presentation of matched or unmatched figures (requiring a verbal response of "yes" or "no") resulted in superior reaction times in comparison to right visual field presentation. They reported the opposite hemisphere advantage for letters.

Klatzky and Atkinson (1971) found that in a memory test, the right hemisphere was superior to the left hemisphere in using pictures of common objects for stimuli (the opposite was found with letters).

Terrace (1959) reported that seventeen out of thirty Ss recognized forms presented in the left visual field better than forms presented in the right visual field (but seven out of thirty had reversed superiorities, while six Ss showed no visual field preferences).

Levy, Trevarthen, and Sperry (1972) reported a number of experiments with split-brain patients showing different right-left hemisphere superiorities. They found that the left hemisphere was dominant only when a verbal response was required.

Kimura and Durnford's (1974) finding of a right hemisphere superiority for identification of line orientation conflicted with White's 1971 finding of a left hemisphere superiority. Kimura and Durnford suggest that White's results may have occurred because his Ss had previously taken part in a letter identification task. Kimura (1957)(unpublished Master's thesis)(1959) had found that visual field differences can be influenced depending on the prior perceptual task. If a form identification is presented following a letter perception task, the left-right visual field differences are affected, but a letter identification task is not affected by the prior perceptual task. This finding suggests that material which is not ordinarily lateralized to one particular hemisphere, could be so lateralized as the result of the hemisphere being particularly engaged in the previous task.

In contrast to the finding by Bryden and Rainey (1963), also Wyke and Ettlinger (1961), that familiar objects are more easily identified by the left hemisphere, Kimura and Durnford (1974) do not obtain this finding, and suggest that it is because Bryden and Rainey had alphabetical material presented in among the pictures of objects such that the left hemisphere would have been engaged by the letters.

Another possible factor in the obtaining of White's 1971 result of a right field superiority for identification of a line orientation may be that because he only used three line orientations, verbal mediation may have been facilitated. Berlucchi (1973) has found that increasing the number of slopes between horizontal and vertical induces a shift towards right hemisphere processing.

With regard to lateralization of vigilance phenomena, Dimond and Beaumont (1971b) found that the left hemisphere produced more false positives responses in a signal detection experiment (though the overall number of signals detected was the same for both right and left hemispheres). This finding suggested that the left hemisphere may be more perceptually sensitive or that the motor control mechanism may be more sensitive. It may be that the left hemisphere is keyed to a motor response to a stimulus and not to the finer details of a stimulus.

Among Dimond and Beaumont's other studies, they found that the left hemisphere is superior for the paired-associate learning of visually associated material (1973b)(digits and key symbols associated).

Dimond and Beaumont suggested that this is an example of effortful intentional symbolic learning; in an earlier study of theirs, they found in contrast incidental (apperceptive)learning to be hemispherically equal. They also suggested that the paired-associate task might be considered a sequential one, and that therefore serial ordering is somehow a function of the left hemisphere.

The question of which, if either, hemisphere is the superior one in handling numerical calculations has found conflicting answers. On the basis of the early surgically-bisected cases, Sperry (1968) had found the right hemisphere unable to calculate. In later work, Sperry and Biersner had found evidence for calculation of at least simple numbers in the right hemisphere, as did Levy-Agresti (1968).

Dimond and Beaumont (1972e) tested normal Ss (in addition and subtraction of two-digit series) and found a greater number of correct responses from the right hemisphere (but no differences in response times). The Ss were required to respond with the hands, and not through speech.

Dimond and Beaumont (1973c) also offer as evidence that the right hemisphere operates at a "higher level" the results of a word association test. The left hemisphere was found to provide significantly more common responses, while the right hemisphere produced less common responses. The response times were the same for both hemispheres. Dimond and Beaumont suggest that this finding can be taken to indicate that the right hemisphere is specialized for the creative aspects of thought, "as concerned with the more inventive, exploratory and improvisatory aspects of mental activity".

Right Hemisphere Functions

Kimura and Durnford (1974) reviewed their work on the special functions of the right hemisphere in normal Subjects. They concluded that the right hemisphere especially served complex visuo-spatial functions, but in addition has functions which are basic to visual perception. These basic visual processes involve depth perception (Durnford and Kimura, 1971), visual point location (Kimura, 1969), perception of line orientation, and rapid scanning of a number of stimuli (1966). However, they also concluded that no left visual field superiority had been found for pattern identification tasks.

Opposite Superiorities of the Right and Left Cerebral Hemispheres.

Rizzolatti, Umilta and Berlucchi (1971) in an article in Brain suggested that whereas they had found that no functional difference between the hemispheres had been observed in a simple visual reaction time study (1971), this functional symmetry would not be expected in more complex tasks requiring "discriminative responses to visual patterns, whose recognition is subserved by neural activities located predominantly in one particular hemisphere". Rizzolatti et al. predicted that RTs would be longer in the case where the visual input is directed to the non-specialized hemisphere (and presumably must cross to the other hemisphere for analysis) than where the visual input is sent directly to the specialized hemisphere. That is, they suggested that the difference in RTs should "reflect the time necessary for interhemispheric transmission of visual information from the non-specialized hemisphere". It may be, however, that difference in response times reflect the less efficient analysis of the material by the non-specialized hemisphere.

In a choice reaction-time experiment, they utilized two types of visual stimuli, single capital letters, and photographs of faces of unknown individuals which were tachistoscopically projected to the right or to the left of a central fixation point. Specifically, the purpose of their experiment was, 1. "to show a hemisphere superiority, opposite in sign, for the two types of stimuli by a choice RT method, and 2. to find the time characteristics of the exchange of visual information between the dominant and non-dominant hemisphere".

Their results confirm their predictions that alphabetical material is more quickly processed when presented in the right visual field than the left visual field, and the opposite superiority occurs with the faces (Letters:Mean RT in Right Field = 431.5 msec., in Left Field = 450 msec., Difference = 18.5 msec.; Faces: Mean RT in Left

Field = 594.5 msec., in the Right Field = 610 msec., Difference = 15.5 msec.). They interpret these results as signifying stimulus-dependent hemisphere differences which favour the left hemisphere in the case of recognition of letters and the right hemisphere for the recognition of faces.

Eleven of their twelve Ss showed the left hemisphere advantage for letters and another eleven out of twelve Ss the right hemisphere advantage for faces recognition. This is a larger percentage of Ss showing laterality preferences than is found in most studies. It may be that their particular go-no go technique accounts for this finding. We felt it would be a good idea to replicate a part of this study (the faces experiment) to see whether we would replicate the results in terms of the number of Ss obtaining right hemisphere superiority. We repeated their letter experiment, altering the design to a choice "go-go" design, rather than the choice go-no go design they used, in order to double the amount of data obtained in the same time period they had used and in order to make a comparison with the types of decision they had required the S to make.

Rizzolatti et al. also examined the error rates for their four conditions of visual field X hand. They found no statistically significant relation between number of errors and either visual field or responding hand. All of their error rates were under 5%, and only slightly more errors were made on faces than on letters.

Geffen, Bradshaw and Nettleton (1972) had looked at error rates in connection with visual field differences for the physical or name matching of letters, and while they got opposite field-superiorities in reaction times, they found no visual field differences in errors.

CHAPTER TEN

DEVELOPMENTAL STUDY OF HEMISPHERE SPECIALIZATION FOR PHYSIOGNOMICAL MATERIAL (FACES) IN NORMAL SUBJECTS

Introduction

Hecaen and Angelergues (1962) reported that they had found facial agnosia to be almost exclusively associated with right hemisphere lesions. This defect was, however, found to be relatively rare. The reason for this finding may be that the area of the brain where face recognition occurs is small and not likely to be lesioned. It may be that face recognition is not generally lateralized to the right hemisphere; that is, it may more usually be a lateral recognition process.

Warrington and James (1967) in a study of Ss with lesions in either the right hemisphere or the left hemisphere found that those with right hemisphere lesions did not recognize well-known faces as well as those patients with left hemisphere lesions. Nor did the right-hemisphere lesioned patients perform as well as the left-lesioned patients on tests of immediate memory of previously unknown faces.

Further, the split-brain patients of Sperry were tested on a face recognition task by Levy, Trevarthen, and Sperry (1972) and it was found that the right hemisphere had the strong advantage.

Levy et al.'s experiment involved tachistoscopically presenting a split stimulus to the patient such that he saw half of one face in one visual field and half of another face in the other visual field. The two half-faces were joined in the middle. If the S was fixating on the mid-point, one half-face went to one hemisphere and the other half-face went directly to the other hemisphere. The

Ss were then to point to one picture in a free-vision array which corresponded to what they had seen flashed on the screen.

After this part on the experiment, Ss were taught the names of the three faces used. Levy reports that this was a difficult and time-consuming procedure, which required mnemonic aids such as "Dick has glasses", and they concluded that the left hemisphere could not remember the overall form of a face. When the split-faces were presented tachistoscopically, and the S asked to name the face, on 49% of the trials, the S named the face seen by the left hemisphere; on 36% of the trials, the face seen by the right, and 15% errors.

The error rate was high for the face-naming experiment, 15% as compared with an error rate of 3% for the face-pointing experiment. This high error rate suggests that the task was difficult. There was a reversal of hemisphere advantage toward the left hemisphere in the face-naming experiment, which indicates the left hemisphere response dominance in this case. The fact that the rate of right hemisphere correct responses was higher than the error rate, suggests that the right hemisphere is able to name things; to "speak".

Levy suggests that perhaps the right hemisphere "is designed for imagistic encoding, the left for linguistic encoding, and that a task which requires a learned association between the two is enormously difficult for either disconnected hemisphere."

Rizzolatti, Umilta and Berlucchi (1971) have found faces to be more quickly recognized when they are presented tachistoscopically to the left visual field than the right visual field.

Bradshaw, Geffen, and Nettleton (1972) used faces constructed from the "Identi-Kit" material to look at laterality differences. They found that when a face was first flashed centrally, and then a face to be matched to that one was flashed left or right of fixation, that the matching face identification was more easily made to faces appearing in the left visual field. The S was to press one button if the faces were the same, another button when the faces were different.

In order to determine which of two posited interpretations could best account for the left visual field result, Bradshaw, Geffen and Nettleton ran the same experiment again, requiring the Ss to say "Yes" or "No" rather than pressing buttons. If each hemisphere is restricted entirely to processing verbal material for example, or spatio-temporal, then the time differences obtained reflect the time taken to transmit the information across from one hemisphere to another. That is, a face projected to the right hemisphere, for example, would be immediately processed, but then a signal would have to be send over to the left hemisphere to initiate the vocal response. If a face were projected to the left hemisphere, then it would have to be transmitted across the corpus callosum to the right hemisphere for processing and then a signal to initiate the vocal response sent back across the corpus callosum. Thus, Bradshaw, et al., reasoned, a vocal response would preserve the asymmetry in RTs.

Alternatively, it may be that both hemispheres can process both verbal and visuo-spatial material, but each hemisphere can process one sort of stimulus faster than the other. If this were the case, then a face projected to the right hemisphere would be analyzed more quickly but a slower vocal response would be initiated than if the face were projected to the left hemisphere for analysis, where the processing would be slower but the vocal response faster. This could result in the two processes cancelling each other out so that there would be no RT differences. This is the hypothesis which

Bradshaw et al.'s data support.

Buffery (1974) found that in a series of tests of short term memory, the right-hemisphere was more accurate at matching faces (cartoon faces of four features) than the left hemisphere. The response required was a judgment of "same" or "different" (different being one feature different). Buffery was investigating a series of five types of information which he designated along a dichotomy of "easy to verbalize" (EV) versus "difficult to verbalize" (DV). The two "easy to verbalize" tests both involved words, in one case meaningful four-letter words, in the other 'nonsense' words. The "difficult to verbalize" stimuli were in one test the four-feature faces; in another, inverted four-feature faces (patterns); and in the third case "doodles" made up of four facial features randomized. Generally, he found the EV stimuli best matched (remembered) in the Right Visual Field and the DV stimuli best matched in the Left Visual Field.

Buffery (1974) had made some pathway predictions in regard to easy to verbalize and difficult to verbalize stimuli matching. In each test there were four sample/match conditions:
1. Sample to left hemisphere/Match to left hemisphere; 2. Sample to left hemisphere/Match to right hemisphere; 3. Sample to right hemisphere/Match to left hemisphere; 4. Sample to Right hemisphere/Match to right hemisphere. This was the order of accuracy for the easy to verbalize conditions. The order of accuracy for the difficult to verbalize conditions was: 4,2,3,1. Buffery had predicted that the response latencies for the correct matches in an easy to verbalize condition would be shorter where the match stimulus is initially presented to the left hemisphere than to the right hemisphere. He reasoned that this would be the case because it would take longer for the neural trace to spread to the appropriate

hemisphere where the comparison of stimuli would take place from the inappropriate hemisphere. He predicted, however, in the case of difficult to verbalize stimuli that there should be no difference in the response latencies for the four sample/match conditions because the comparisons are made in whichever hemisphere receives the stimulus first.

Furthermore, response latencies should be shortest when the hand used to respond is contralateral to the hemisphere making the comparison to the stimuli (where both the match stimulus has been initially received and the delayed comparison performed). So that in the "words" tests, the use of the right hand with the match stimulus initially registered in left hemisphere should be the fastest combination. In the difficult to verbalize tests, the contralateral hand and the hemisphere which initially received the stimulus should produce the fastest latencies. Buffery found these predictions to be supported.

Rizzolatti, Umilta and Berlucchi's Method.

In the experiment using FACES as stimuli, Rizzolatti, Umilta and Berlucchi used twelve Ss who were University students, male, right-handed, and between the ages of 19 and 24 years. Six Ss used their right eye (while the other eye was occluded by a mask) throughout the testing, and six used their left eye throughout. Each S attended for four sessions, which were run on different days. Each session consisted of a total of twenty practice trials and 164 regular trials. Each session consisted of four experimental Conditions of Hand/Visual Field combinations. The four Hand/Visual Field combinations were: right-field stimulus/right-hand responding; right-field stimulus/left-hand responding; left-field stimulus/left-hand responding; and left-field stimulus/right-hand responding. Each

Condition consisted of five practice trials and forty-one regular trials. Of the four faces presented, two were identified as positive stimuli (key to be pressed when face appeared on screen), and two were identified as negative stimuli (key not to be pressed). The face appeared at a visual angle of five degrees from the central fixation point. A regular trial was preceded by a warning signal and an "irregular fore-period of from two to three seconds, during which the S had been instructed to fixate on the central target." If the S did not respond within two seconds of the onset of the stimulus, the trial was discontinued. Apparently, incorrect items were not replaced. No information was reported about the lighting controls of the testing situation, and no statement about criterion performance on practice, if any criterion performance was required. They only state that "before actual testing, Ss learned to recognize positive and negative stimuli while being familiarized with the experimental situation".

Method

Four FACES were presented to the Subject one at a time and to either the right or the left of a central fixation point. The Model was a go-no go design. When the Subject saw either of two of the four faces, he was to press the response key (which was centrally placed in front of him) as fast as he could. The faces were the same faces as Rizzolatti, Umilta, and Berlucchi had used (1971). The faces were presented randomly to either side of the fixation point with the restriction that the same face would not appear more than twice in succession on the same side. Rizzolatti et al. did not present the faces randomly to either left or right of fixation, but rather all trials were uniformly on left or right of fixation during a particular Condition for Visual Field/Hand Responding. We felt this would encourage the S to look at that one side rather than centrally fixate, therefore we randomly presented the stimuli left and right of central fixation. However, a report by Geffen et al. (1972) suggests that the S's pre-knowledge of which side the stimulus will appear on, neither increases nor decreases the lateral asymmetry. However, Geffen et al.'s Ss appear to have had their vision carefully monitored, while Rizzolatti's were not.

There were four trays of thirty-six slides each to be presented in each testing session. Each session was of approximately one hour's duration. Testing was carried out on four different days at the same time each day, and the effort was made to test on consecutive days. Four different Conditions were administered each day; each Condition corresponding to one tray of thirty-six slides. The Conditions are: Condition I, Right Eye receives stimulus/Right hand responds; Condition II, Right eye/Left hand; Condition III, Left eye/Right hand; Condition IV, Left eye/Left hand. The trays are all counterbalanced such that within each set of 36 slides there are 18 Right Visual Field (RVF) and 18 Left Visual Field (LVF) stimuli, which are further broken down into nine (9) positive (key is pressed) and Nine (9) negative (key is not pressed) stimuli within each set of 18. The total number of regular trials each day was 144. Over four days' testing, the total number of trials was 576. The order of presentation of the Conditions and the trays of slides were according to a Latin Square randomization. For example, S Number 1 received:

DAY I: C1T1 (Condition 1, Tray 1), C2T2, C3T3, C4T4.
DAY II: C2T4, C3T1, C4T2, C1T3.
DAY III: C3T2, C4T1, C1T4, C2T3
DAY IV: C4T3, C1T2, C2T1, C3T4.

S Number 2 would then have received:

DAY I: C2T4, C3T1, C4T2, C1T3.
DAY II: C3T2, C4T1, C1T4, C2T3.
DAY III: C4T3, C1T2, C2T1, C3T4.
DAY IV: C1T1, C2T2, C3T3, C4T4.

and so on.

The faces were projected at a visual angle of five degrees from the edge of the face to the central fixation point of the screen. The Subject's eye was positioned at about 72 cm. in a straight line from the center fixation dot forming a right angle to the screen.

The Subject was positioned with his head on a chin rest which had side bars to structure the position of the head. One eye was covered by an eye-patch while the other eye was in use. The response key was in front of the S, and the S rested her forefinger lightly on the top of the key.

The Subject was told that he would hear a buzzer and that would be the signal to fixate with the designated eye on the central point. The face would appear immediately when the buzzer stopped. The buzzer was on for 1.8 seconds during which time the slide change occurred. The face was presented for 180 msec. (the 180 msec. figure was arrived at after a brief pilot study. The 100 msec. used by Rizzolatti et al. was too brief an exposure period for our young Ss to be able to learn the task in a reasonable time. We wanted to keep the exposure time well under 200 msec. to avoid the possibility of eye movements while stimulus was exposed.) The Subject was told that it was very important to be sure he was fixating when signalled to do so, because he might not see the face if he was looking to one side or the other.

Prior to the main part of each condition, the Subject was given a number of practice trials to familiarize himself with that particular condition. This number of practice trials varied with each Subject, the criterion for going on to the main part of the test being the general one that the Subject should be making very few or no errors in the practice section. The intent was that the Subject should have learned the face-response association well, prior to the main part of the experiment. This was to be a recognition task, not a learning task. To help the Subject learn the task initially, at the beginning of the day's session he was shown a series of eight slides comprising all FACE-VISUAL FIELD combinations. When he could get them all correct, the main part of the experiment was begun (the fallacy with this procedure was that the Subject could learn the <u>order</u> of the faces, rather than the faces themselves and could go on to the main part without thoroughly knowing the faces, and thus make quite a few errors). In the short practice section, usually of five trials before the beginning of each condition, the FACE-VISUAL FIELD presentation was randomized.

During one set of practice trials, a TV camera monitored the position of the Subject's eye during the time the Subject was instructed to fixate on the center point of the screen. None of the Subjects had any trouble fixating on being signalled to do so.

The timer was set to begin when the projector shutter opened exposing the stimulus and stopped when the Subject responded. If a Subject did not respond within 3.5 seconds the trial was terminated. Errorful trials were repeated after the main part of that particular test Condition. If very few errors were made, extra trials were interjected among the repeats, so that the Subject wouldn't know which face and where it would appear. The relatively long response period of 3.5 seconds limits was utilized (Rizzolatti et al. abandoned the trial after two seconds) because we expected the young children might be quite slow in responding.

A single channel group tachistoscope with 150mm lens was used. This is a GAF 603 automatic slide projector which used a 500 watt super Halogen Lamp. The projector had been modified (by Forth Instruments) by the addition of a high speed galvanometer which operated a shutter membrane to obscure the light path. The rise and fall time of the shutter was 1.5 msec. for each operation (total 3.0 msec.). The opening of the shutter was simultaneous with the activation of a msec. counter (accurate to one msec.). The material was projected on to a back-projection screen. A neutral density filter was placed in front of the projector to cut down the amount of light coming through when the stimulus was exposed (the 500-watt lamp was too powerful for comfortable viewing).

<u>Subjects</u>. Three Age Groups were used in this developmental study. There were 12 female <u>S</u>s used in each of the three groups. The youngest group were seven and eight years of age (Mean age = 7 years 9 mos.) with an age range from 7 years 3 mos. to 8 years 4 months. The Middle Age Group were thirteen and fourteen year old <u>S</u>s (Mean Age = 13 yrs. 10 months) with an age range from 13 years 6½ mos. to 14 years 4 mos. The oldest group was a University Age Group between 18 years 3 mos. and 20 years 8 mos. (Mean Age = 19 years 6 mos.).

All the Subjects were right-handed except two left-handers (non-familial) in the 7/8 year old group and one non-familial in the University age group. It was originally intended to use only right-handers, but we felt that the handedness of the youngest group might not be clearly stabilized, and we therefore used the 12 oldest female children in one particular school classroom on the assumption that we might get a better picture of what we were looking at if we didn't select out certain children.

The Subjects from the youngest group were from one class of a local Scottish primary school. The middle age group were volunteers from different classes of the junior school to get a wider range of intelligence than would be obtained from one class. The adults were University students at St. Andrews University and most were first or second year Psychology students. All of the adults were likewise unpaid volunteers.

Results

An Analysis of Variance of all three Age Groups combined was computed (Table I).

There is a significant ($p < .05$) Age Group difference. Inspection of the Total Means for each Age Group indicates that there is not much difference between the Adult and 14-year-old Groups, but there is a large difference in Mean length of Reaction Time between the two older groups and the Youngest Group (7/8-year-olds). The Total Mean RTs are: Adult, 967.6 msec., 14-year-olds, 1005.5, and Children (7/8-year-olds), 1362.5 msec. The Adults have faster RTs than the children.

The Visual Field Factor is also significant ($p < .05$). There is an overall Left Visual Field superiority for Face Recognition. This result is in accordance with the Rizzolatti et al. (1971) finding.

The Age Groups X Visual Field Interaction is significant ($p < .05$). The prediction, which is supported, was that the two older

TABLE I. FACES. Seven-Way Analysis of Variance on Data for All Three Age Groups.

Source of Variance	Sum of Squares	df	Mean Squares	F	* (sig.)
Between Subjects	169061547.5	35			
A (3 Age Groups)	72913167.4	2	36456583.7	11.9110	* .01
B (Faces 1+3 vs 2+4)	2715276.2	1	2715276.2		
AB	1610353.8	2	805176.9		
Error Between	91822750.1	30	3060758.3		
Within Subjects	311000092.5	2268			
C (Sub-Groups of Ss)	5895866.4	1	589566.4	8.4804	* .01
AC	1800041.9	2	900021.0	1.2946	not sig.
BC (Faces) (Face Groups)	42125441.0	1	42125441.0	60.5915	* .01
ABC (Age Groups X Faces)	335454.5	2	167727.2		
Error (C)	20857117.1	30	695237.2		
D (Visual Fields)	1878415.8	1	1878415.8	6.4630	* .05
AD (Age Groups X VF)	2990859.7	2	1495429.8	5.1453	* .05
Error (D)	8719188.7	30	290639.6		
CD	912643.8	1	912643.8	11.0480	* .01
BCD (Face/Groups X VF)	423848.4	1	423848.4	5.1309	* .05
Error (CD)	2478209.0	30	82607.0		
E (Hands)	8908.8	1	8908.8		
AE (Age Groups X Hands)	141903.8	2	70951.9	1.0207	not sig.
Error (E)	2085448.9	30	69515.0		
BCE (Face/Groups X Hands)	248673.7	1	248673.7	3.7242	not sig.
ABCE (Age Groups X Face/Groups X Hands)	1184534.6	2	592267.3	8.8700	* .01
Error (CE)	2003160.0	30	66772.0		
DE (Visual Field X Hands)	8249.7	1	8249.7		
ADE (Age Groups X VF X Hands) (Pathway)	129390.6	2	64695.3	1.4535	
Error (DE)	1335269.4	30	44509.0		
F (Eyes)	177947.7	1	177947.7		
G (Days)	33374888.6	3	11124962.9	30.7225	*.01

TABLE I. FACES (Continued).

Source of Variance	Sum of Squares	df	Mean Square	F * (sig.)
AG (Groups X Days)	3431807.6	6	571967.9	1.5795 not sig.
Error (G)	32589966.2	90	362110.7	
Error (F)	6477115.2	30	215903.8	
DG (Visual Field X Days)	1027479.5	3	342493.2	5.2216 * .01
Error(DG)	5903294.3	90	65592.2	
ABCDEFG	230659.9	6	38443.3	
Error (CDEFG)	3827851.0	90	42531.7	
+				

+ No other Interactions are significant.

groups would have Left Visual Field superiorities for recognition of FACES, and that the 7 and 8 year-olds would not be as strongly lateralized as the older groups. The Mean differences between Visual Fields are for Adults, +118 msec.; 14-year-olds, +97 msec.; and for 7/8 year-olds, -44 msec. Inspection of the individual S Means for RVF versus LVF (Right Visual Field versus Left Visual Field) (Table II) reveals that each of the 12 Adult Ss and each of the 12 14-year-old Ss had a Left Visual Field (Right Hemisphere) superiority in Reaction Time to FACES. Of the 12 children, four Ss showed a Mean Left Visual Field superiority and eight Ss showed a Mean Right Visual Field superiority.

There is a highly significant ($p < .01$) FACE difference over the three Age Groups, with FACE 2 responded to most quickly, then FACE 3, FACE 4, and FACE 1 (slowest response), We assume that length of Reaction Time is relative to difficulty of recognition; the longer the RT, the more difficult the face to recognize.

There is an overall significant ($p < .05$) FACE X Visual Field Interaction, which is that FACES 1,3, and 4 are responded to more quickly when they appear in the Left Visual Field than in the Right Visual Field, but FACE 2 is responded to more quickly when it appears in the Right Visual Field than when in the Left Visual Field. This is possibly somehow related to ease of discriminability, FACE 2 being more easily recognizable than the other FACES. It may be that FACE 2 was easier to put a verbal label on and so was processed differently.

The Right/Left Hand differences and the Right/Left Eye differences were not found to be significant.

The Visual Field X Hand Interaction was not found to be significant. This is in accordance with Rizzolatti, Umilta, and Berlucchi's finding. Rizzolatti et al. state that they found in their

TABLE II. Individual *S* Means for Right and Left Visual Fields: All Three Age Groups. Reaction Time in Msecs. to FACES.

ADULTS	RVF	LVF
S 1	648.9	591.2
S 2	1061.8	901.2
S 3	932.8	784.8
S 4	829.3	792.0
S 5	1397.8	1332.8
S 6	945.8	911.7
S 7	861.8	771.0
S 8	1402.2	1074.6
S 9	996.1	815.3
S 10	887.6	885.6
S 11	954.8	838.0
S 12	1402.6	1202.7

MIDDLE (Age 14)	RVF	LVF
S 1	849.0	827.5
S 2	1009.4	868.6
S 3	1006.1	897.1
S 4	749.2	725.7
S 5	1258.6	1055.5
S 6	1193.6	1066.3
S 7	773.0	699.4
S 8	921.8	824.1
S 9	1102.4	1000.0
S 10	1198.9	1134.3
S 11	1379.4	1296.9
S 12	1175.7	1088.1

YOUNGEST (Age 7/8 yrs)	RVF	LVF
S 1	1705.3	1606.9
S 2	1296.7	1916.4
S 3	1345.9	1351.3
S 4	1226.8	1256.0
S 5	1217.2	1253.4
S 6	1062.6	1105.1
S 7	1617.6	1495.2
S 8	1466.1	1423.3
S 9	1090.9	1176.4
S 10	1355.8	1163.4
S 11	1025.7	1105.5
S 12	1674.9	1726.5

data a trend for "a faster response with the hand ipsilateral to the stimulus." Our hypothesis was that the order of Means for Visual Field/Hand would be:

Model: LVF/LH (Fastest), LVF/RH, RVF/LH, RVF/RH (Slowest).

This order of pathway speed is based on the model that FACES are best (most quickly) analyzed in the Right Hemisphere (and what is seen in the Left Visual Field goes directly to the Right Hemisphere), and the motor response for the Left Hand is initiated in the Right Hemisphere (the contralateral hemisphere). Thus the most efficient hemisphere for analyzing faces and the most efficient motor response for the Left Hand is initiated in the Right Hemisphere, and without necessity to posit transfer of any information across the Corpus Callosum. Therefore, LVF/LH should result in the shortest RT. The RVF/RH should result in the slowest RT because what is seen in the Right Visual Field goes directly to the Left Hemisphere which is the less efficient hemisphere for dealing with faces, and we would suggest that the information about the face is transferred across the Corpus Callosum to the Right Hemisphere for analysis and back across the Corpus Callosum to the Left Hemisphere where the motor response to the Right Hand is then initiated (thus we get two crossings of the Corpus Callosum).

The order of the two middle pathways is suggested because analysis of the visual stimuli received by the "wrong" hemisphere takes longer than in the "best" hemisphere and in either of the two cases only one crossing of the Corpus Callosum is it necessary to posit to get the most "efficient" motor response, or because the stimulus received by the "wrong" hemisphere is transferred to the hemisphere best suited to deal with it.

For our three Age Groups combined Analysis, the order of the Visual Field/Hand Means was:

LVF/LH (fastest); LVF/RH; RVF/LH; RVF/RH (slowest), which is the same order as in our pathway model. However, looking at the VF/Hand Means for each Age Group separately (Table III), we find that while the 14-year-olds' group accords with our model, the adult order changes slightly, being:

LVF/LH (fastest); LVF/RH; RVF/RH; RVF/LH (slowest), instead of the Model's 1,2,3,4, we get 1,2,4,3. The youngest Age Group (7/8-year-olds) exhibits the order:

RVF/RH (fastest); RVF/LH; LVF/RH; LVF/LH (slowest).

Table III FACES, Pathway Means for Each Age Group (Visual Field/Hand)

	LVF/LH	LVF/RH	RVF/LH	RVF/RH
Adults	905.421	911.400	1031.838	1021.761
Middle Group (14 year olds)	956.711	957.215	1028.757	1079.125
Youngest Group (7/8 year olds)	1387.516	1381.478	1349.019	1331.879

* 12 Ss in each age group.

Rather than the Model 1,2,3,4, we get here: 4,3,2,1. It is interesting that this is exactly the order we would expect were the study verbal in nature. None of these Pathway orders reaches significance, although there seems to be a trend ($p < .25$) for the 14-year-old Age Group (which order is the same as our Model).

What can we say about whether our RT results for FACES reflects interhemispheric transmission time, or less efficient analysis of a non-dominant hemisphere?

Our Analysis of Variance does not find pathways (Visual Field X Hand) significant, but the overall trend is in the same order as our hypothesized Model. However, breaking down the data into each age group, only the 14-year-olds accord with our model, while there is a trend in the same direction with our adults, but the youngest group is exactly reversed from our model. We do find some support for our model of interhemispheric transmission, particularly with the Middle Age Group. The older group fits in with a more efficient hemisphere vs less efficient hemisphere model in that Left Visual Field is faster than Right Visual Field, and the RVF/RH pathway, which we would expect to be slowest in this case because our interhemispheric model would require the RVF stimulus to Left Hemisphere to cross the Corpus Callosum to be analyzed in the Right Hemisphere and back across to the Left Hemisphere for motor response to be initiated (thus requiring two crossings) is not the slowest.

Overall, there seem to be quite large differences between Left Visual Field and Right Visual Field, which suggests that it is more than a matter of interhemispheric transmission time effects. If the stimulus goes to the left hemisphere first, it may be that the signal is degraded by the less efficient hemisphere and some of the signal is thereby lost for transmission to the more capable hemisphere.

For all three Age Groups combined, there is a significant difference between days with DAY 1 having the longest Mean RTs, and decreasing RTs until DAY 4 which has the shortest RTs. We had expected that there would be such a practice effect. There is also a significant Visual Field X DAYS Interaction, but this is apparently due to the effect of the Youngest Age Group. A comparison of the means for the 14-year-old Age Group (VF X DAYS)(Not Significant) and 7/8 year old Group (significant VF X DAYS) suggests this is the case.

A separate Analysis of Variance of the Seven/Eight-year-old Age Group's responses to the four FACES shows no significant

TABLE IV. FACES. Six-Way Analysis of Variance on Data for Seven and Eight-Year-Old Group of 12 Normal Ss.

Source of Variance	Sum of Squares	df	Mean Square	F	* (sig.)
Between Subjects	36673919.0	11			
A (Sub-Groups of Ss)	4358.4	1	4358.4		not sig.
Error Between	36669560.6	10	3666956.1		
Within Subjects	125956814.4	756			
B (Faces 1 +2 vs 3+4)	5794831.8	1	5794831.8	14.6727	* .01
AB (Faces) (Face/Groups)	17051247.8	1	17051247.8	43.1744	* .01
Error (B)	3949386.2	10	394938.6		
C (Visual Field)	372515.4	1	372515.4		not sig.
Error (C)	6945859.5	10	694585.9		
ABC (Faces X VF)	292490.4	1	292490.4	2.0851	not sig.
Error (BC)	1402771.7	10	140277.2		
D (Hands)	25785.1	1	25785.1		
Error (D)	875735.9	10	87573.6		
ABD (Faces X Hands)	1266074.7	1	1266074.7	17.4058	* .01
Error (BD)	727384.6	10	72738.5		
CD (Visual Field X Hand) (Pathways)	5916.6	1	5916.6		mot sig.
Error (CD)	531298.6	10	53129.9		
ABCD (Faces X VF X Hands)	272.6	1	272.6		not sig.
Error (BCD)	761304.7	10	76130.5		
E (Eyes)	20530.8	1	20530.8		not sig.
Error (E)	2901009.3	10	290100.9		
CE (VF X Eyes)	360669.9	1	360669.9	4.0725	not sig.
Error (CE)	885617.3	10	88561.7		
F (Days)	6314788.2	3	2104929.4	8.1661	* .01
Error (F)	7732889.9	30	257763.0		
CF (VF X Days)	1215981.1	3	405327.0	3.7056	* .05
Error (CF)	3281466.4	30	109382.2		
ABCDF	584034.3	3	194678.1	2.9981	* .05
Error (BCDF)	1947988.6	30	64933.0		
ABCDEF	239241.5	3	79747.2	1.1764	not sig.
Error (BCDEF)	2033679.8	30	67789.3		

+ No other Interactions are significant.

Visual Field (Hemisphere) differences, which is as we predicted (Table IV). This result supports our suggestion that this age group is not yet clearly lateralized for the recognition of FACES, whatever the process of recognition involves.

There is a highly significant difference in mean response times to the different faces, with FACES 1 and 4 being more difficult to recognize than FACES 2 and 3. FACE 2 (round-shaped face) was the easiest face to recognize (fastest response times), then FACE 3, FACE 4, and FACE 1, in that order.

The FACE X Visual Field Interaction did not reach significance, though we had thought the level of difficulty of recognition might affect the degree of lateralization. There did seem to be a trend in this regard, however, which was that FACE 2 (presumably the 'easy' face to recognize) was more strongly lateralized and also lateralized to the Right Visual Field (left Hemisphere) than the other faces. This apparent lateralization of a face to the Left Hemisphere is interesting because it suggests that faces per se are not lateralized to the Right Hemisphere, but that something about what information is used in the processing of a face is lateralized. It may be that the 'easy' face was 'verbalized' by these young Ss. It may be that only one element, the roundness, was needed to identify the face.

We have found support for the notion of ease of discriminability in Buffery (1974) which we have discussed in the Introduction to this study.

Still referring specifically to the 7/8 year old group, there was no significant difference between Right and Left Hands in responding. There was no significant Visual Field X Hand interaction, to suggest anything about pathways for the transmission of the information involved in recognizing and responding to the visual stimulus.

There are no significant differences between Right and Left eyes, and there is no significant Visual Field X Eye Interaction.

The difference between DAYS is significant; the first day being the day of slowest Reaction Times, and the fourth day being the day of fastest Reaction Times, such that there is a strong practice effect simply in overall Reaction Times.

There is a significant Visual Field X DAYS Interaction, which is that on the first day, there was a LVF superiority, and on the subsequent three days, there was a RVF superiority. The net effect of this interaction was to cancel out any apparent Visual Field lateralization effect. It may be that when the task is new and the stimuli unfamiliar, that is when this young age group will lateralize faces generally to the Left Visual Field (Right Hemisphere). Once they are familiar with the task, they will then reverse the apparent lateralization (when the faces become easy to recognize). Perhaps they begin to verbalize the task with practice. Perhaps they are just variable in the apparent lateralization of their performance, that lateralization is not stabilized for them, but dependent upon some unknown factors such as immediately preceding situation the Subject was in, thus having engaged the 'attention' of the particular prevailing hemisphere. That is, whether the immediately preceding set was predominantly verbal or nonverbal for example, if that is the relevant dichotomy.

What does this particular task of face recognition require of the S to perform it? The S is asked to "learn" four faces that were previously unknown to her. This requires the faces to be put in a memory store, then when a particular face is flashed on the screen, it serves as a memory probe. A comparison between what was flashed on the screen, and the faces in the memory storage is necessary before a response is decided upon. The comparison may be that it is this face, not this or this or this; if it is this face, do I press the key? If Yes, press key. We are putting the possible strategy into words here, but it may be a nonverbal strategy, or in the case of the "difficult" faces, a nonverbal strategy; in the case of the "easy" face, a verbal strategy. The strategy we described appears to be a serial one. Another strategy might be sometimes that the face that is just flashed on the screen is the same/different as the one responded to before, or this may be part of the previously described strategy.

An effort was made to get at how the S̲s recognized the faces or analyzed the faces, by simply asking them, after the experiment was over, what they had done, how did they tell the faces apart? Many S̲s were fairly vague generally, but had perhaps picked out one or two elements they felt differentiated the faces. Most S̲s said that one face was different from the others because it was round (the easy face to recognize). The children were more unlikely to come up with anything of a description or verbal label. Some of the responses were, "Well, this face is brown," (faces were in black and white). This one has a moustache. This one has heavy eyebrows. This one looks mean. This one looks down. This one looks straight at me. One adult gave the faces names. This face is thinner. They did appear to pick one feature, often something about the eyes, with which to identify the faces. The face most consistently labelled was the round face. These are the impressions of the Experimenter's inquiry, not statistically recorded.

Looking again at our adult data, we see that in comparison to Rizzolatti et al.'s data, our Mean RT was 967 msec., while Rizzolatti's was about 602 msec. This seems to indicate that the task was more difficult for our Ss than for Rizzolatti's. Possibly the fact that Rizzolatti's Ss knew which side of the central fixation point the stimulus was going to show up on made the task easier generally, if it did not contribute to a lateral asymmetry. A further contribution to the possibility of a wandering eye from central fixation was that Rizzolatti's Ss had a delay of from two to three seconds between warning signal and appearance of stimulus. Our stimuli were presented for a longer period of time (180 msec. compared to Rizzolatti's 100 msec), which should have made the task easier for our Ss. It may be that the "foreignness" of the faces affected our Ss, such that our British Ss found them more difficult to identify, but this seems unlikely. It is likely that our stimuli were presented in less brightly illumined conditions and the stimuli themselves were less bright (intense) than in Rizzolatti's conditions.

Our Ss also made more errors than Rizzolatti's. Their error rate was less than five percent and not significantly different for hands or side of stimuli.

Looking at the relationship between error rates and lateralization of cerebral function, we compared the error rates between the 14-year-old Group and the 7/8 year old group, and the Adult Group.

For the 14 year-old Group there were more Right Visual Field than Left Visual Field errors (207/1728 RVF versus 123/1728 LVF errors). A Wilcoxon Matched-Pairs Signed-Ranks test showed this difference to be significant at $<$ .05 level of Significance. It appears that the faster hemisphere is also the more accurate in the recognition of faces. More errors were made on FACE 4 > FACE 1 > FACE 3 > FACE 2, indicating the levels of difficulty. The error rate was .1198 for the RVF, and .0712 error rate for the LVF (these are errors where S failed to press the key). The overall error rate was .0954 = 9-10% error rate.

Examining the error rates for the 7/8 year-old Group, we find more Left Visual Field errors than Right Visual Field errors (406/1728 LVF versus 255/1728 RVF errors). This difference in errors between RVF and LVF is significant at < .01 level two-tailed test (Wilcoxon Matched-Pairs Signed-Ranks Test). The Reaction Time difference between Visual Fields was not significant, though there was a trend to faster response to RVF (which is opposite that of the older groups). Half the Young Ss had a RVF trend and half a LVF trend to faster RT. The difference in accuracy perhaps tells us more about how the youngest Group is lateralized in regard to face recognition, as the error rate is opposite to what we might expect in adults, that is, in this youngest Group there appears to be a lateralization in regards to accuracy of recognition, but it is opposite that of the 14-year-olds; RVF (Left Hemisphere) being more accurate than the LVF (Right Hemisphere) in this younger Group.

In this youngest Group there were more errors made on FACE 1 > FACE 4 > FACE 3 > FACE 2. This order of difficulty is similar to the 14-year-old group essentially, except that the two more difficult faces were reversed in order of number of errors for the older group.

The overall error rate for each face (for the Youngest Group of Subjects) correlates with the length of Reaction Time for each face: that is, FACE 2 has fewest errors and fastest Reaction Time, while FACE 1 has most errors and slowest Reaction Time.

In the 7/8-year-olds, the apparent lateralization of FACE 2 to the Left Hemisphere found reflected in the differences in Reaction Time to FACE 2, is also reflected in the apparently strong lateralization in terms of accuracy of recognition to the Left Hemisphere for this face. The Visual Field differences are not so great for the accuracy of recognition of the other faces, though they are in the same direction as FACE 2 (i.e., Left Hemisphere more accurate).

Half of the youngest group of Ss had a Left Visual Field reaction time trend and half of the Ss had a Right Visual Field RT trend, but the error rate does not reflect this 50-50 trend, in that 11 of the 12 Ss had fewer errors in the RVF (left hemisphere) than in the LVF.

The overall error rate for the 7 and 8 year-olds was 19%. This is higher than we would like, but we were restricted as to duration of exposure of stimuli and practice time. The RVF error rate was 15%, and the LVF error rate was 23%.

The youngest group made twice as many errors as the 14 year-old group.

For the adult group, there were more RVF errors than LVF errors (230 RVF errors versus 212 LVF errors), as for the 14-year-old group, but in this case the difference did not reach significance on the Wilcoxon Matched-pairs Signed-Ranks Test. More errors were made on FACE 1 (199) $>$ FACE 4 (135) $>$ FACE 3 (63) $>$ FACE 2 (44), as for the 7/8 year-old group. The error rate for RVF was 13.3% and for LVF was 12.3%. Overall error rate was 12.8%.

For the Adult Group, five Ss show more LVF errors and seven Ss show more RVF errors.

For the Adult Group, FACE 2 does not appear to be lateralized to one hemisphere or the other, nor does FACE 3, while there is more of a visual field difference trend for FACES 1 and 4 (but in opposite directions). For the 14-year-old group, the Visual Field differences for the four faces all go in the same direction, but in this case FACE 1 appears more lateralized than FACE 3 > FACE 2 > FACE 4. So this aspect of the error data for the two older groups is not consistent.

SUMMARY OF FINDINGS FOR FACES EXPERIMENT

To summarize our findings: The 14-year-old girls and the University student age group showed the Right Hemisphere superiority for face recognition. The 7/8 year-old girls showed no overall Visual Field differences for faces.

There is a significant overall difference in Reaction Time for the three Age Groups, with the adults being fastest in response and the children slowest.

There is a significant Visual Field X FACE interaction such that the "easiest" face to recognize is more quickly responded to when it appears in the Right Visual Field than the Left Visual Field. We see this as support for our notion that ease of discriminability versus complexity of discrimination contributes to lateralization of the cerebral hemispheres. The ease of verbalization may be part of the ease of discriminability.

The Pathway (Visual Field X Hand difference) was not found to be significant.

The Visual Field differences in error rates were analyzed for all three groups and found to be significant for the 7/8 year olds and 14 year olds (but opposite in direction), and not significant for the adults though the directional trend was the same as for the 14-year-olds. Rizzolatti et al. had not found a significant error rate for their adults either.

CHAPTER ELEVEN

DEVELOPMENTAL STUDY OF HEMISPHERE SPECIALIZATION FOR ALPHABETICAL MATERIAL (SINGLE LETTERS)

Introduction

We initially decided to do a developmental study of the lateralization of letter recognition replicating the design of Rizzolatti, Umilta and Berlucchi's (1971) experiment on adults (which we have described previously with particular reference to our faces experiment). We have altered the experimental design somewhat as will be described in the METHODS Section. We have already described Rizzolatti et al's finding of a Right Visual Field Superiority for single letters tachistoscopically presented and some other relevant Right Visual Field superiorities found by other researchers. We include here a few more findings relevant to the issue of hemisphere superiorities in response to visually presented language-related stimuli.

In contrast to the earlier report by Heron (1957), McKeever and Huling (1971a) found that when two words were flashed simultaneously, one to each visual field, the right visual field was superior to the left visual field. This effect may have been due to better control of central fixation (a digit which had to be reported was exposed at the fixation point prior to exposure of the words). Further, the exposure times were of the order of only 20 msecs., and we know that laterality differences can be facilitated when minimal exposure times are used. McKeever and Huling suggested that the left hemisphere superiority may be due to the delay involved in transcallosal transmission of information or the loss of information in this transfer.

Coltheart and Arthur (1971) found neither right nor left advantage when they presented letters in a line across both visual fields and required the Ss to report letters in different positions.

Kimura (1966) presented letters to the right or left visual field of some 15 male and 30 female right-handed nurses and found the letters presented in the right visual field were easier to identify.

In this developmental study of hemisphere lateralization, our main prediction which we expect to confirm is that the youngest group of Subjects will not demonstrate as much hemisphere lateralization for recognition of single letters as the older groups of Subjects.

Further, we intend to analyze other factors which may provide information about hemisphere interactions. We want to get a more clear idea about what factors are involved and to what extent differing variables contribute to the total variance. Specifically, we want to examine pathway differences, hand differences and eye differentials, if any, and to make comparisons of reaction times across our age groups as well as with Rizzolatti et al.'s (1971) data.

We want to compare error rates in our age groups with reaction time results as possible indicators of hemisphere superiorities. We also will examine visual field error rates in each age group for each letter to determine whether a specific letter error rate is related to a particular visual field.

Method

Four letters (A, K, F, R) were presented to the Subject one at a time and to either the right or the left of a central fixation point. When the Subject saw either 'F' or 'R' he was to press one of the two response keys as fast as he could. When he identified either of the other two letters he was to press the other key. The letters were selected initially as the ones used by Rizzolatti et al. (1971), then one was changed ('E' changed to 'K') because it was noted that only one feature differed between the original pairs of letters. The letters were presented randomly to either side of the fixation point with the restriction that the same letter would not appear more than twice in succession on the same side.

There were four trays of 36 slides each to be presented in each testing session. Each session was of approximately 50-55 minutes duration. Testing was carried out on four different days at the same time each day and the effort was made to test on consecutive days. Four different Conditions were administered each day; each condition corresponding to one tray of 36 slides. The Conditions are: Condition I, Right Eye /Right Hand; Condition II, Right Eye/ Left Hand; Condition III, Left Eye/Right Hand; and Condition IV, Left Eye/Left Hand. The trays are all counterbalanced such that within each set of 36 slides there are 18 Right Visual Field (RVF) and 18 Left Visual Field (LVF) stimuli which are further broken down into 9 negative (to be responded to on key A) and 9 positive (to be responded to on Key B) stimuli within each set of 18. The total number of regular trials each day was 144. Over four days' testing, the total number of trials was 576. The order of presentation of the Conditions and the trays were counterbalanced according to a Latin Square randomization. For example, S̲ Number 1 received:

DAY I: C1T1 (Condition 1, Tray 1). C2T2, C3T3, C4T4.
DAY II: C2T4, C3T1, C4T2, C1T3
DAY III: C3T2, C4T1, C1T4, C2T3
DAY IV: C4T3, C1T2, C2T1, C3T4

S 2 would then have received:

DAY I: C2T4, C3T1, C4T2, C1T3

DAY II: C3T2, C4T1, C1T4, C2T3

DAY III: C4T3, C1T2, C2T1, C3T4

DAY IV: C1T1, C2T2, C3T3, C4T4

and so on.

The letters were projected 7.6 cm. from the mid-point of the letter to the central fixation point of the screen. The Subject's eye was positioned at 72.3 cm. in a straight line from the center fixation point forming a right angle to the screen. This gave a visual angle of approximately 6 degrees, allowing for some variation in the distance of the letter from the central point due to shifting of the position of the slide when changing from one slide to another. However, the variation was not more than one degree.

The Subject was positioned with his head on a chin-rest which had side-bars to structure the position of the head. One eye was covered by an eye-patch while the other eye was in use. The response keys were positioned toward the same side as the hand being used and the Subject rested his forefinger lightly on the top of and centered between the two keys.

Whether the Subject was using his right or his left hand, the same keys were always in the same relative position to each other. That is, Key A was always on the right of Key B regardless of whether both keys were positioned to the right or the left of the midline of the Subject. For half the Subjects the actual keys were switched, but letters A, K were always responded to on the left-oriented key and F, R were always responded to on the right-oriented key.

The Subject was told that he would hear a buzzer and that would be his signal to fixate with the designated eye on the central point. The letter would appear immediately when the buzzer stopped. The buzzer was on for 1.8 seconds during which time the slide change occurred. The letter was presented for 100 msecs. The Subject was told that it was very important to be sure he was fixating when signalled to do so, because he might not see the letter if he was looking to one side or the other.

Prior to the main part of each Condition, the Subject was given a number of practice trials to familiarize himself with that particular Condition. This number of practice trials varied with each Subject, the criterion for going on to the main part of the test being the general one that the Subject should be making very few errors or no errors in the practice section. The intent was that the Subject should have learned the letter-key associations well, prior to the main part of the experiment. This was to be a recognition task, not a learning task.

During one set of Practice Trials, a TV camera monitored the position of the Subject's eye during the time the Subject was instructed to fixate on the centre point of the screen. None of the Subjects had any trouble fixating on being signalled to do so.

The decision was made not to do an exact replication of Rizzolatti et al.'s experiment, with the notion that random presentation to either side of fixation would enhance the probability of central fixation during stimulus onset; and with the use of two keys in a "go-go" design which still required a choice decision but had the advantage of doubling the amount of data collected, as well as providing a contrast in designs (the possible disadvantage was that there might be a key orientation effect).

Subjects: We used three Age Groups, 12 Ss in each group. The oldest group was of University students (mostly first and second year), the middle group was made up of 13 and 14 year old females from a local school, and the youngest group was made up of 7 and 8 year old girls. All Ss were right-handed in the adult and middle age groups, but a couple of the youngest group were left handers, though not familial left-handers.

Results

An Analysis of Variance of all three age groups combined was computed. This was a six-factor analysis (Summary Table I). We find that there are significant differences between the three Age Groups (overall Reaction Time Means are: Adults: 517 msec., 13/14 year olds: 506 msecs.; and 7/8 year olds: 1005 msecs.). The youngest group is much slower in responding.

There is an overall significant Visual Field Difference in the direction of the predicted Right Visual Field superiority for letters (RVF X = 668 msecs.; LVF X = 684 msecs.; an overall Mean Difference of 16 msecs.). Analyzing the three Age Groups separately shows that the Adult and 14 year old Groups each have significant Visual Field differences in the predicted direction. The Youngest Group, the 7/8 year olds, while they have a larger Mean difference (see Table II) between Visual Fields, and in the same direction as the older groups, this difference is not significant. This is presumably because of the greater variation in responses in the young children, indicating unstable lateralization.

Over all groups there is a significant Right Hand versus Left Hand difference. There is also a significant Hand X Age Group interaction. Looking at the groups separately, the two older groups do not show a significant difference between Right and Left Hands

TABLE I. LETTERS. Six-Way Analysis of Variance on Data for All Three Age Groups.

Source of Variance	Sum of Squares	df	Mean Squares	F	*(sig.)
Between Subjects	161190256	35			
A (Age Groups)	124857232	2	62428608	56.7017	* .01
Error Between	36333008	33	1101000		
Within Subjects	25566464	2268			
B (Visual Field)	143579	1	143579	15.0037	* .01
AB (Age Group X VF)	14907	2	7454		
ERROR (B)	315796	33	9570		
C (Keys)	203572	1	203572	10.6697	* .01
AC (Age Group X Keys)	101800	2	50900	2.6678	not sig.
Error (C)	629620	33	19079		
BC (VF X Keys)	356387	1	356387	29.7203	* .01
ABC (Age Group X VF X Keys)	59974	2	29987	2.5007	not sig.
Error (BC)	395715	33	11991		
D (Hands)	60018	1	60018	4.1913	* .05
AD (Age Groups X Hands)	114754	2	57377	4.0069	* .05
Error(D)	472543	33	14319		
BD (Visual Field X Hands) (Pathways)	7264	1	7264		
ABD (Age Group X Pathway)	1834	2	917		
Error (BD)	255689	33	7748		
CD (Key X Hand)	22291	1	22291	5.2136	* .05
ACD	10691	2	5345	1.2502	not sig.
Error (CD)	141094	33	4276		
E (Eyes)	16891	1	16891		
AE (Groups X Eyes)	29870	2	14935		
Error (E)	1074231	33	32552		
F (Days)	828654	3	276218	5.9008	* .01
AF (Age Groups X Days)	740357	6	123393	2.6360	* .05
Error (F)	4634182	99	46810		
CEF	37627	3	12542	2.8755	* .05
Error (CEF)	431824	99	4362		

+ No other Interactions Significant.

(less than one msec. difference). In the Analysis of the youngest group, the F does not (just barely) reach significance (Table III). However, the overall group Hand Difference seems primarily due to the youngest group with a large difference of 30 msecs. between the two hands in favour of the faster Right Hand.

Table II: Letters. Visual Field Means for All Three Age Groups.

	Right Visual Field	Left Visual Field
Adult (12 Ss)	511.6219	522.9404
Middle Group (12 Ss) (14 year olds)	499.5177	512.6586
Youngest Age Group (12 Ss) (7/8 year olds)	993.9604	1016.8659

There is no significant Pathway difference (Visual Field X Hand Interaction) over all three Age Groups, and no suggestion of a difference.

There is a significant Key X Hand Interaction over all three Age Groups, which indicates that while both hands respond faster on the left key than on the right key, the right hand responds much faster on the left key than the left hand. There is not much difference between hands on the right key.

There is no eye difference over all three age groups.

There is a significant DAYS difference. There is also a significant Age Group X DAYS Interaction. The two oldest groups were slowest the first day and fastest the fourth day as one would expect from a practice effect, and this is a significant DAYS difference. The youngest group was slowest the fourth day and fastest the second day (the order of days from slowest to fastest being Day 4, Day 1, Day 3, then Day 2)., but the separate analysis of variance for this age group showed this DAYS difference not to be significant.

TABLE III. LETTERS. Five-Way Analysis of Variance on Data for 7/8 Year-Old Age Group of 12 Normal Ss.

Source of Variance	Sum of Squares	df	Mean Squares	F	* (sig.)
A (Visual Field)	100734.8	1	100734.8	4.2160	not sig.
B (Keys)	257484.7	1	257484.7	7.9919	* .05
AB (VF X Keys)	267049.3	1	267049.3	9.2196	* .05
C (Hands)	174577.7	1	174577.7	4.8323	not sig.
AC (VF X Hand) (Pathway)	7085.3	1	7085.3		not sig.
BC (Keys X Hands)	18138.1	1	18138.1	2.2477	not sig.
D (Eyes)	41423.2	1	41423.2		
AD (Visual Field X Eyes)	3904.7	1	3904.7		
CD (Hands X Eyes)	45628.7	1	45628.7	1.2261	not sig.
E (Days)	906273.4	3	302091.1	2.6993	not sig.
AE (Visual Field X Days)	80877.6	3	26959.2	1.4754	not sig.
Error (AS)	262825.7	11	23893.2		
Error (BS)	354401.9	11	32218.4		
Error (ABS)	318619.2	11	28965.4		
Error (CS)	397398.0	11	36127.1		
Error (ACS)	238018.5	11	21638.0		
Error (BCS)	88763.8	11	8069.4		
Error (DS)	1019185.2	11	92653.2		
Error (ADS)	134376.4	11	12216.0		
Error (CDS)	409343.7	11	37213.1		
Error (ES)	3693242.5	33	111916.4		
Error (AES)	602983.5	33	18272.2		
Subjects	34384707.8	11	3125882.5		
+					
Total	55473881.7	767			

+ No other Interactions Significant.

Looking at the separate Analysis of Variance for the youngest group, the 7 and 8 year olds, there is no significant difference between right and left Visual Fields, though this Visual Field difference is in the same direction as the older groups and appears to be larger (overall Mean Visual Field difference for 7/8 year olds is 23 msecs.). Nine of the twelve Subjects have Right Visual Field superiorities in terms of differences between the Means. There is a significant VF X Key Interaction which indicates a tendency to respond in the direction of the stimulus. There is a significant Key difference in that responses were faster on the left key than the right key (it wouldn't appear that this reflects ease of physical response movement because on the right hand the finger moves more easily left than right, but vice versa for the left hand forefinger, so that this should cancel out). The same letters were always tied to the same left/right key orientation (F, R was on the right key and A, K was on the left key) and this may be what is reflected in the key difference -- possibly faster response to the letter A particularly, probably the easiest letter to recognize in this group of four letters).

For the 7/8 year olds, the Hand difference is not quite significant (F = 4.83; significance level would be 4.84). There is a 30 msecs. difference between Right and Left Hands in favour of the Right Hand. It seems rather a quibble over the significance level as strictly speaking, it didn't reach our required level of significance, but we feel there may be a 'real' Hand difference here.

There is no suggestion of a statistically significant Pathway difference for the 7/8 year olds. However, the Pathway order from fastest to slowest for the 7/8 year olds is:

RVF/RH (fastest) LVF/RH RVF/LH LVF/LH (slowest).

The fastest and the slowest are in the order of our model we would hypothesize for adults:

Model: RVF/RH (fastest) RVF/LH LVF/RH LVF/LH (slowest). Our model is based on the idea that there is a more efficient hemisphere for handling alphabetical material which is the left Hemisphere, and that the most efficient motor response is from the contralateral pathway connection (that is, right hand directed from Left Hemisphere, left hand from Right Hemisphere). RVF/RH would be fastest because no interhemispheric transmission is required and Left Hemisphere is most efficient for handling letters and for initiating motor response in Right Hand. LVF/LH is expected to be slowest because it requires two interhemispheric transfers to get the information processed by the most efficient hemisphere. That is, the letter received by the Right Hemisphere is transferred to the Left Hemisphere for analysis and then this information is transferred back to the Right Hemisphere to initiate left hand motor response.

In the case of our youngest group of Subjects, it appears that which hand is responding is more important than which hemisphere the stimulus is directed to, at least in the case of both pathways which require in our model one crossing of the corpus callosum.

The pathways for our two older groups are the same, namely: RVF/LH (fastest) RVF/RH LVF/RH LVF/LH (slowest). This order, compared to our model, is 2, 1, 3, 4,. In the case of these older groups it appears that which hemisphere receives the stimulus initially is more important than which hand is responding, in contrast to the 7/8 year old group.

Compared to Rizzolatti et al.'s findings for letters, our Mean overall RTs for Adults and 14-year-olds of 517 msecs. and

506 msecs., respectively, compared to Rizzolatti's 441 msecs. is not a greatly increased RT. Our Visual Field differences of 11 and 13 msecs. respectively, are comparable with Rizzolatti's RVF superiority of 18.5 msecs. These differences between Rizzolatti et al.'s data and ours possibly reflect the differences in design and therefore in the choice the Subject had to make (we used two keys, the S had to press one or the other). Possibly our smaller Visual Field differences are due to our using an easier letter (letter A) to recognize (that is, easier for the Right Hemisphere). Our task may have been more difficult because the S did not know which side of the fixation point the stimulus would appear. This could increase overall response times.

Rizzolatti et al. looked at error rates and found no statistically significant relationships between error rates and either side of stimulus or responding hand.

We found for the 7/8 year old Group, the error rate for respective Visual Fields is 6.25% for the Left Visual Field, and 5.3% for the RVF. This error rate is slightly greater for the LVF than for the RVF. The overall error rate for this youngest Age Group is 5.8%. Five Subjects had more RVF errors than LVF errors; seven Subjects had more LVF errors than RVF errors. A Wilcoxon Matched-Pairs Signed-Ranks Test for Visual Field differences in error rates does not reach significance.

More errors were made on the right key (letters F, R) (6.9% error rate) than on the left key (letters A, K) (4.6% error rate).

The total errors in regard to visual fields for each letter are:

		RVF	LVF	VF Difference	Total errors
Right key	F	35	73	+38	108
	R	50	82	+32	132
Left key	A	43	19	-24	62
	K	54	42	-12	96

The letter A appears to be the easiest letter to recognize, followed by K, F, R in that order. Perhaps A and K having a rhyming sound makes them easier to recognize. We cannot be certain that the accuracy is not related to key position rather than ease of recognition, as this is a confounding variable in this experiment. The error rate for letters F, R combined (right key) was 6.9% as compared to letters A, K combined (left key) error rate equal to 4.6%.

The error rate trend for Visual Field differences is compatible with the direction of difference for Response Times for the 7/8 year olds. That is, there was a nonsignificant RVF superiority (faster) in Reaction Time and there are fewer errors committed by the Left Hemisphere also. The Mean error difference between Visual Fields for each Subject is 2.8 errors difference between Right and Left Visual Fields ($\bar{X}$ RVF per *S* = 15.2 errors versus $\bar{X}$ LVF per *S* = 18.0 errors).

The 14 year old Group had an overall error of 10.2%. The error rate for the RVF was 9.5% compared to 10.9% for the LVF. The lower error rate is associated with faster reaction times in the left hemisphere (RVF).

Six Subjects had more RVF errors than LVF; five *S*s had more LVF errors than RVF errors; one *S* showed no Visual Field differences in number of errors. The Wilcoxon Matched-Pairs Signed-Ranks Test for Visual Field differences does not reach significance.

More errors were made on the right key (letters F, R) (error rate 11.4%) than on the left key (letters A, K) (Error rate 9.0%).

The Mean number of errors per S in the RVF was 27.3 errors. The Mean number of errors per S in the LVF was 31.4 errors. The Mean number of errors difference between Visual Fields per each S was 4.1 errors.

The total errors in regard to Visual Fields for each letter are:

		RVF	LVF	VF difference	Total errors
Right key	F	80	137	+57	217
	R	69	107	+38	176
Left key	A	67	33	-34	100
	K	112	100	-12	212

The letter A appears to be the easieast letter to recognize, followed by R, K, F in that order. In this case it looks as if the accuracy of recognition is related to the particular letter, rather than the key position.

The Adult Group had an overall error rate of 4.6%. The error rate for the RVF was 5.0% compared to 4.1% for the LVF. In contrast to the 14 year old Group, the lower error rate for Adults is associated with the slower reaction times to the LVF.

Eight Ss had more RVF errors than LVF errors; three Ss had more LVF errors than RVF errors; one S showed no difference. The Wilcoxon Matched-Pairs Signed-Ranks Test for Visual Field differences is significant at the .02 level (two-tailed test), which is in contrast to the failure to reach significance in the 14 year old Group (also 7/8 year olds). This finding of significance is in contrast to Rizzolatti et al.'s finding of non-significance for error rate differences between Visual Fields for their Adult Ss.

In contrast to the 14 year olds, more errors were made on the left key (A,K) than on the Right Key (F,R).

The Mean Number of errors per S in the RVF was 14.5 errors. The Mean Number of errors per Subject in the LVF was 11.5 errors. The Mean number of errors difference between Visual Fields per each S was 4.1 errors.

The total errors in regard to Visual Fields for each letter are:

		RVF	LVF	VF difference	total errors
Right key	F	40	42	+2	82
	R	40	29	-11	69
Left key	A	21	16	-5	37
	K	73	55	-18	128

The letter A appears to be the easiest letter to recognize, followed by R, F, and K in that order. In this case, it looks as if the accuracy of recognition is related to the letter, rather than the key position. More errors were made on the left key than the right key, in contrast to the finding for the 14-year-old Group and the 7/8 year-old Group. We would not expect the 14 year olds to vary much from the adults, so our inconsistencies leave us puzzled as to an explanation.

The error rate for the 14 year-old group is twice that for both the adult group and the 7/8 year old group. On the one hand, comparing the 14 year-olds with the 7/8 year olds, we wonder if there was not a difference in strategy, with the youngest group going for slower RTs with greater accuracy, while the 14 year olds went for faster RTs and less accuracy, but this doesn't explain why the adults were both fast and more accurate than the 14 year old group. However, the Mean RT for the adults was 11 msecs. longer than for the 14 year-olds, but that is not likely to account for the difference.

SUMMARY OF FINDINGS FOR LETTERS EXPERIMENT

To summarize our findings: The 14 year-old girls and the University student group showed the Left Hemisphere superiority for recognition of letters. The 7/8 year old girls showed no significant Visual Field differences for letters.

There is a significant difference between the three age groups in overall reaction time to letters, with the 7/8 year-old children being slowest in Reaction Time.

There is no significant Pathway difference over all three age groups.

There is an overall significant Hand difference in favour of the right hand, but none of the groups analyzed alone have significant Hand differences.

There is a significant VF X Key Interaction which indicates a tendency to respond in the direction of the stimulus in the 7/8 year-olds.

The error rates for Visual Field differences were analyzed for all three age groups, and found not to be significant for the 7/8 year-old group, nor for the 14 year-old group, but are significant for the adult group. The lower error rate is associated with the LVF, the higher error rate with the RVF (faster responses). This finding of a significant error rate for adults is in contrast to Rizzolatti's lack of significant Visual Field error rate differences.

COMPARISON OF LETTERS WITH FACES EXPERIMENT

Making a comparison between the FACES Experiment and the LETTER Experiment, it is interesting that the pathway order for the letter experiment for our two older groups is exactly the reverse of the order of the faces experiment for our adult group (in neither case is the order precisely that of our hypothesized model). In the older groups, which hemisphere receives the stimulus is more important than which hand is responding in terms of effect on Reaction Time. With the youngest group, on the letters experiment, which hand is responding seems to affect the RT more than which hemisphere receives the stimulus, but on the FACES experiment, which hemisphere receives the stimulus seems to have more effect on the RT than which hand is responding (but the hemisphere superiority looks to be reversed from the adult expectation). Why in the one case (letters) should Hand responding make more difference than in the other case (faces) (in the case of the 7/8 year olds to which we are referring, these were the same <u>S</u>s in both experiments)? Perhaps it is related to the fact that two keys were used in the letter experiment, and one key in the faces experiment.

For the youngest group, Letters Experiment, the Pathway order was: RVF/RH LVF/RH RVF/LH LVF/LH, for Faces the order was: RVF/RH RVF/LH LVF/RH LVF/LH. We see the fastest and the slowest pathways are the same for both kinds of stimuli. It may be that in 7 and 8 year olds the apparent left hemisphere lateralization for Faces in terms of pathway order may be related to the non-lateralization of letters (language). That is, it may be that as the left hemisphere is becoming lateralized for Letters it is ultrasensitive to other kinds of stimuli also. Or it may be that the 7/8 year old brain is using a different strategy on Faces than the adults, rather than the same strategy in a different place. We should remember that in neither case (letters or faces) did the differences in reaction time reach our required level of statistical significance.

In the Faces Experiment, the youngest group of Ss had half of the Ss with a Right Visual Field superiority and half with a Left Visual Field superiority in terms of Reaction Time. The Letters experiment had nine out of the twelve youngest Ss with a RVF superiority. In terms of the number of Subjects who show a directional difference, it appears that faces are not lateralized and letters are lateralized at ages 7 and 8.

A comparison of error rates between Visual Fields shows that for letters the accuracy of recognition in left versus right Visual Fields is not significant for either 7/8 year-olds or 14 year olds, but is for the adult group. For adults the greater accuracy is in the slower hemisphere/visual field. The accuracy of recognition for Faces in left versus right Visual Fields is significant for both the 7/8 year-old group and the 14 year-old group, but in different directions: the RVF (left hemisphere) is significantly more accurate for 7/8 year-olds, the LVF (right hemisphere) is significantly more accurate for 14 year-olds. The finding of a significant difference in error rate for Letters is in contrast to Rizzolatti et al.'s result for adults. We find, however, a significant difference in VF error rates for children and 14 year olds in recognition of Faces, but not for adults, while Rizzolatti et al. did not find significance in their (adult) subjects.

DISCUSSION

To what are Visual Field differences due?

Kinsbourne (1970) put forward a theory that visual field differences are due to "attentional" processes rather than to functional differences between the cerebral hemisphere. He assumes that the activity of one or the other hemispheres biases attention to the contralateral visual field. However, the assumed initial bias in attention would most likely be the result of differences in processing mechanisms in the two cerebral hemispheres.

Geffen et al. (1971) proposed that hemisphere differences could be due to either transmission time from one hemisphere to another, or to an asymmetry in the speech of the hemispheres to process different sorts of material.

Cohen (1972) also suggests that differences in Reaction Times may be due to the time it takes to transmit information via the corpus callosum from right to left hemisphere where linguistic mechanisms are called upon to process the information (that is, assuming that linguistic functions are lateralized to the left hemisphere).

McKeever and Huling (1971b) found a right visual field superiority for words, and had the notion that one hemisphere appeared to lag behind the other. When the word appearing in the left visual field was presented slightly earlier than the word in the right visual field, the recognition of the left visual field words did not improve. Their results indicate that the inferiority of the recognition of the left visual field is due to something more than the greater length of time it takes for the word to travel across the corpus callosum to arrive at the point of speech output. Dimond and Beaumont (1974) suggest that KcKeever and Hulings' results lend support to the view that there is a difference in the fidelity or strength of the signal after passing across the callosum, and that it is this factor rather than the temporal one which results in RVF superiority for letters.

Levy-Agresti and Sperry (1968) suggested that the two hemispheres have different modes of functioning. The left hemisphere uses sequential analytic procedures, and the right hemisphere uses some sort of synthetic Gestalt apperception.

Seamon and Gazzaniga (1973) demonstrated that coding strategies may be manipulated by instructing the S to use rehearsal or relational imagery. All of their Ss showed a left hemisphere superiority when using rehearsal and five of six Ss when instructed to use relational imagery showed a right hemisphere superiority in a (reaction time) recognition task.

Stuart Dimond (1972) feels that his research supports the notion that "each half-brain analyses separately the information it receives. The total capacity of the brain is different from that which might be assumed by supposing that the brain carries out only one function at a time, or that it consists only of a single channel of limited capacity." He assumes that "--each hemisphere analyses separately the information presented to it before sharing with the other. In other words, there is in the brain a double perceptual analysing system and the use of two hemispheres may often be better than the use of one."

Face recognition seems to depend on the memory for the faces being available to the right hemisphere (more so than to the left). But it may be that it is not faces only, but any object or shape which lacks a name.

Levy et al. (1972) presented bilaterally symmetrical shapes to both hemispheres as they had done with faces, first with the shapes unnamed and then naming them as "moose", "elk", and "deer" (because they resembled antlers), and obtained essentially the same results as with the faces (i.e., a switch to left hemisphere processing), which does suggest that the recognition of faces is not a special ability different from form recognition generally (by the right hemisphere). The results also suggest that the particular hemisphere advantage depends on whether the object has a name.

A third study by Levy et al. (1972) used nameable pictures (an "eye", "bee", "rose") and obtained the same hemisphere lateralization as with the unnameable shapes and with the faces. In this case, there was a much lower error rate. It must be remembered that these experiments were carried out on split brain patients and the results may not be the same with normals.

The findings from Levy et al.'s series of chimeric studies and other investigations has led Levy (1974) to conclude that each hemisphere performs a particular set of cognitive tasks which the other hemisphere "finds difficult or distasteful or both". Levy suggests that the two sets of functions may be logically incompatible; the right hemisphere synthesizes over space, the left hemisphere analyzes over time. "The right hemisphere notes visual similarities to the exclusion of conceptual similarities. The left hemisphere does the opposite. The right hemisphere codes sensory input in terms of images, the left hemisphere in terms of linguistic descriptions. The right hemisphere lacks a phonological analyser; the left hemisphere lacks a Gestalt syntehsizer.".

Our own data, when more closely analyzed, indicates that lateralization is not a simple functional matter of right hemisphere analyses faces, left hemisphere analyzes letters. It appears from the Reaction Time data that one or more of the four faces were analyzed in the "other" hemisphere. The analysis of errors in the letters experiment indicates that one or more of the letters were analyzed in the non-dominant hemisphere.

CHAPTER TWELVE

A DISCUSSION OF OUR EXPERIMENTS

This chapter summarizes our principal findings and indicates how they relate to relevant earlier work. It also makes tentative suggestions about how we think our work points up the directions that future studies of hemisphere differences and inter-hemispheric relations might take.

Principal Findings

Tactile Tasks

A. Bimanual motor coordination.

The Acallosal and her sister were tested on several simple motor coordination tasks. The acallosal tended to be as efficient as the normal and mental match controls, on two of the tasks, but was slower at the string-winding task than almost all normal and mental match controls. On the Pegboard task, the acallosal was slower than the controls when using the non-dominant hand. When using the dominant hand alone or both hands together, the same tendency was observed, though less pronounced. We are not certain what the slower unimanual performance should be attributed to, presumably not the lack of the corpus callosum.

Her sister gave a less efficient performance on the bead-stringing task than either the acallosal or the controls. She performed the same as the acallosal on the task which required the S to fit cubes in a box bimanually and similarly on the Pegboard task. On the string-winding task, the sister performed normally.

These tasks had been undertaken in order to compare our results with Jeeves' (1964, 1965) findings of 'less efficient' motor coordination performance. Our acallosal was more efficient on all of the tasks than Jeeves' acallosal, except fitting cubes into a box. On the Pegboard task, Jeeves' Ss are consistently slower than his control Ss, unimanually as well as bimanually. This finding is consistent with our results.

Sperry (1968), (although reporting no data), reported that his 20-year-old college girl who was a diagnosed agenesis patient scored distinctly below normal controls on tests similar to Jeeves' studies.

Surgical bisection patients have not been found to show deficits in motor coordination attributable to the sectioning of the corpus callosum. Data have not been reported.

It appears that data on manual coordination performance have been reported on four acallosal patients only. We suggest that systematic observations should be continued on agenesis patients and would like to see them compared in this respect with surgically bisected patients.

B. Transfer of Tactual Training: Formboard Task and Maze Learning Task.

On the Formboard task, neither the Acallosal nor the sister showed a savings in transfer from the dominant to the non-dominant hand. However, four of our sixteen control Ss did not show any savings at all. Overall, for our control Ss there was an 8% savings. The Acallosal's Mean response times for both dominant and non-dominant hand exceed the Means for the Control Ss. The Sibling tends to be slower than the Controls.

Although we used the same sort of Formboard that Jeeves (1965) used, both his Control Ss (normal Ss matched for mental age) and agenesis S were slower in completing the task than our Ss, suggesting that there was some difference in procedure. His Control Ss show a Mean 38% savings on the transfer from dominant to non-dominant hand, while his agenesis patient shows no transfer.

Of other reports in the literature on acallosals, Myers' 8 year-old agenesis patient and Solursh et al's 14 year old S both show savings in transfer. However, Solursh et al.'s patient is slower on both hands than their Controls. Russell and Reitan's (1955) 19 year-old agenesis S did not show a transfer.

It appears to us that acallosals not only tend to be slower than normals and mental match controls with either hand on the formboard task, but they also tend not to save time in transfer. This, however, is not a definitive task, distinguishing acallosals from normals. We suggest that more data is needed from Ss previously untested on this task.

From the surgical-patient literature, we find one patient's performance reported by Goldstein and Joynt (1969). Their patient did not demonstrate transfer.

Turning now to maze learning, our acallosal showed a savings in transfer from one hand to the other of 67% in number of trials (85% savings in errors and a 92% saving in time). In contrast, Lehmann and Lampe (1970) reported that acallosals did not significantly transfer from the dominant to the non-dominant hand.

The surgical literature contains reports by Smith and Akelaitis (1942), who found an impaired efficiency in transfer of learning, and Gazzaniga, Bogen and Sperry (1962), who found a surgically bisected patient could transfer learning from either hand to the other.

For reasons discussed in Chapter Three, we did not compare our acallosal with a group of Controls. It may be that she would show an impaired efficiency on transfer of learning. The same criticism, i.e., lack of Controls could be made of Gazzaniga, Bogen and Sperry's report on a surgically-bisected-patient. We suggest that it would be desirable to collect data on a group of Controls suitable for comparison with our acallosal. It would also be useful to test a group of Control Ss for the Gazzaniga et al. patient.

We felt that it was worth noting that our acallosal was unable to learn the small maze and was able to learn the large maze, even though both contained the same number of 'choice' points. She had been reported by the hospital Psychologist who examined her to have a slight visual memory deficit and significant impairment of auditory memory. We think there is a tactile memory deficit also. We wonder how much of these impairments are attributable to the absence of the corpus callosum. It appears from her performance on the two mazes that there is something she can do to facilitate tactual memory in certain circumstances (perhaps as Gazzaniga, Bogen and Sperry (1963) suggest in regard to their patients, she used body movements and adjustments to help her 'remember').

C. Tactile Cross-Identification of Objects.

The Acallosal, the Sibling and the group of Normal Controls had no difficulty with this task of retrieving and identifying objects by tactile manipulation and verbal identifications.

Our finding supports Saul and Sperry's (1968) report that their agenesis patient had no difficulty in cross-identification of objects.

Ettlinger et al. (1972) found that two of their three total agenesis patients tested demonstrated transfer of tactual discrimination training from one hand to the other. Their items were presented in pairs and trials were repeated four times, such that their task was much less difficult than ours.

Except for one of Ettlinger's Ss, the acallosals seem to have had no difficulty in transfer of identification of objects. This is in marked contrast to the surgical-bisection literature. Bogen (1974) stated that every one of the 16 completely commissurotomized patients studied to date has an anomia of the left hand.

It is possible that the acallosals tested do have some sort of impairment on this task that is not immediately apparent, but which another kind of testing situation might reveal in the form of, for example, increased latencies in identification.

It is also possible that there really is no impairment on cross-identification of objects. This suggests language processes (including speech) occurring in the right hemisphere of right-handed acallosals. We find support for this hypothesis in our acallosal who was Left Visual Field superior in a tachistoscopic recognition of letters task (from which we infer that she has language processes in the right hemisphere.)

D. Tactile Cross-Localization.

Our acallosal and her sister both showed impaired performance on the tactile cross-localization test which was statistically significant when compared to the Controls.

Our finding is in agreement with the report of Ettlinger et al. (1972), who found a similar deficit in their Total Agenesis patients.

These findings may be contrasted to the report by Gazzaniga of a "dramatic inability" to cross-localize on the part of the surgically-bisected patients. Gazzaniga did not, however, report any data.

Ettlinger et al. (1974) have gone a step further in investigating whether this impairment in tactile cross-localization of light touch stimuli in acallosals is generalized to other tasks involving cross-integration of tactile information. They did not find differences between acallosals and neurological controls in spatial localization or size cross-matching, but we think this question should be pursued further in the acallosals as well as the surgical patients.

Dichotic Listening Experiments (Auditory Perception)

A. Recall of digits (Experiment I).

The Acallosal and Sibling were tested on six different recall conditions which varied the pace of presentation of digits and the instructions to the S as to order of report of the digits (that is, for example, which ear the S should report first). This investigation was based on Bryden and Zurif's (1970) report of a 15 year-old acallosal boy, although their experiment was not replicated in our findings.

Our Acallosal performed best on the "report in any order condition" and worst on the Post-Ordered Condition. The instruction as to which ear to report first after hearing the digits probably interferes with the memory for digits. The time delay the Post-order Condition imposes before responding probably also contributes to the poorer performance on this condition.

The Acallosal was right-ear dominant in all Conditions except the slow-pre-ordered Condition where she showed a slight left-ear superiority. She was better on the slow conditions than on the fast conditions (and the improvement is primarily reflected in the left ear score).

The Sibling also performed best on the free-recall Condition. She shows an even greater right-ear superiority than the Acallosal. The Sibling performance is characterized by considerable left-ear suppression, such that her performance approaches that reported for surgically-bisected patients.

The Acallosal and Sibling show a larger ear difference than the range of Mental Match Ss and Normals. They are both right-ear superior (from which we infer a left-hemisphere superiority for short-term memory for digits presented auditorily), but they are more like the surgically-bisected patients than like the normals in strength of the right-ear effect. The performance of our acallosal and her sister do not support our hypothesis of bilaterality of speech mechanisms. It will be recalled that we began our study using dichotic listening techniques with the hypothesis that if our acallosal girl had speech mechanisms and language processes represented equally in both cerebral hemispheres, she would show no difference between scores for right and left ears for digits presented dichotically in either condition of recall or recognition, while the normal right-handed Subjects would demonstrate a right-ear superiority.

Bryden and Zurif's Acallosal did not appear to differ from their Normal Controls, except that he was more accurate on the left ear than on the right and he showed a smaller laterality effect than the Control average in most conditions. This is contrary to our findings.

Ettlinger et al. (1972) reported two total agenesis patients to be more accurate on the left ear than the right, however, their results are difficult to interpret because these patients were left-handed.

B. Recognition of dichotic digits and tonal patterns (Experiments II and III).

The investigation of functional asymmetry had not been pursued in agenesis patients with regard to non-verbal material presented dichotically prior to our study. Kimura (1964) established that there was a left-ear superiority in recognition of melodic patterns in Normals. We wanted to find out whether we would obtain opposite superiorities of the right and left hemispheres for tonal patterns and dichotic digits.

We did not discover an ear difference for our Acallosal on tonal patterns, but neither did we find an ear difference for our Control Subjects. Since we did not find an ear difference for the Normals, we can not draw conclusions about the possible bilateralization of tonal patterns in the acallosal.

We suggest that future investigations using dichotic listening techniques on agenesis <u>S</u>s and surgically-bisected patients would reveal more about hemisphere differences and relations if they would use the <u>same technique</u> to present different material (e.g., verbal and non-verbal) in order to look at possible opposite superiorities. It would also be useful to present the <u>same material</u> using different techniques (such as the comparison of recall and recognition techniques). We need more intensive investigations of individuals. The use of different techniques within the same Subject allows us to get a better understanding of what the processes are which are involved in asymmetry (such as memory processes, for example).

<u>Studies of Reaction Time to a Simple Visual Stimulus: Comparisons of "Interhemispheric Transmission Times".</u>

The Acallosal and Sibling were tested on a Reaction Time Task which in one Condition required the <u>S</u> to respond with both hands to a light flashed randomly to the nasal retina of either eye. In another Condition, the light stimulated the temporal retina. In another Experiment, single-handed responding rates to nasal stimulation was recorded. Their data was compared with data reported by Jeeves (1969) (Jeeves and Dixon, 1970) collected on two acallosals and samples of Normal Ss. Our acallosal was also compared to an acallosal tested by Kinsbourne and Fisher (1970).

Jeeves found lengthened interhemispheric transmission times in his acallosals over those reported for normals on a two-handed responding task, nasal and temporal stimulation conditions.

Kinsbourne and Fisher (1970) reported pathway differences for an acallosal S of an order compatible with Jeeves' findings but they did not reach statistical significance on a single-handed responding task.

Our acallosal demonstrated statistically significant lengthened interhemispheric times over Normals on both two-handed and single-handed responding tasks.

Ettlinger et al. (1972) did not find significant differences between acallosals and neurological controls on a similar RT task. It is probable that the fact that many fewer trials were used in Ettlinger et al.'s and Kinsbourne and Fisher's experiments accounts for their failure to find significant differences in pathways. We feel that the important point is not whether the acallosal is significantly different in pathways within her own performance, but whether she is different from the Control Ss.

We also concluded that the Sibling performs similarly to the Acallosal, suggesting that she, the Sibling is acallosal also. The argument could be strengthened by testing neurological controls for the Sibling.

A left visual field superiority for reaction time to a point source of light has sometimes been reported for normals. However, we find that there does not tend to be a difference between responses to the different visual fields in the acallosal.

Interocular Transfer of Movement Aftereffects

We found that our Acallosal did not show any Interocular transfer of Movement aftereffects, while our Normals did show transfer. This finding supports that of Dixon and Jeeves (1970).

We feel that a test of the surgically-bisected patients would be a useful comparison to make with our acallosal on this task, in order to provide further evidence on the role of the corpus callosum in interocular transfer of movement aftereffects, and to separate out the role of the corpus callosum from other cerebral contributions.

Tachistoscopic Recognition Tasks of Alphabetical and Facial Stimuli.

We have done studies of our acallosal and her sister compared to Normals of the same age, and a developmental study of normals to examine hemisphere differences and relationships. We were particularly investigating the opposite superiorities of right and left hemispheres for reaction time to single letters and faces found by Rizzolatti et al. (1971) in normal adults.

Our acallosal responded significantly faster to letters presented in the left visual field. This is opposite to our finding of a right visual field superiority for our normals. However, our finding for Normals was in agreement with the Rizzolatti et al. finding.

We had predicted that we would not find a visual field difference for our acallosal if she had bilateral language representation. Our results indicate that she does not have equal bilateral language representation. Neither is she like the Normals, because she has a left visual field superiority. The acallosal was found to show significant pathway effects for recognition of letters. This pathway order indicates that she is faster on ipsilateral pathways than contralateral pathways. This finding suggests that either hemisphere can deal equally well with the letter stimuli (in contrast to the finding of a left visual field superiority). Sperry (1968) had suggested that lack of behavioural deficit in agenesis patients may have to do with an increase in use of ipsilateral pathways.

The finding that the acallosal is left-visual field superior for recognition of letters and right-ear superior for recall of dichotic digits suggests a kind of bilaterality of language representation across modalities, i.e., auditory and visual. It may be that there are different kinds of verbal representations in the two hemispheres. It has been pointed out to me by David Milner that Ettlinger et al.'s data (1972, 1974) also shows opposite-hemisphere superiorities in their acallosals for dichotic digits and tachistoscopic presentation of words. We feel that these results call for an investigative approach which would present the same material to both auditory and visual modalities for more direct comparisons.

The acallosal showed a left visual field superiority for faces in one task, but in another did not show a significant visual field difference. She seemed to show differences in degree of lateralization depending on the particular face, as did the normal Ss. These findings suggest that it is something about the nature of the task, other than the stimuli per se, which results in apparent differences in hemisphere specialization.

These studies on the acallosal provide indications of the complexity of the interhemispheric relationships. We feel that further systematic studies across modalities within individual Ss would be useful.

Our study of normal Subjects provided evidence that the processes involved in recognition of letters and faces develop with increasing age in childhood. The results of our FACES experiment indicate that seven and eight year olds are not yet lateralized for processing faces while the thirteen and fourteen year olds and adults are. For the LETTERS experiment, the youngest group did not show statistically significant visual field differences, while the older groups did.

Examination of the data trends for individual Subjects showed more variation among the youngest group of Subjects than among the older groups. This finding suggests a greater plasticity or flexibility in processing stimuli among the younger Subjects than among older Subjects. (These studies used females; we suggest comparisons with males also.) We feel that more systematically controlled developmental studies such as ours would be useful in unravelling the complex interhemispheric relationships.

We would like to pursue our own investigations in Normals in this regard, and, further, to make an effort to match up the neurophysiological processes with the behavioural processes, particularly by monitoring evoked potentials associated with presentation and processing of visual and auditory stimuli.

Conclusions.

Our acallosal patient was able to perform every task except the interocular transfer of movement aftereffects. This ability to perform tasks presumably requiring interhemispheric transmission of information suggests the use of alternative neural pathways such as other commissural pathways.

The acallosal patient's performance on tactile tasks which was less efficient than that of the control Subjects suggests that even though there is probably considerable development of use of ipsilateral neural pathways as well as specialized development of extra-callosal commissures, these developments are not fully compensatory.

The right-ear advantage over the left ear for recall of auditory dichotic digits, which the acallosal demonstrated, was greater than that for the controls. This finding taken together with the finding of a left visual field superiority for recognition of letters suggests that the acallosal develops compensation in a way not suggested by previous reports. It appears that there may be a compensatory development of language processes in different modalities, i.e., auditory and visual, in opposite hemispheres to different degrees. That is, for example, in our Subjects, while letters presented visually may be processed in either hemisphere, they are processed better in the right hemisphere, while dichotic digits are processed more efficiently in the opposite hemisphere. This would be a practical solution to the problem of the acallosal brain's ability to cope in the real world, where information input is usually not restricted to one sensory modality as it may be in the laboratory. This kind of compensation implies increased use of ipsilateral (or uncrossed, noncommissural) pathways.

The reliance which a particular acallosal hemisphere may place on the input of information from a specific sense modality could account to some extent for observed individual differences in performance among acallosals. This could be related to the kinds of information input and the stress placed upon the different sensory modalities during the developmental years of the acallosal individual. This is related to the degree of plasticity that developing brains show, as for example, in the performance of our youngest group of Subjects in the developmental study, who demonstrate considerable variability in degree and direction of lateralization.

The suggestion that the auditory and visual sensory process mechanisms have opposite hemisphere superiorities could possibly be investigated via a test of the single channel hypothesis. We would expect the acallosal to retain more visual and auditory information presented simultaneously than normal mental match control Subjects.

Finally, we think that the acallosal's short-term memory deficit as revealed by the dichotic digits experiments suggests that the corpus callosum is involved in short-term memory. In the agenesis S the fidelity of stimulus transmission may be reduced through necessary reliance on uncrossed (non-commissural) pathways.

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Addendum

Persson, G. (1970) Untersuchungen bei drei Fallen mit angeborenem Balkenmangel. Psych. Neurol. and Med. Psychol. 22, 448-455.

Appendix I

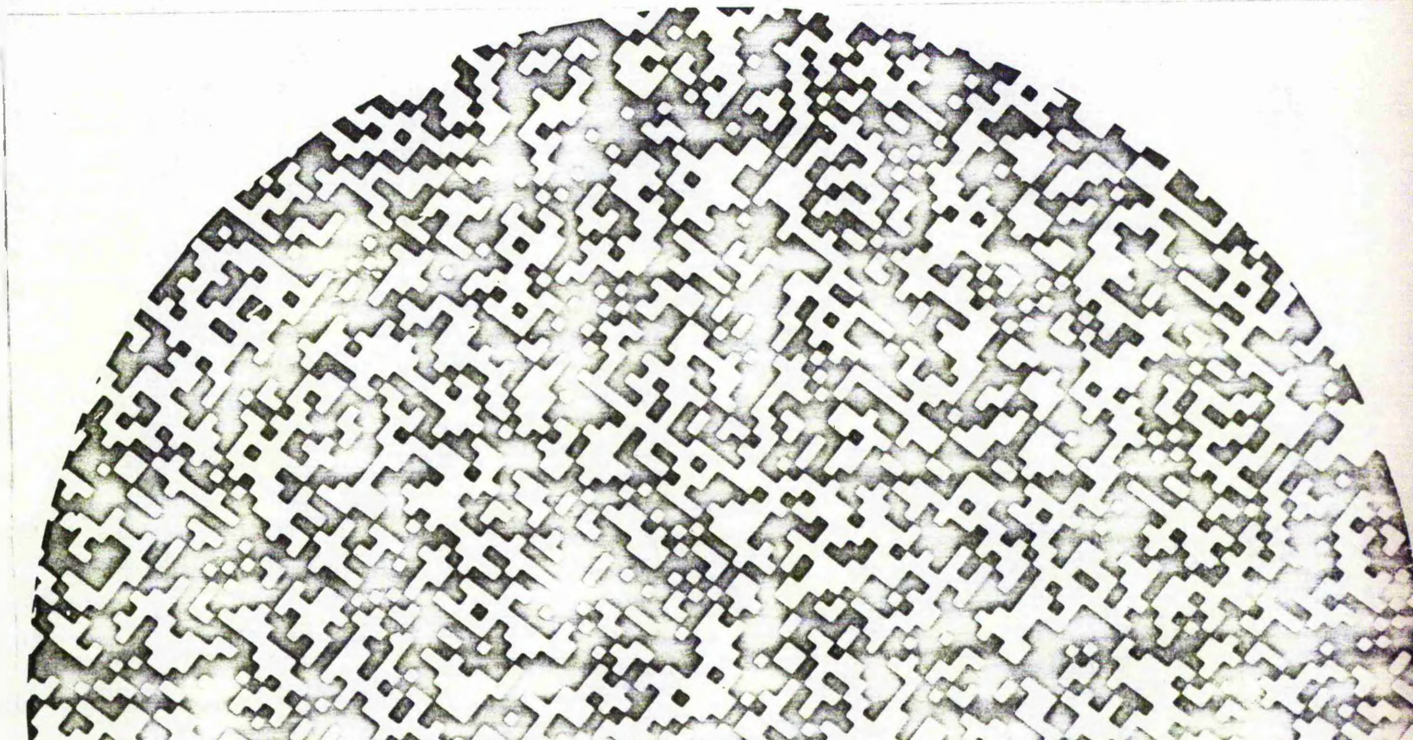
List of Items Used in Tactile Cross-Identification of Objects Task

Test Object — Other Objects

1. button / two-pence piece, eraser, button, thread spool, ring.
2. pipe / torch, pipe, candle, ruler, crayon.
3. playing card / playing card, sandpaper, bar soap, puzzle piece, eraser.
4. pistol / comb, toothpaste, knife, pistol, pipe.
5. paintbrush / toothbrush, pencil, paintbrush, can opener, scissors.
6. ball / yarn, ball, soap, sponge, change purse.
7. plug / egg cup, plug, small car, spoon, soap.
8. hard-boiled egg / rubber ball, ball of string, yarn, eraser, egg.
9. key / coin, clothespin, safety pin, paper clip, key.
10. screwdriver / nail file, scissors, fork, screwdriver, candle.
11. glue bottle / change purse, glue, clothespin, torch, toothpaste.
12. scissors / puzzle piece, cup, scissors, spoon, a square.
13. pencil / pencil, crayon, knitting needle, knife, ruler.
14. sponge / glove, sponge, string ball, yarn, orange.
15. ring / button, paper clip, coin, ring, key, safety pin.

Appendix II

Stimulus for Movement Aftereffects Test: Conditions I and II.



Appendix II

Stimulus for Movement Aftereffects Retest.