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Development of Interhemispheric Communication
Speed in Middle and Late Childhood

by

Gerald W. Munt

Thesis submitted to the School of Graduate Studies
of the University of Ottawa in partial fulfillment of the
requirement for the Doctor of Philosophy Degree
in Child Clinical Psychology

Ottawa, Canada, 1984

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Abstract

The development of interhemispheric communication speed in children was investigated using behavioural reaction time (RT) paradigms. One hundred and twenty right-handed male children, 30 from each of four age levels (5-, 7-, 9-, and 11-years) were tested individually following independent screening for handedness, visual acuity and stereopsis. A series of six RT tasks were administered; two tasks were administered using vibratory tactual stimulation. The first was a control procedure requiring manual responding (lifting a finger) to bilateral stimulation, the second constituted a simple RT experiment requiring a similar motor response to unilateral stimulation. Four RT tasks were also administered requiring similar manual responses to structured visual stimuli; the first was a control procedure with bilateral stimuli, while the second represented a simple RT experiment with unilateral stimuli. Two complex choice RT tasks were administered with each serving as a mutual control condition for the other; these included a letter discrimination task and a line orientation task. All of the responding was counterbalanced within each task; all RT tasks were also administered to a nineteen-year-old acallosal male subject.

The older children responded faster than the younger children to bilateral stimulation for both control tasks. In comparison with older children, the younger children exhibited significantly greater response delay to crossed stimulation on the two simple visual and tactual-RT tasks and also in the complex choice RT experiment. The relatively faster responses to crossed stimuli in the older children were attributed to maturational development of the forebrain commissures and were interpreted as behavioural evidence of developmental changes in interhemispheric transmission time. The overall pattern of relatively slower responding to crossed stimulation in the younger children was most clearly evident for the vibratory tactual RT experiment as opposed to the visual simple and complex choice RT tasks, suggesting differential maturation of the commissural systems. Results for the acallosal subject indicate that the vibratory tactual RT task has good face validity and may be sensitive to the assessment of individual differences in cerebral development. The results of the present study were interpreted within the context of a brain-behaviour relationship model.

My dissertation is dedicated to Linda Jean Corsini, my wife, who has given me her encouragement and support from the beginning of my career in Psychology.

CURRICULUM STUDIORUM

Gerald W. Munt was born February 21, 1946, in Hamilton, Ontario. He received the Honours Bachelor of Arts degree in Psychology from McMaster University in 1971. He received the Master of Arts degree in Psychology from the University of New Brunswick, Fredericton, New Brunswick, in 1978. The title of his master's thesis is: Effects of Cycloheximide on Learning and Memory, as Investigated in the Rat Hippocampus and Brain Stem Reticular Formation.

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Chapter I

INTRODUCTION

Over the past forty years neuropsychological research has focussed increasingly on elucidating the structure and functions of the forebrain commissures and, in particular, the corpus callosum. With regard to human callosal functioning, much of our knowledge has come from behavioural experimentation with adult patients who either have had the callosum surgically sectioned or who have been born without a corpus callosum. More recently, increased attention has been given to the development of interhemispheric communication in children. This trend has resulted not only in a more accurate and complete picture of callosal function, but has also contributed valuable knowledge about the changing functional nature of interhemispheric communication.

With respect to the development of interhemispheric communication, Gazzaniga (1970) made what he described as a "novel interpretation of the developing cerebrum, suggesting that the normal neonate is born for all practical purposes with a split-brain" (p. 129). Today, findings from anatomical and physiological studies provide evidence in support of Gazzaniga's (1970) early contention. Yakovlev and Lecours (1967) had, however, recognized even earlier the completion of myelination in the corpus callosum and other fibre systems as a structural indication of functional maturity, paralleling the emergence of various behaviour patterns.

Salamy (1978) was the first to establish the existence of developmental increases in human interhemispheric communication velocities by using evoked potentials (EP). His results showed a progressive decrease in crossed latencies of all peaks of EPs with increasing age, despite stable uncrossed responses. He attributed the latency decreases to initiation and development of myelination. Since axon myelination greatly increases conduction speed of the action potential (Carpenter, 1976) and is considered to be a major characteristic of late development of the human central nervous system (CNS) (Elberger, 1982), it may be a prime factor in understanding many developmental changes in interhemispheric communication. The majority of the investigators of interhemispheric communication development in children have attributed positive findings to initiation and completion of myelogenesis.

Most children who serve as subjects in such studies, show a developmental increase in efficiency with which information is transferred between the two cerebral hemispheres; however, in none of these studies has there been any definitive attempt to assess whether the resulting chronological changes in organization of behaviour reflect underlying developmental changes in speed of interhemispheric transmission. Presently, it is believed that much of skilled human adult functioning depends upon rapid and dynamic interhemispheric communication (Creutzfeldt, 1981; Powell, 1981; Berlucchi, 1983; Dimond, 1983). In this regard, it is possible that many instances of functional ineptness on the part of the child may be due to relatively slow interhemispheric communication. While investigation of interhemispheric transmission rates in acallosal patients (Jeeves, 1965, 1969; Kinsbourne & Fisher, 1971; Reynold & Jeeves, 1974; Milner & Jeeves, 1979; Milner, 1982) and in normal intact adult subjects (Jeeves, 1969; Jeeves & Dixon, 1970; Berlucchi, Heron, Hyman, Rizzolatti, & Umilta, 1971; Berlucchi, Crea, Di Stefano, & Tassinari, 1977; Milner & Lines, 1982) has recently increased, the developmental nature of interhemispheric transmission is still incompletely understood, especially with respect to very young children (Jeeves, 1972; Salamy, 1978). Furthermore, slowed interhemispheric transmission has been shown to interfere with successful task completion in acallosal children (Sauerwein & Lassonde, 1981; Sauerwein, Lassonde, Cardu, & Geoffroy, 1983), which taken together with the above information indicates a need for better understanding of its development in normal children. However, to date no behavioural experimental attention has been given to the development of speed of interhemispheric communication.

The purpose of the present study, then, is to provide a focused picture of the development of interhemispheric communication speed. It represents an attempt to substantiate existing physiological findings using a behavioural reaction time (RT) paradigm, as well as an initial behavioural attempt to validate and document effects of maturation on interhemispheric communication speed. Specifically, the dissertation will explore the effects of maturation upon responses to contralateral and ipsilateral, unilateral, visual and tactual stimuli in children of

5-, 7-, 9- and 11-years-of-age.

REVIEW OF THE LITERATURE

Recent theoretical interest in the area of callosal functioning, has focussed increasingly on the belief that skilled human functioning in the intact adult often depends upon rapid and dynamic interhemispheric communication, as opposed to a more rigid dichotomy of lateralized functioning (Brown & Jaffe, 1975; Davis & Wada, 1977; Dimond, 1972; Franco, 1977; Harnad & Doty, 1977; Luria & Simernitskaya, 1977; Zangwill, 1960). In this respect, Luria and Simernitskaya (1977) assume that all behavioural processes are governed by both hemispheres, but that each hemisphere makes its own specific contribution. Creutzfeldt (1981) implicates the forebrain commissures as a key cortical link for the sensory systems. Powell (1981) concludes that perhaps the most important and essential function of the cortex (including the forebrain commissures) is the intergration and interpretation of information from several different sensory pathways and the formulation of the response to them.

From the large body of literature concerning callosally injured or diseased, brain-bisected and acallosal subjects, several views of the functional importance of the mature, intact forebrain commissures have been elaborated. Gazzaniga and LeDoux (1978) have concluded that these fibre bundles serve as a mechanism by which neural activity (sensory, perceptual, motor, cognitive and perhaps emotional and motivational) of specific cell populations in one half-brain is almost simultaneously duplicated in the interrelated population of the opposite hemisphere, providing for mental unity or interhemispheric equilibrium. Berlucchi (1983) argues that the functional significance of these connections lies in the unification of primarily sensory information coming from the two halves of the body or visual field and, in general the equalization of activity in corresponding regions of the two hemispheres. He believes that the commissures serve to ensure yoked synchronous and congruent activity in interrelated areas of the two hemispheres. Dimond (1983) holds that the pathways across the callosum are as specific in their routes as are the trains of the New York subway. As such he believes that the callosum has within itself a map of the rest of the brain, the fibres of the callosum serving as a vast and specific network of communication, allowing activation and inhibition in precise locales, while interconnecting all important aspects of the individual via specific callosal fibres. Bianki (1981) has argued that transcallosal excitation performs three functions, which are the modulation of the size, concentration and displacement of the thalamocortical flow of excitation, the goal of which is to help integrate cortical activity. Humphries (1982) has suggested that in the mature brain commissural presence may simply represent an extensive and elaborate fail-safe system.

While these diverse views are not necessarily mutually exclusive, the exact functional nature of interhemispheric communication in the intact human brain is still not well understood. Although some clarification has been given to the roles played by the forebrain commissures, the primary purpose and functional nature of these fibre bundles remain relatively obscure. Notwithstanding the tentativeness of our present knowledge, however, it seems that all of the various theoretical perspectives mentioned above share a common, underlying or basic, dynamic model of brain organization in which both cerebral hemispheres benefit from sensory input from the other (via the forebrain commissures) for the representation of the ipsilateral half of corporeal and extracorporeal space (Pucetti, 1981). This interhemispheric duplication effect for sensory representation has been known for a long time (Pucetti, 1981) but has only recently become the focus of research from a developmental perspective (Salamy, 1978). Much still is unknown about interhemispheric communication, not only with respect to the intact adult's brain, but especially about the immature child's brain. In view of this fact, the present study will attempt to add to our knowledge of the developing brain. It explores one particular facet of ontogenesis, as yet not behaviourly examined in the child, the speed of interhemispheric communication. The existing behavioural, anatomical and physiological studies which the next three sections will review, provide a picture of our current understanding of the development of callosal interconnections.

Behavioral Correlates of the Development of the Corpus Collosum

Gazzaniga (1970) made what he described as a "novel interpretation of the developing cerebrum, suggesting that the normal neonate is born for all practical purposes with a split-brain" (p. 129). He stated "that the young child may be functionally split during early development" (p. 379, Gazzaniga, 1974). More specifically, Gazzaniga (1971, 1974, 1981) believes that interhemispheric communication may develop more slowly than intrahemispheric processing, because of a relatively late postnatal maturation of the forebrain commissures, which would show up behaviourally in young children as interhemispheric "unconnection", resembling an interhemispheric disconnection syndrome. Indeed, while Gazzaniga provided no data in support of his hypothesis, eight independent behavioural studies, which employed various sensorimotor tasks with an emphasis on tactual, proprioceptive and kinesthetic input, have provided behavioural evidence of a developmental increase in efficiency with which information is transfered between the two hands or two body sides.

Elliot and Connolly (1974) have investigated the development of what they describe as competent integration between body sides of simple and complex hand movements, whether in sequence or simultaneously, in the use of a toy called the Labarynth Game. Briefly, the game consists of attempting to roll a marble through a maze, while avoiding pitfalls, by controlling the balance of the maze platform with two external knobs, one for each hand. The subjects were male and female children from 3- to 6-years-of-age. Correct timing of movements between hands and the development of bilateral asymmetric movements appeared only in older children. One possible interpretation of these data is that successful problem solving performance in the older children reflected improved interhemispheric communication. This particular interpretation was not suggested by the authors; however, it seems consistent with their understanding of development.

Finlayson (1976) administered a tactual-motor learning task, Reitan's six-block version of the Halstead Tactual Performance test (TPT), to right-handed male and female children, aged from 5- to 15-years. Intermanual transfer of learning was significant only after eight years of age; unfortunately, Finlayson's results may have been influenced by changes in lateral asymmetry which were not controlled for in the study .

In another study, right handed children of both sexes between 5- and 10-years-of-age were asked to localize, out of sight with the thumb, a spot touched on the same hand (uncrossed lateralization) or the homologous spot on the opposite hand with the opposite thumb (crossed lateralization). The youngest children made few uncrossed errors, but many crossed errors. By age 8 or 9, most children made no uncrossed errors and a relatively small number of crossed errors (Galin, Diamond, & Herron, 1977). In a further study, Galin, Johnstone, Nakell, and Herron (1979) asked 3- and 5-year-old right-handed girls to feel and compare pillows of various fabrics with either the same hand (uncrossed condition) or opposite hand (crossed condition). Crossed errors were a significantly larger proportion of total errors in 3-year-olds than in 5-year-olds. Both studies included appropriate control conditions with which alternative interpretations were evaluated and eliminated as unlikely, for example, disorientation or memory dysfunction to crossed stimuli.

O'Leary (1980) tested right-handed male and female children at ages 5-, 7- and 9-years-of-age on a battery of tasks. Only the results of the reproduction of a linear movement task supported the developmental hypothesis of increased efficiency in interhemispheric communication with increasing age. The child was required without the aid of vision to reproduce a line of specific length, following the passive movement of either hand while grasping a felt-tip marker, along an open-ended slot provided for guidance. Improvement was measured as a decrease in the performance difference between crossed and uncrossed hand conditions, that is, performance closer to the "standard" by both hands. This result was achieved only with the 9-year-old group in comparison to the 5- and 7-year-old groups combined, and most significantly with the left-hand performance. There was no sex difference.

Denckla (1973) investigated the development of speed in repetitive and successive finger movements in normal right-handed children, aged between 5- and 8-years. Both types of movement were performed more rapidly with increasing age. However, while the percentage of children performing repetitive taps faster with the right hand increased with age, the magnitude of the right-hand superiority decreased with age. Successive movements with both right and left hands were performed more rapidly by girls. Only boys, in decreasing percentage with age, failed to perform finger succession ~~and~~ failure was as symmetrical as success. Initially, relatively poor left-sided, repetitive index-finger-to-thumb performance rapidly improved to show only a very narrow right-left difference in repetitive finger tapping speed. Denckla (1973) concluded that improvements on the left side may be accounted for by postulating transfer of learning from one hemisphere to the other, suggesting that "some neurophysiological substrates" (the corpus callosum?) which develops with age makes such a transfer possible.

Denckla (1974) made a further assessment of the development of motor coordination in normal right-handed children from 5- to 8-years-of-age. Balancing and hopping was usually achieved on one foot first, followed by symmetrical performance in 80 percent of the children over 8 years. Girls showed greater right/left difference than boys, but to a significant degree only in the two youngest age groups. Denckla proposed as the most likely neural mechanism underlying this developmental pattern, the development of interhemispheric connections, so that the left hemisphere could dominate motor output from the right hemisphere.

Maxwell (1981) in a recent unpublished dissertation gave a small battery of tests to right handed 3- and 5-year-old children of both sexes. On a motor task (tapping), the speed of bimanual coordination matured relatively later than the unimanual speeds. On a visual-motor task (an original simplified version of the Reitan Trail Making Test), there was evidence for a developmental change regarding the unidirectional intermanual transfer of visual-motor information. Results on both tasks for the younger children are not unlike the performance seen by patients who have had the callosum surgically sectioned or by patients who have been born without a corpus callosum (Dennis, 1976; Ferriss & Dorsen, 1975; Kreuter, Kinsbourne, & Trevarthen, 1972; Preilowski, 1972; Zaidel & Sperry, 1977). As well, the results on all of the tasks decribed above (for example, Elliot, & Connolly, 1974; Finlayson, 1976; Galin et al., 1977; Galin et al., 1979; O'Leary, 1980; Denckla, 1973, 1974) for the younger children, are similar to the performance seen in acollasal and surgically split-brain patients (Chiarello, 1980; Jeeves, 1979).

In summary, although alternative interpretation may be possible, these eight different behavioural investigations have produced findings consistent with an hypothesis that behavioural changes accompany a gradual maturation of the commissural systems, possibly reflecting ever-greater efficiency of interhemispheric communication with increasing age. This hypothesis was also proposed by O'Leary (1980). These data also suggest specifically that interhemispheric communication may develop relatively slower than intrahemispheric processing since in every instance uncrossed unimanual performance tended to mature in advance of successful crossed (bilaterally symmetrical or asymmetrical) performance. In the last ten years, numerous investigators have hypothesized that relatively late progressive myelination of the corpus callosum may underlie these behavioural changes, representing gradually increasing efficiency of interhemispheric transfer of information in the preschool and middle childhood years into late childhood, or beyond. The question arises concerning the likelihood of this explanation, especially in regard to the particular age range of the majority of children examined in these behavioural studies? An examination of the existing relevant anatomical and physiological studies follows, and may help to answer this question.

Anatomy of Corpus Callosum During Development

Although our knowledge is still incomplete, advances in the analysis of the neural substrates of interhemispheric communication have provided anatomical and physiological evidence in further support of Gazzaniga's (1970) early contention that "the normal neonate is born ... with a split-brain". A descriptive account of the temporal sequence of events leading to the formation of the mature pattern of interhemispheric organization has ermerged.

In the mature brain, neurons projecting to the corpus callosum are distributed primarily in cortical layer III, while the callosal fibre terminals are selectively distributed to all cortical layers (Powell, 1981). Most brain areas contain both homotopic and heterotopic callosal connections. This laminar distribution of callosal neurons and axon terminals is known as the radial distribution (meaning across cortical laminae). In the mature brain, callosal cell bodies and terminals are also normally restricted to cortical patches surrounded by or alternating with other patches almost totally devoid of collosal connections (Wise, & Jones, 1976). An intricate fine spatial distribution of callosal fibre terminations is usually mirrored by a similar distribution of callosal projection neurons, with every hemisphere seeming to have a unique "callosal fingerprint" (Van Essen, Newsome, & Bixby, 1982). This distribution of callosal connections is known as the tangential distribution (meaning parallel to the cortical surface). While the functional significance of both these distributions remains an unresolved puzzle, it is known that both distributions change dramatically as part of normal postnatal development. Neonatal animals present with an indiscriminate or continuous distribution of callosal connections, virtually throughout the entire neocortex. With time, this immature distribution is refined to the discrete adult pattern as many callosal cells of origin and axonal terminations "disappear", presumably as part of normal cortical cellular migration (Elberger, 1982). The intial ingrowth is seen as diffuse with the laminar pattern or radial distribution developing later. In contrast, the selective modification of the initially diffuse tangential distribution is seen as due in large part to postnatal sensory experience, as some kind of functional validation of existing connections (Elberger, 1982). These changes from diffuse to disjunctive patterns are rapid in the cat, rat and monkey (Jones, 1981); but it is uncertain how long such postnatal development takes in the human, perhaps being complete in infancy or toddlerhood, perhaps as late as preschool age.

It is also uncertain whether massive cell death is important or whether elimination of transitory collosal axons from an initial presence of "super abundant" connections is occuring, so-called "exuberant" projections. The diffuse to patterned developmental trend associated with the thalamo-cortical systems may extend to commissural systems (Goldman-Rakic, 1982). Elberger (1982) has indicated that some of the mature distribution of callosal connections is also genetically determined. In this regard, Schwartz and Goldman-Rakic (1982) have identified a novel category of mature cortical neurons that has both an ipsilateral and contralateral axon. The target in the contralateral hemisphere can be either a homotopic or heterotopic site. Cingulate neurons can project simultaneously to the frontal cortex of one hemisphere and the parietal cortex of the other. These single neurons having axon collaterals to ipsilateral and contralateral cortex, were found to be present to the same degree in fetal, newborn and adult monkeys, unlike the neurons that have two axons only transiently during development. Perhaps such early-existing interhemispheric connection may be important for interhemisphere transfer and integration during early development.

Many of the major developmental events (for example, dorsal and ventral induction, neuronal proliferation, migration and organization) in the growth of the human CNS occur prior to birth, but can extend a few years postnatally (Gabriel, 1980). As part of the CNS, the growth of the corpus callosum fits within this time frame. The axons making up the forebrain commissures cross from one hemisphere to the other during early prenatal development. All of the forebrain commissures are absent prior to the ninth embryonic week. While the anterior commissure is fully formed by 11 to 12 weeks postconception, the inital occurance of callosal fibres crossing the midline is at 12 to 13 weeks, with the corpus callosum assuming adult-like shape and position by 18 to 20 weeks (Chiarello, 1980; Elberger, 1982; Selnes, 1974). Prior to the establishment of the corpus callosum, all neocortical areas are interconnected via the anterior commissure. By the twentieth postconceptual week, however, the commissural projections are rerouted through the corpus callosum (Berlucchi, 1981). Initially, callosal fibres are 0.5 to 1.5 microns (um) in diameter, the majority being about 0.5 um. Larger diameter fibres are added at different ages, but by late adulthood only about 20 percent of the total number of fibres are in the 2.0 - 6.0 um range (Elberger, 1982). Callosal fibres increase in both diameter and length, as well as in total number during postnatal development (Elberger, 1982).

The earlier events of the growth of the human CNS are thought to establish the elaborate circuitry and set the stage for the final crucial developmental event, myelination or myelogenesis (Volpe, 1981). Myelination is seen to be a structural indication of functional maturity and the gradual completion of myelination in a fibre system may be significantly related to the gradual emergence of particular behaviours (O'Leary, 1980). In Yakovlev's (1962) words, "the myelination of the cerebral cortex ... follows an orderly sequence which parallels the successive phases of the organization of behaviour patterns" (Yakovlev, & Lecours, 1967; Lecours, 1975). Myelination of the axon provides an enormous increase in conduction speed of the action potential (Wiggins, 1982), lowers response threshold and renders the fibre relatively indefatigable (Carpenter, 1976; Eyzaguirre, & Fidone, 1975).

The order of myelination in ontogeny suggests that the cerebral commissures and the long association fibres of the frontal, temporal and parietal association cortices are among the last brain structures to become fully functional in development. Myelination is initiated later in these brain structures than in others and is fully completed only years or even decades after the rest (Yakovlev, & Lecours, 1967). First, myelination begins in the peripheral nervous system. Second, shortly thereafter, and still prior to birth, myelin appears in the CNS in components of major sensory systems (e.g., medial lemniscus for somesthesis and optic tract for visual stimuli, including all specific thalamocortical radiations) as well as in components of the major motor systems (e.g., corticospinal and pyramidal tract). Third, myelination within the cerebral hemispheres, particularly in those regions traditionally thought to be involved in higher level association functions and sensory discriminations (e.g., association areas, intracortical neuropil and cerebral commissures) occurs well after birth and progresses over decades (Volpe, 1981). The reticular formation is also a slow and very late myelinating structure. The core commissural and long association fibre systems joining the neocorticies only begin myelination by the fourth postnatal month, a process which is protracted at least until the 10th birthday and possibly even to the third decade of life (Yakovlev, & Lecours, 1967).

At most, only about 60 percent of the commissural fibres become myelinated (Blinkov, & Glezer, 1968). It is been suggested that although complete myelin rings may be present in the corpus callosum at 5 months postnatally, probably the myelination does not yet ensheath the entire axon length; furthermore, the chemical nature of the myelin present at 5 months may not be the same as that of the adult (Luttenberg, 1966). Therefore, the functional significance of myelin at 5 months is highly questionable (Elberger, 1982); however, to reiterate, the period of myelination is considered to be a major characteristic of late development in the human CNS (Elberger, 1982; Wiggins, 1982).

In summary, these anatomical investigations show that postnatal development of the corpus callosum results in increases in length, diameter and number of fibres, with concurrent addition of myelin ensheathment. Redistribution of the axons and the formation of axodendritic and axosomatic contact also occurs (Jones, 1981). However, in the young child, the myelination process may be the prime factor in the normal development of much skilled behaviour requiring dynamic and rapid interhemispheric communication. The physiology of the corpus callosum also changes from infancy into late childhood. In fact, maturational changes in the electrophysiological properties of the callosum are considered central to the mature functioning of the fibre systems (Salamy, 1978; Yakovlev & Lecours, 1967).

Maturational Changes in Physiological Properties of the Callosum

EP has been used to track the development of interhemispheric communication. Waveform changes in amplitude, latency and duration with increasing age have been found in the Kitten (Grafstein, 1963), the rat (Seggie & Berry, 1972), and young children until 10 years of age (Salamy, 1978). Grafstein (1963) and Seggie and Berry (1972) attributed increase in amplitude to an increase in axodendritic and axosomatic synaptic contacts of the callosal fibres. In agreement with these investigators, Salamy (1978) attributed increases in interhemispheric transmission velocities to the initiation and development of myelination. Changes in conduction velocities may also be accounted for by growth of callosal axonal diameter and increase in the number of myelinated callosal axons.

Salamy (1978) delivered vibratory stimulation to the left-and right-index-fingers of his subjects, ranging from two-years-of-age into adulthood. The results showed a progressive decrease in crossed latencies of all peaks of EPs with increasing age, despite stable uncrossed responses, or a progressive decline in the crossed-minus-uncrossed difference, asymptoting at about 10 years of age, and conforming to the known myelogenic cycle of the forebrain commissures. Prior to 3.5-years-of-age, reliable crossed activity could not be obtained. Topological adult EP studies have consistently shown the crossed response as slower and smaller in amplitude than the uncrossed response, interpreted as due to commissural delay (Andreassi, Okamura, & Stern, 1975; Ishiko, Hanamori & Myrayama, 1980; Swanson, Ledlow, & Kinsbourne, 1978; Rugg & Beaumont, 1978; Wolpaw, & Penry, 1977).

Since only the faster callosal axons were likely to be measured by Salamy's technique, mediated through axons 2.4 to 6.0 um in diameter, possibly not more than about 20 percent of the callosal axon population was involved in his study (Swadlow and Waxman, 1979; Swadlow, Geschwind, & Waxman, 1979; Tomasch, 1954). Salamy (1978) felt that his finding would prove useful in assessing cases in which maturational delay was suspected. Salamy, Fenn, and Bronshvag (1979) also observed a strong relationship between human brainstem development and amplitude changes in brainstem EP indicating that electrical physiological maturation of brain structures is widespread and not unique to the forebrain commissures, at least to the age of five years.

In summary, the available evidence shows that numerous behavioural changes can accompany the gradual maturation of the commissural systems, suggesting (i) increasing efficiency of interhemispheric communication with increasing age, and (ii) possibly both less reliable and slower interhemispheric communication in younger children. The anatomical and physiological findings are compelling evidence for believing that myelogenesis is a key factor in determining changes in the speed of interhemispheric communication from early childhood into adolescence.

This developmental review places emphasis on the corpus callosum. Other less prominent routes of interhemispheric communication include the massa intermedia, the hippocampal, habenular, anterior and posterior commissures, the quadrigeminal plate, and the fornix, as well as the commissure of the superior colliculi. In most instances the anatomical and physiological maturation of the corpus callosum has been thought to herold functional ability.

Various behaviours such as intermanual sharing of information and timing of movements between hands, and a developing hierarchy of behavioural skills are seen as improved with increasing age. These behavioural changes are thought to reflect the development of functional maturity of the corpus callosum and are seen as being primarily dependent upon the myelogenic timetable, especially beyond infancy into middle and late childhood; since the mature pattern of anatomical connectivity may already be established in infancy or early childhood.

It may be fruitful to make a prediction regarding normal callosal development in the child on the basis of the accummulated evidence. Given that the period of myelination is the major characteristic of late development in the human nervous system, it is reasonable to predict that changes in interhemisphere transmission time would be prevelant and even paramount in childhood development, appearing along with other developmental changes in interhemispheric communication. Salamy's (1978) work shows this to be already a physiological fact. However, a specific prediction is that important behavioural changes in

RT may accompany or be a correlate to the already known physiological, maturational changes of callosal latencies of tactual EPs. In fact, similar important, behavioural, developmental RT correlates may also be hypothesized to exist in regard to visual, callosal, physiological activity. Maturation of interhemisphere transmission rates may be an important factor in the development of the commissural fibre systems for optimal functional interaction among all the various cortical areas in each hemisphere. Thus, a developmental, behavioral RT study would substantiate the existing physiological data and would also validate and document the chronological maturation of any similar behavioural processes, especially in view of the recent theoretical portrayal of the mature intact human as operating with dynamic, rapid interhemispheric communication and almost simultaneous, synchronous interhemispheric duplication of neural activity.

RT measurements _per se_ are not a common component of clinical assessment batteries despite the fact that slowing of RT is a salient behavioural characteristic of brain disease (Hansher, & Benton, 1977). However, RT determinations have been conducted in both adult (Benton, & Joynt, 1958; Blackburn, 1958; Bruhn, & Parsons, 1971; De Renzi, & Faglioni, 1965; Olbrich, 1972) and child clinical populations (Czudner, & Rourke, 1970; Rourke, & Czudner, 1972; Stevens, Boydstun, Ackerman, & Dykman, 1968) in order to determine the degree of cerebral integrity. To date, however, there have been no known behavioural studies conducted regarding developmental changes in the rate or speed of interhemispheric communication in young children. The present dissertation has undertaken such an investigation through middle to late childhood.

One of the properties of mental events that can be studied directly in the intact organism while the events are taking place is their duration through the use of RT as a dependent variable (Pachella, 1974). The time required to convey information between the two cerebral hemispheres over the forebrain commissures is referred to as interhemispheric transfer or transmission time, or transcallosal transmission time (ITT). This transmission rate was first estimated by Poffenberger (1912) in his doctoral dissertation in which he introduced an experimental task and paradigm, that relies on measuring RT to laterally presented stimuli. His basic task and paradigm (including a method of subtraction refined from Helmholtz) is still very widely used and has been adopted in the present study. Relevant studies have evolved in part from Poffenberger's (1912) work and in part from the split-brain studies of Sperry (1961) and Gazzaniga (1967, 1969). The Poffenberger (1912) model was used in the current study to assess the effects of maturation on the speed of interhemispheric communication through middle and late childhood. So-called "split-brain" phenomena are notoriously difficult to investigate due to the inherent bilateral organization of the human CNS. However, due to the reported success of studies using this model with normal and clinical populations and its applicability to different age levels, it was adopted for use in the current investigation. Studies employing this model generally measure unilateral responses to unilateral stimuli; however, the various stimulus and response factors are powerful and require careful consideration and control. In view of this fact, a careful perusal of the relevant factors was completed; a detailed summary follows, including discussion concerning the anatomical rationale of the model, the model's logistics, its general findings, and previous results from specific populations.

RT Study and ITT Estimation

To begin, an understanding of the rationale for the use of behavioural RT to determine ITT is required. The underlying anatomical perspective has regarded afferent input as being acted upon initially by the hemisphere opposite or contralateral to the side of the body being stimulated. Similarly, motor commands for the distal musculature (e.g., hand and finger movements) have been regarded as being initiated in the contralateral hemisphere. That is, the geniculostriate pathway guarantees that all visual stimuli arriving from the right visual half-field (RVF) will initially terminate in the contralateral or left occipital cortex, and similarly all visual stimuli from the left visual half-field (LVF) will initially terminate in the right occipital cortex. Most of the optic tract fibres (75%) project to the lateral geniculate nucleus, the remaining fibres mostly terminate in the superior colliculi of the midbrain tectum, but still remain fully lateralized (Antonini, Berlucchi, Marzi, & Sprague, 1979; Berlucchi, 1972; Edwards, 1977; Gross, Bender, & Mishkin, 1977).

The degree of lateralization in the somatosensory system may be dependent upon the task (Gazzaniga, & LeDoux, 1978). The dorsal-column-medial-lemniscal pathway is entirely crossed, joining different points on the body with the contralateral hemisphere. The thalamic termination of this system is the ventral posterior lateral nucleus, which has only contralateral cells. Gazzaniga and LeDoux (1978) state that we should expect to find crisp lateralization of dorsal-column information (active touch, proprieception, and vibratory sensibility) but various degrees of lateralization for information transmitted by way of the spinothalamic system (passive touch, including roughness, texture, form and localization discriminations; as well as pain and temperature), which has homolateral projections (Azylay & Schwartz, 1975; Gibran, 1962; Ishiko et al, 1980; LaMotte & Mountcastle, 1975; Poggio & Mountcastle, 1960; Wall, 1970; Willis & Grossman, 1977).

The motor pathways from the cerebral cortex generally cross the midline during their descent to innervate muscle groups on the contralateral body side, particularly for relatively independent finger movements. This capacity is mainly provided by the pyramidal tract and probably especially by the fibres from the precentral gyrus to the contralateral motorneurons of distal extremity muscles (Brinkman, & Kuypers, 1973; Haaxma & Kuypers, 1975; Kuypers & Brinkman, 1970; Lawrence & Hopkins, 1976; Lawrence & Kuypers, 1968b; Matsunami, & Hamada, 1981).

Poffenberger (1912) argued that the time required for information to be conveyed between the two hemispheres could be determined by taking the difference between the RT latencies for each hand. He predicted that if both sensory input and movement initiation take place within the same hemisphere (the short pathway), then those RTs obtained in that situation should be shorter than when sensory input and movement initiation occur within opposite hemispheres (the long pathway), therefore requiring interhemispheric communication.

In fact, as Poffenberger (1912) found, if a subject is asked to lift his finger quickly in response to a brief light flash, right hand responses will usually be faster when signals are presented in the RVF (an uncrossed reaction) than when they are presented in the LVF (a crossed reaction). Similarly, left hand responses will most often be faster when signals appear in the LVF (an uncrossed reaction) than when they occur in the RVF (a crossed reaction). These findings have been reported in a number of recent investigations of simple motor responses to unilateral visual and tactual stimulation. When simple RTs are averaged across both hands, and both hemispheres the crossed-minus-uncrossed difference provides a mean ITT estimate, an average measure of the speed of interhemispheric transmission. The crossed-minus-uncrossed difference has been labelled (CUD) by Milner and Lines (1982) and is synonymous with the ITT definition of the present study.

Studies designed to determine ITT may be categorized along several dimensions, such as (a) nature of stimulus, <u>patterned</u> (e.g., geometric figures, letters, words, faces) versus unpatterned (e.g., dots, flashes of light); (b) nature of response, manual versus vocal; and, (c) nature of task, that is, simple RT (e.g., requiring an invariant finger movement following every stimulus) versus two major models of choice RT tasks (e.g., requiring a go/no-go response to a particular stimulus, or different responses dependent upon different stimuli). Patterned stimuli are usually employed in conjunction with an identificatory response, whereas unpatterned stimuli usually serve when simple detection of the stimulus is required.

In this section studies of simple RT tasks to determine ITT will be reviewed. All of these studies have a number of salient features in common. The subject is required to maintain fixation on a central point, while awaiting a very brief unpatterned or simple visual half-field stimulus, to be directed unilaterally to the nasal or temporal hemiretina. Its duration of usually less than 200 msec is too brief to permit foveation of the target. The subject is required to respond as quickly as possible, with a single finger movement, without any eye movement, to half-field visual stimulation.

In a similar testing situation, Poffenberger (1912) reported an ITT between 5 and 6 msec, and his hypothesis has been confirmed by almost every replication of his procedure, employing visual stimuli (Anzola, Bertoloni, Buchtel, & Rizzolatti, 1977; Berlucchi et al, 1977; Berlucchi et al, 1971; Di Stefano, Morelli, Marzi, & Berlucchi, 1980; Jeeves, 1969; Jeeves & Dixon, 1970, McKeever & Hoff, 1979; Milner & Lines, 1982). With one exception (Jeeves, 1965), the recent estimates of the average CUDs have ranged in value from 1.0 msec to just over 3.0 msec.

An interesting note to this general finding is that not every subject within any one study has achieved a positive CUD. Occasionally, subjects would achieve a positive CUD with one hand and a negative CUD with the other. In fact, in the Anzola et al., (1977) study, an unreported negative CUD is apparent from the data which is presented for overall left hand performance. Smith (1938) reported a negative CUD for half of the 12 cases which he examined, the reverse finding being obtained for the other half of his cases. The fastest RTs are sometimes seen when the right hemisphere receives the stimulus and the left hemisphere initiates the response by the right hand; followed by the right hemisphere receiving, and the right hemisphere initiating the response with the left hand (Jeeves, 1969, 1972; Jeeves, & Dixon, 1970).

Notwithstanding this variability in findings, enough research has been done to ensure the reliability of the ITT measure to be near the value of 3 msec in the intact adult brain, when manual responses are measured in simple RT tasks, using unilateral visual stimulation. The consistency of the ITT estimates may reflect the simplicity of the stimulus content, the uncomplicated and invariant nature of the motor response, and the absence of any necessity to discriminate between stimuli or chose particular responses. Similar conclusions have been drawn by Bashore (1981).

Gazzaniga (1981b) has suggested that the simple RT task may in fact, be mediated subcortically. While this assumption is a contentious point, it seems reasonable to assume that increasing RT task complexity would certainly engage different cortical processes and changes in the nature or degree of interhemispheric communication. Evidence to be examined in the next two sections shows that adding complexity (i.e., requiring stimulus categorization or discrimination and/or response selection) can alter the overall latency to respond and apparent length of time needed for interhemispheric communication. However, some support for Gazzaniga's (1981b) view comes from the work of LaMotte and Mountcastle (1975) who examined the capacities of humans and monkeys to discriminate between vibratory stimuli of different frequency and amplitude. They concluded that those aspects of sensation whose codes require only the detection that a simple change has occurred in a certain set of neuronal elements do not depend on cerebral cortex, at least not uniquely.

With respect to choice RT tasks, in the go/no-go RT situation, on any given trial, a stimulus is either presented or withheld from the subject whose task consists of making a response every time the stimulus appears. Basically, the model for this choice RT task is said to involve two stimuli and only a single response that is required for only one of the two stimuli but not for the other, thus the descriptive term simple choice RT task. Unlike the simple RT task, in which the subject regards every trial as identical, the cognitive field has become more complex. Now every trial requires a decision in terms of stimulus categorization; is the stimulus present or absent, black or white, one word or another, located to the left or right, etc.? This particular increase in task complexity, that is, the requirement for stimulus categorization, is reflected in longer RTs and a much greater range of ITT estimates (Berlucchi et al, 1977; Bowers, Heilman, & Van Den Abell, 1981; Isseroff, Carmon, & Nachshon, 1974; Kleinman, Carron, Cloninger, & Halvachs, 1976; Moscovitch, & Smith, 1979; Smith, & Moscovitch, 1979; Swanson, & Ledlow, cited in Swanson, Ledlow, & Kinsbourne, 1978). These values range from 185 to 391 msec and from 2.7 to 48 msec, respectively.

There exists a still more complex choice RT task, consisting of two stimuli and two responses, and a one-to-one mapping between them. The judgments or decisions required, include both stimulus categorization and response selection, thus the term complex choice RT task. The subject is presented with one of two stimuli, and must respond consistently with one of two available responses.

Filbey and Gazzaniga (1969) had subjects move a lever to the left or right depending upon the detection of a dot or blank visual half-field. Anzola et al., (1977) required subjects to respond with the left or right hand depending upon visual field stimulation. Bradshaw and Perriment (1970) had subjects use different digits in each hand depending upon left or right visual field stimulation. Finally, Harvey (1978) required his subjects to rest a finger on a middle key, moving it to another key on the left or right to correspond with visual half-field stimulation. In this group of studies, ITT estimates ranged from 10 to almost 50 msec. RT values ranged from 189 to 450 msec. These complex choice RT studies provide a similar range of RT and ITT values to those obtained in the simple choice RT studies.

A sizeable number of studies have attempted to "split" the normal brain with vocal responses, using choice RT tasks. The major group of studies have requested subjects to respond vocally and differentially to half-field stimuli, primarily utilizing letters, simple geometric figures, or dot-present or absent investigations. Results have been inconsistent with scores varying from no significant CUDs to estimates over 40 msec (Amodeo, Roemer, & Shagass, 1977; Gazzaniga, 1969; Gibson, Filbey, & Gazzaniga, 1970; McKeever, & Gill, 1972; McKeever, Gill, & Van Deventer, 1975; Moscovitch, & Catlin, 1970).

The major problem with all of the vocal RT studies is that the apparent CUDs could be due to either the time taken to cross from one cerebral hemisphere to the other or to asymmetries between the hemispheres in their capacity to process various types of material, or to process differently, similar stimuli (Geffen, Bradshaw, & Wallace, 1971; or Isseroff et al., 1974). There is no adequate control condition, however, since speech is normally a left hemisphere function.

Two studies have attempted using simple RT procedures to measure CUDs with nonidentificatory vocal responses to lateralized, patterned visual stimuli. The Geffen et al., (1971) study yielded no significant results; however, Milner and Lines (1982) found significant CUDs ranging in value from 14.01 through 8.16 to 6.33 msec, decreasing in latency as stimulus intensity increased. In a similar manual response experiment, the mean CUD showed no trend toward a decrease as intensity increased. Vaughan, Costa, and Gilden (1966) using bilateral visual stimulation demonstrated an overall RT increase as stimulus intensity was decreased. Thus, while manual simple RT tasks almost always yield consistent ITT estimates, the use of vocal responses yields more variable findings in both simple and choice RT conditions.

In summary, ITT estimates appear to vary as a function of task complexity. ITT determination in simple RT tasks, involving unilateral visual stimulation requiring an invariant finger movement, yields a very robust measure averaging approximately 3 msec. Increasing task complexity by introducing either stimulus categorization or response selection decisions, or both, produces ITT estimates varying more widely in value. Employing vocal responding may widen the scope of variability even further. Increasing task requirements may involve engagement of different cognitive processes with concomitant changes in intrahemispheric processing and perhaps interhemispheric communication. While simple RT tasks seem to provide consistent ITT estimates, it is less clear what portion of ITT estimates obtained from complex RT task can actually be attributed to the time required for interhemispheric information transfer.

Although the contribution of vision to the execution of certain sensorimotor tasks is incontrovertible, the role of somesthesis remains relatively enigmatic. Connolly (1970) concludes that on the whole a child has to monitor his motor output more than an adult, adding that the child often needs vision to tell him where his hand is or where he must place his foot in a staircase. Gradually, visual input is required less as proprioceptive and/or kinesthetic cues take over the monitoring functions of vision. In the case of adults, there is evidence indicating an increased dependency on proprioception as the skill improves.

Evidence hints at the importance of somesthetic input. Berman and Berman (1973) found that forelimb deafferenation in infant monkeys prior to delivery resulted in severely retarded finer movements of the distal musculature. Laszlo (1966) demonstrated that performance on a number of skills was markedly disrupted under ischemic nerve block, for example repetitive tapping, as well as replication of finger movements (Glencross, & Oldfield, 1975). Provins (1957) showed that when the finger is anesthetized distal to the metacarpal-phalangeal joint, the accuracy of reproducing a particular pressure by flexion is impaired. Asanuma (1981) has argued for the necessity of somesthetic afferent input from the periphery to the motor cortex in order to control the distal extremeties, especially fine movements of the hand and fingers. Asunuma (1981) believes that cortico-peripheral loops may be involved primarily in terms of facilitory excitation to the motor cortex. Twitchell (1970) has suggested a similar mechanism which may explain the case of the child with hemiplegia in which the so-called contact facilitator is lacking. Rothwell, Traub, Day, Obese, Thomas and Marsden (1982) studied manual function in a man deafferrented by a severe peripheral sensory neuropathy. They found that motor power, preprogrammed finger movements, and individual finger movements were uneffected; however, his hands were reportedly almost useless to him in daily life. Part of his difficulty lay in the absence of any automatic reflex correction in his voluntary movements, and also his inability to sustain constant levels of muscle contraction without visual feedback over periods of 1 or 2 seconds. He was also unable to maintain long segments of simple motor programmes without vision. In this regard, Moberg (1983) has pointed out that cutaneous afferents appear to provide dominant input in motor function of the hand. In fact, many cutaneous receptors in the hand are activated during movements of a finger even if no object is touched.

Finally, several studies argue for the relative importance of the right hemipshere in tactual recognition (Dodds, 1978; Harris, & Carr, 1981). Evidence also exists supporting developmental changes in tactual thresholds (Ghent, 1961), tactual-spatial ability (Flanery, & Balling, 1979), and tactual recognition, with each study emphasizing the increasing primacy of the right hemisphere through early development. In view of the apparent importance of somesthesis, a review of the very few extant RT studies utilizing tactual stimulation is germane to the present thesis.

Moskatova (1966) delivered a brief discharge of air to the wrist of 10 subjects. The response was the closing of the thumb and index finger, to one of which was attached a plastic thimble, to the other, a contact plate. The mean RT via the short pathway was 4.6 msec (ranging in value from 2 to 8 msec) less than the RT via the long pathway. In each of the 10 subjects, the CUD difference was positive, although only significantly so in five of the subjects. Moskatova planned to use what he described as "this very sensitive index in diagnosis" (Moskatova, 1966, p. 25).

Efron (1963a, 1963b) examined judgments of light or electrical shock onset simultaneity from either visual half-field or either index finger, respectively. For lights (~~a~~ bright 1 msec flash) or shocks (a 1 msec square pulse) of the same intensity to be judged as simultaneous in their onset, the left stimulus must precede the right stimulus by 2.0 to 6.0 msec. Efron concluded that the time delay was accounted for by transfer of information through the corpus callosum to the dominant hemisphere, where he said the comparison is made. This model accounted well for all of his data.

Muram and Carmon (1972) administered (electromechanical) pressure stimulation to the back of the hand of 12 subjects in a simple RT paradigm. Crossed RTs were longer by 10 msec, on the average, than uncrossed RTs, and vocal RTs to unimanual stimulation were the same for both hands. The range of increase was between 1 and 27 msec.

In another simple RT study, subjects were asked to depress a key with the requisite index finger when they detected a solenoid pin dropped onto the middle fingernail from a distance of 2 mm (Moscovitch, & Smith, 1979). Latencies were fastest to stimuli having direct access to the hemisphere controlling the responding hand. The ITT estimate was approximately 8.5 msec, with values ranging from 4 to 14 msec.

In summary, ITT estimates from four tactual/manual simple RT studies, in terms of magnitude, are in approximate agreement with the estimates produced in the visual/manual simple RT experimentation which has been reviewed, with the present estimates being somewhat larger and ranging in value from 4.6 to 10 msec. Again exceptional results were obtained by Jeeves (1965) employing vibratory stimulation.

Only a few studies have been conducted with brain-bisected or acallosal patients. Smith (1947) examined six brain-bisected patients, using a complex choice RT procedure, finding no significant CUD, either pre- or post-operatively. Only two of the six patients had complete sectioning of the corpus callosum; however, data from his normal control subjects were consistent with the Poffenberger (1912) hypothesis. Gazzaniga, Bogen, and Sperry (1965) reported that crossed visual reactions were not possible at all in their first brain-bisected patient in early post-operative tests. Twenty-four months after surgery, however, crossed responses were possible, but remained inferior to uncrossed responses in speed, accuracy and general coordination. A second brain-bisection case is described in the same report as showing "no difference between ipsilateral and contralateral combinations in RT to a simple flash of light in either half-field". No further information was given (Milner, & Jeeves, 1979).

Regarding acallosal patients, Milner and Jeeves (1979) have concluded that their skilled performance may suffer from lengthening of interhemispheric transfer time. Lengthening of ITT in an acallosal patient was first reported by Jeeves (1965). Jeeves (1969) found that in two acallosal subjects crossed RTs were much longer than uncrossed (17.0 and 61.3 msec longer). In two further experiments with adolescent acallosal patients, further lengthy delays were noted, 12.4 and 13.1 msec (Kinsbourne, & Fisher, 1971), and 13.7, 12.2 and 30.4 msec (Reynolds, & Jeeves, 1974). All of this acallosal data was collected from visual/manual simple RT experimentation.

Very recently, Milner (1982) has tested a young acallosal woman using three different intensity levels of visual stimulation on a simple RT task. Crossed responses were found, on the average to be about 20 msec longer than uncrossed responses using manual responding. An inverse relation was found between stimulus intensity and magnitude of the CUD. Variation in stimulus intensity resulted in a concomitant inverse not only in RT but also in CUD, such that in the brightest condition CUD averaged 14.0 msec, but only 24.3 msec in the faintest stimulus condition.

Vocal RTs were also recorded displaying a large advantage of 18 msec for RVF stimulation, but vocal RTs were not affected by changes in stimulus intensity. These results can be contrasted with those obtained in a similar RT study (Milner, & Lines, 1982) examining normal adults, in which vocal responding yielded ITT measures which were sensitive to variation in stimulus intensity, while manual responding yielded relatively insensitive ITT measures. Presently this discrepency remains unexplained.

Two investigators have reported negative findings in examining six acallosal patients. While Persson (1970) examined patients with only partial agenesis, Ettlinger, Blakemore, Milner and Wilson (1972) did not even find a clear retardation of crossed relative to uncrossed reactions in three total and three partial agenesis cases. Notwithstanding these negative findings, the simple RT studies conducted with acallosal subjects provide strong evidence of the fact that interhemispheric communication in the absence of the corpus callosum requires a substantial amount of time.

Milner and Jeeves (1979) have recently contended that impaired acallosal performance on spatial and bimanual tasks is due to lengthening of interhemispheric transfer time. Supportive evidence comes from work with two acallosal siblings of 10 and 17 years of age, in which both were impaired in bimanual operations with regard to speed; but, no differences were found between the acallosal and control subjects on any transfer task (Sauerwein, Lassonde, Cardu, & Geoffroy, 1981). In another study, this acallosal sibling pair were able to effect intra- and interhemispheric comparisons from either visual half-field, but they responded more slowly, especially in the bilateral condition where they also made more errors than controls. Sauerwein and Lassonde (1983) suggest the intertectal commissures as the most likely interhemispheric pathway of visual information in the absence of the corpus callosum. Finally, Meerwaldt (1983) tested an 8-year-old girl with agenesis of the corpus callosum on a rod orientation test requiring tactile manipulation. When compared with ten neurologically normal children, this acallosal child had defective performance and the longest mean duration in the tactile part of the test, but only when using her right hand. Apparently, according to the investigator, for an accurate motor response of the right hand in the rod orientation test, "cross-talk" with the right posterior region is necessary. Disrupted or delayed interhemispheric communication is characteristics of both brain-bisected and acallosal patients, and is considered central to understanding different behavioural limitations in both of these patient groups (Chiarello, 1980; Gazzaniga, 1965, 1966, 1967, 1969; Gazzaniga, Bogen, & Sperry, 1963, 1965, 1967; Gazzaniga, Risse, Springer, Clark, & Wilson, 1975; Jeeves, 1979; Kinsbourne & Fisher, 1971; Milner, 1982; Milner & Jeeves, 1979; Reynolds & Jeeves, 1974, 1978; Sperry, Gazzaniga, & Bogen, 1962). Possibly both the acallosal and brain-bisected patient may represent an analogue or model of brain organization with which to understand some aspects of the development of interhemispheric communication in children.

One study only (Jeeves, 1972), using a simple RT task, has examined hemisphere differences in response rates to visual stimuli in children. The subjects were 20 boys whose ages ranged from 9 years 6 months to 11 years 5 months. The experimental task was identical to that used in an earlier study with adult subjects (Jeeves & Dixon, 1970), previously discussed. Ten of the boys described themselves as right-handed and 10 as left-handed. The mean ITT obtained was 1.30 msec for all 20 boys and 3.31 msec for right-handed boys only. Adults (Jeeves, 1970) have responded faster than these children, the magnitude of this difference being in the order of 50 msec. These particular children also have tended to yield a wider range of ITT scores than their adult counterparts.

Although this latter study offers no evidence for developmental changes in the rate of interhemispheric transmission, data from other sources, including the anatomical, physiological and behavioral studies already reviewed, provide evidence of postnatal increases in the efficiency of interhemispheric communication, as well as incentive to undertake an empirical investigation of ITT in much younger children. The simple RT literature for normal intact subjects, including 9- to 11-year-old boys, shows that transcallosal transmission time can be as fast as 1 to 3 msec. This very rapid interhemispheric communication ability has been shown to be slowed (from 2.7 to at least 50 msec) in more complex RT tasks, requiring categorization and/or response decisions; however, the idea that equally rapid interhemispheric transmission can occur in both the adult and young child's brain seems unlikely. The evidence suggests that in some instances sensory interhemispheric transfer may not even occur before the age of 3.5 years (Salamy, 1978).

Statement of the Problem and Hypotheses

Over the last decade, we have begun to accumulate knowledge concerning the development of interhemispheric communication. While various aspects of this development have attracted experimental attention, one rather less prominent but perhaps crucial parameter has remained uninvestigated in the child and incompletely understood in the adult; this parameter is the speed of interhemispheric transfer. The belief that optimal human functioning depends upon rapid interhemispheric transmission, the apparent delay of interhemispheric information transfer in acallosal patients, its association with further problems of poor performace in these patients, and its possible association with normal development indicate a need to investigate this parameter further. This knowledge may be valuable in beginning to determine the manner and degree to which speed of interhemispheric transmission contributes to normal behavioural development and in elucidating its role in clinical populations such as learning-disabled children.

Behavioural RT studies in the literature assessing intact adults, indicate that interhemispheric transmission normally lags behind intrahemispheric processing by a small but reliable time lapse; however, no comparable behavioural RT studies have been conducted through normal childhood. Since the one existing developmental, electrophysiological study of interhemispheric communication speed (Salamy, 1978) did not determine whether any behavioural differences existed in RT to ipsilateral (uncrossed) versus contralateral (crossed) stimulation, it is not known from this study whether young children are, in fact, substantially slower than older children or adults in behaviourally responding to crossed versus uncrossed stimulation. Therefore, the present study proposed to clarify the issue of whether behavioural responding in young children to crossed stimulation is significantly delayed when compared to that of older children.

In addition to determining simply the degree of delay, the present study will use a protocal which will more fully explore how young children might show delayed crossed performance and thereby increase further the applicability of its findings beyond those of the previous electrophysiological study. While the previous studies involving acallosal patients used a protocal which de-emphasized cognition, through the use of simple RT tasks, the current study proposed to determine whether the young child's performance would be more sensitive to interhemispheric delay in a situation requiring more cognitive work. In elaborating the present study then, both simple and complex choice RT tasks using visual stimulation are included. Since Gazzaniga (1981b) had pointed out that simple RT tasks may not require cognitive involvement, an experimental condition using a complex choice RT tasks was also designed and included. It was recognized that in the complex choice RT task latency to respond might be traded off to perform stimulus categorization (which stimulus to respond to) and a response decision (which hand to use) followed by the response, consequently providing an ITT estimate which may be fundamentally different than an ITT estimate derived from a simple RT paradigm. Moreover, the cortex and other brain structure (the cerebellum?) are probably essential to organize and allow the response at least in the complex choice RT task and possibly in the simple RT tasks as well. In this regard, one may consider Brook's (1981) proposal that when accuracy of responding is required, kinesthetically sensitive, slow, precentral neurons are engaged, whereas when speed is of the essence, kinesthetically less sensitive fast precentral neurons are recruited as well. This interaction apparently can be achieved through cerebello-thalamic circuits by targetting particular groups of precentral neurons. Regarding the present study, these findings suggest the possibility that some precentral neurons may be involved in the performance of both the simple and complex choice RT tasks.

Furthermore, in the case of the visual complex choice RT task, an attempt had to be made to control for the possibility of lateral asymmetry of function. The traditional view has of course recognized a verbal/nonverbal dichotomy in describing cerebral lateralization. In regard to adults, verbal material is usually responded to more quickly in the RVF, with nonverbal material receiving faster responses in the LVF (Geffen _et al._, 1971; Isseroff _et al._, 1974). Hemispheric differences have also been recognized in the discrimination of line orientation. Researchers (Umilta, Rizzolatti, Marzi, Zamboni, Franzini, Carmarda & Berlucchi, 1974) have shown that rectangles oriented with their major axes along the vertical and horizontal direction are recognized fastest in the RVF, whereas similar stimuli oriented along other directions are recognized faster in the LVF. In fact, one group of investigators (Fried, Mateer, Ojemann, Wohns, & Fedio, 1982) have shown that the right cerebral hemisphere may be specialized in the adult for the perception and memory of faces and line orientation.

With children, identificatory asymmetric responses to letter shapes may not occur prior to seven years of age, whereas asymmetric responses to nonverbal shapes appear even sooner (Broman, 1978; Reynolds, & Jeeves, 1978). Carmon, Nachshon and Starinsky (1976) found a clear RVF superiority for perception of verbal material by the fifth grade, but a slight LVF superiority in the first grade. Young and Ellis (1976) investigated developmental differences in ability to recognize faces presented to the left and right cerebral hemispheres of children aged 5-, 7- and 11-years. The results indicated right hemisphere superiority at all three ages.

A more recent counter-poising perspective must be considered, however. Bradshaw and Nettleton (1981) have examined the nature of hemispheric specialization in man and have suggested that the traditional dichotomy is inadequate for completely describing cerebral lateralization. They propose that more fundamentally the left hemisphere is characterized by its mediation of discriminations involving duration, temporal order, sequencing and rhythm at the sensory (tactual, visual and auditory) level, and especially at the motor level (for limbs, fingers, and speech apparatus). From their theoretical perspective, spatial aspects are said to characterize the right hemisphere, the mapping of the exteroceptive body, and the position of the fingers, limbs and perhaps articulartors, with respect to actual and target positions. They say that there is a continuum of function between the hemispheres, the difference being quantitative and by degree, with all action taking place in a unified temporal-spatial continuum involving both hemispheres. Some independent support for the temporal-processing emphasis of the model comes from work with dyslexic (Carmon, 1981) and langauge delayed children (Tallal, 1981).

Bradshaw and Nettleton (1981) state that hemispheric specialization is determined not by the categorical "nature" of the stimulus (i.e., verbal or melodic) but rather by how it is perceived. Sergent (1982) in a recent discussion of basic determinants of visual field effects, has also argued similarly that when the task demands are set equal for verbal and nonverbal stimuli, and when the conditions of presentation allow for the achievement of a visual representation of similar quality, there is no hemispheric asymmetry as a function of verbal or visual spatial stimuli processes.

Thus, in the present study, the question of possible lateral asymmetry of function was addressed from both the traditional and more recent dynamic perspective. Two different tasks (a letter discrimination task and a line orientation task) were chosen in an attempt to control for the possibility of lateral asymmetry of function, since each task may differentially tap the functional specificity of each hemisphere. At the same time, the task demands and the presentation conditions of the verbal and nonverbal stimuli were designed to be sufficiently equal and congruent so as to possibly eliminate any hemispheric asymmetry as a function of verbal or visual-spatial lateral asymetry.

In view of the known myelogenic timetable the following hypotheses are presented regarding performance in the simple and complex choice visual RT experiments:

I. Younger children will exhibit a significantly greater response delay to crossed stimulation in the simple visual RT experiment than will older children.

II. Younger children will exhibit a significantly greater response delay to crossed stimulation in the complex choice RT experiment than will older children.

Somesthesis appears to be a crucial factor in normal motor activity especially regarding fine movements of the hand and fingers, as well as being an important component of right hemispheric functioning. For these reasons, a tactual stimulation task was included in the present study. An additional reason for examining tactual stimulation in the present study stems from a philosophical perspective. Carmon (1981) has reiterated the belief of the American philospher Samuel Alexander that "existence is viewed by us in two modes, one of space and one of time, with time being a point in space and space a point in time". These two dimensions are said to account for the totality of perception. Many of are perceptions are thought to be inherently both temporal and spatial. In fact, Gestalt or temporal-spatial contours of stimuli are believed to be represented both clearly and not so-clearly by the spatial-temporally distributed activity in the neocorticies (Creutzfeldt, 1981). Most importantly, both visual or tactual modalities can be used by us to execute our various temporal spatial discriminations. The degree to which young children actually are slower in responding behaviourally to crossed tactual stimulation has never been assessed, however.

Regarding performance in the simple tactual RT experiment, it is hypothesized that:

III. Younger children will exhibit a significantly greater response delay to crossed stimulation in the simple tactual RT experiment than will older children.

The current investigation will also assess developmental changes in behavioural RT measures to bilateral visual and tactual stimulation. With respect to bilateral stimulation, it is proposed to determine what age differences exist during performance on the bilateral RT tasks. Existing evidence suggests that older children in comparison to younger children may respond faster to bilateral visual or tactual stimulation.

Regarding responding on the bilateral visual or tactual stimulation tasks, it is hypothesized that:

IV. Older children will respond faster to bilateral stimulation, then younger children.

Finally, the face validity or the sensitivity of the experimental tasks to the effects of callosal agenesis will be investigated. The ability of these tasks to accurately reflect recognized performance limitations in acallosal patients was judged important for determining their future use in research and potential treatment of delayed or slowed interhemispheric information transfer. Since it is characteristic of acallosal patients to demonstrate delayed responses to crossed stimulation it is expected that their crossed response rates on these tasks will be most like the younger children of the present study. A prediction regarding the sensitivity of these same tasks to surgical brain-bisection would be more speculative because of the pausity of information available concerning performance of brain-bisected patients on RT tasks designed to assess ITT. Although no brain-bisected patient is available, a nineteen-year-old, male acallosal patient will be asked to attempt all of the tasks in the current study.

Regarding his performance in all of the tasks, it is hypothesized that:

V. The acallosal patient will exhibit significantly slower responses to crossed stimulation, as compared with older children.

Chapter II.

METHOD

Subjects

The sample chosen consisted of 120 right-handed male children from four separate age groups: 30 from each age level of 5-, 7-, 9- and 11-years. The children had to fall into one of the following age ranges (i) 4 years 6 months to 5 years 6 months; (ii) 6 years 6 months to 7 years 6 months; (iii) 8 years 6 months to 9 years 6 months, and, (iv) 10 years 6 months to 11 years 6 months. The children were selected from two public schools of the Ottawa Board of Education, with approximately half of the children coming from each school. The majority of the older children came from one school. Concerning social and economic status most of the children in these two schools are believed to come from middle or upper-middle class families. The subjects of the present study did not constitute a "normal" or random sample, since all of the 120 children tested on the five tasks were right-handed. However, almost all of the children who have served as subjects in the interhemispheric communication literature have been selected on the basis of right-handedness. Warrington and Pratt (1981) have suggested that right- and left-handers may have differences in organization of cerebral function. This notion is supported by an RT study with right and left-handed children in which the left-handed children demonstrated a significantly different pattern or inter- and intra-hemispheric response rates than the right-handers (Jeeves, 1972). Maxwell (1981) has suggested that selecting for right-handedness may select out some variance in cerebral organization normally encountered in the population.

None of the children included in the study were known to have any neurological emotional or physical disorders, including learning or behaviour problems, according to their teachers' and the examiner's observations. Five subjects were excluded from the study because they were identified by their parents as having learning difficulties. Twelve subjects were also excluded from the study because they were unable to perform any of the experimental tasks as well as in some instances some of the screening tasks. Subjects were selected for the study after obtaining parental permission and after administration of a screening procedure. The screening required the children to be right handed and have age appropriate levels of visual acuity and stereoscopic depth perception ability; consecutive qualifying children were included in the study.

The Screening

The children were tested by the investigator over two, three month periods, from early April to late June, 1981, and from early September to early December, 1981. All testing took place on an individual basis in a quiet room, which served as a laboratory within the school. All of the 11- and 9-year-old children were tested in four, thirty minute sessions, whereas 7- and 5-year-olds were tested in either five or six, thirty minute sessions, depending upon the child's continued good cooperation and apparent level of attention during each session. Testing sessions for each child were spread over a six to eight week period, with a seven to fourteen day interval between sessions. The screening procedures always preceded the experimental testing.. Generally, rapport between the children and the examiner established initially during the screening was well maintained, with a number of children expressing enjoyment of the "flashing light games", in particular, the complex choice RT experiment.

Handedness was determined by observation of both preference and performance. Hand preference was determined by instructing the subject to pick up a pencil presented at midline and then write or print his name. The hand used to execute the response was recorded as the preferred hand. If the subject could not write or print his name, as was the case with about half of the 5-year-olds, he was asked to draw a circle, and complete it as a "happy face". A second measure of hand preference was obtained by observing which hand was used in response to commands from the examiner to "show me how you would throw a ball" and "show me how you would cut with a pair of scissors". All children included in this study showed a right hand preference on all of these tasks.

After determining hand preference and performance, each child was given a test of visual acuity (Snellen E Letter Chart; Imperial

Optical, Number 2), followed by a test of stereoscopic depth perception ability or stereopsis (Titmus, Stereo Tests, Titmus Optical). Only those children who showed age appropriate normal and equal levels of eye acuity (20/20 = ±10) and stereopsis (at least to 80 seconds of angle) were included in the study. No child was accepted as a subject if he normally wore eye glasses. Dumais (1980) found that stereopsis (binocular vision) is present in human infants, but depends on an intact corpus callosum. Stereopsis is apparently dependent upon normal callosal development in experimental animals (Elberger, 1979; Pettigrew, 1974).

The Apparatus and Procedures

A series of six RT tasks were designed. Two RT tasks were administered using tactual stimulation. The first was a baseline control procedure employing bilateral tactual stimulation. The second constituted a simple RT experiment requiring manual responding to unilateral tactual stimulation. Four RT tasks were administered using visual stimulation. Again, the first was a baseline control procedure employing bilateral visual stimulation. The second constituted a simple RT experiment requiring manual responses to simple unilateral visual stimulation. The third and fourth tasks combined, constituted one complex choice RT experiment.

For each child, testing was completed first in the tactual modality, then in the visual modality. In both modalities, control procedures were administered first, followed by administration of the simple RT experiments. The complex choice RT experiment was conducted last and only in the visual modality. The tasks were administered in this particular order because of the gradually increasing difficulty in their execution as experienced by the children. All of the experimental and control tasks were administered to one 19-year-old acallosal boy, a neurological patient of the Children's Hospital of Eastern Ontario. Since he was not a resident of this community, the entire battery was completed in one morning of testing, in a truncated version. Unfortunately, a reduced number of trials on the experimental tasks may have reduced the reliability of his results.

The tactual apparatus will be described first, followed by a detailed account of the procedures involving this apparatus. Subsequently, the visual apparatus and procedures will be discussed in detail. Some general comments regarding the experimental apparatus and procedures will be made throughout the chapter.

The Tactual Apparatus

The tactual RT apparatus consisted of two sources of vibratory stimulation, one for each hand, and two response keys, one for each hand. The vibratory sources were constructed from an identical pair of small speakers (Hokutone, 8 ohms, 0.2 watts) each measuring 5 cm in diameter. Each speaker was suspended face up on a similar sized 0.5 cm thick ring cut from anti-static foam, supported by a large polystyrene foam base and housed in a plexiglass frame. The diaphragm of each speaker was free to vibrate; however, the diaphragms per se were not well suited in shape or size for uniformly conducting vibrations to the subject's fingers. Therefore, a circular disk (0.5 cm thick, by 3 cm in diameter) cut from anti-static foam was affixed to the centre of each diaphragm. This disk provided a level surface which was free to pulsate in union with the diaphragm. Atop this surface was laid a large firm triangular piece of anti-static foam (0.5 cm thick, 18 cm long, by 10 cm wide) which provided the vibratory surface upon which the child would place his fingers in order to detect the stimulus. This vibratory surface was fitted with structural guides allowing freedom of vertical movement, but fixing the surface in the horizontal plane.

During experimentation, speaker diaphragms when pulsed, vibrated very briefly at the rate of 60 cycles per second, for a duration of 75 msec. The stimulators could be pulsed independently or simultaneously. The similarity s in vibration intensity of the two sources was assessed using an oscilloscope. In order to control for the possibility of significant differences in vibration intensity between the two stimulators, the position of the stimulators was interchanged half way through an experimental session for each child. The stimulators were independent, moveable, free standing structures. An attempt was also made to reduce the auditory signals from the stimulators, by wiring in series, a resistor (10 ohms), and in parallel, a capacitor (100 microfarads, 0.63 volts).

All of the children sat in an adjustable chair which accommodated to the child's overall stature and size, as well as to his arm length. Each vibratory stimulator stood adjacent to one response key, so that the child could depress the key with his index finger, while spreading his other three fingers comfortably on the vibratory surface. The child's finger pads were in contact with the vibratory surface. The two response keys, which formed an integral part of the RT circuit, were constructed from microswitches (Micro Switch, V3L-131-D8) and installed one in each arm-rest.

An electronic counter (Dawe Digital Frequency Meter, Counter and Timer, serial 1066, type 901A) measured to the nearest hundred of a millisecond the interval between the onset of the RT signal and the release of the key, in all of the RT tasks of the present study.

Finally, each subject was required to wear a set of stereo headphones (Koss, PRO/4AAA) through which a white noise was generated to mask any auditory signals regarding stimulus onset. The wearing of these headphones with the accompanying white noise was also required in every RT task of the present study. All "onset" signals were satisfactorily masked.

The Tactual Control Procedure

In order to identify developmental changes in RT independent of stimulus lateralization a control procedure was conducted in which a simple unilateral response was required to bilateral tactual stimulation. A total of 32 trials was administered, in two blocks of 16 trials each, using the right or left hand in each block.

For all of the RT tasks included in the present study, formal testing began only after an informal practice period during which the child was acquainted with the particular experimental situation. The younger children usually required a larger number of practice trials in order to achieve smooth coordinated performance, to a criterion of eight out of eight correct responses for all ages levels.

A trial was initiated when a subject indicated his readiness to begin by pressing down the right (left) key and placing the other fingers of both hands as indicated above. In this control procedure, the stimulators were pulsed bilaterally. The child was asked to lift the appropriate finger immediately following the stimulus delivery. All of the RT tasks in the present study were introduced as a game. The wording was made appropriate to each child and each age level. Following the 32 tactual control trials, the subject's mean RTs for each hand were calculated for subsequent analysis. The order in which hands were tested was counterbalanced across subjects.

The tactual control testing was not initiated at the start of the thesis experimentation but was introduced later; consequently not all of the subjects in the study provided data on this particular measure.

The Tactual Simple RT Experiment

The general procedural plan of the simple RT experiment was as follows: the subject was asked, first, to hold down one key with the right (left) index finger, having appropriately placed the other fingers of both hands, and second, to lift his right (left) index finger, as fast as possible following a vibratory stimulus to either hand. The stimuli were applied to the finger pads of the right and left hands an equal number of times, on a fixed-random basis, with no runs of more than three same-side stimuli.

The entire tactual simple RT experiment consisted of 96 formal trials, having 48 trials for each hand. Twenty four trials were administered to the right (left) hand, followed by 24 trials to the left (right) hand, at which point the stimulators were interchanged between the two hands, and the procedure was repeated. The order of responding (right- or left-hand first) was counterbalanced across subjects. As in the tactual control procedure, each trial lasted 5 seconds, with a 1 to 3 second interval between trials. For the analysis of the data, the mean RTs were calculated for each of the four stimulus/response combinations: stimulus to the right hemispehre/right hand responding; stimulus to the right hemispehre/left hand responding; stimulus to the left hemisphere/right hand responding; and stimulus to the left hemisphere/left hand responding. Each stimulus/response situation was represented by 24 trials.

Each session was conducted with two experimenters. In both tactual RT tasks, each trial was initiated by one experimenter, who also monitored the child's finger positions and motor behavior. A second experimenter, who also monitored the child's finger positions and motor behavior, recorded the response latencies after each trial onto individual score sheets. The data was also automatically recorded onto videotape for all of the RT tasks in the present study.

The Visual Apparatus

The visual RT apparatus consisted of two display windows with two response keys, one for each hand. Each of the display windows (15 cm x 21.5 cm) was constructed of 1 cm thick matte black plastic through which was mounted a series of 23 red point source light emitting diodes (LED). Each LED (0.4 cm in diameter) was placed precisely 1 cm apart, measured from the diode centres, forming an (4.5 cm x 6.3 cm) array or matrix. Overlapping portions of the matrix could be independently illuminated to produce various stimulus patterns. Each LED subtended 0.4 degrees of visual angle with a luminance output of 16.0 millicandela (Fairchild, MV5 752). The LED stimuli were lighted very briefly for a 75 msec duration, using a 6 milliampere current at 1.9 volts, with a rise and fall time shorter than one msec.

Both display windows were mounted on a matte black background screen (63.8 cm x 79.2 cm). The subject was seated directly in front of the screen with his head positioned in an adjustable head-and-chin rest. He was asked to fixate on a clearly visible point of the screen. Each window was equidistant (53.5 cm) from the eye it was to stimulate and was tilted slightly inward, so that the display surfaces were effectively part of a visual curve, such that virtually all stimulus points, including the point for central fixation, were equidistant from the subject's eyes. A shiny unlit LED provided the mark for central fixation.

Depending upon which specific LED patterns were illuminated, four well-circumscribed visual images could be flashed one at a time into either or both visual half-fields. The stimuli included (a) the letters "T" or "L", (b) two "luminous lines" or "bars of light", one oriented vertically, the other horizontally, and (c) one simple lighted "star" or "cross" appearing as a five point (LED) cluster. The LED display windows were positioned on opposite sides of and level with the fixation mark. The stimuli extended from approximately 20.5 to 24.5 degrees of visual angle from fixation and the distance between the fixation point and the centre of the stimuli was approximately 22 cm or 22.5 degrees of visual angle. Each star stimulus subtended 4.7 x 4.7 degrees of visual angle; each letter stimulus, 4.7 x 6.8 degrees; and each line or bar stimulus, 4.7 x 0.4 degrees of visual angle. The bar or line stimuli would have produced the smallest amount of intensity of stimulation, compared to the other stimuli.

The apparatus was constructed in such a way that the stimuli were directed only to the nasal hemiretina of each eye. The child's visual field was divided by two opaque screens which ran parallel to his line of vision. One screen was inserted 5 cm to the right of the LVF display, the other screen, 5 cm to the left of the RVF display. The screens had the effect of directing singals from each window exclusively to only one of the hemiretina. Each screen extended at right angles from their respective display windows for a distance of 43.5 cm to ensure that the child saw only the correct window. These dividing screens could be adjusted, but once set, they suited all of the children without need for further rearrangement.

Each display window was covered with a 1 cm thick piece of transparent dark red plexiglass, intended to eliminate the preempting of any stimulus, by its unlit configuration within the matrix. Although the plexiglass was clear or transparent, its red colour was deep enough to prevent the subject from discerning the unlit LED array.

Immediately behind the central fixation mark, and partially occluded by it, was the lens of a closed circuit T.V. camera and recording system, which allowed the experimenter automatically to observe and record whether the child had fixated before signals for the response were given. With this technique, the eyes of each child were clearly visible, and a deflection of less than 2 degrees of visual angle could be reliably detected. The experimenter always restored the child's eye position after every lateral eye movement, rest or pause.

Finally, each response key, similar to those used in the tactual RT tasks, was mounted in a plexiglass case and positioned to the child's side, comfortably accommodating his arm.

The General Visual Procedure

The general procedure required the child to fixate the mark, depress the key(s) with the requisite index finger(s), and lift the correct finger as fast as possible following the appropriate stimulus, while maintaining fixation. Care was taken in emphasizing the importance of always looking directly at the fixation point. The child was reminded to "look at the spot" every time his gaze deviated. The form of this instruction sometimes varied to help minimize the possibility of its being ignored. The child was told that this was the best way to see the light flashes and that the experimenter would carefully watch his eyes through the camera behind the screen. Both eyes remained open at all time, except when the child blinked.

Each session was conducted with two experimenters. One experimenter monitored the child's eye positions over the closed circuit T.V. while recording the RT for each trial. The second experimenter sat beside the child similarly monitoring the child's eye fixation and initiating the individual trials. This experimenter could also directly monitor the child's finger positions and motor responses. When a trial was initiated by the experimenter, a videotape recording of the child's direction of gaze was begun automatically two seconds before the stimulus was delivered and continued for three seconds following the stimulus onset. Both experimenters monitored a coordinated split-screen image which synchronized the direction of the child's gaze with the stimulus onset and his response latency, all of which could be observed while the events were taking place, as well as being permanently recorded. All of the visual RT trials had a 5 second duration, with a 1 to 3 second interval between trials.

The Visual Control Procedure

Again, in order to identify developmental changes in RT independent of stimulus lateralization, a control procedure was conducted in which a simple unilateral response was requested this time to bilateral visual stimulation. The instructions which the subject had to follow were to maintain fixation and lift his right (left) index finger as fast as possible following bilateral stimulation. The procedure was repeated in a block of 16 trials for each hand, for a total of 32 trials. The order of responding was counterbalanced (right or left hand first) across subjects. The star stimulus was presented bilaterally on each trial. At the end of the 32 trials, the mean RTs were calculated independently for each hand.

The Visual Simple RT Experiment

The general procedural plan of the visual simple RT experiment was similar to that of the tactual simple RT experiment. The subject was requested first, to hold down one key with the right (left) index finger while maintaining fixation, and second, to lift the same finger, as fast as possible following a visual stimulus (star) in either hemifield. This entire simple RT experiment consisted of 64 formal trials, having two blocks of 32 trials, one block for each hand. The order of responding (right- or left-hand first) was counterbalanced across subjects. Within each block of trials, the stimulus appeared equally often in both hemifields, on a fixed-random basis, with no runs of more than three same-side stimuli. For the analysis of the data, the mean RT's were calculated for each child from each of the four stimulus/response combinations: stimulus to the right hemisphere/right hand responding; stimulus to the right hemisphere/left hand responding; stimulus to the left hemisphere/right hand responding; stimulus to the left hemisphere/left hand responding. Each stimulus/response situation was represented by 16 trials.

The Visual Complex Choice RT

This complex choice RT experiment involved the combining of two independent complex choice RT tasks with each task serving as a mutual control condition for the other. These included a letter discrimination task and a line orientation discrimination task.

The Letter Discrimination Complex Choice RT Task

In this task, two different stimuli were used, the letters T and L. The task involved two experimental conditions, A and B. In condition A, the child was required to respond to the T stimulus which appeared in either hemifield, with his right hand only, thereby known as his T-hand; similarly, he was required to respond to the L stimulus with his left hand (his L-hand). Condition B was identical to condition A in every respect, except for a reversal in the use of the hands. In this case, the left hand became the T-hand and the right hand became the L-hand. The general instructions required the child to maintain fixation, depress both keys, one with each index finger, and quickly lift the requisite finger following a T or L flash in either hemifield.

For half of the time, the T or L stimuli were presented in the RVF, and for half of the time in the LVF, on a fixed-random basis. No more than two identical stimuli in a row were presented in either hemifield. The order of conditions A and B was counterbalanced across subjects, as was the order of left and right hands within conditions A and B. Both conditions were made up of 64 trials each, for a total of 128 trials in the entire task. The overall task consisted of 8 stimulus/response combinations: stimulus (T or L) x stimulus position (right or left of fixation) x hand responding (right or left). There were 16 trials for each stimulus/response combination. The data was made up of the mean RTs for each of the eight possible combinations.

The Line Orientation Discrimination Complex Choice RT Task

The procedural plan was similar to the letter discrimination task plan, except that in this final task, two luminous "lines" of different orientation, one vertical (V) and one horizontal (H), were used as stimuli. The task involved two experimental conditions, A and B. In condition A, the child was required to respond to the vertical line which appeared in either hemifield, with his right hand only, thereby known as his V-hand (the hand used for a line that stands up on its end); similarly, he was required to respond to the horizontal stimulus with his left hand (his H-hand) (the hand used for a line that lays flat on its side). Condition B was the same as condition A in every respect, except for a reversal in the use of the hands. In this case, the left hand became the V-hand, and the right hand became the H-hand. The general instructions required the child to maintain fixation, depress both keys, one with each index finger, and quickly lift the requisite finger following a vertical or horizontal line flash in either hemifield.

For half of the time, the vertical and horizontal stimuli were presented in the RVF, and for half of the time in the LVF, on a fixed-random basis. No more than two identical stimuli in a row were presented in either hemifield. The order of conditions, A and B, was counterbalanced across subjects, as was the order of left and right hands within the two conditions. Both conditions consisted of 64 trials each, for a total of 128 trials in the entire task. The overall task was made up of eight stimulus/response combinations: Stimulus (vertical or horizontal) x Stimulus Position (right or left of fixation) x Hand Responding (right or left). There were 16 trials for each stimulus/response combination. The data consisted of the mean RTs for each of the eight possible combinations.

In order to aid the child in responding with the correct hand in both of the complex choice RT tasks, a small 13 cm square piece of masking tape was applied to the back of each hand at the time of the task introduction. In the letter discrimination task, with a felt-tip pen, T or L labels were attached to the appropriate hands. In the line orientation discrimination task, a simple vertical or horizontal stroke or line was applied to each hand, indicating a line standing on its end, or laying flat on its side, respectively.

The combined data from both tasks constituted the data for the visual complex choice RT experiment.

Trials in which a RT measure fell outside the range of 150 to 3,000 msec was excluded and replaced. The number of RTs excluded were rare and distributed evenly between hands.

Finally, in an attempt to ensure that the child was attending to the task at hand, the electronic logic of the apparatus was so designed that a stimulus could not be delivered unless the requisite key was actively held down by the child.

The Analysis of the Data

The major independent variables within the three major experiments of the present study are (a) age range; (b) side (hemisphere) of stimulation; and, (c) hand (hemisphere) responding. Within the two control experiments of the present study, the independent variables include (a) age range; and, (b) hand (hemisphere) responding. All performance data was analyzed using analysis of variance with repeated measures. With respect to these analyses, the particular computer programme which was used would print only the degrees of freedom and indicate an F value of less than unity, without printing its specific value, whenever the F value was less than one.

Chapter III

RESULTS

Performance

Response latencies for a total of 480 formal trials were required from each child. Less than 1 percent of the responses fell outside of the range of 150 to 3,000 msec; the upper limit was chosen since on some RT tasks split-brain patients produce response latencies in a 2,000 to 3,000 msec range. Very short RTs may have been due to anticipation, as opposed to a real response to a stimulus; at the other extreme, very long RTs may have reflected a lapse of attention.

The children differed widely with respect to the number of incorrect responses. Errors were made in all four age ranges. Approximately twenty percent of the subjects made virtually no errors at all. In contrast, about 20 percent of the children made numerous errors (on as many as 8 out of every 10 trials), requiring many replacement trials. Incorrect responding occurred about twice as often in the two younger age groups.

Specifically, incorrect responding was extremely rare on either task in the tactual modality, and equally rare in the control and simple RT experiments of the visual modality. Most of the errors were made in the complex choice RT visual experiment. Errors appeared equally often in every hand responding/hemisphere stimulated combination, occurring usually when the target stimulus differed from the immediately previous stimulus. In these instances the subject may have expected the same stimulus to be repeated and consequently may have responded to the signal without analysing it completely. The majority of the children were immediately aware of their incorrect responses, as indicated by their comments, such as "oops" or "I made a mistake", as well as by sighs, groans, grimaces and remarks of disgust. Interestingly, about 10 percent of the subjects who consistently responded incorrectly appeared to be oblivious or indifferent to their errors, as they continued to make mistakes on the same stimulus repeatedly for as many as 6 trials in a row before responding correctly. However, poor performers were as likely to produce CUDs in the predicted direction for their age group as were relatively "perfect" responders, which suggests that incorrect responding was independent of efficiency or speed of interhemispheric communication. Errors sometimes seemed to stem from a failure to remember the appropriate response to a particular stimulus. Missed trials virtually never occurred. Only correct responses were included in the statistical analyses.

The children also varied widely in respect to their ability to maintain fixation on the central fixation point. Although this difficulty was present at every age level, the greatest difficulty was demonstrated by the 5-year-olds. Because of their failure to fixate on every trial, some children required 2 to 3 times the ordinary number of trials in order to complete the task; however, most of the subjects had little or no difficulty in maintaining fixation. Interestingly, Kershner, Thomae, and Callaway (1977) have shown that fixation control methods which require an identificatory response from five- and six-year-old children can induce visual half-field biases.

Control Experiments for Tactual and Visual Response Latencies

Response Latency to Bilateral Tactual Stimulation

Response latency to bialteral tactual stimulation was assessed separately for each hand. The means and standard deviations appear in Table 1. The significance of main effects and interactions was tested in an analysis of variance with repeated measures. The factor of age as the only between-subjects factor was very highly significant (F (3,49) = 21.6932, $p < 0.0001$). The factor of hand responding, as the only within-subjects factor, was not statistically significant (F (1,49) < 1.0), nor was the interaction of these two factors (F (3,49) < 1.0). Thus, although the subjects responded significantly faster at each age level to the bilateral stimulation, superiority in speed of responding was not demonstrated by either hand, at any age level. Since the decision to collect control data in the tactual modality was not made until late into the study, a large number of subjects were no longer available for testing, especially in the two older subject groups.

Table 1

Mean Reaction Times and Standard Deviations in msec

Tactual Modality - Bilateral Stimulation

Age (years)	5	7	9	11
Number of Ss	(17)	(22)	(9)	(5)
Right Hand:				
X	590.59	497.89	356.41	311.22
SD	110.99	103.93	82.60	45.89
Left Hand:				
X	606.48	478.23	363.16	307.10
SD	112.10	103.31	52.57	44.34

Note:
S = subject
X = mean
SD = standard deviation

Response Latency to Bialteral Visual Stimulation

Response latency to bilateral visual stimulation was also assessed separately for the right and left hands. The means and standard deviations are given in Table 2. Using an analysis of variance with repeated measures, the factor of age (F (3,116) = 42.31, $p <$ 0.0001) was found to be very highly significant. The factor of hand responding also emerged as significant (F (1,116) = 4.9835, $p <$ 0.025). The interaction of these two factors did not achieve statistical significance (F (3,116) = 1.1463, $p <$ 0.3). Thus, the children performed faster with increasing age, and consistent superiority in speed for the right hand may have existed at the 5-year-old level, but did not change significantly with increasing age. This unilateral right hand superiority in response speed in the visual modality contrasts with the absence of any such superiority in the tactual modality.

The Tactual Simple RT Experiment

Developmental changes in the speed of interhemispheric communication were initially assessed by administering vibratory tactual stimuli separately to the right and left hands of each child, in each of the four age groups, and comparing the ipsilateral (uncrossed) and contralateral (crossed) response latencies. The means and standard deviations according to age level are presented in Table 3.

Table 2

Mean Reaction Times and Standard Deviations in msec

Visual Modality - Bilateral Stimulation

Age (years)	5	7	9	11
Number of <u>S</u>s	(30)	(30)	(30)	(30)
<u>Right Hand:</u>				
X	529.07	436.67	377.25	308.85
SD	96.17	79.33	87.43	53.97
<u>Left Hand:</u>				
X	529.78	440.15	397.85	327.24
SD	83.16	73.88	83.20	70.55

Note:
S = subject
X = mean
SD = standard deviation

Table 3

Mean Reaction Times, Standard Deviations, CUDs in msec,
and CUD/RT Ratios
(Simple RT Paradigm)
Tactual Modality - Lateralized Stimulation

Children at Different Age Levels	Hand Responding	RT for Stimulation to the Right Hemisphere (Left side)	RT for Stimulation to the Left Hemisphere (Right side)	Difference in RTs to Stimulation to Different Hemispheres (CUD)	Mean CUD Average Over Both Hands	CUD Expressed as Percentage of Intra-Hemispheric RT
5 years (N = 30)	**Right Hand:** X	651.78	607.79	43.99	41.92	6.79%
	SD	(138.06)	(114.55)			
	Left Hand: X	626.68	666.53	39.85		
	SD	(144.22)	(126.90)			
7 years (N = 30)	**Right Hand:** X	621.71	576.59	45.12	46.67	8.21%
	SD	(141.21)	(118.22)			
	Left Hand: X	559.93	608.14	48.21		
	SD	(112.36)	(114.60)			
9 years (N = 30)	**Right Hand:** X	430.90	438.80	2.10	4.04	0.74%
	SD	(110.07)	(96.93)			
	Left Hand: X	432.67	438.64	5.97		
	SD	(90.15)	(92.74)			
11 years (N = 30)	**Right Hand:** X	357.73	356.43	1.30	4.46	1.15%
	SD	(98.09)	(82.66)			
	Left Hand: X	348.61	355.43	6.82		
	SD	(80.54)	(90.60)			

Note:
N = number of subjects
X = mean
SD = standard deviation

Figures 1 through 4 show the response latencies to crossed and uncrossed vibratory tactual stimulation for each hand, at the four different age levels. These RTs for each hand were initially analyzed in a three-way analysis of variance with repeated measures on the two within-subjects factors of hand responding and hemisphere stimulated. The age of the child was a nonrepeated, between-subjects factor. The analysis revealed a very highly significant main effect of age (F (3,119) = 51.4605, $p < 0.0001$), but no significant main effect of hemisphere stimulated (F (1,116) < 1.0), or hand responding (F (1,116) < 1.0). The interaction between hand responding and hemisphere stimulated was, however, highly significant (F (1,116) = 34.012, $p < 0.0001$). As indicated in Table 3, the CUDs for each hand emerged as positive values in all four age groups. This finding is represented in the significant two-way interaction. These positive CUDs also can be seen in Figures 1 through 4, by comparing the RTs for each hand for a stimulus delivered to the same and then to the opposite hemisphere.

When the tactual vibratory stimulus is presented to the left hand (i.e., to the right hemisphere), the left hand usually responds faster than the right. An overall left hand superiority to left hand stimulation is demonstrated consistently at all age levels and is thought to reflect the shorter or uncrossed, intrahemispheric anatomical pathway. The slower right hand response to the same stimulus is thought to reflect the longer crossed, interhemispheric anatomical pathway. Right and left hand responses to right hand stimulation can be similarly understood. That is, the right hand usually responds faster

FIGURE 1

RTs to Tactual Vibratory Stimuli in 5-year-old Children

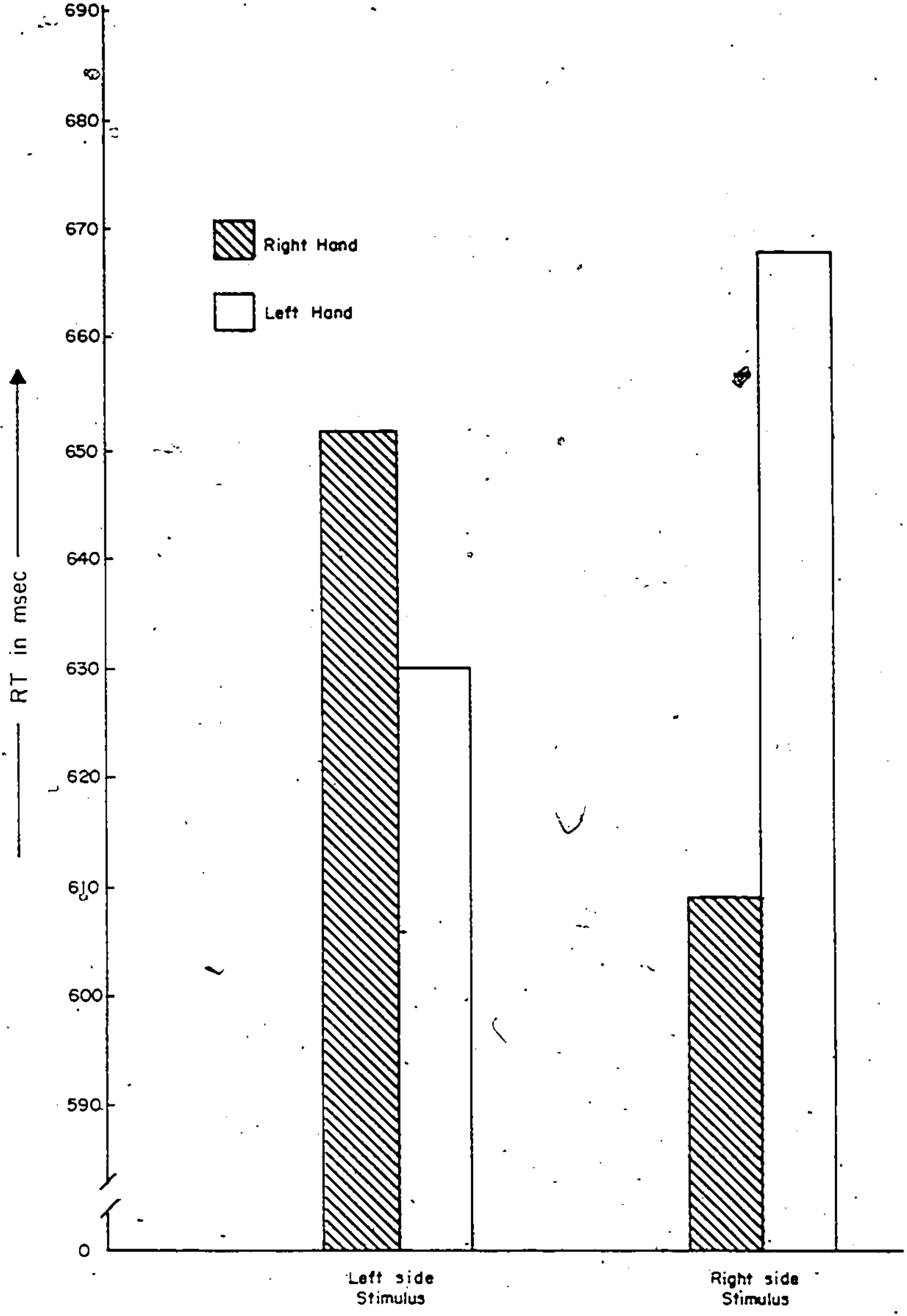


FIGURE 2

RTs to Tactual Vibratory Stimuli in 7-year-old Children

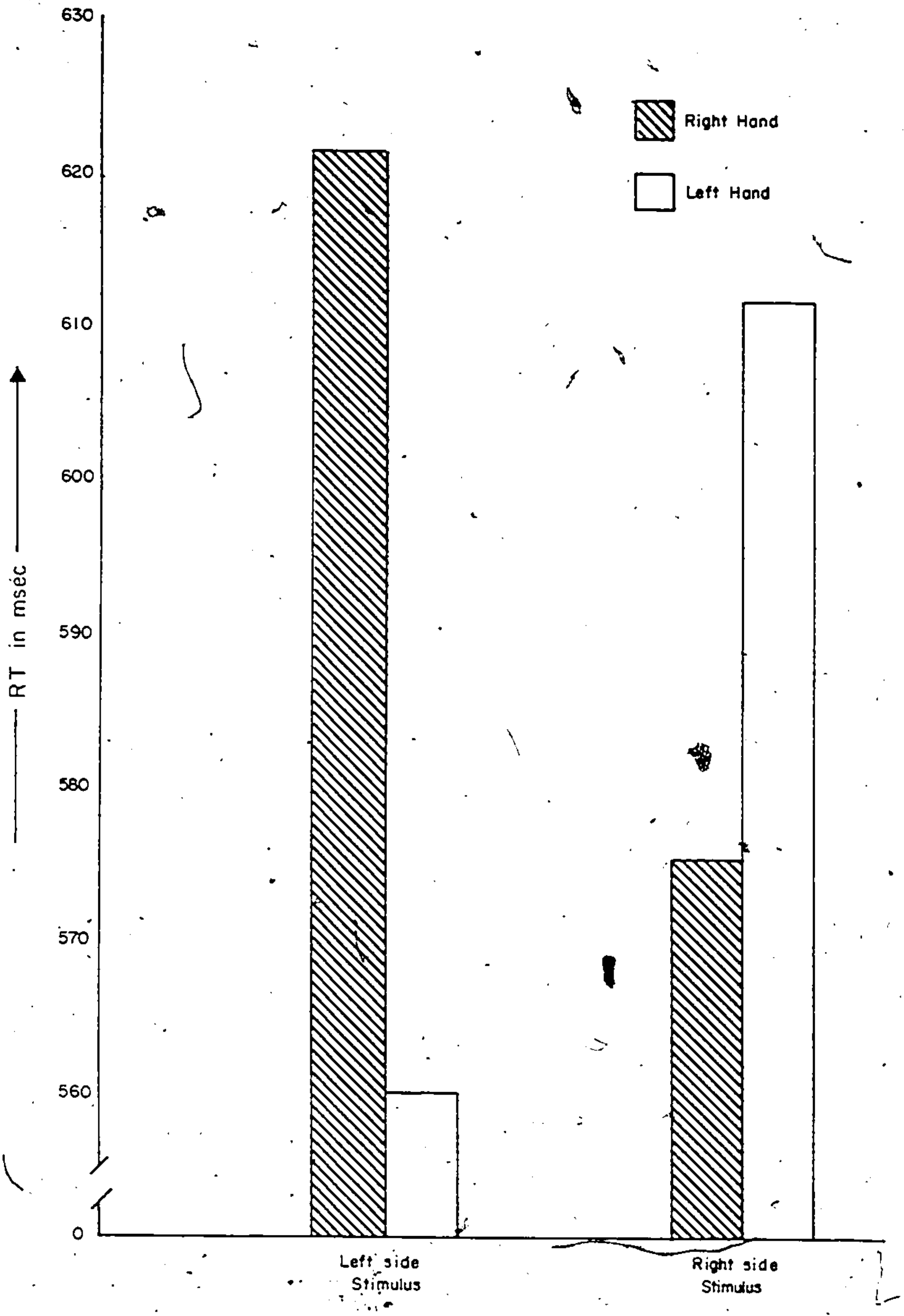


FIGURE 3

RTs to Tactual Vibratory Stimuli in 9-year-old Children

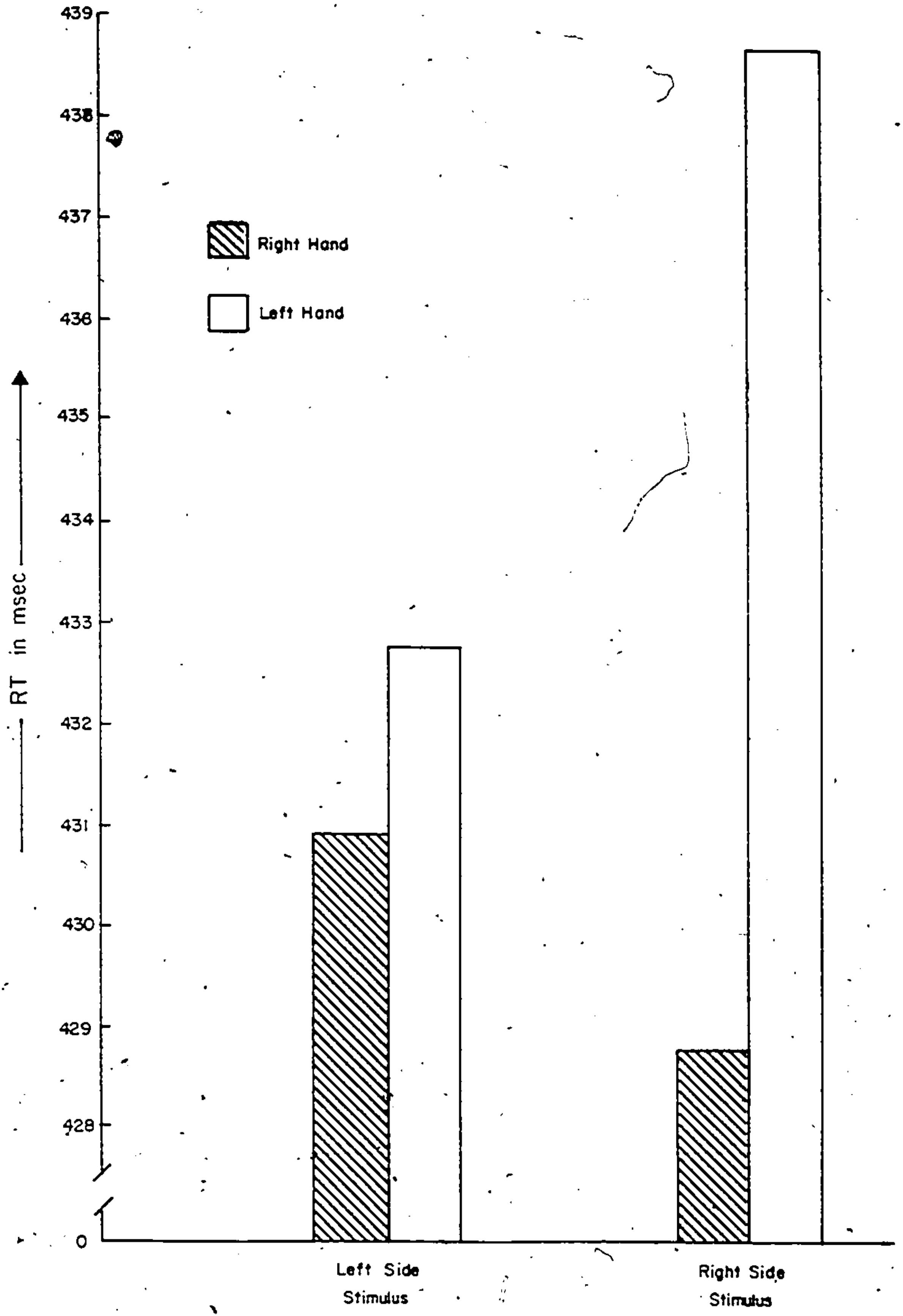
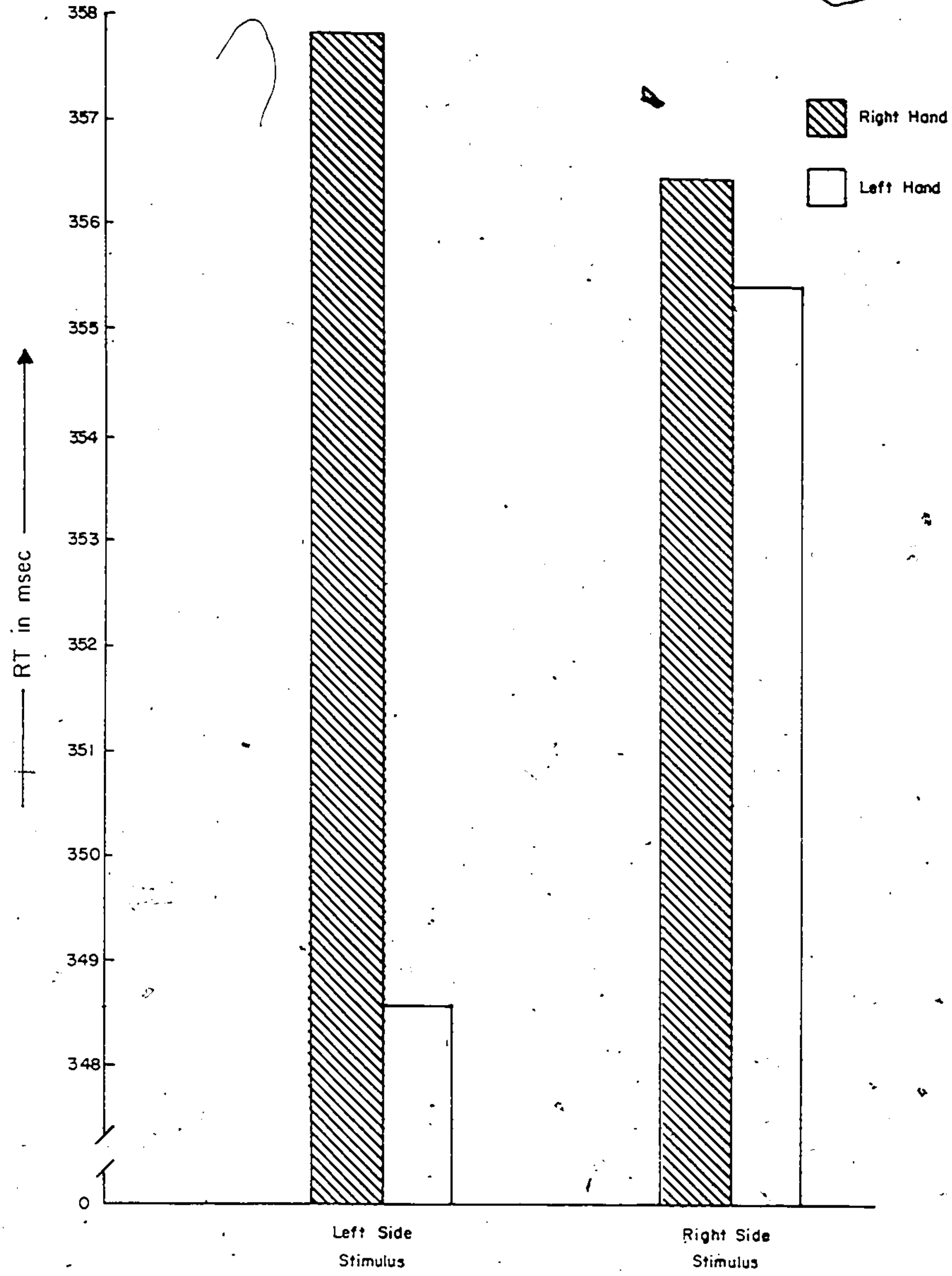


FIGURE 4

RTs to Tactual Vibratory Stimuli in 11-year-old Children



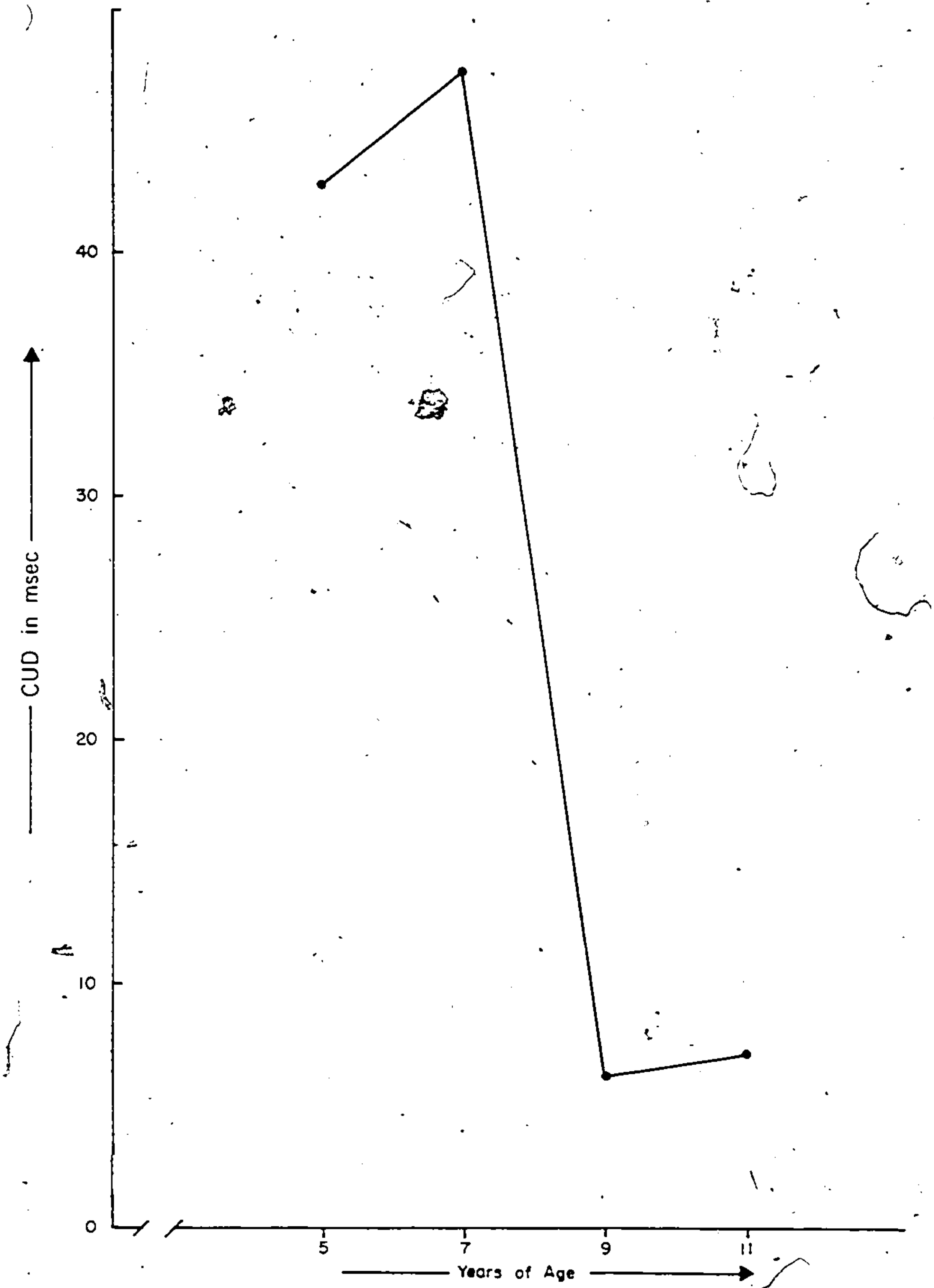
than the left hand following stimulation of the right hand, reflecting the shorter anatomical pathway. The relatively delayed response of the left hand to the same stimulus is thought to reflect the longer anatomical pathway.

Further visual examination of the data (see Table 3 and Figures 1 through 4) shows that the size of the CUD obtained for each hand tends to decrease with increasing age. This apparent developmental change is reflected in a significnat triple interaction of age x hand responding x hemisphere stimulated (F (3,116) = 7.8921, $p < 0.001$), and may represent a developmental change in the speed of interhemispheric communication.

The data are presented in a different manner by averaging the RTs for left hand responding/left hand stimulated and right hand responding/right hand stimulated (uncrossed responding) and by averaging the RTs for the left hand responding/right hand stimulated and right hand responding/left hand stimulated (crossed responding). The resulting mean CUDs are plotted as a function of age in Figure 5. These values can also be seen in the second to last column of Table 3. Separate two-way analyses of variance with repeated measures were conducted for each hand separately to determine the appropriateness of combining the data in this manner. For the right hand, the factors of age (F (3,116) = 43.5508, $p < 0.001$) and hemisphere stimulated (F (1,116) = 14.908, $p < 0.001$) were both highly significant, as was the interaction of these two factors (F (3,116) = 4.2773, $p < 0.001$). Similar results were obtained for left hand performance, that is,

FIGURE 5

CUD Plotted as a Function of Age:
From a Simple RT Paradigm, Using Tactual Vibratory Stimuli



highly significant effects of age (F (3,116) = 50.2237, $p < 0.001$) and hemisphere stimulated (F (1,116) = 20.9867, $p < 0.001$), as well as a significant two-way interaction (F (3,116) = 3.997, $p < 0.001$). Given the similarity in performance of each hand, the combining of the data across both hands and hemispheres seems appropriate. These statistical results show that the apparent developmental change in response latencies to crossed lateralized vibratory stimuli cannot be considered to be unidirectional, but applies to interhemispheric transfer of excitation in both directions, that is, left to right and right to left. This combining of the data also provides an opportunity to examine the speed of interhemispheric communication independent of the effects of either hand or hemisphere alone.

It is clearly observable (Table 3 and Figures 1 through 4) that response latencies to both crossed and uncrossed vibratory stimuli tend to decrease with increasing age; however, the rates at which these two response latencies decrease across ages appear to differ. In an attempt to understand how the relationship between these two rates changes over development, ratios comparing obtained CUDs to uncrossed response latencies were created and examined. The mean CUD value obtained at each age level represents the numerator term of the desired ratio, while the corresponding mean RT required to respond to the uncrossed stimulus at the same age level, constitutes the denominator term. The ratio is multiplied by 100 in order to provide a simple descriptive statistic which shows the CUD as a percentage of the response latency to uncrossed stimulation. These ratios appear in the far right column of Table 3. The ratios were found to decrease in size with increasing age suggesting that interhemispheric processing initially lags behind intrahemispheric processing, then begins to catch up later in development.

Table 3 shows that response latencies to crossed vibratory stimuli in 5- and 7-year-old children respectively remain 41.92 and 46.97 msec slower than responses to uncrossed stimuli. By the age of 9 and 11 years, crossed response latencies improve to a level of only 4.04 and 4.46 msec respectively behind uncrossed latencies. To formally test the significance of these differences, additional analyses were conducted which examined the components of the significant triple interaction, addressing whether the differences between the crossed and uncrossed response latencies were the same at each age level. An analysis of the simple interaction effects showed that the differences obtained between the crossed and uncrossed response latencies were significant for the 5-year-olds (F (3,116) = 25.6586, $p < 0.0001$) and the 7-year-olds (F (3,116) = 31.7446, $p < 0.0001$), but not for the 9-year-olds (F (3,116) < 1.0) and the 11-year-olds (F (3,116) < 1.0). Thus, the performances of the two younger groups of children are similar to one another, as are the performances of the two older groups. A further three-way analysis of variance with repeated measures appraised the RT performances of the chidren considered as either younger or older children. A highly significant triple interaction also emerged (F (1,118) = 24.01, $p < 0.001$) providing statistical support for an apparent developmental change in ITT, especially between the ages of 7- and 9-years-of-age.

In summary, there are significant differences between the RTs to crossed and uncrossed vibratory stimulation in the developing child of 5- and 7-years-of-age. These RT differences are subject to developmental influences, especially between the ages of 7- and 9-years-of-age, such that the response latency to crossed as distinct to uncrossed stimulation improves greatly at this time. To reiterate, at each age level, the obtained mean CUD represents an ITT esimate which can be regarded (as a ratio) in relationship to the uncrossed response latency. For example, at 5- and 7-years-of-age, the obtained mean ITT estimates of 41.92 and 46.67 msec respectively represent values of 6.79 and 8.21 percent of the uncrossed response latency. While at 9- and 11-years-of-age, the obtained ITT estimates of 4.04 and 4.06 msec respectively represent values of only 0.74 and 1.15 percent of the uncrossed response latency. These results show a large relative improvement in RT to crossed versus uncrossed vibratory stimulation between the ages of 7 and 9 years, which suggests that the speed of interhemispheric communication is subject to developmental influences and improves relative to intrahemispheric processing most clearly between the ages of 7- and 9-years, as determined in a simple tactual RT paradigm. These ratios are presented as a function of age in Figure 6.

FIGURE 6

CUD Expressed as a Percentage of Short-Pathway RT and Plotted as a Function of Age: From a Simple RT Paradigm, Using Tactual Vibratory Stimuli

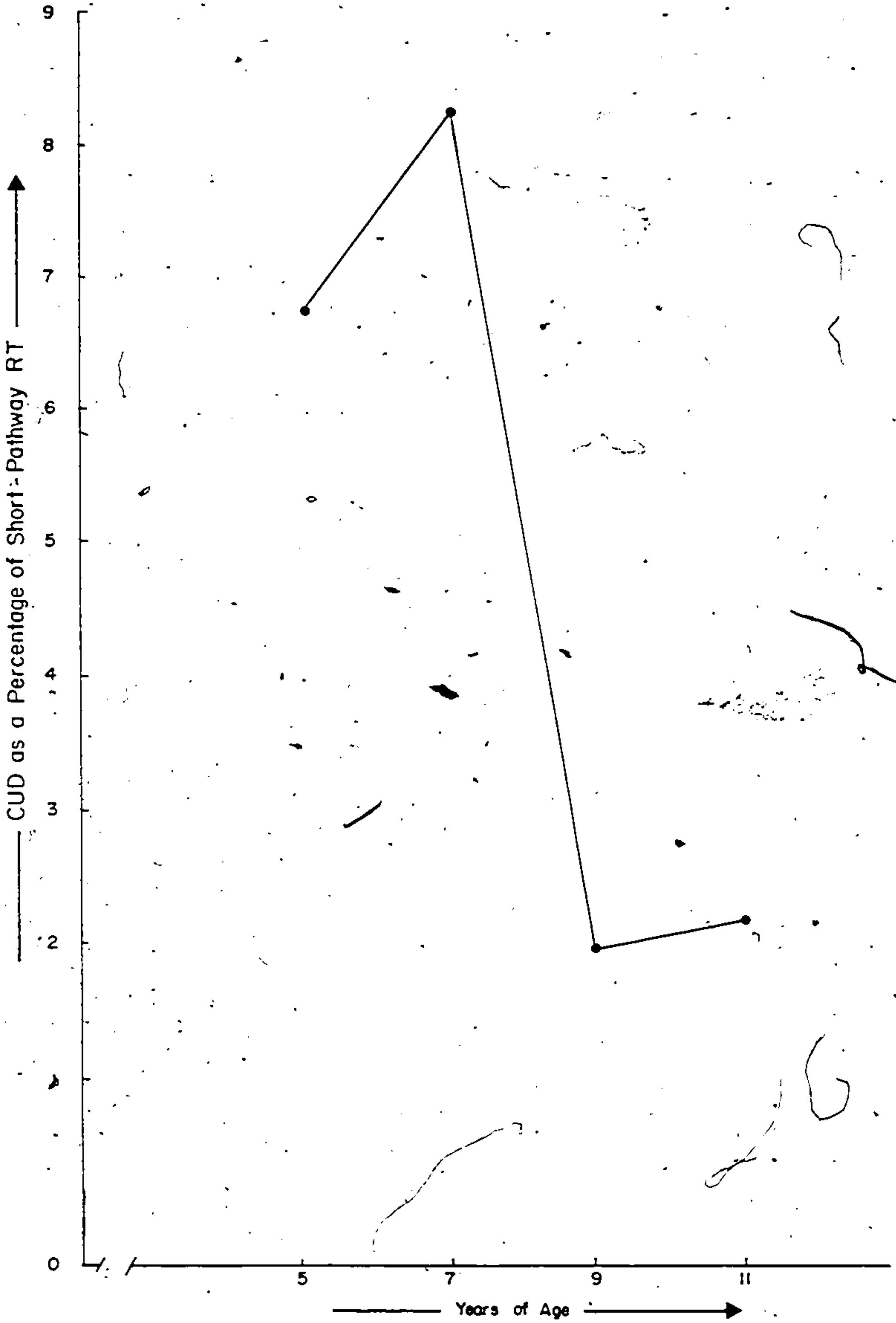


Table 4

Mean Reaction Times, Standard Deviations, CUDs in msec,
and CUD/RT Ratios
(Simple RT Paradigm)
Visual Modality - Lateralized Stimulation

Children at Different Age Levels	Hand Responding		RT for Stimulation to the		Difference in RTs to Stimulation to Different Hemispheres (CUD)	Mean CUD Average Over Both Hands	CUD Expressed as Percentage of Intra-Hemispheric RT
			Right Hemisphere (Left side)	Left Hemisphere (Right side)			
5 years (N = 30)	Right Hand:	X	617.47	576.57	40.90	44.25	7.8%
		SD	(100.97)	(89.03)			
	Left Hand:	X	575.03	622.62	47.59		
		SD	(80.67)	(123.02)			
7 years (N = 30)	Right Hand:	X	489.44	478.47	10.97	13.67	2.89%
		SD	(130.52)	(93.93)			
	Left Hand:	X	486.24	502.60	16.36		
		SD	(95.80)	(111.26)			
9 years (N = 30)	Right Hand:	X	419.08	414.95	4.13	3.26	0.8%
		SD	(92.96)	(86.23)			
	Left Hand:	X	427.78	430.16	2.38		
		SD	(92.33)	(76.39)			
11 years (N = 30)	Right Hand:	X	348.39	345.88	2.51	5.38	1.58%
		SD	(79.77)	(81.04)			
	Left Hand:	X	354.16	362.41	8.25		
		SD	(83.31)	(84.01)			

Note: N = number of subjects
X = mean
SD = standard deviation

The Visual Simple RT Experiment

Developmental changes in interhemispheric transfer time were also assessed by administering simple structured visual stimuli separately in the right and left visual half-fields of each child, in each of the four age groups, and comparing the ipsilateral (uncrossed) and contralateral (crossed) response latencies. The means and standard deviations according to age level are presented in Table 4.

Figures 7 through 10 show the response latencies to the crossed and uncrossed simple visual stimuli for each hand at the different age levels. A three-way analysis of variance with repeated measures revealed a very highly significant main effect of age (F (3,116) = 44.4813, $p < 0.0001$) and a significant main effect of hand responding (F (1,116) = 4.7709, $p < 0.05$), but no significant effect of hemisphere stimulated (F (1,116) < 1.0). The interaction between hand responding and hemisphere stimulated was highly significant (F (1,116) = 21.2137, $p < 0.001$). Table 4 shows that the CUDs for each hand emerged as positive values in all four age groups. This finding is reflected by the above significant two-way interaction. These positive CUDs can be seen also in Figures 7 through 10 by comparing the RTs of each hand for a stimulus delivered to the same then different hemisphere.

When the visual stimulus is flashed to the nasal hemiretina of the left eye (i.e., to the right hemisphere), the left hand usually responds faster than the right hand. An overall left hand superiority to left visual half-field stimulation is obtained consistently at all

FIGURE 7

RTs to Simple Visual Stimuli
in 5-year-old Children

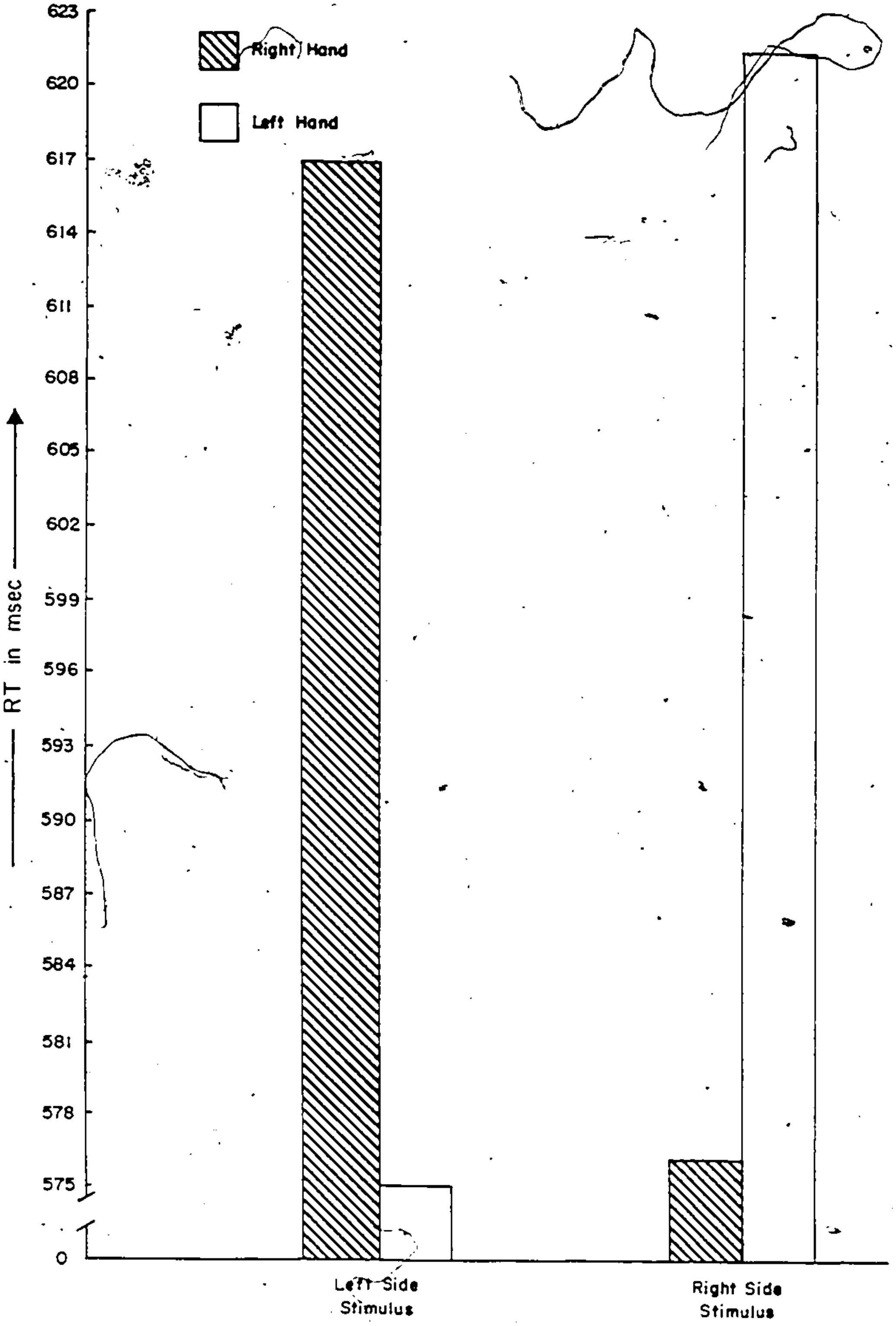


FIGURE 8

RTs to Simple Visual Stimuli in 7-year-old Children

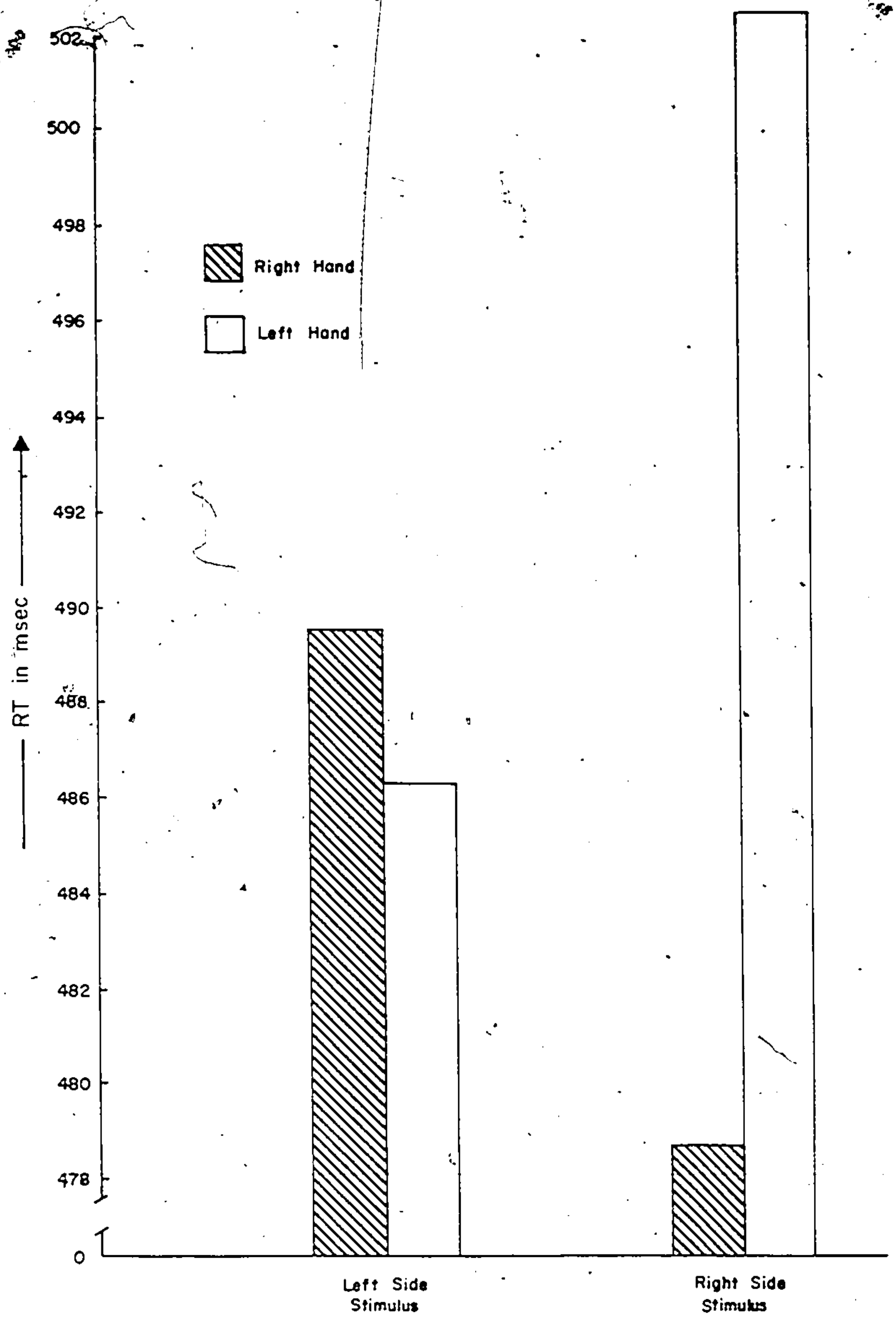


FIGURE 9

RTs to Simple Visual Stimuli in 9-year-old Children

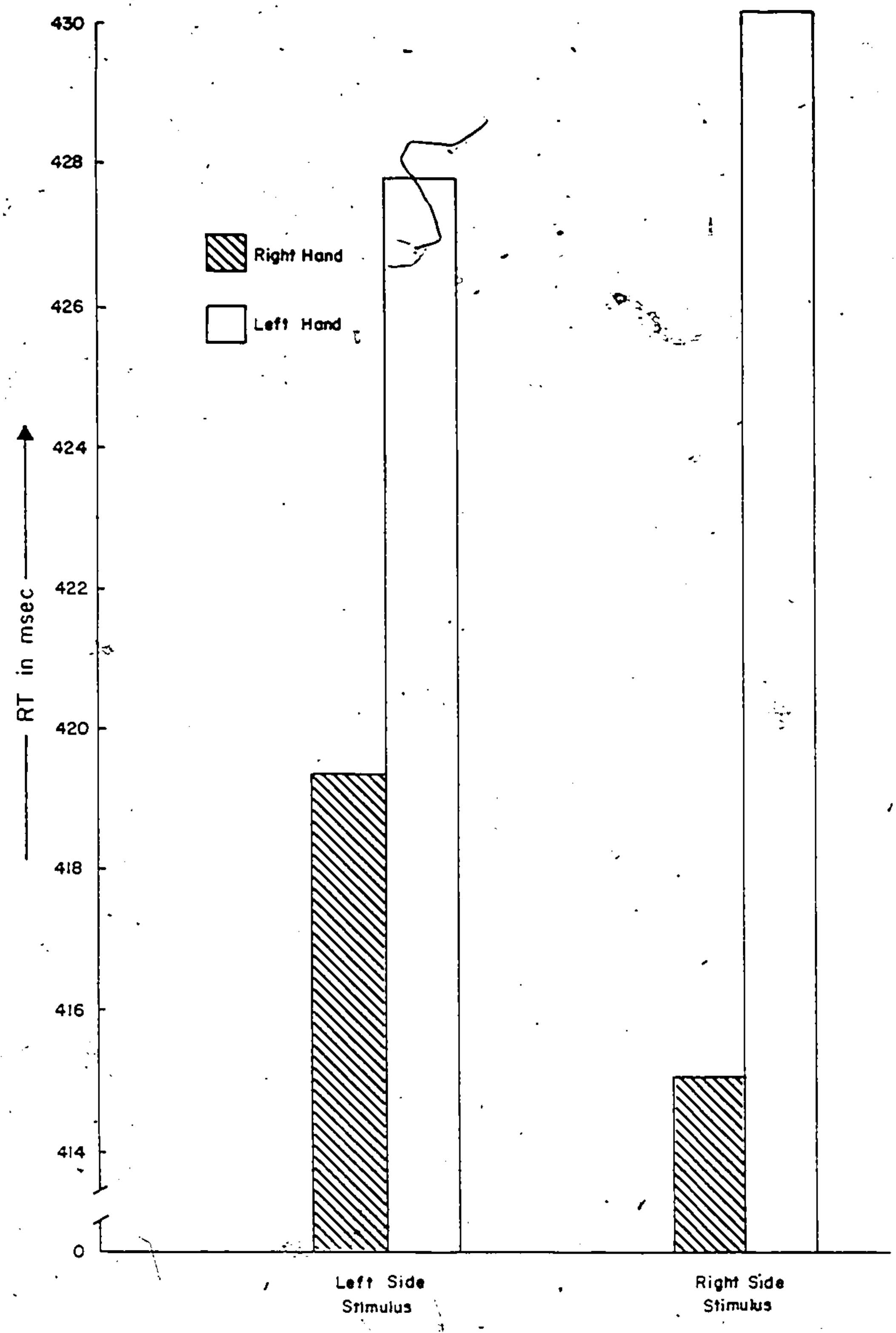
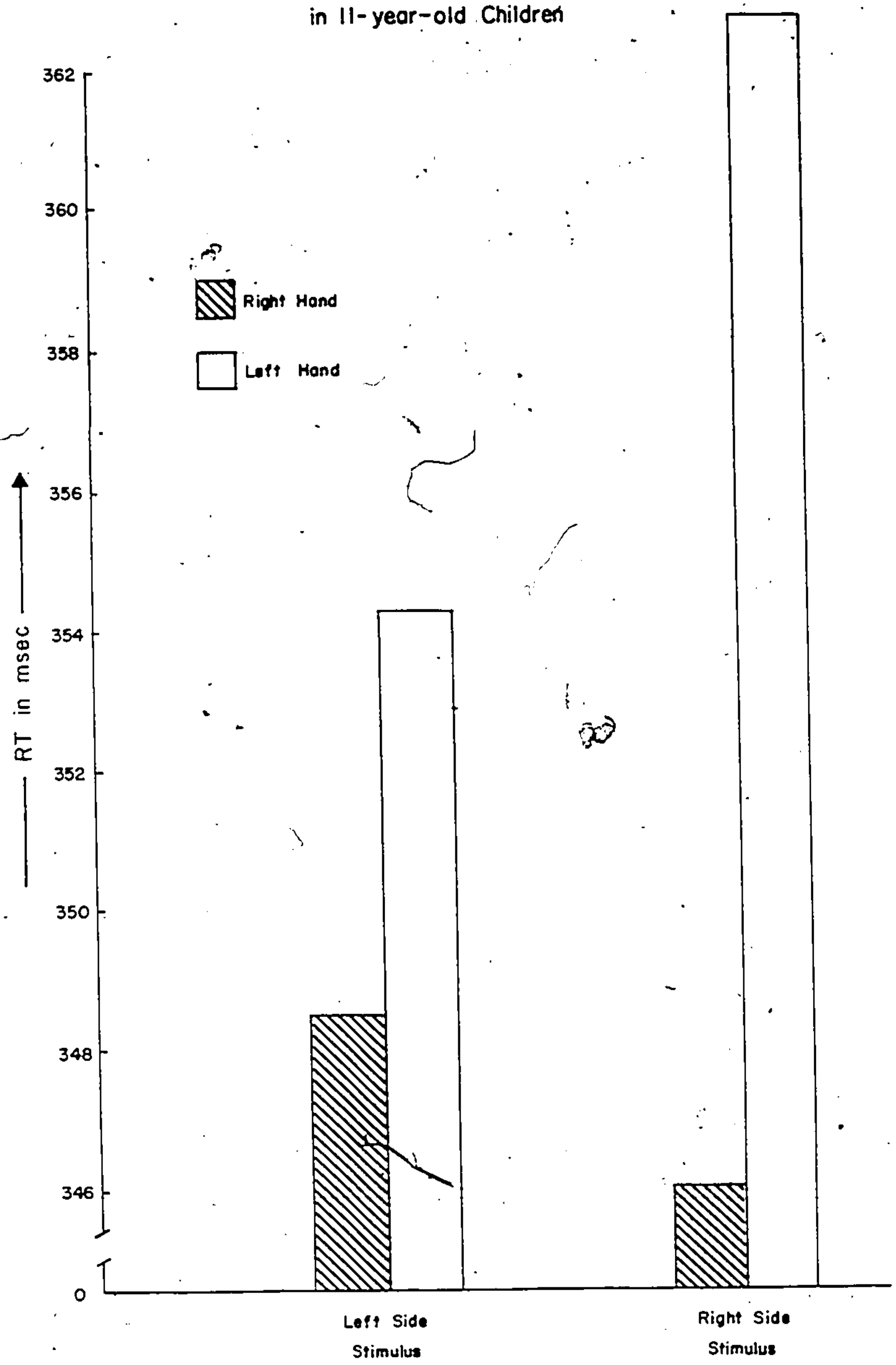


FIGURE 10

RTs to Simple Visual Stimuli in 11-year-old Children



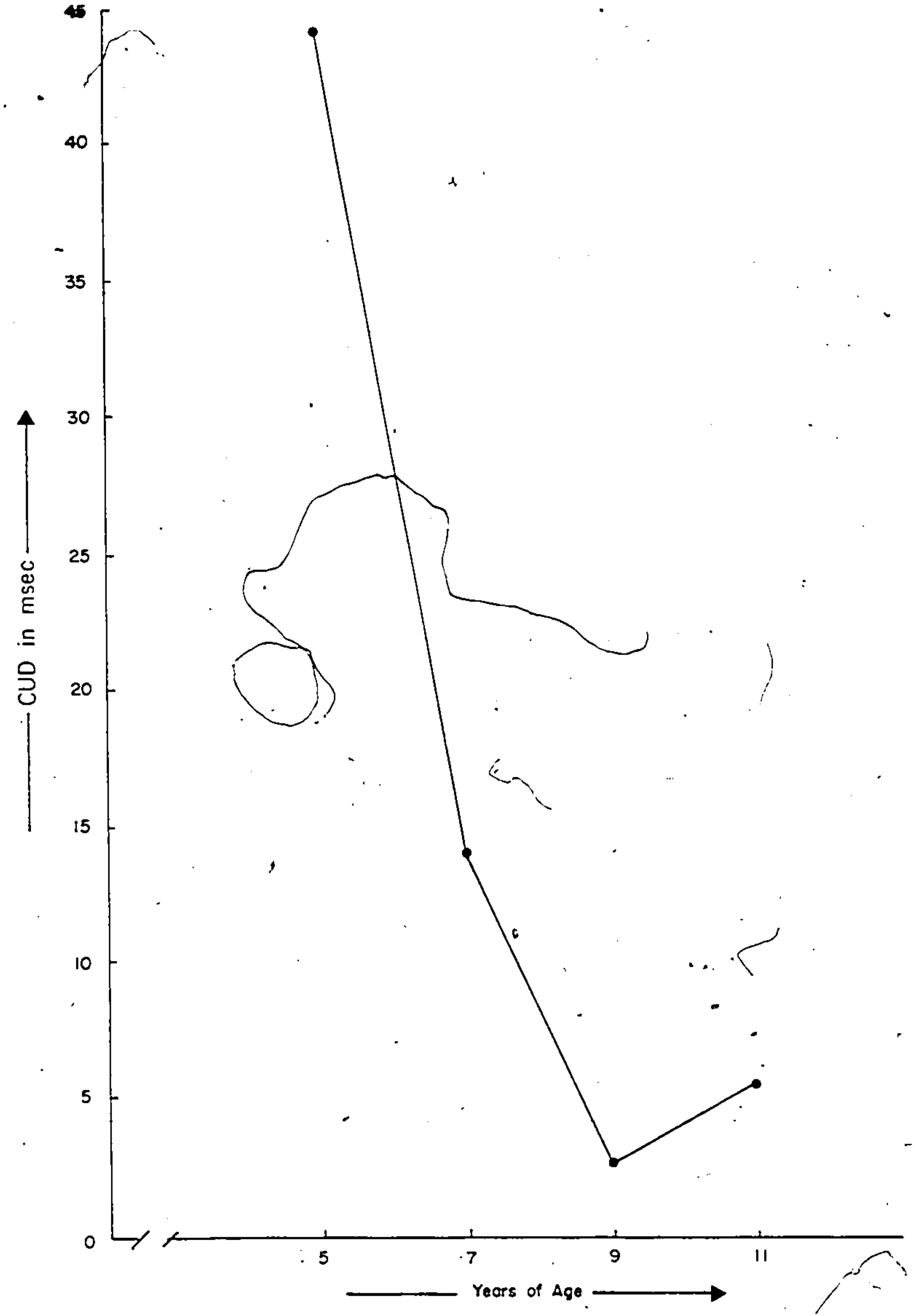
age levels and is thought to reflect the shorter or uncrossed, intrahemispheric anatomical pathway. The slower right hand response to the same stimulus is thought to reflect the longer, interhemispheric anatomical pathway. Similarly, the right hand usually responds faster than the left, following stimulation to the nasal hemiretina of the right eye, reflecting the shorter, anatomical pathway. The realtively delayed response of the left hand to the same stimulus is assumed to reflect the longer, anatomical pathway.

Further examination of the data (Table 4 and Figures 7 through 10) shows that the size of the CUD obtained for each hand tends to decrease with increasing age. This apparent developmental change is reflected in a significant triple interaction of age x hand responding x hemisphere stimulated ($\underline{F}$ (3,116) = 6.8945, $\underline{p} < 0.001$), and may represent a developmental change in interhemispheric transmission time.

As in the tactual RT experiment, the data may be considered from another perspective, by averaging the RTs for left hand responding/right hemisphere stimulated and right hand respoding/left hemisphere stimulated (uncrossed responding), and by averaging the RTs for left hand responding/left hemisphere stimulated and right hand responding/right hemisphere stimulated (crossed responding). The resulting mean CUDs are plotted as a function of age in Figure 11. They can also be seen in the second to last column of Table 4. Separate two way analyses of variance with repeated measures were conducted with each hand to determine the appropriateness of combining the data in this manner.

FIGURE II

CUD Plotted as a Function of Age:
From a Simple RT Paradigm, Using Simple Visual Stimuli



For the right hand, the factors of age (F (3,118) = 76.7703, $p <$ 0.0001) and hemisphere stimulated (F (1,118) = 9.7361, $p < 0.0002$) were both significant, as was the interaction of these two factors (F (1,118) = 5.7757, $p < 0.02$). Similar results were obtained for left hand performance, that is, highly significant effects of age (F (3,116) = 39.3861, $p < 0.0001$) and hemisphere stimulated (F (1,116) = 10.6053, $p < 0.002$), as well as a significant two-way interaction (F (3,116) = 3.0822, $p < 0.03$). Given the similarity in performance of each hand, the combining of the data across both hands and both hemispheres seems appropriate. As in the vibratory stimulation task, the statistical results suggest that the apparent developmental change in response latencies to crossed lateralized simple visual stimulation cannot be considered to be unidirectional, but applies to interhemispheric transfer of excitation in both directions. This combining of the data provides an opportunity to examine the speed of interhemispheric communication independent of the effects of a single hand or single hemisphere.

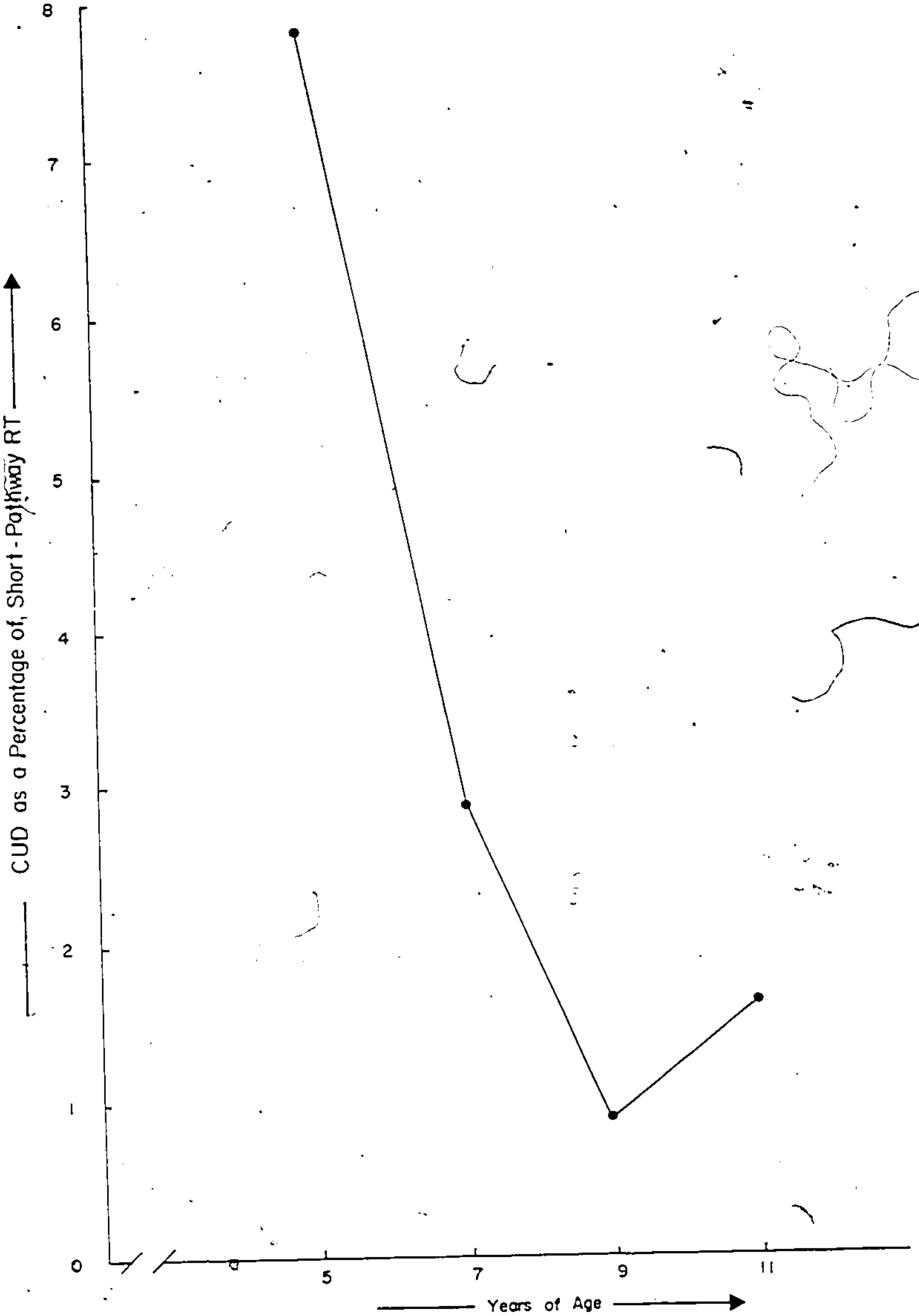
Table 4 and Figures 7 through 10 show that response latencies to <u>both</u> crossed and uncrossed stimuli tend to decrease with increasing age. However, as in the vibratory stimulation task, these two response latencies decrease at different rates. Moreover, the ratio comparing CUD to uncrossed RT tends to decrease in size with increasing age, again suggesting that interhemispheric conduction time initially lags behind intrahemispheric conduction time, then begins to catch up later in development. These ratios appear as percentages in the far right column of Table 4, and are presented as a function of age in Figure 12.

Table 4 shows that response latencies to crossed simple visual sitmuli in 5- and 7-year-old children respectively remain 44.25 and 13.67 msec slower than responses to uncrossed stimuli. By the ages of 9 and 11 years, crossed response latencies have respectively improved to a level of 3.26 and 5.38 msec behind uncrossed latencies. An analysis of the simple interaction effects of the obtained triple interaction indicates that the differences obtained between the crossed and uncrossed response latencies were significant for the 5-year-olds (*F* (3,116) = 37.70, $p < 0.001$) and the 7-year-olds (*F* (3,116) = 5.802, $p < 0.001$), but not for the 9-year-olds (*F* (3,116) < 1.0) and the 11-year-olds (*F* (3,116) < 1.0).

The performance of the two younger groups of children, differ from one another in that the mean CUD of the 5-year-olds appears to be greater than that of the 7-year-olds. In contrast, the performance of the two older groups of children resemble one another closely with respect to size of the mean CUD for each group; however, taken as a group, the 5- and 7-year-old children generally demonstrate slower response latencies than the 9- and 11-year-old children. A three-way analysis of variance with repeated measures appraised the RT performances of the children considered only as two groups of younger and older children. A highly significant triple interaction emerged (*F* (1,118) = 11.0574, $p < 0.001$) providing statistical support for a developmental change in ITT between the ages of 7- and 9-years of age.

FIGURE 12

CUD Expressed as a Percentage of Short-Pathway RT and Plotted as a Function of Age: From a Simple RT Paradigm, Using Simple Visual Stimuli.



However, there would also appear to be important developmental changes in ITT occurring between the ages of 5 and 7 years also.

In summary, there are significant differences between the RTs to crossed and uncrossed simple visual stimuli in the developing child of 5- and 7-years-of-age. These RT differences are subject to developmental influences apparently between the ages of 5 and 7 years, and between the ages of 7 and 9 years. The response latency to crossed as distinct to uncrossed stimulation shows relative improvement at both of these developmental junctures. At 5- and 7-years-of-age the obtained ITT estimates of 44.25 and 13.67 msec respectively represent values of 7.8 and 2.89 percent of the uncrossed response latency. At 9- and 11-years-of-age the obtained ITT estimates of 3.26 and 5.38 msec respectively represent values of only 0.8 and 1.58 percent of the uncrossed RT. These results show large relative improvements in RT to crossed versus uncrossed simple visual stimulation between the ages of 5 and 7 years, and between the ages of 7 and 9 years, but not between the age of 9 and 11 years. These results therefore, suggest that the speed of interhemispheric communication is subject to developmental influences and improves relative to intrahemispheric processing between the ages of 5- and 9-years-of-age, as determined in a simple visual RT paradigm.

The Complex Choice RT Experiment

The combined data from the two complex choice RT tasks (i.e., the letter discrimination and the line orientation discrimination tasks) constitute the body of data for the complex choice RT experiment. The resulting composite data matrix is actually a condensation of two entirely separate tasks. Moreover, each of these "subordinate" tasks is itself a condensation of two response conditions for each task; that is, each discrimination task is initially administered having only one particular hand responding to a particular stimulus. Subsequently, each task is replicated, but with the opposite hand responding to the same stimulus. Since the two discrimination tasks serve as mutual control conditions for one another for the purposes of the present study, they cannot be appropriately interpreted or understood as independent experimental tasks. The means and standard deviations of the composite data are shown in Table 5. A three-way analysis of variance with repeated measures over two factors, hand responding and hemisphere stimulated, was conducted. The main effect of age (the only nonrepeated factor) was highly significant (_F_ $(3,116) = 22.9867$, $p < 0.0001$) as was the main effect of hand responding (_F_ $(3,116) = 6.9522$, $p < 0.001$). The factor of hemisphere stimulated was not significant, the interaction of hand responding and hemisphere stimulated was highly significant (_F_ $(1,116) = 36.3375$, $p < 0.001$). Table 5 shows that positive CUD values were obtained at each of the four age levels which is reflected in this significant two-way interaction. These positive CUDs also can be seen

Table 5

Mean Reaction Times, Standard Deviations, CUDs in msec, and CUD/RT Ratios (Complex Choice RT Paradigm) Visual Modality - Lateralized Stimulation

dren at erent Levels	Hand Responding	RT for Stimulation to the Right Hemisphere (Left side)	RT for Stimulation to the Left Hemisphere (Right side)	Difference in RTs to Stimulation to Different Hemispheres (CUD)	Mean CUD Average Over Both Hands	CUD Expressed as Percentage of Intra-Hemispheric RT
	Right Hand:					
	X	1021.59	948.85	72.74		
	SD	(251.70)	(237.46)			
ars 30)					76.54	8.00%
	Left Hand:					
	X	964.22	1044.55	80.33		
	SD	(240.53)	(248.67)			
	Right Hand:					
	X	905.73	851.83	53.9		
	SD	(196.63)	(167.87)			
rs 30)					46.67	8.21%
	Left Hand:					
	X	875.61	897.97	22.36		
	SD	(178.60)	(174.10)			
	Right Hand:					
	X	731.15	710.09	21.06		
	SD	(134.34)	(141.68)			
rs 30)					17.14	2.4%
	Left Hand:					
	X	724.73	737.94	13.21		
	SD	(142.26)	(140.89)			
	Right Hand:					
	X	666.99	641.41	25.58		
	SD	(128.24)	(126.58)			
years = 30)					20.58	3.2%
	Left Hand:					
	X	663.05	679.22	16.17		
	SD	(129.43)	(133.56)			

ote:
N = number of subjects
X = mean
SD = standard deviation

FIGURE 13

RTs to Complex Visual Stimuli
in 5-year-old Children

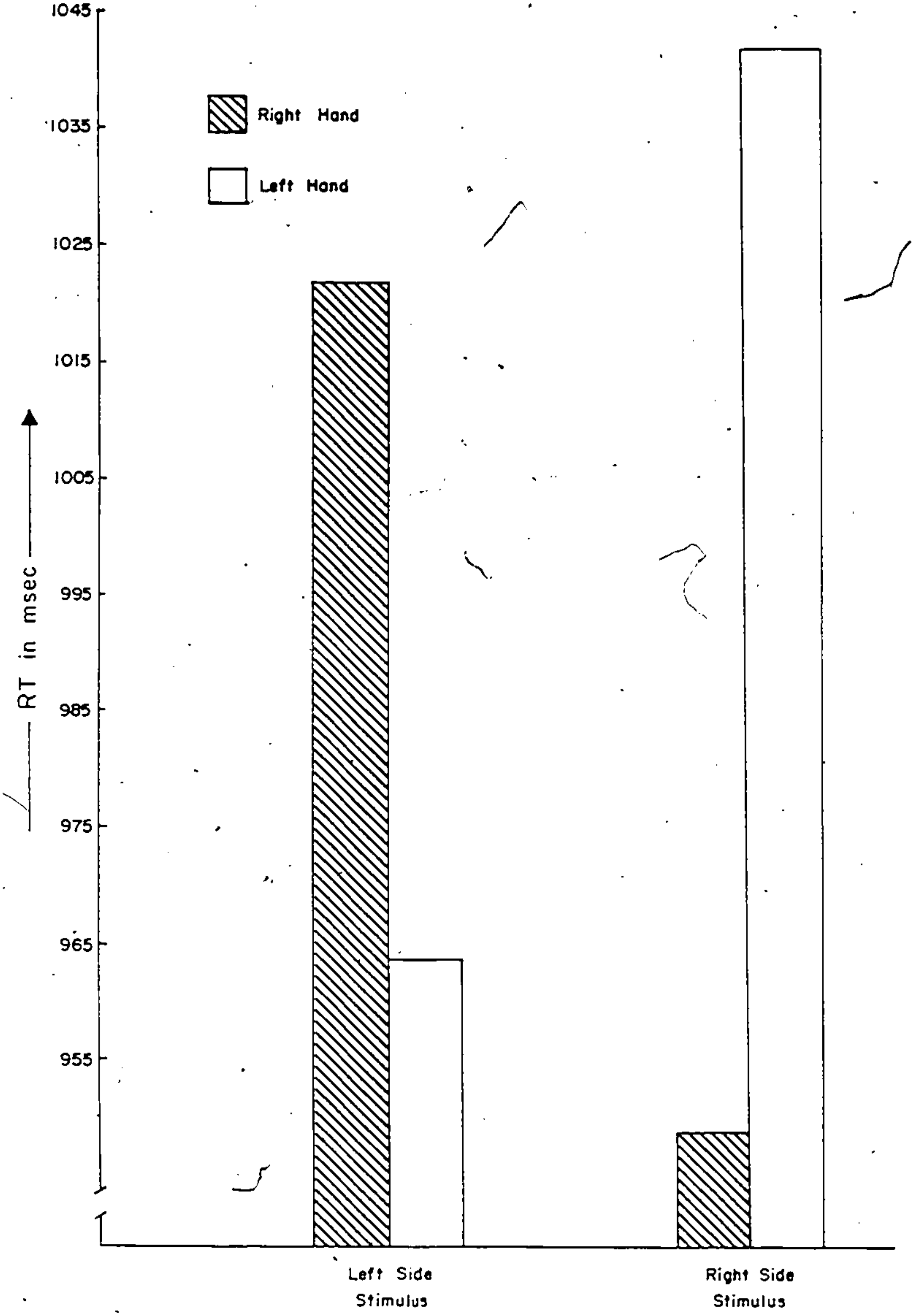


FIGURE 14

RTs to Complex Visual Stimuli
in 7-year-old Children

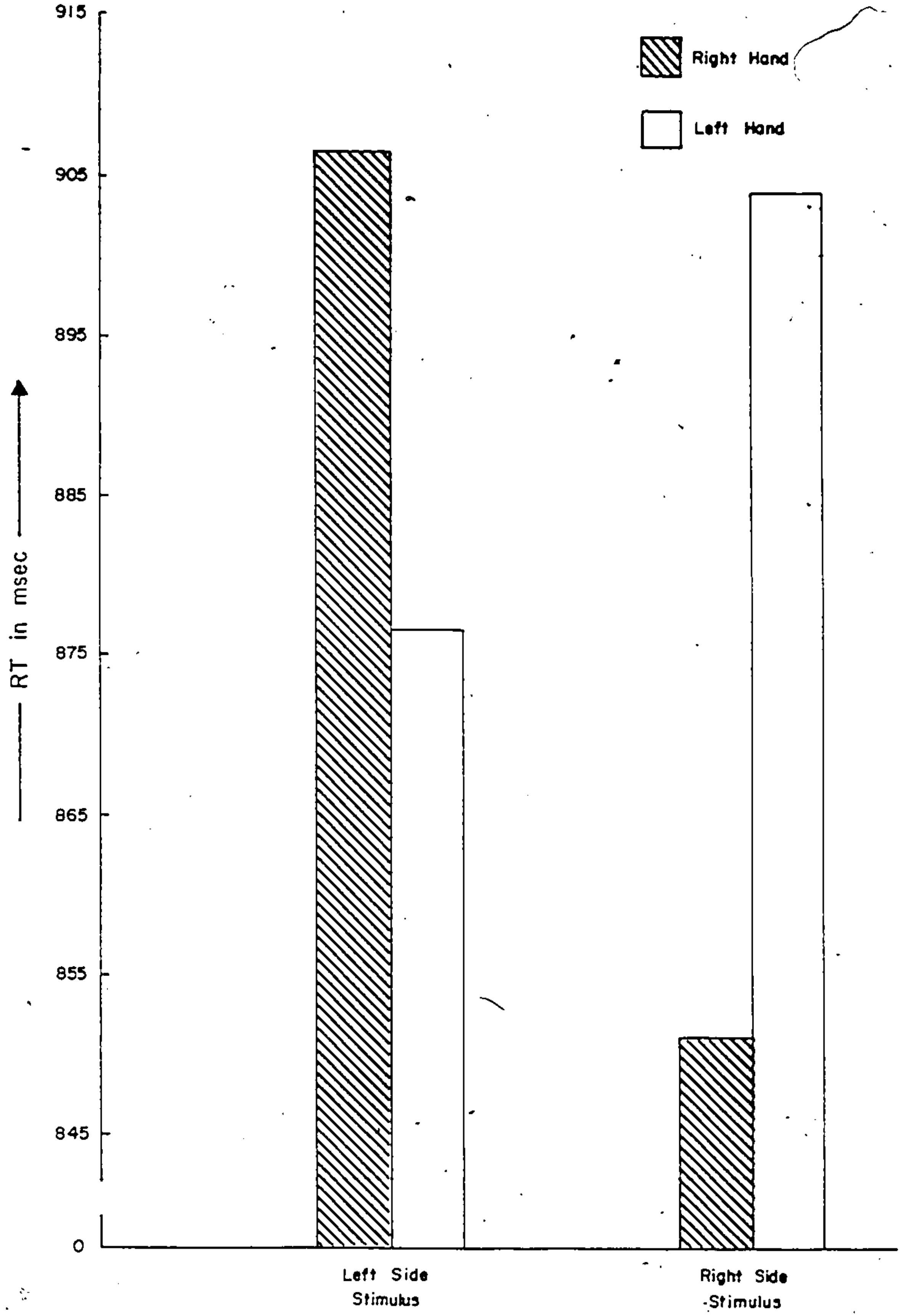


FIGURE 15

RTs to Complex Visual Stimuli in 9-year-old Children

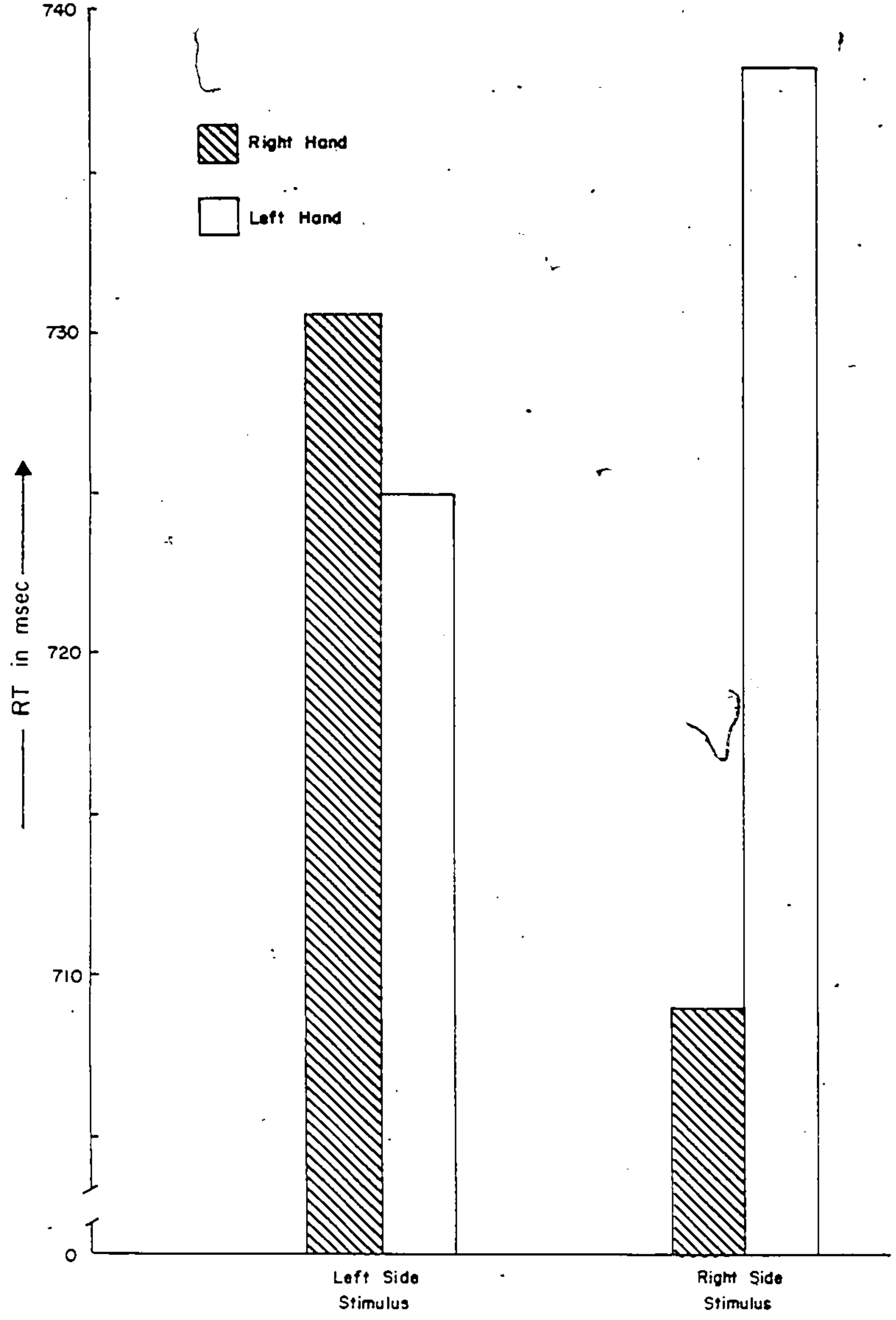
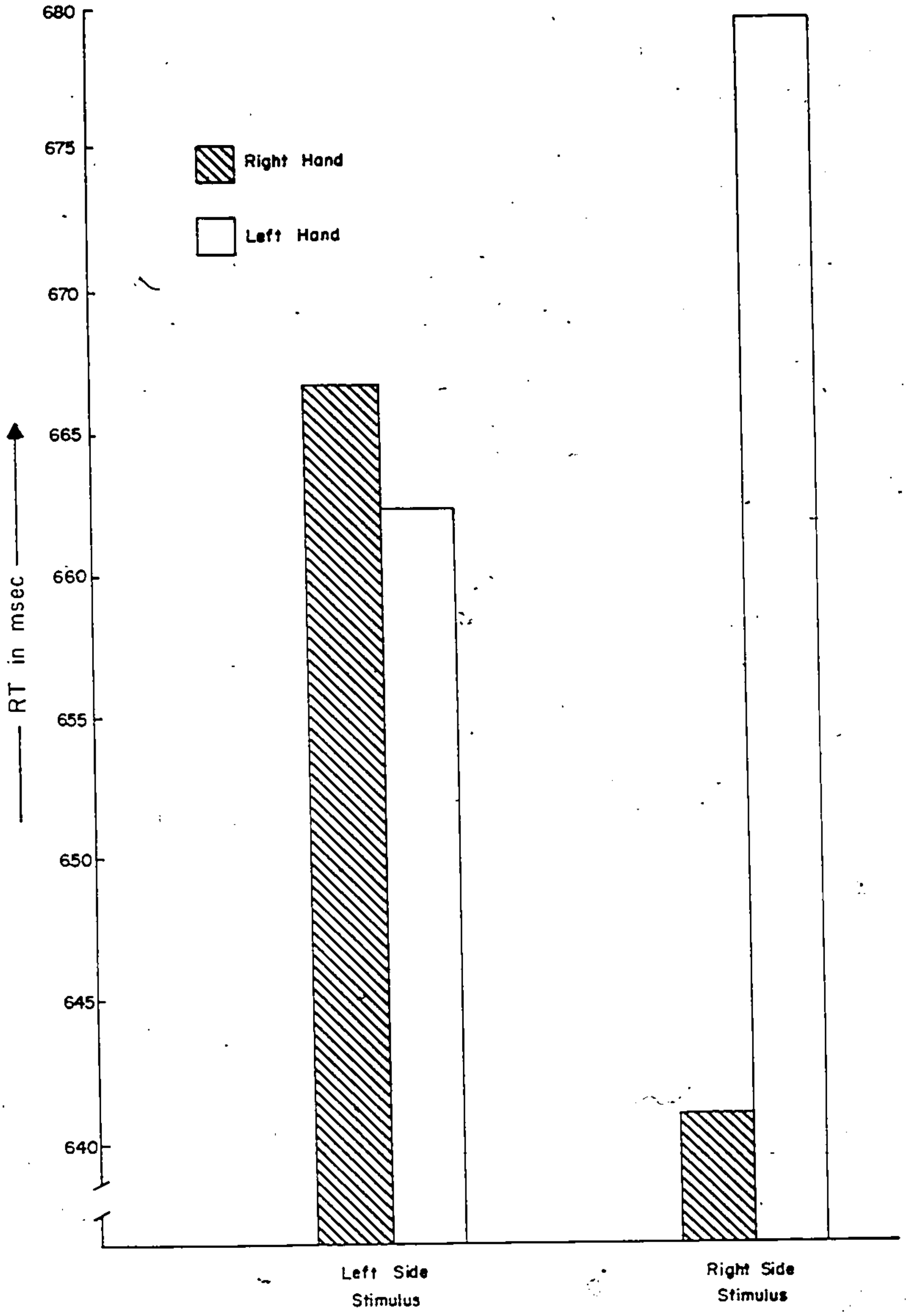


FIGURE 16

RTs to Complex Visual Stimuli in 11-year-old Children



in Figures 13 through 16, by comparing the RTs of each hand for a stimulus to the same hemisphere as the one initiating the response and then to the opposite hemisphere.

When a particular visual stimulus (the letter "L" and "T", or a line of horizontal or vertical orientation) is flashed to the nasal hemiretina of the left eye (i.e., to the right hemisphere), the left hand usually responds faster than the right hand. As in the simple visual and tactual RT tasks, a left hand superiority to left-sided stimulation is obtained consistently at all age levels and is assumed possibly to reflect the shorter or uncrossed, intrahemispheric anatomical pathway. The slower right hand response to the same stimulus is again assumed possibly to reflect the longer or crossed, interhemispheric anatomical pathway. Similarly, regarding right half-field stimulation, the right hand usually responds faster than the left.

Further examination of the data (Table 5 and Figures 13 through 16) shows that the size of the CUD obtained for each hand tends to decrease with increasing age. This developmental change is reflected in a significant triple interaction of age x hand responding x hemisphere stimulated ($\underline{F}$ (3,116) = 4.5749, $\underline{p} < 0.001$). The question arises of whether the performance of the two hands are the same or different. In an attempt to address this concern two-way analyses of variance were conducted on the performance of each hand.

Both analyses yield significant main effects of age and hemisphere stimulated. Age ($\underline{F}$ (3,116) = 22.3573, $\underline{p} < 0.001$) and hemisphere stimulated (F (1,116) = 30.2128, $p < 0.001$) are highly significant for right hand performance, as are age (F (3,116) = 22.3879, $p < 0.001$) and hemisphere stimulated (F (1,116) = 21.7002, $p < 0.001$) for left hand performance. However, whereas a highly significant two-way interaction of age x hemisphere stimulated (F (3,116) = 5.0475, $p < 0.001$) emerges for left hand performance, the two-way interaction misses significance for the right hand performance (F (3,116) = 2.2384, $p < 0.07$). A high degree of data variability may have precluded the possibility of obtaining an acceptable significance level regarding right hand performance. Interestingly, however, when a further analysis is conducted regarding right hand performance, in which age is examined as a two-level factor of older and younger children, the expected two-way interaction of age x hemisphere stimulated emerges as significant (F (1,118) = 6.5886, $p < 0.01$). In this case the 5- and 7-year-olds are regarded as one group of subjects, as are the 9- and 11-year-olds. Thus, it may be acceptable to regard the performance of both hands as being similar, at least in terms of yielding positive CUDs which appear to change over the four age levels being examined in the present study.

Additionally, the composite data matrix may be regarded from the perspective of overall crossed versus uncrossed performance, by averaging the RTs for left hand responding/right heisphere stimulated and right hand responding/left heisphere stimulated (uncrossed) and by averaging the RTs for left hand responding/left hemisphere stimulated and right hand responding/right hemisphere stimulated (crossed). The resulting mean CUDs are plotted as a function of age in Figure 17. the mean values can be seen in the second to last column of Table 5.

Figures 13 through 16 and Table 5 show that response latencies to <u>both</u> crossed and uncrossed stimuli tend to decrease with increasing age. However, the rates at which these two response latencies decrease across ages differ. Moreover, the ratio of the CUD to the uncrossed response latency tends to decrease in size with increasing age, once again providing support for the notion that interhemispheric conduction time initially lags behind intrahemispheric conduction time, then begins to catch up later in development. These ratios can be seen in the far right column of Table 5, and are plotted as a function of age in Figure 18.

Table 5 shows that the mean RTs to crossed structured visual stimuli in 5- and 7-year-old children remain on the average 76.54 and 38.13 msec respectively slower than responses to uncrossed stimuli. By the ages of 9 and 11 years, crossed responses remain on the average 17.14 and 20.88 msec respectively behind uncrossed responses. An analysis of simple interaction effects of the significant triple interaction shows that the differences obtained between the mean crossed and uncrossed RTs are significant for the 5-year-olds ($\underline{F}$ (3,116) = 36.62, $\underline{p} < 0.0001$) and the 7-year-olds ($\underline{F}$ (3,116) = 11.0428, $\underline{p} < 0.001$), but miss significance for the 9-year-olds ($\underline{F}$ (3,116) = 1.7897, $\underline{p} < 0.10$) and the 11-year-olds ($\underline{F}$ (3,116) = 2.6438, $\underline{p} < 0.10$).

A three way analysis of variance with repeated measures appraised the RT performances of the children considered as two groups of younger

FIGURE 17

CUD Plotted as a Function of Age:
From a Complex Choice RT Paradigm, Using Complex Visual Stimuli

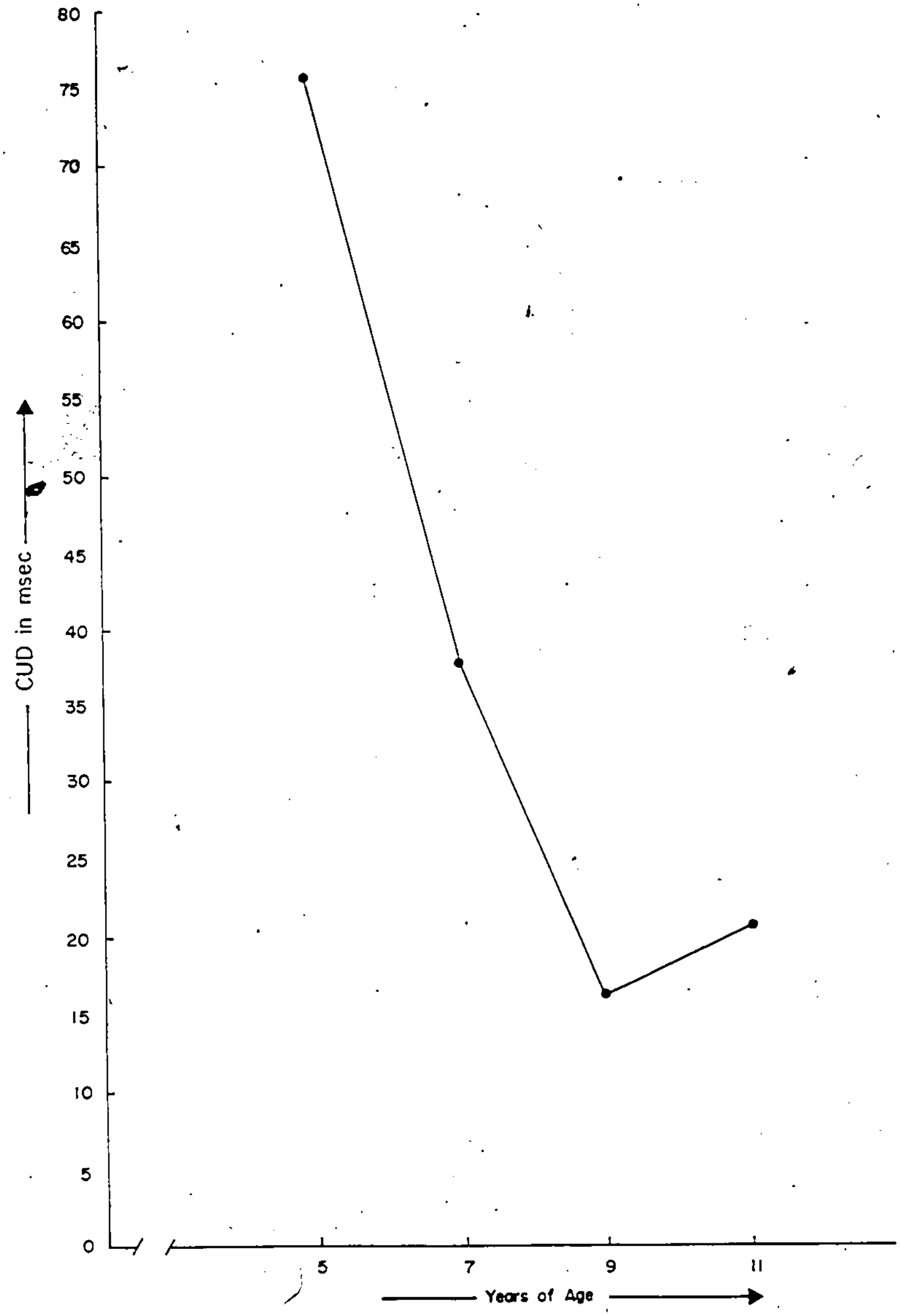
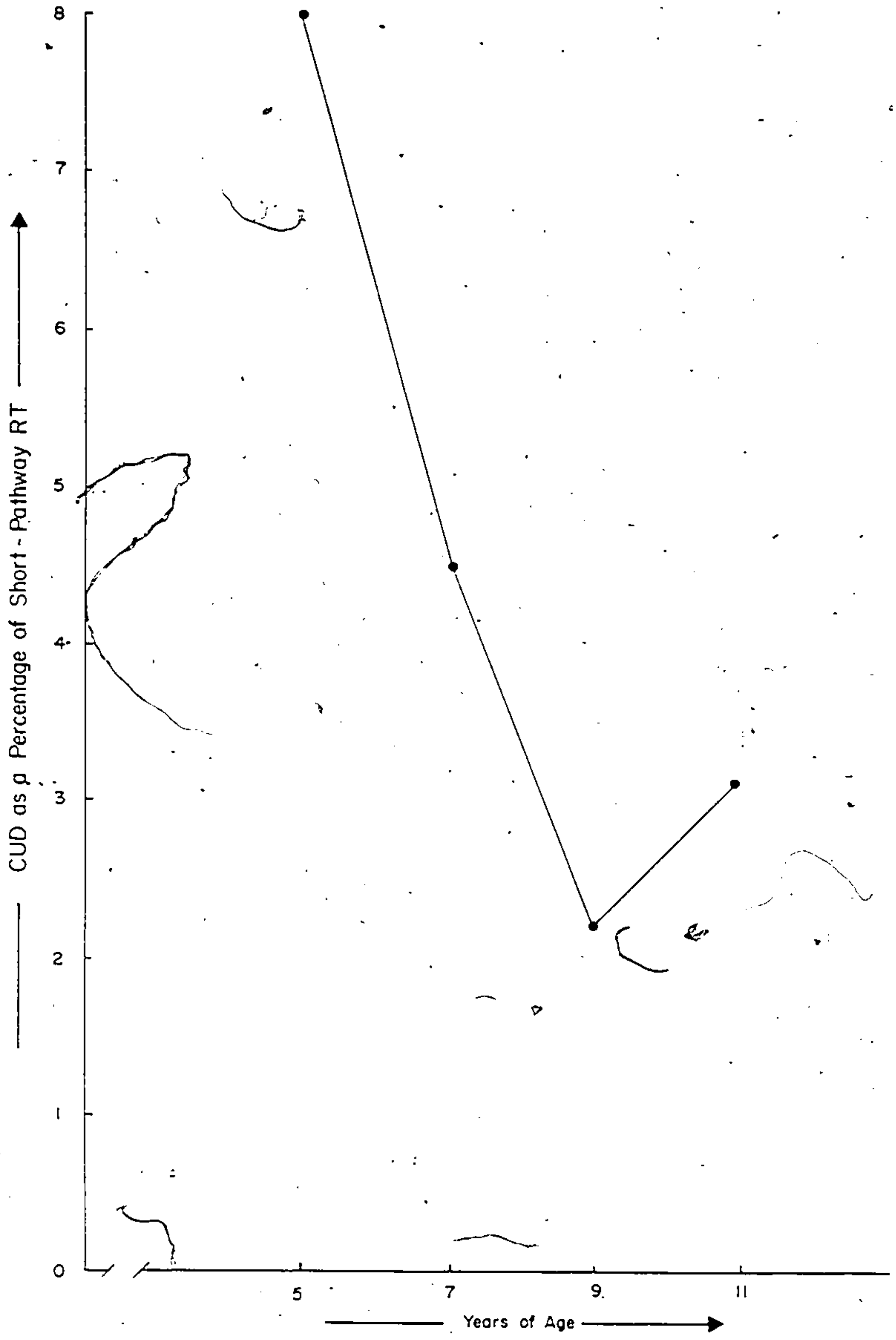


FIGURE 18

CUD Expressed as a Percentage of Short-Pathway RT and Plotted as a Function of Age: From a Complex Choice RT Paradigm, Using Complex Visual Stimuli



or older subjects. A highly significant triple interaction emerged (F $(1,118) = 35.9002$, $p < 0.001$) providing further statistical support for a developmental change in ITT between the ages of 7 and 9 years. The overall results, suggest that there are significant differences between the RTs to crossed and uncrossed structured visual stimuli in the developing child, of 5- and 7-years-of-age and these RT differences apparently are subject to developmental influences between the ages of 5- and 7-, and 7- and 9-years-of-age. The overall RT to crossed versus uncrossed stimulation shows relative improvement at both of these developmental junctures.

At 5- and 7-years-of-age, the obtained mean ITT estimates of 76.59 and 38.13 msec respectively represent values of 8.0 and 4.4 percent of the uncrossed response latency. At 9- and 11-years-of-age, the obtained ITT estimates of 17.14 and 20.88 msec respectively represent values of 2.4 and 3.2 percent of the uncrossed response latency. These results suggest a relative improvement in RT to crossed structured visual stimuli between the ages of 5 and 7 years, and again between the ages of 7 and 9 years, but not between the ages of 9 and 11 years. Clearly developmental changes occur with regard to ITT as the child matures beyond his fifth birthday. It is also clear that by the ninth birthday, no further decrease occurs in regard to ITT, as determined in a complex choice visual RT paradigm.

However, performance differences may exist in regard to the left and right hand RT scores, especially of the 7-year-old children, in this particular complex choice visual RT paradigm; that is, while the

CUD obtained by the left hand of the 7-year-old is 53.9 msec, his right hand performance is only 22.36 msec, which resembles the average CUD obtained by the 9- and 11-year-old subjects. CUDs obtained by left hand performance decrease precipitously in size between the ages of 5 and 7 years, and thereafter change relatively little. In contrast, CUDs obtained by right hand performance appear to decrease between the fifth and seventh years, as well as between the seventh and ninth years, while remaining relatively unchanged between the ninth and eleventh years.

These apparently asymmetrical findings may possibly reflect an underlying asymmetry in neurological maturation, which is expressed in response to the particular task requirements. The presence of asymmetry in performance is unexpected, however; and the apparent asymmetrical performance may be an artifact of this particular combination of tasks. The latter alternative seems unlikely, since the asymmetry in performance was present prior to the data recombination, for the composite complex choice RT data matrix.

RT Performance of a Young Adult Acallosal Male

A nineteen-year-old acallosal male, Ron N., also performed truncated versions of all of the above tasks. Ron described himself as left handed and printed his name without difficulty using this hand. He was also able to print his name with very little difficulty using his right hand, albeit somewhat more slowly. Since all of his testing had to be completed in a span of a few hours, only half of the normal number of trials could be administered. Even this amount of testing seemed to be tiring for the subject. Overall, Ron made only three errors and experienced only mild difficulty in fixation on the complex choice RT tasks. He required a total of 12 replacement trials due to the same number of fixation failures.

Regarding baseline measures, Ron responded to bilateral tactual vibratory stimulation somewhat slower than a 7-year-old child (right hand, 500.71 msec; left hand, 527.36 msec), demonstrating a possible right hand superiority in speed. His RTs to bilateral visual stimulation differed more widely between hands. His right hand speed (371.51 msec) was similar to the mean RT of a 9-year-old child, while his left hand speed (303.47 msec) resembled the mean performance of an 11-year-old child. The apparent change from right to left hand superiority in response speed remains unclear.

Regarding lateralized vibratory tactual stimulation, Ron obtained an overall CUD of 53.11 msec which is somewhat slower than the average 5-year-old's score on the same task. His right hand response latencies to crossed (634.19 msec) and uncrossed (606.79 msec) stimulation yielded a CUD of 27.40 msec. His left hand response latencies to crossed (690.53 msec) and uncrossed (611.71 msec) stimulation, yielded a 78.82 msec CUD. Ron's overall RTs here are in the same range as those obtained by 5-year-old subjects.

The results of Ron's attempts to respond to lateralized visual stimuli are relatively perplexing. Regarding simple visual stimuli, his right hand RT to crossed (439.45 msec) and uncrossed (397.6 msec) stimulation yielded a CUD of 41.78 msec. While his overall right hand response speed is similar to speeds produced by 9-year-old subjects, his obtained CUD, produced by his right hand alone, is consistent with the performance of some 5-year-olds. In contrast, Ron's left hand performance on the same task is difficult to explain. His obtained response latencies to crossed (394.69 msec) and uncrossed (459.60 msec) stimulation, yielded a negative value CUD of 64.91 msec, which indicates that Ron may respond faster to crossed than uncrossed visual stimulation with the left hand.

The results of Ron's performance in the complex choice RT experiment are equally enigmatic. On these tasks, his overall left hand performance to crossed (681.78 msec) and uncrossed (634.88 msec) stimulation, yielded a CUD of 46.9 msec. These response latencies are similar to 11-year-old level performance, but yield an ITT estimate more consistent with that produced by a 7-year-old; however, Ron's corresponding right hand performance at this time is difficult to explain. His overall right hand RT to crossed (676.48 msec) and uncrossed (786.76 msec) stimulation, yield a negative value CUD of 90.47 msec, suggesting again faster responding to crossed rather than uncrossed complex visual stimuli with the right hand.

It is interesting to note that similar, "inconsistent" performances occurred in about 15 percent of the subjects in the present study, at all age levels and on all tasks. The phenomenon, however, occurred most often with the youngest subjects on the complex choice RT tasks.

No attempt was made in the present study to conduct an analysis of the simple main effects, although such an analysis could be done. The present interpretation of the data was based on an analysis of the simple interaction effects of the significant triple interactions and on visual examination of the data.

Chapter IV

DISCUSSION

Performance Effects

Performance measures from the simple visual RT experiment support the first hypothesis, that younger children in comparison with older children exhibit significantly greater response delay to crossed stimulation.

The performance profile shows that RTs to crossed stimulation in 5- and 7-year-olds in comparison to 9- and 11-year-olds are significantly more delayed, and that speed of interhemispheric communication improves relative to intrahemispheric processing between the ages of 5- and 9-years, but not between the ages of 9- and 11-years. While these results indicate that at least from the age of 5-years, children are able to respond with increasing speed to crossed stimulation relative to gradually improving uncrossed responding, they also suggest that by the age of 9-years the progressively decreasing crossed latencies are approching values more similar to the uncrossed latencies and that relatively little change may be occurring beyond this point. In the current experiment, the mean ITT estimates decreased consistently up to the ninth birthday, after which an apparent exception to the consistent CUD decrease was obtained, suggesting that further developmental changes in interhemispheric transmission rates may be unlikely beyond late childhood. It seems likely, however, that there are real differences between the obtained crossed and uncrossed RTs in the older children, since ITT estimates of about 3 msec have been obtained employing visual behavioural RT paradigms with normal intact adults (Anzola et al., 1977; Berlucchi, 1972; Berlucchi et al., 1971, 1977).

The present pattern of results substantiates and extends the findings of Jeeves (1972) who, using a simple visual RT task, found that right-handed 9- to 11-year-old boys exhibit a mean ITT of 3.31 msec. The ITT estimates obtained in the present experiment for similar age boys range in value from 2.38 to 8.25 msec. The present study extended Jeeves' findings downward, thus illuminating previously unrecognized developmental changes in young children's ability to respond behaviourally to contralateral and ipsilateral visual stimulation. Moreover, although Jeeves (1972) made no attempt to assess developmental changes in RT, his young subject group's performance was characterized by overall slower responses than those previously found in the adult population. The trend of his findings is consistent with the overall slower performance of the younger children in the current experiment.

With respect to the second hypothesis, the complex choice RT experiment requires the child to make a rapid stimulus discrimination and response decision, in addition to maintaining strict eye fixation and motor readiness as in the simpler RT tasks. Again, as in the visual and tactual simple RT tasks, the mean CUD decreases in size with increasing age, however, with the overall pattern of findings resembling more closely those obtained in the visual simple RT experiment. The performance profile suggests that ITT improves relative to intra-hemispheric processing between the ages of 5- to 9-years, but not thereafter, supporting hypothesis II, that younger children in comparison with older children exhibit a significantly greater response delay to crossed visual stimulation in a complex choice RT situation.

Once again, as in the two simple RT situations, the statistical analyses indicate no significant difference between the RTs to crossed and uncrossed stimuli for the 9- and 11-year-olds. The absence of a significant difference may be due to large error variance, especially in view of the magnitude of the ITT estimates obtained (from 13.21 to 25.58 msec) which easily fall within the range of ITT estimates (from 10 to 50 msec) obtained in complex choice visual RT paradigms examining normal intact adult subjects.

The simple RT paradigm was also used in the present study in conjunction with tactual stimuli. In this experiment, the mean CUD and the CUDs obtained for each hand independently do not decrease uniformly with increasing age, although a dramatic decrease in response latency to crossed vibratory stimulation is evident between the ages of 7- and 9-years. It is not possible to differentiate between the 5- and 7-year-olds, nor between the 9- and 11-year-olds on the basis of the CUD magnitude, suggesting either no developmental changes in ITT during those two time periods or relatively slow developmental changes. It seems unlikely that speed of interhemispheric communication actually decreased at these age levels. However, since CUD expressed as a percentage of uncrossed RT tended to remain relatively unchanged in magnitude between the ages of 5 and 7 and again between the ages of 9 and 11, speed of interhemispheric communication may have actually kept pace with improving intra-hemispheric processing during these two time periods; consequently, the present evidence provides support for hypothesis III, that younger children in comparison with older children exhibit a significantly greater response delay to crossed tactual stimulation.

The current performance profile also suggests interhemispheric transmission speed clearly improves relative to intra-hemispheric processing between the ages of 7- and 9-years, but perhaps not thereafter. Conversely, there is no clear evidence of similar improvement between the fifth and seventh birthdays. Furthermore, it seems likely that there are real differences between the obtained crossed and uncrossed RTs in the 9- and 11-year-olds, since stable ITT estimates of about 4 to 10 msec have been found using simple tactual RT paradigms with normal adults. Large error variance may have precluded the possibility of these values being seen as representing significant differences. The current findings, however, substantiate the electrophysiological findings of Salamy (1978) who showed a progressive decrease in crossed latencies of all peaks of EPs with increasing age and a progressive decline in the CUD asymptoting at about 10-years-of-age. A lack of correspondance between the present findings and those obtained by Salamy is evident in comparing the gradualness of his ITT decline in contrast to the precipitous ITT decline of the present experiment. This difference may reflect the addition of a behavioural component which was not present in the Salamy study.

With respect to baseline measures, hypothesis IV, is suported; older children will respond faster than younger children to bilateral stimulation. Support is present for both control tasks and is consistent with all of the experimental RT task results of the current study. This overall ability to respond faster with increasing age may reflect anatomical and physiological maturation, increased ability to attend and maintain concentration and increased motivational effort (Elliot, 1972). Myelination of the requisite brain structure would have been complete by four years of age except for the fibres of the reticular formation, the non-specific thalamic radiations and the intra-cortical, neuropil and association areas (Yakovlev, & Lecours, 1967).

When a comparison is made, between response latencies to bilateral stimuli versus unilateral stimulation an interesting problem arises; however, that is, while one can identify the hemisphere presumed to be initially stimulated in the unilateral condition, one cannot determine in the present circumstances which hemisphere may have been initially stimulated in the bilateral condition. In the present study, since identical stimuli were presented simultaneously to each hemisphere, both hemispheres may have contributed to detecting the presence of the stimulus in order to initiate the response. This is not an uncommon finding in the case of bilateral stimulation and has been described as a "facilitation" effect (Peters, 1983). In the present study, children tend to respond, on the average, about 50 msec sooner to bilateral versus unilateral stimuli in the simple RT paradigm; however, when attempting to compare RTs to unilateral stimuli in the simple versus complex choice RT paradigm, children in the simple RT task respond about 400 msec faster than in the complex choice RT task. This latter comparison emphasizes the notion that simple RT tasks may be qualitatively different from complex choice RT tasks. While "stimulus and response decision making time" may help explain the 400 msec descrepency, an alternative hypothesis may be required to explain the approximately 50 msec descrepency in the case of bilateral versus unilateral stimulation in the simple visual RT paradigm. It is possible that the so called "second" visual system may facilitate responding in a condition of bilateral visual stimulation requiring directed attention. The collicular-pulvinar-parietal lobe pathway, not the geniculostriate pathway, may be important for the detection of events, their location in space, and the control of orienting responses to them for subsequent identification by the first system (Zihl & Von Cramon, 1977). Supportive evidence for the existence of two such functionally and anatomically distinguishable visual systems comes from recent work with patients following midline section of the corpus callosum. While commissurotomy patients are impaired at explicit interfield comparisons, the other visual system appears to have access to both visual half-fields (Holtzman, Sidtis, Volpé, Wilson, & Gazzaniga, 1981). Holtzman et al. (1981) suggested that crossed visual representation may be provided directly via collicular-cortical projections, or indirectly via the intact anterior commissure.

With respect to hypothesis V, evidence from a young acallosal male was gathered in an attempt to demonstrate the face validity of the RT tasks employed in the present study. The pattern of results obtained was unfortunately ambiguous. On the bilateral tactual stimulation task, Ron responded somewhat slower than a 7-year-old child; whereas, on the bilateral visual stimulation task, his response speed was between the 9- and 11-year-old performance levels. On the simple tactual RT task, Ron's overall RTs were in the 5-year-old performance range. His right hand performance yielded a positive CUD of 27.40 msec, his left, a positive CUD of 78.82 msec, consistent with the performance of younger children. Ron's CUDs obtained on the tactual simple RT task are similar in value to those obtained by other acollosal patients tested in visual simple RT paradigms. The present results support hypothesis V, that in comparison with the older children the acallosal subject will exhibit significantly slower responses to crossed stimulation. Ron, however, showed striking inconsistencies between his right and left hand performances on both visual RT tasks. On the simple RT task, his right hand yielded a positive CUD of 41.78 msec, while his left hand yielded a negative CUD of 64.91 msec. Essentially, the reverse situation obtained on the complex choice RT task, in which his left hand yielded a positive CUD of 46.9 msec, and his right hand, a negative CUD of

90.47 msec. The present negative results fail to support hypothesis V, while the positive results are in accordance with it.

On the basis of the results obtained from Ron's performance on the simple tactual RT task, this test seems to have adequate face validity, in that the test may be capable of accurate behavioural assessment of interhemispheric communication speed. If this is so, test results from "normal" children could be obtained on this test and used to evaluate interhemispheric maturational delays in clinical evaluations. However, it is unclear on the basis of Ron's results for the visual RT tasks what the exact status of the face validity of these two tasks should be. For example, Ron's "inconsistent" performances may reflect the small number of trials administered. It was already noted, however, that 10 to 15 percent of the subjects on all tasks in the present study occassionally produced negative CUDs, with one or the other hand, sometimes both. Moreover, the literature has many examples of this phenomenon. Alternatively, Ron's aberrant results may have been due to mixed handedness. Approximately 70 percent of acollosals described in the literature are right handed, only 30 percent being "ambidextrous" or left- or mixed-handed (Milner, & Jeeves, 1979). Further, Jeeves (1972) has shown that both children and adults who are left-handed show an aberrant pattern of RT results compared to right-handers. Thus, the design of the simple visual RT task used in the present study may be adequate to assess transcollosal transmission rates, especially in view of the history of its use since Poffenberger

(1912). The case for clinical application of the design used in the visual complex choice RT experiment requires more discussion, however.

It was not the intention of the present study to examine explicitly any hypothesis in regard to lateral asymmetries of manual performance per se; however, examples of right hand superiority in speed of responding were evident in each visual RT task, but not in any tactual RT task. There is no obvious explanation for why a handedness effect was observed in response to visual but not tactual stimulation. In this regard, it is important to note that if more subjects had been available for testing in all of the four subject age groups on the bilateral tactual task, especially for the two older groups, different results might have been obtained. Berlucchi et al. (1971) and Anzola et al. (1977) have stated that anatomical superiority is usually not present in simple RT experiments; whereas Jeeves and Dixon (1970) have shown right hand superiority in simple visual RT tasks, in both adults and children (Jeeves, 1972). Right hand superiority, however, is a common finding in choice RT experiments (Simon, Hinrichs, & Craft, 1970; Wallace, 1971; Brebner, Shephard, & Cairney, 1972; Anzola et al., 1977); Anzola et al. (1977) have suggested that this right hand superiority in speed may reflect left hemisphere superiority in RT experiments requiring a decision about which hand is to be used, possibly indicating that something about the decision process itself favors the motor (or premotor) areas of the left hemisphere.

Simple RT experimentation has also sometimes yielded slight hemispheric asymmetries, which when significant, have almost always occurred in the same direction, that is, RTs to left visual half-field being faster. No such asymmetries occurred in any of the RT tasks of the present study (Bisiach, Mini, Sterzi, & Vallar, 1982; Davidoff, 1975, 1977; Milner, Jeeves, Ratcliff, & Cunnison, 1982). The present negative results suggest that the cerebral hemispheres of the developing child are equally capable of responding in a variety of RT situations, and fail in this respect to support Semmes' (1968) hypothesis that the two cerebral hemispheres have inherently different neural organization.

In summary, the five experimental hypotheses of the current study are supported by the data obtained; in particular, the findings from the latter three experiments provide behavioural evidence of developmental changes in speed of interhemispheric communication and support the notion of later maturation of interhemispheric communication relative to the development of intra-hemispheric processing as Gazzaniga (1970, 1974, 1981a) has suggested. In this regard, the small body of literature (Elliot & Connolly, 1974; Finlayson, 1976; Galin et al., 1977, 1979; O'Leary, 1980; Denckla, 1973, 1974; Maxwell, 1981) which has been reviewed, shows behavioural changes accompanying the gradual maturation of the commissural systems, and in particular, unilateral performance maturing in advance of successful crossed or bilateral performance, often between the ages of 7- and 9-years or earlier. The present findings thus suggest that intra-hemispheric information processing is faster and therefore possibly more efficient than inter-hemispheric processing for younger children. The findings also suggest that the known myelogenic timetable can account for the observed developmental changes. These suggestions will be amplified, however, since additional information suggests a more complicated picture:

Validity of Interpretations

Swanson, Ledlow, and Kinsbourne (1978, p. 288) concluded that ITT estimates based upon any behavioral RT method are "too variable to provide a good estimate of these physiological reaction times". They stated that there were too many uncontrolled sources of variation "(uncertainty of stimulus location, stimulus-response compatibility, specialized cognitive processing, etc.)" to obtain valid findings. While recognizing that the transfer of information between the two hemispheres is complex, Bashore (1981) and Belucchi (1977) have independently concluded, however, that simple behavioral RT paradigms can provide valid estimates of ITT that closely approximate electrophysiological measures. In fact, the existing EP literature shows a wide range of values for ITT estimates from 1.5 to in excess of 150 msec (Andreassi et al., 1975; Brerner, 1958; Grafstein, 1959; Swanson, Ledlow, & Kinsbourne, 1978; Rugg & Beaumont, 1978; Salamy, 1978; Teitelbaum, Sharpless, & Byck, 1968); and results from both the simple and complex choice RT tasks of the current study are in accordance with these findings, which suggest that either paradigm allows valid, but independent inferences regarding interhemispheric transmission speed. However, while some complex choice RT studies have yielded positive CUDs, these differences have been attributed to stimulus-response (S-R) compatibility, thereby challenging the significance of the anatomical connectivity emphasized by Poffenberger and suggesting that the delay between crossed and uncrossed responses may be due merely to compatibility, without any reference to a contribution by the anatomical relationships of hemiretinae and hands. In choice RT situations it has been found that RT to a lateralized stimulus can be affected by changing the spatial position of the responding hand. Thus, if the hands are crossed such that the right hand is on the left side of the body and the left hand on the right side, stimuli coming from the left are now responded to faster by the right hand and stimuli from the right are responded to faster by the left hand. This apparently paradoxical finding has been thought to reflect the natural tendency to respond to lateralized stimuli with the hand that is in the appropriate spatial position (Anzola <u>et al</u>., 1977).

Other, studies have shown that S-R compatibility does not have any effect in a simple RT experiment nor in ("go-no-go") simple choice RT studies. Berlucchi <u>et al</u>. (1977, p. 511) suggests that "the interfield differences in choice RT are likely to reflect hemispheric asymmetries and to be related both to interhemispheric transfer and to the deterioration of information taking place during such a transfer ...". Equivocal results from various studies make it difficult to determine the degree of importance that should be attached to S-R compatibility (Anzola <u>et al.</u>, 1977; Bowers, <u>et al</u>., 1981). It is not known what cortical mechanisms underly the S-R compatibility effects and what interactions might exist between these effects and intra- versus interhemispheric information processing (Bashore, 1981; Bowers et al., 1981; Gardner, & Ward, 1979). More experimental research is needed in order to develop adequate controls for the case of complex choice RT tasks. While the absence of any behavioral S-R compatibility controls in the present study does not call into serious question the results of the complex choice RT experiment, it does sound the need for caution in interpreting the ITT estimates derived from these results.

It is interesting to note that since postnatal development (including myelination) of primary motor and sensory corticies may come to completion by the end of the second year (Blinkov, & Glezer, 1965; Yakovlev, & Lecours, 1967) it may follow that sensory and motor skills would appear early in childhood, followed by more complex problem-solving abilities which continue to mature into adulthood (Fletcher, & Satz, 1980; Hiscock, & Kinsbourne, 1980; Piaget, 1952; Reitan, 1974). This notion has been suggested by Maxwell (1981). Some evidence can indeed be found which suggests that motor and sensory or perceptual skills mature before cognitive skills, since motor and sensory tasks have been found by some investigators to be more sensitive to early brain damage than are tasks requiring cognitive reasoning skills (Boll, & Reitan, 1972; Fitzhugh, Fitzhugh, & Reitan, 1962; Reed, Reitan, & Klove, 1965; Reitan, 1971; Reitan, 1972; Rudel, Teuber, & Twitchell, 1974). However, some data contradicts this notion. For example, Boll (1973) has shown that the earlier brain damage occurs in childhood, the more likely residual impairment will be demonstrated on complex tasks requiring abstract thinking, problem solving and verbal processing. In fact, Ernhart, Graham, Eichman, Marshall, and Thurston (1963) have found no significant difference in the impairment of vocabulary, perceptual motor, and conceptual abilities (Graham, Ernhart, Craft, & Berman, 1963). Rourke (1982) concludes that early and very severe brain damage results in generalized intellectual impairment. Thus cognitive skills may mature earlier than initially thought. These findings may have implications in terms of what behaviours to expect during early periods of callosal development; since the requisite brain structures needed for later demonstration of cognitive skills may be maturing at the same rate as those brain structures required for noncognitive sensory-motor tasks. A similar conclusion was reached by Finlayson and Reitan (1976) who stated that tactile-perceptual deficits found in younger children may well limit their eventual level of cognitive development. Moreover, Woods (1980) has found that patients who suffered right hemisphere lesions before the age of 1-year, demonstrated impaired verbal and performance ratings on Wechsler Test data in late life. An implication of these findings for the present study, is that developmental effects would be as likely for the simple RT experiments as for the complex choice RT experiment, even though the latter task may require a much greater degree of cognitive skill than the former task, for its successful completion. Indeed, legitimate questions arise concerning what the different ITT values observed in the different current experiments really mean.

One question that can be raised concerns the nature of the information presumed to cross between the hemispheres in the current study: does a direct representation of the sensory input to one hemisphere get relayed to the opposite hemisphere? Peters (1983) states that it must be assumed that the information which crosses the callosum represents at all times a processed version of the sensory input to the receiving hemisphere. Alternatively, the possibility exists that what is being measured in all instances of interhemispheric communication in the present study is a motor command or motor program. The design of the present experiments, however, does not allow the possibility of distinguishing between any of the alternatives.

Earlier studies indicate that the visual-premotor and premotor-motor pathways are the major pathways subserving visual-motor intergration (Busk, & Galbraith, 1975). Some investigators believe that the motor cortex must act on instructions from association cortex. Both premotor and parietal association cortex are in a position to exert an influence. Premotor cortex (Broadman area 6) projects directly to motor cortex (area 4) and superior parietal cortex (area 5) projects both to area 6 and to the supplementary motor cortex which in turn sends connections to area 4 (Halsband, & Passingham, 1982). The classical evidence would thus suggest that in none of the present visual RT tasks was stimuli delivered directly from the occiptal cortex to the motor cortex. However, Asanuma (1981) has argued for the necessity of direct somesthetic afferent input from the periphery to the motor cortex. Thus, it is not clear if subjects in the present study responded to precentral or postcentral neuronal tactual stimulation. In fact, it is possible that not only motor, but also both sensory and association corticies received direct input from the sensory thalamus (Clemo, & Stein, 1982).

To reiterate, it is clear that the data of the present study provides little indication of what brain structures are primarily involved in any of the RT tasks, and perhaps in some instance the differences are really a matter of emphases as opposed to absolute differences. Regardless of how it is understood, however, it is clear that additional cortical representation areas, additional cortical association areas, and additional action systems may have been required to execute the complex choice visual RT task. Perhaps some of the additional brain areas may have been the supplementary motor area, the convexity of the premotor area, and the superior and inferior parietal regions. Tanji, Taniguchi, and Saga (1980) have examined supplementary motor area neuronal response to motor instructions in the monkey. Their observations substantiated the hypothesis that the supplementary motor area plays a part in modifying a sensory-triggered motor output. Roland, Lassen, Larsen, and Skinhoj (1980) in a regional cerebral blood flow (rCBF) study found that the rCBF increases exclusively in the supplementary motor area while subjects were programming a sequence of fast isolated movements of individual fingers, without actually executing it. During execution of the same motor sequence, there were equivalent increases of the rCBF in both supplementary motor areas, but only in the contralateral primary motor area. They concluded that the primary motor area and the part of the motor system it projects to by itself can control ongoing simple ballistic movements with the self same body part, but that a sequence of different isolated finger movements requires programming in the supplementary motor areas.

Furthermore, while it seems impossible to have been able to predict any specific findings in regard to the reticular formation (RF) or the reticular activating system in regard to ITT estimates at any age level, these portions of the nonspecific somatosensory system may have played a role. For example, impulses generated in ipsilateral limbs usually reach the caudal bulbar RF before those from contralateral limbs, whereas in the midbrain RF the contrary is the case, contralateral limbs stimuli generally having a shorter latency than ipsilateral. Interconnections between, or common projections of these two regions would form a basis for comparisons that would give information on site of stimulation (Bowsher, 1975).

In summary, it is not possible to state with certainty the nature of the excitation transfer between hemispheres in any of the present experiments; that is, whether the information was motor or sensory in nature, processed or unprocessed? Nor can we state with certainty what specific interhemispheric pathway would have been used in the various tasks. It does seem likely, however, that the corpus callosum played a key role and that the maturing corpus callosum and the maturing brain contributed to the overall pattern of findings.

Regional Implications

Improved interhemispheric transmission rates, infered from the relatively faster responses to crossed stimuli in the older chilaren, were confirmed by statistical analyses in all three, unilateral RT experiments. The overall pattern of relatively slower responses to crossed stimuli in the younger children in comparison to the older children were also described by these results. Most notable was the clear differentiation of the children into two groups, either older or younger. This pattern was most clearly evident in the tactual vibratory experiment, but was also present in both visual, unilateral RT experiments. The common decrease in CUD magnitude present in all three experiments, between the ages of 7- and 9-years, implies a loose temporal relationship between maturation of interhemispheric transmission rates independent of modality or task complexity. Conversely, the relatively sharp decline in CUD between the seventh and ninth birthdays in the tactual stimulation task, suggests that axon growth (including myelination), duplication and redistribution may not be uniform throughout the corpus callosum during development.

However, it is not entirely unexpected that the various tasks of the present study would produce similar results, since the entire corpus callosum follows a general set of rules to determine anatomical connections (Elberger, 1982). In this respect, Harris and Carr (1981) have suggested that visual and tactual perception may be virtually identical processes, with tactual perception perhaps being even more inherently temporal-spatial than visual perception, requiring the deliberate and active integration of separate points in space and time. Their explanation stems in part from the work of O'Regan and Levy-Schoen (1983) who argue that trans-saccidic fusion does not exist. Alternatively, it would appear to be a mistake to suggest that the cerebral commissures be considered as a single structural or functional unit. The lack of correspondence between the performance profile of the three unilateral, RT experiments of the present study can perhaps best be understood within the following framework.

The mature corpus callosum is known to be functionally divided with regional variations in function corresponding closely with the cortical regions they interconnect (Berlucchi, Gazzaniga, & Rizzolatti, 1967). The interhemispheric fibres passing through the posterior area or splenium project primarily to the occipital lobe. The body of the callosum projects to the parietal lobe, and the anterior regions interconnect the frontal lobes. The temporal lobe is interconnected via the anterior commissure and the caudal parts of the body of the callosum. The posterior 3 cm of the corpus callosum may be the structure that is necessary to provide the "sensory window" through which each hemisphere shares, visual, sensory (tactual), and motor information from the contralateral field (Volpé, Sidtis, Holtzman, Wilson, & Gazzaniga, 1982). The anterior corpus callosum may be a "cognitive window", insufficient for transfer of sensory information or motor programs, but able to transfer information after some higher order abstraction (Sidtis, Volpé, Holtzman, Wilson, & Gazzaniga, 1981).

Sectioning of the middle of the corpus callosum can result in a specific loss of intermanual transfer of tactual information with no other intermanual disconnection signs (Dimond, Scammell, Brouvers, & Weeks, 1977). Partial commussurotomy patients show behavioural signs of disconnection specific to the region disconnected (Damasio, Chui, Kassel, & Corbett, 1980; Gazzaniga, Risse, Springer, Clark, & Wilson, 1975; Springer, & Gazzaniga, 1975; Zihl & Von Cramon, 1977). Some controversy exists around the possible contribution of the anterior commissure to interhemispheric communication. Risse, LeDoux, Springer, Wilson, and Gazzaniga (1978) have provided evidence suggesting that this fibre bundle is capable of mediating multisensory interhemispheric messages of a complex nature. More recently, McKeever, Larrobee, Sullivan, Ferguson, and Rayport (1981) have provided evidence countering the above claims, and have concluded that the anterior commissure is not an effective commissure in the transfer of stimulation effects on visual auditory or tactual tasks. Powell (1981) has concluded that the functions of individual cortical areas are dependent upon their connections, and the differences in the origin and termination and of the ratios between them determine the differences in function between architectonic areas. Powell has stated that commissural connections may cause even adjoining parts of the cortex to differ profoundly in regard to their functional significance.

Moreover, while the structural and functional variation present in the mature corpus callosum, is well documented, no information is available which attempts to correlate the initial expression of commissural function with the maturation of its anatomy and physiology. Indeed, disagreement even exists as to what part of the corpus callosum myelinates first. The first parts of the corpus callosum to become myelinated are according to Yakovlev and Lecors (1967) the splenium, forceps major and the tapetum, and the process of myelination is said to spread gradually towards the genu, rostrum and forceps minor. Data from Luttenberg (1966) suggests in contrast, that myelination starts first at the genu, while de Villaverde (1919) found that the truncus develops myelin sheaths earlier than those of the genu or splenium, according to Selnes (1974).

Finally, in the adult brain, the bulk of the evidence suggests that the primary and secondary sensory and motor areas of the hand and foot have very scant or no interhemisphereic connections (Ebner & Myers, 1965; Innocenti, 1982; Jones & Hendry, 1980), whereas the areas representing the axis or midline are well connected with each other interhemispherically (Pandya & Vignolo, 1971). However, Mishkin (1979) has argued for the potential importance for the learning of somesthetic discriminations of bilateral receptive fields in area SII of the monkey in analogy with the visual bilateral receptive fields in the infero-temporal cortex (Berlucchi, 1981). Results from rats, rabbits, cats, and monkeys suggest that the mature callosal connections of areas 17, 18, and 19 of the visual cortex are largely restricted to regions which receive information from the middle of the visual field. The extent of this representation has been said to vary from 1 degree to more than 35 degrees of visual angle from the midline (Rocha-Miranda, Bender, Gross, & Mishkin, 1975). Bilateral cells have been found to extend more than 60 degrees into the ipsilateral visual field, especially in the Clare-Bishop or posteromedial-lateral-suprasylvian area (Berlucchi, 1981). It is possible that commissural fibres may be capable of transmitting as much information as can be accurately perceived in the peripheral visual field. Thus, while differential maturation of interhemispheric communication, including developmental changes in axon growth (increase in diameter, length and redistribution, plus myelination) and relative efficiency of specific commissural regions, may have explained some of the variation in the results obtained in the present study between the simple and complex choice RT tasks, or between the results obtained from tactual versus visual stimuli, not enough is known to have made any specific predictions.

The Nature of the Developmental Changes

As previously mentioned, Gazzaniga and LeDoux (1978) have characterized the mature intact adult brain, as each half-brain being provided with nearly simultaneous representations of both sensory spheres, so that interhemispheric perceptual equilibrium is achieved. In the absence of the forebrain commissures following surgery, however, "the patient's left hand no longer shares in the experiences of his right hand, and the visual world of each hemisphere is now totally contralateral. Only by continuous head and eye movements can the entirety of visual space be seen by both hemispheres. In addition, binocular depth perception is impaired. Use of the left side of the body in a linguistic setting is limited, as are the manipulospatial abilities of the right side." Bimanual motor coordination is also disturbed, and there can be distortion of consciousness (Gazzaniga & LeDoux, 1978).

In contrast, characterization of the acollosal brain has been more difficult to achieve. Chiarello (1980) has pointed out that unlike the commissurotomy cases, acallosals show few symptoms of hemispheric disconnection. Behavioural strategies, use of noncallosal commissures (e.g., the tectal commissures), elaboration of ipsilateral pathways, and bilateral representation of function are suggested as possible mechanisms of compensation. The compensation does not appear to be complete, however. In this regard, Milner and Jeeves (1979) has stated that "an absent corpus callosum cannot be compensated for where cross-mapping of fine-grain sensory information in vision or in touch is necessary". They argue that "clear constraints also exist upon the rate at which skilled movements can be coordinated and upon spatial intelligence". Milner and Jeeves (1979) cite as a possible cause of the difficulties for acallosals in motor coordination or skilled performance, the lengthening of simple RT which has been well documented in acallosal patients. The differences between interhemispheric transfer in normal and acallosal subjects may represent a difference in degree or amount of (successful) interhemispheric communication, as well as a difference in speed of interhemispheric communication. Apparently, neither can be totally compensated for in the acallosal person; on the other hand, in comparing interhemispheric transfer between normals and commissurotomy patients, the major difference may also be one of quantity of (successful) interhemispheric communication. The status of commissurotomy patients at this time in regard to RT tasks designed to measure the speed of interhemispheric communication is unclear. The question arises of how to characterize the changing nature of interhemispheric communication throughout childhood in respect to the evidence from the current study.

Briefly, the present evidence indicates consistently that younger children respond more slowly to crossed stimulation then do older children. With increasing age the response rates change depending upon the nature of the stimulus (visual or tactual) or the task (simple or complex choice RT). The different rates of change obtained are not totally independent processes, however, but appear primarily to reflect the underlying myelogenic timetable, in addition to changes in axon growth and redistribution. From the present evidence, taken in conjunction with existing knowledge, a graduated developmental model of interhemispheric communication can be constructed.

Very young children initially show behavioural limitations which are similar to those found both in the cummissurotomy patient and in the individual with callosal agenesis. In the case of normal development, as children mature, behavioural limitations are shed or decrease in severity since interhemispheric transmission speed improves and changes relative to intrahemispheric processing; and children begin to behaviourally resemble acallosal patients more closely than brain-bisected patients. At or near the end of late childhood children show relatively few or no behavioural signs of either group - their behaviour being now most similar to normal intact adults.

This model is consistent with the notion that the mature intact cerebral commissures normally compel the two hemispheres to work closely together, while recognizing that even in the intact adult split-brain phenomena can be found. With respect to disconnection features in the normal brain, Dimond and Beaumont (1974) have shown that there is a capacity for independent information analysis at each side of the brain and that information may fail to transfer from one hemisphere to the other under conditions of difficult percpetual analysis. With respect to increased speed of interhemispheric communication with increasing age, this model may explain improved timing and coordination of movements between hands on the Labarynth Game (Elliot & Connolly, 1974), increased velocity of intermanual transfer on the TAT (Finlayson, 1976), and successful bimanual co-ordination of older children on Tapping tasks (Maxwell, 1981). Moreover, the model predicts that younger children may not be able to successfully complete certain cognitive tasks that older children could, due to slower transfer of information between the two half-brains. In this regard, two additional studies are of interest, since they appear to address cognitive functions more than sensorimotor functions.

Kraft, Mitchell, Languis, and Wheatley (1980) examined hemispheric EEG alpha asymmetries on Piagetian conservation (e.g., identity of water volume in two different-shaped containers) and reading tasks. They found greater right hemispheric processing during encoding of information (e.g., watching the physical transformation) and greater left hemispheric processing during retrieval and verbal or logical expression (e.g., explanation - why do you think so?) of the information, which suggests according to the investigators, interhemispheric processing within the tasks. These results were not obtained in nonconservers or in children who failed to answer subsequent questions correctly, suggesting that efficient interhemispheric communication is necessary for success on Piagetian conservation tasks.

Rawn Joseph (1982) has very briefly described an as yet unpublished study in which interhemispheric communication is so poor when pictorial stimuli are presented tachistoscopically to the right hemisphere, that young children of four years of age will respond when questioned with large information gaps, which they erroneously fill with confabulatory responding. Maxwell (1981) has reported a somewhat similar finding. Note also that this is a common finding in brain-bisected patients (Gazzaniga, & LeDoux, 1978). Joseph (1982) hence infers that the left hemisphere of a young child has at least incomplete knowledge of the contents and activity in the right. He argues that the development of commissural transmission as a result of myelination, allows the left hemisphere access to right hemisphere impulses-to-action before the action occurs rather than forcing it to make sense of the behaviour after its completion. Moreover, Joseph (1982) has suggested that the development of thought is in part determined by the development of interhemispheric communication, thereby allowing the left hemisphere to then actively engage in the formulation of behaviour through rapid ongoing communication with the right hemisphere.

The latter two studies are particularly fascinating in their implications for the emergence of thought, control of action, and cognition in the developing child. The findings of the latter two studies are also consistent with the results of the present study.

Furthermore, the findings of the present study are consistent with the model of hemispheric specialization proposed by Bradshaw and Nettleton (1981). They described a continuum of function between the hemispheres, the difference being quantitative and by degree, in which functioning of the left hemisphere is said to primarily involve duration, temporal order, and sequencing; the actual status of the role of temporal factors in interhemispheric processing remains unclear. McKeever and Huling (1971, a, b) examined word recognition performance in adults using bilateral simultaneous tachistoscopic presentations, in which they found that delaying presentation in either visual field did not alter right half-field recognition superiority. However, as McKeever (1981) points out the search for basic hemisphericity is reminiscent of the search for the fundamental faculty of intelligence; is it digital memory, narrative memory, attention, abstraction, fluency, judgment, etc? He concludes that it is none of these yet all of these, it is a coordinated "global capacity", as Wechsler concluded. He states then that cerebral specialization is not likely to be less complex or more "captured" by labelling one of its attributes, for example, temporal processing.

While lateralization of function was not a focus of major interst in the present study, its discussion does have some relevance to the results obtained. The concept of cerebral lateralization is a difficult concept to define or measure (Colburn, 1978). Performance on any task may depend upon the processing capability of each hemisphere, and may be altered depending upon whether the motor processing in each hemisphere changes, whether the nature and efficiency of transcallosal transfer of information changes (Birkett, 1977), or whether these and other various processes interact (Bryden & Spratt, 1981; Eling, 1981; Levy, 1983; Marshall, Caplan, & Nolmes, 1975; Richardson, 1976; Stone, 1980). Despite the confusion, however, numerous attempts have been made to assess laterality in early development and attempts have been made to relate laterality findings to interhemispheric development (Denenberg, 1981; Orton, 1937). A sizeable amount of research (Gardiner & Walter, 1977; Ingram, 1975a, 1975b; Molfese, Freeman, & Palermo, 1975; Wada, Clark, & Hamm, 1975; Witelson, 1977; Witelson & Pallie, 1973) shows that lateral asymmetries of functions and hemispheric specializations are already present in infancy or at least by 5-years-of-age. Kinsbourne and Hiscock (1977) provide evidence that lateralization remains constant at least from the age of three. Hiscock and Kinsbourne (1980) have provided evidence to support a developmental invariance hypothesis at least of language lateralization. The question is whether the maturation of the corpus callosum has any causal relation to the development of lateralization.

Several lines of evidence favour normal lateralization rather than bilateral duplication of abilities in most acallosal patients, despite an absence of the corpus callosum throughout their development (Milner & Jeeves, 1981). On the basis of these findings, however, it should not be concluded that maturation of the corpus callosum has no role to play in the development of skilled functioning throughout childhood. Indeed, evidence from acallosal patients suggests that while the corpus callosum may not be needed to determine the degree of lateralization of a function, it may be needed for the adequate or optimal development of many "lateralized" functions. In fact, one of the possible roles of developing interhemispheric communication may be to prevent the behavioural expression of hemispheric functional specialization due to increased efficiency of interhemispheric communication. A possible reason for decreasing or unchanging lateral asymmetries during development is that speed of interhemispheric communication may increase giving each body side greater access to ipsilateral hemispheric functioning.

While the present study provides evidence for a developmental increase in interhemispheric communication, it does not directly address Kinsbourne's (1973, 1975) "attentional hypothesis", in which the corpus callosum is given the role of allowing a rapid redisposition of attention between the two cerebral hemispheres. Results from some studies (Ellenberg, & Sperry, 1979, 1980) have suggested that the cerebral commissures maintain attentional unity in the intact brain, while other studies have indicated that considerable caution should be exercised in proposing the attentional bias view point as an explanation for lateral asymmetries (Berlucchi, Brizzolara, Marzi, Rizzolatti, & Umilta, 1974; Boles, 1979). Finally, controvery exists over the possible existence and role for inhibitory commissural functions (Denenberg, 1981; Selnes, 1974; Berlucchi, 1983), but such functions would be difficult to understand from behavioural evidence presented in the current study.

Controversy also exists regarding the existence of sex differences in the morphology and functioning of the adult and child brain (Buffery, & Gray, 1977; Ray, Morell, & Frediani, 1976; Rizzolatti, & Buchtel, 1977; Knox, & Kimura, 1970; Jones, & Anuza, 1982; Wolff, & Hurwitz, 1976). On the basis of these findings a decision was made to examine only boys in the present study even though girls have been included in a number of studies which investigated interhemispheric communication in children. However, following the data collection of the present study, evidence of sexual dimosphism in the human corpus callosum became available (De Lacoste-Utamsing, 1982). Preliminary observations suggest a sex difference in the shape and surface area of the splenium, the caudal or posterior portion of the corpus callosum. The female splenium is both more bulbous and larger than the male counterpart. The author concludes that since peristriate, parietal and superior temporal fibres course through the splenium, this finding could be related to possible gender differences in the degree of lateralization for visual spatial functions.

Applications and Recommendations

In the present study, no children demonstrated any remarkable differences of abilities between tasks, althought one 5-year-old and one 7-year old child demonstrated faster contralateral and ipsilateral RTs than their peers, performing overall more like 9- and 11-year-olds. These two children also appear to be quite bright. Moreover, it often seemed that the brightest children in the study, were the children who provided the most consistent performance in their respective age groups. Specific results reported for the acallosal subject in this study suggested that at least the tactual simple RT task was consistently sensitive to individual differences in cerebral functioning. This is encouraging from the point of view that the task may be sensitive to differential development of function and structure. As demonstrated by the present investigation, however, comprehensive assessment involving performance measures from both modalities on both simple and complex RT tasks would provide the most thorough information. In the interest of reliability and practicality, the simple tactual RT task may be the best choice; although all of the tasks can be easily administered repeatedly, and are amenable to assessment of small changes or degrees of improvement.

There was no opportunity in the present study to examine the effects of interhemispheric development on standard measures of cognitive ability, such as the Wechsler scales. However, it is unclear what predictions one might have made. For example, Zaidel, Zaidel, and Sperry (1981) examined responses to the Raven's Progressive Matrices following brain bisection and hemidecortication. They found only slight hemispheric advantages, and concluded that the data best supported a primary ability model of intelligence with localized and neurologically dissociable cerebral organization. An interesting finding of Campbell, Bogen, and Smith (1981) was that in addition to other roles, the forebrain commissures can also serve as "standby" or "reserve" structures on cognitive tasks. The case is reported of a patient in whom the middle sagittal third of the corpus callosum had been excised because of an underlying anginoma. The patient suffered cognitive improverishment, including the inavailability of complex ideas and the absence of emotional communication (Dimond, et al., 1977). Cognitive functioning was also extensively evaluated in a recent callosum-sectioned patient; standardized tests as well as a sophisticated hypothesis testing task were administered both pre- and post-operatively. No post-operative deficits were obtained. Conversely, this patient demonstrated marked improvement in almost every measure utilized. The investigators concluded that cognitive processing of complex information is not necessarily dependent upon the integrity of the corpus callosum, but rather that cognitive processing is largely an intrahemispheric process.

While it is unclear what role interhemispheric function plays in intelligent behavior, it is now clearly established according to Jensen (1980) that RT, particularly choice RT, has some significant relationship with "psychometric g". Jensen has found among college students that the intra-individual standard deviation in RT over trials is more highly correlated with standard measures of cognitive function than any other single variable derived from the RT paradigm. The implications of his findings are that trial-to-trial variation in RT increases either as the efficiency of neural processing decreases or as the complexity of the task becomes greater. T. S. Carlson and C. M. Jensen (1982) replicated and extended Jensen's work on a sample of 20 ninth-grade girls. Relationships between RT and motor time and Raven's Progressive Matrices scores were found to be negative and moderate to high, thus replicating Jensen's findings. It would be a great interest to examine a normal child population similar to the subjects used in the present study with the choice RT apparatus designed by Jensen (Jensen, 1980, p. 680). In particular, it might be worthwhile to conduct the study using the scleral contact lense apparatus constructed by Zaidel (1975) which permits continuously lateralized visual presentation with free ocular scanning of the stimuli. It would be of considerable interest to present the Wechsler and Raven's tests, and possibly other cognitive tasks in this same continuously lateralizaed fashion to these subejcts. Stuss, Bensen, Kaplan, Weir, Naesser, Lieberman, and Ferrill (1983) however, have pointed out in their research with orbito-frontal patients how subjective evaluation and/or standard IQ tests may fail to identify important cognitive limitations. With the use of the appropriate tests such a study may provide some insight regarding the roles of the cerebral commissures in normal development of cognitive functioning.

In this regard, Goldman-Rakic and Schwartz (1982) has recently shown that in the prefrontal association cortex of macaque monkeys, associational projections from the parietal lobe of one hemisphere interdigitate with callosal projections from the opposite frontal lobe, forming adjacent columns (Schwartz, & Goldman-Rakic, 1982). The implications are exciting in terms of future research in regard to a child planning and organizaing his own behavior. For example, tasks could be designed in which information for problem solving could be presented to either hemisphere for a certain period of time. One could determine whether faster or more accurate problem solving and behavioural planning was achieved when problem presentation and solution was experimentally imposed upon only one hemisphere, versus when an attempt was made to employ both hemispheres, across chronological ages in children. Indeed, in this sense gifted children may respond more like older children in regard to speed of interhemisphere transfer.

Even if any of the present tasks could identify commissural maturational lags in any clinical population, the results of the present study do not immediately suggest any particular remedial procedure. There are, however, several clinical populations that could address themselves to RT tasks similar to the ones used in the present study.

First, some of the procedures used in this study may be applicable to the identification of interhemisphere deficits following head injury (Geschwind, 1970, 1975; Rubens, Geschwind, Malowald, & Mastri, 1977).

Second, several investigators have attempted to demonstrate that interhemispheric dysfunction is present in psychiatric disorders, including schizophrenia (Flor-Henry, 1976; Green, 1978). For example, Jones and Miller (1981) examined interhemisphere conduction time in 12 schizophrenics using somatosensory EPs which they found to be "effectively zero".

Third, verbal tasks are typically assumed to be processed by the left cerebral hemisphere, but the right heisphere may have some role both in language and in learning. In this regard, evidence comes from work with commissurotomized patients suggesting the importance of the right hemisphere for reading (Bradshaw, Nettleton, & Spehr, 1982; Gordon, 1980; Landis, Regard, & Serrat, 1980; Sugishita, Toyokura, Yoshioka, & Ymada, 1980; Zaidel, & Peters, 1981). Further, Ornstein, Herron, Johnstone, and Swencionis (1979) recorded EEG alpha from homologous central and parietal scalp locations in intact adults. Reading stories engaged the central area of the right hemisphere more than reading technical material, with no significant difference in reading speed. These investigators concluded that some aspects of reading differentially involved the right hemisphere. Commissural development has been implicated in the lateralization of language skills (Badian, & Wolff, 1977, Hatta, Yamamoto, Kawabata, & Tsuti, 1982; Ingram, 1975a, 1975b; Knox, & Kimura, 1970; Molfesse, et al., 1975; Satz, Bakker, Teunissen, Goebel, & Van Der Vlught, 1975) and in learning disabilities (Badian, & Wolff, 1976; Beaumont, 1976; Rourke, 1982; Sechgzer, Folstein, & Geiger, 1977; Vellutino, Bentley, & Phillips, 1978; Witelson, 1975, 1977). The behavioral tests described in the present study may be useful in isolating interhemispheric lags in learning disabled children. Knights and Studdert (1981) have pointed out, however, that neurodiagnostic evidence is commonly less clear-cut for the minimally brain damaged and the learning -disabled child, than for the normal or clearly brain damaged child.

No attempt was made in the present study to assess interhemispheric development in regard to auditory stimulation, because of the inherent difficulty in lateralizing the auditory stimuli to only one hemisphere. The importance of the corpus callosum in the normal functioning of the auditory cortex is well documented, however (Sparks, & Geschwind, 1968; Gordon, 1975; Simon, 1968; Zaidel, 1976).

Finally, a reasonable extention of the present thesis would be to combined the use of EPs and the behavioral tasks of the present study to explore developmental changes in interhemispheric communication. This seems especially true in regard to complex RT tasks, since in this case behavioral performance measures alone fail to adequately elucidate integration of information at the cortical level. Bashore (1981) has pointed out how such a procedure might allow a demonstration of dissociation between RT and components of the EPs. In this regard, Courchesne (1978) completed some recent work. It would be valuable to replicate this study while attempting to lateralize stimulation and responses, in order to assess the contributions of interhemispheric communication during normal development.

Summary and Conclusions

The present study represents an initial behavioural investigation of the development of speed of interhemispheric communication in the child. Behavioural RT paradigms were used which examined manual response latencies in either the tactual or visual modality. Motor responses which were initiated by the directly stimulated hemisphere were subtracted from those made by the indirectly stimulated hemisphere to arrive at estimates of interhemispheric transmission time. It was assumed that the subtraction method would provide accurate and independent measures of interhemispheric transmission time for either the simple or complex choice RT paradigms.

The salient findings are described as follows. All of the children in the present study were able to respond to crossed and uncrossed stimuli alike, suggesting that interhemispheric communication is present at least as early as the age of 5-years. RTs to both crossed and uncrossed tactual and visual stimuli decreased with increasing age, between the fifth and eleventh birthdays; these results were obtained in both the simple and complex choice RT paradigms, including the two control tasks. On both the simple and complex choice experimental RT tasks, the younger children exhibited a significantly greater response delay to crossed sensory stimulation than the older children. On the simple tactual RT task, response latencies to crossed stimulation decreased greatly between the ages of 7- and 9-years, whereas on the simple and complex choice visual RT tasks response latencies appeared to decrease earlier, between the ages of 5 and 7, and again between the ages of 7- and 9-years. For all of these RT tasks decreases in response latencies to crossed stimulation relative to uncrossed stimulation were most evident at the ages indicated, but may have been changing gradually between the fifth and eleventh year. These uneven developmental changes in transcallosal transmission rates suggest that maturational factors in addition to the myelogenic timetable may need to be taken into consideration.

Apparent differences in the rates of change of interhemispheric transmission times, depending upon both the nature of the RT tasks and the nature of the stimuli, suggest that different subsystems of the cerebral commissures may mature at different rates. However, while changes in speed of interhemispheric transmission occurred across the ages examined, it was not possible to determine whether the information transferred was purely sensory in nature or a motor command. Nor was it possible to determine the degree to which information was processed prior to transfer. Nonetheless, the basic assumption that measures of crossed-minus-uncrossed response latencies would provide both valid and distinct estimates of interhemispheric transmission times for a complex choice RT paradigm as well as for a simple RT paradigm appears to be supported within the context of the present study.

The findings of this study are consistent with the hypothesis of the cerebral commissures playing an integral role in the development of skilled human functioning through childhood, in terms of increasing speed of interhemispheric communication with increasing age. The results of the study suggest a model which helps explain how the two hemispheres become one structural and functional unit, in terms of transcallosal transmission rates. Slow interhemispheric transmission early in development may underlie apparent inefficient interhemispheric information transfer in the same time period. The present study provides a heuristic model for further investigation and elucidation of interhemispheric communication in children. Moreover, the pattern of results obtained for the acallosal patient suggest that the tactual, simple RT task, in comparison to the visual, simple and complex choice RT tasks has the greatest face validity and may be usefully applied in a clinical setting.

References

Amadeo, M., Roemer, R. A., & Shagass, C. Can callosal speed of transmission be inferred from verbal reaction times? Biological Psychiatry, 1977, 12 (2), 289-297.

Andreassi, J. L., Okamura, H., & Stern, M. Hemispheric asymmetries in the visual cortical evoked potential as a function of stimulus location. Psychophysiology, 1975, 12 (5), 541-546.

Antonini, A., Berlucchi, G., Marzi, C. A., & Sprague, J. M. Importance of corpus callosum for visual receptive fields of single neurons in cat superior colliculus. Journal of Neurophysiology, 1979, 42, 137-152.

Anzola, G. P., Bertoloni, G., Buchtel, H. A., & Rizzolatti, G. Spatial compatibility and anatomical factors in simple and choice reaction time. Neuropsychologia, 1977, 15, 295-302.

Asanuma, H. Functional role of sensory inputs to the motor cortex. Progress in Neurobiology, 1981, 16, 241-262.

Azulay, A., & Schwartz, A. S. The role of the dorsal cuniculus of the primate in tactile discrimination. Experimental Neurology, 1975, 46, 315-332.

Badian, N. A., & Wolff, P. H. Manual asymmetries of motor sequencing in boys with reading disability. Cortex, 1977, 13, 343-349.

Bashore, T. R. Vocal and manual reaction time estimates of interhemispheric transmission time. Psychological Bulletin, 1981, 87 (2), 352-368.

Beaumont, J. G. The cerebral laterality of "Minimal Brain Damage" children. Cortex, 1976, 12, 373-383.

Benton, A. L., & Joynt, R. J. Reaction time in unilateral disease. Confin. Neurologia, 1958, 19, 247-256.

Berlucchi, G. Anatomical and physiological aspects of visual functions of the corpus callosum. Brain Research, 1972, 37, 371-392.

Berlucchi, G. Recent advances in the analysis of the neural substrates of interhemispheric communication. In Brain Mechanisms of Perceptual Awareness and Purposeful Behaviour, O. Pompeiam and C. Marsan (Eds.). New York: Raven Press, 1981.

Berlucchi, G. Two hemispheres but one brain. The Behavioural and Brain Sciences, 1983, 1, 171-172.

Berlucchi, G., Brizzolara, D., Marzi, C. A., Rizzolatti, G., & Umilta, C. Can lateral asymmetries in attention explain interfield differences in visual perception. Cortex, 1974, 10, 177-185.

Berlucchi, G., Crea, F., Di Stefano, M., & Tassinari, G. Influence of spatial stimulus-response compatibility on reaction time of ipsilateral and contralateral hand to lateralized light stimuli. Journal of Experimental Psychology: Human Perception and Performance, 1977, 4, 505-517.

Berlucchi, G., Gazzaniga, M. S., & Rizzolatti, G. Microelectrode analysis of transfer of visual information by the corpus callosum. Archives Italiennes de Biologie, 1967, 105, 583-596.

Berlucchi, G., Heron, W., Hyman, R., Rizzolatti, G., & Umilta, C. Simple reaction times of ipsilateral and contralateral hand to lateralized visual stimuli. Brain, 1971, 94, 419-430.

Berman, A. P., & Berman, D. Fetal deafferentation: The ontogenesis of movement in the absence of peripheral sensory feedback. Experimental Neurology, 1973, 38, 170-176.

Bianki, V. J. Interaction between transcallosal and thalamocortical excitation. Neurosciences and Behavioural Physiology, 1981, 11 (4), 328-335.

Birkett, P. Measures of laterality and theories of hemispheric processes. Neuropsychologia, 1977, 15, 693-696.

Bisiach, E., Mini, M., Sterzi, R., & Vallar, G. Hemispheric lateralization of the decisional stage in choice reaction times to visual unstructured stimuli. Cortex, 1982, 18, 191-198.

Blackburn, H. Effects of motivating instructions on reaction in cerebral disease. Journal of Abnormal Psychology, 1958, 56, 359-366.

Blinkov, S. M., & Glezer, I. I. The Human Brain in Figures and Tables: A Quantitative Handbook. New York: Plenum Press, 1968.

Boles, D. B. Laterally biased attention with concurrent verbal load: multiple failures to replicate. Neuropsychologia, 1979, 17, 353-361.

Boll, T. J. Effect of age at onset of brain damage on adaptive abilities in children. Proceedings, 81st Annual Convention, APA, 1973, 509-510.

Boll, T. J., & Reitan, R. M. Motor and tactile-perceptual deficits in brain-damaged children. Perceptual and Motor Skills, 1972, 34, 343-350.

Bowers, D., Heilman, K. M., & Van Den Abell, T. Hemispace-VHF compatibility. Neuropsychologia, 1981, 19 (6), 757-765.

Bowsher, D. Characteristics of central nonspecific somatosensory systems. In the Somatosensory System. H. H. Kornhuber (Ed.). Stuttgart: Georz Theime, 1975.

Bradshaw, J. L., & Nettleton, N. C. The nature of hemispheric specialization in man. The Behavioural and Brain Sciences, 1981, 4, 51-91.

Bradshaw, J. L., Nettleton, N. C., & Spehr, K. Braille reading and left and right hemispace. Neuropsychologia, 1982, 20 (4), 493-500.

Bradshaw, J. L., & Perriment, A. D. Laterality effects and choice reaction time in a unimanual two-finger task. Perception and Psychophysics, 1970, 7 (3), 185-188.

Brebner, J., Shephard, M., & Cairney, P. Spatial relationship and S-R compatibility. Acta Psychologica, 1972, 36, 1-15.

Bremer, F. Physiology of the corpus callosum. Research Publications of the Association for Research of Nervous and Mental Diseases, 1958, 36, 424-448.

Brinkman, J., & Kuypers, H. G. J. M. Cerebral control of contralateral and ipsilateral arm, hand and finger movement in the split-brain rhesus monkey. Brain, 1973, 96, 653-674.

Broadbent, D. E. Division of function and integration of behaviour. In The Neurosciences Third Study Program, The MIT Press, Cambridge, Mass., F. OO. Schmitt & F. G. Warden (Eds.), 1974.

Broman, M. Reaction-time differences between the left and right hemispheres for face and letter discrimination in children and adults. Cortex, 1978, 14, 578-591.

Brooks, V. B. Task-related cell assemblies. In Brain Mechanisms of Perceptual Awareness and Purposeful Behaviour. O. Pompeiano & C. Marsan, (Eds.), New York: Raven Press, 1981.

Brown, J. W., & Jaffe, J. Hypothesis on cerebral dominance. Neuropsychologia, 1975, 13, 107-110.

Bruhn, P., & Parsons, O. A. Continuous reaction time in brain damage. Cortex, 1971, 7 (1), 278-291.

Bryden, M. P., & Spratt, D. A. Statistical determination of degree of laterality. Neuropsychologia, 1981, 19 (4), 571-581.

Buffery, A. W. H., & Gray, J. A. Sex differences in the development of spatial and linguistic skills. In Gender Differences: Their ontogeny and significance. C. Ounsted & D. C. Taylor (Eds.). Churchill Livinston, London, 1972.

Busk, J., & Galbraith, G. E. EEG correlates of visual-motor practice in man. Electroencephalography and Clinical Neurophysiology, 1975, 38, 415-422.

Campbell, A. L., Bogen, J. E., & Smith, A. Disorganization and reorganization of cognitive and sensori motor functions in cerebral commissurotomy: Compensatory roles of the forebrain commissures and cerebral hemispheres in man. Brain, 1981, 104, 493-511.

Carlson, J. S., & Jenson, C. M. Reaction time, movement time, and intelligence: A replication and extension. Intelligence, 1982, 6, 265-274.

Carmon, A. Temporal processing and the left hemisphere. The Behavioural and Brain Sciences, 1981, 4, 66-67.

Carmon, A., Nachshon, I., & Starinsky, R. Developmental aspects of visual hemifield differences in perception of verbal material. Brain and Language, 1976, 3, 463-469.

Carpenter, M. B. Human Neuroanatomy. Baltimore: Williams and Wilkins, 1976.

Chiarello, C. A house divided? Cognitive functioning with callosal agenesis. Brain and Language, 1980, 11, 128-158.

Clemo, H. R., & Stein, B. E. Somatosensory cortex: A "new" somatotopic representation. Brain Research, 1982, 235, 162-168.

Cohen, L. Interaction between links during bimanual voluntary activity. Brain, 1970, 93, 259-272.

Colbourn, C. J. Can laterality be measures? Neuropsychologia, 1978, 16, 283-289.

Connolly, K. Skill development: problems and plans. In Mechanisms of Motor Skill and Development. K. Connolly (Ed.), London: Academic Press, 1970.

Courchesne, E. Neurophysiological correlates of cognitive development: changes in long-latency event-related potentials from childhood to adulthoood. Electroencephalography and Clinical Neurophysiology,

Creurtzfeldt, O. Diversification and synthesis of sensory systems across the cortical link. In Brain Mechanisms of Perceptual Awareness and Purposeful Behaviour. O. Pompeiano & C. A. Marson (Eds.), New York: Raven Press, 1981.

Cumming, W. J. K. An anatomical review of the corpus callosum. Cortex, 1970, 6, 1-19.

Czudner, G., & Rourke, B. P. Simple reaction time in brain-damaged and normal children under regular and irregular preparatory interval conditions. Perceptual and Motor Skills, 1970, 31, 767-773.

Czudner, G., & Rourke, B. P. Age differences in visual reaction time of "brain-damaged" and normal children under regular and irregular conditions. Journal of Experimental Child Psychology, 1972, 13, 516-526.

Damasio, A. R., Chui, H. C., Corbett, J., & Kassel, N. Posterior callosal section in a non-epileptic patient. Journal of Neurology, Neurosurgery, and Psychiatry, 1980, 43, 351-356.

Davidoff, J. B. Hemispheric differences in the perception of lightness. Neuropsychologia, 1975, 13, 121-124.

Davidoff, J. B. Hemispheric differences in dot detection. Cortex, 1977, 13, 434-444.

Davis, A. L., & Wada, J. A. Hemispheric asymmetries of visual and auditory processing. Neuropsychologia, 1977, 15, 799-806.

De Lacoste-Utarnsing, C., & Holloway, R. L. Sexual dimorphism in the human corpus callosum. _Science_, 1982, _216_, 1431-1432.

Denckla, M. B. Development of speed in repetitive and successive finger-movements in normal children. _Developmental Medicine and Child Neurology_, 1973, _15_, 635-645.

Denckla, M. B. Development of motor coordination in normal children. _Developmental Medicine and Child Neurology_, 1974, _16_, 729-741.

Denenberg, V. H. Hemispheric laterality in animals and the effects of early experience. _The Behavioural and Brian Sciences_, 1981, _4_, 1-49.

Dennis, M. Impaired sensory and motor differentation with corpus callosum agenesis: A lack of callosal inhibition during ontogeny? _Neuropsychologia_, 1976, _14_, 455-469.

De Renzi, E., & Faglioni, P. The comparative efficiency of intelligence and vigilence tests in detecting hemispheric cerebral damage. _Cortex_, 1965, _1_, 410-433.

Dimond, S. _The Double Brain_. London: Churchill Livingston, 1972.

Dimond, S. J. Performance by split-brain humans on lateralized vigilance tasks. _Cortex_, 1979, _15_, 43-50.

Dimond, S. J. The brain is not a simple seesaw. _The Behavioral and Brain Sciences_, 1983, _1_, 172-173.

Dimond, S., & Beaumont, G. Processing in perceptual integration between and within the cerebral hemispheres. _British Journal of Psychology_, 1972, _63_ (4), 509-514.

Dimond, S. J., & Beaumont, J. G. Experimental studies of hemispheric function in the human brain. In Hemisphere Function in the Human Brain, S. J. Dimond, & J. G. Beaumont (Eds.). London: Elek Science, 1974.

Dimond, S. J., Scammell, R. E., Brouvers, E. Y. M., & Weeks, R. Function of the centre section (trunk) of the corpus callosum in man. Brain, 1977, 100, 543-562.

Di Stefano, M., Morelli, M., Marzi, C. A., & Berlucchi, G. Hemispheric control of unilateral and bilateral movements of proximal and distal parts of the arm as inferred from simple reaction time to lateralized light stimuli in man. Experimental Brain Research, 1980, 38, 197-204.

Dodds, A. G. Hemispheric differences in tactual-spatial processing. Neuropsychologia, 1978, 16, 247-254.

Ebner, F. F., & Myers, R. E. Distribution of corpus callosum and anterior commissure in cat and racoon. Journal of Comparative Neurology, 1965, 124, 353-366.

Edwards, S. B. The commissural projection of the superior colliculus in the cat. Journal of Comparative Neurology, 1977, 173, 23-40.

Efron, R. The effect of handedness on the perception of simultaneity and temporal order. Brain, 1963 a, 86, 261-284.

Efron, R. The effect of stimulus intensity on the perception of simultaneity in right- and left-handed subjects. Brain, 1963 b, 86, 285-294.

Elberger, A. J. The role of the corpus callosum in the development of inter-ocular eye alignment and the organization of the visual field in the cat. Experimental Brain Research, 1979, 36, 71-85.

Elberger, A. J. The functional role of the corpus callosum in the developing visual system: A review. Progress in Neurobiology, 1982, 18, 15-79.

Elberger, A. J., Smith, E. L., & White, J. M. Spatial dissociation of visual inputs alters the origin of the corpus callosum. Neuroscience Letters, 1983, 35, 17-24.

Eling, P. On the theory and measurement of laterality. Neuropsychologia, 1981, 19 (2), 321-324.

Elliot, R. Simple reaction time in children: Effects of incentive, incentive-shift and other training variables. Journal of Experimental Child Psychology, 1972, 13, 540-557.

Elliot, J., & Connolly, K. Hierarchical structure in skill development. In The Growth of Competence. K. Connolly & J. Bruner (Eds.), New York: Academic Press, 1974.

Ellenberg, L., & Sperry, R. W. Capacity for holding sustained attention following commissurotomy. Cortex, 1979, 5, 421-428.

Ellenberg, L., & Sperry, K. W. Lateralized diversion of attention in the commissurolomized and intact brain. Neuropsychologia, 1980, 18, 411-418.

G

Ernhart, C. B., Graham, F. K., Eichman, P. L., Marshall, J. M., & Thurstone, D. Brain injury in the preschool child: some developmental considerations. II. Comparison of brain-injured and normal children. Psychological Monographs: General and Applied, 1963, 77 (10), 17-33 (whole number 573).

Ettlinger, G., Blakemore, C. B., Milner, A. D., & Wilson, J. Agenesis of the corpus callosum: A behavioural investigation. Brain, 1972, 95, 327-346.

Eyzaguirre, C., & Fidone, S. J. Physiology of the Nervous System. Year Book, Chicago: Medical Publishers, 1975.

Ferriss, G. S., & Dorsen, M. M. Agenesis of the corpus callosum 1. Neuropsychological studies. Cortex, 1975, 11, 95-122.

Field, M., Ashton, R., & White, K. Agenesis of the corpus callosum: Report of two pre-school children and review of the literature. Developmental Medicine and Child Neurology, 1978, 20, 47-61.

Filbey, R. A., & Gazzaniga, M. S. Splitting the normal brain with reaction time. Psychonomic Science, 1969, 17 (6), 335-336.

Finlayson, M. A. J. A behavioural manifestation of the development of interhemispheric transfer of learning in children. Cortex, 1976, 12, 290-295.

Finlayson, M. A. J., & Reitan, R. M. Tactile-perceptual functioning in relation to intellectual, cognitive and reading skills in younger and older normal children. Developmental Medicine and Child Neurology, 1976, 18, 442-446.

Fitzhugh, L. C., Fitzhugh, K. B., & Reitan, R. M. Sensosimotor deficits of main damaged SS in relation to intellectual level. Perceptual and Motor Skills, 1962, 15, 603-608.

Flanery, R. C., & Balling, J. D. Developmental changes in hemispheric specialization for tactile spatial ability. Developmental Psychology, 1979, 15 (4), 364-372.

Franco, L. Hemispheric interaction in the processing of concurrent tasks in commissurotomy subjects. Neuropsychologia, 1977, 15, 707-710.

Fried, I., Mateer, C., Ojemann, G., Wohns, R., & Fedio, P. Organization of visuospatial functions in human cortex. Brain, 1982, 105, 349-371.

Fletcher, J. M., & Satz, P. Developmental changes in the performance correlates of reading achievement: A six year longitudinal followup. In press, 1980.

Flor-Henry, P. Lateralized temporal limbic dysfunction and psychopathology. Annals of New York Academy of Science, 1976, 280, 777-795.

Gabriel, R. S. Malformations of the central nervous system. In Textbook of Child Neurology. J. H. Menkes (Ed.). Philadelphia: Lea and Febiger, 1980.

Galin, D., Johnstone, J., Nakell, L., & Herron, J. Development of the capacity for tactile information transfer between hemispheres in normal children. Science, 1979, 204, 1330-1332.

Galin, D., Diamond, R., & Herron, J. Development of crossed and uncrossed tactile localization on the fingers. Brain and Language, 1977, 4, 588-590.

Gardiner, M. F., & Walter, D. O. Evidence of hemispheric specialization from infant EEG. In lateralization in the Nervous System. S. Harnad & R. W. Doty (Eds.), New York: Academic Press, 1976.

Gardner, E. B., & Ward, A. W. Spatial compatibility in tactile-visual discrimination. Neuropsychologia, 1979, 17, 421-425.

Gazzaniga, M. S. Psychological properties of the disconnected hemispheres in man. Science, 1965, 150, 372.

Gazzaniga, M. S. Interhemispheric communication of visual learning. Neuropsychologia, 1966, 4, 183-189.

Gazzaniga, M. S. The split brain in man. Scientific American, 1967, 217, 24-29.

Gazzaniga, M. S. Cross cuing mechanisms and ipsilateral eye-hand control in split brain monkeys. Experimental Neurology, 1969, 23, 11-17.

Gazzaniga, M. S. The Bisected Brain. New York: Appleton-Century-Crofts, 1970.

Gazzaniga, M. S. Cerebral dominance viewed as a decision system. In Hemisphere Function in the Human Brain, S. J. Dimond and J. G. Beaumont (Eds.), London: Elek Science, 1974.

Gazzaniga, M. S. Issues in Cognitive Neuroscience. Paper presented at Ottawa General Hospital, January 1981a.

Gazzaniga, M. S. Personnel Communication. January, 1981b.

Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. Laterality effects on somesthesis following commissurotomy in man. Neuropsychologia, 1963, 1, 209-215.

Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. Observations on visual perception after disconnection of the cerebral hemispheres in man. Brain, 1965, 88, 221-236.

Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. Dyspraxia following division of the cerebral commissures in man. Archives of Neurology, 1967, 16, 606-612.

Gazzaniga, M. S., & Le Doux, J. E. The Integrated Mind. New York: Plenum Press, 1978.

Gazzaniga, M. S., Risse, G. L., Springer, S. P., Clark, E., & Wilson, D. N. Psychological and neurologic consequences of partial and complete cerebral commissurotomy. Neurology, 1975, 25, 10-15.

Gazzaniga, M. S., & Sperry, R. W. Language after section of the cerebral commissures. Brain, 1967, 90, 131-148.

Geffen, G., Bradshaw, J. L., & Wallace, J. Interhemispheric effects on reaction time to verbal and nonverbal visual stimuli. Journal of Experimental Psychology, 1971, 87 (3), 415-422.

Geschwind, N. Disconnexion syndrome in animals and man. Brain, 1965, 88, 585-644.

Geschwind, N. The organization of language and the brain. Science, 1970, 170, 940-944.

Geschwind, N. Language and cerebral dominance. In The Nervous System, D. B. Tower (Ed.), vol. 2, New York: Raven Press, 1975.

Geschwind, N., & Levitsky, W. Human brain: Left-right asymmetrics temporal speech region. Science, 1968, 161, 186-187.

Ghent, L. Developmental changes in tactual thresholds on dominant and nondominant sides. Journal of Comparative and Physiological Psychology, 1961, 54 (6), 670-673.

Gibson, A. R., Filbey, R., & Gazzaniga, M. S. Hemispheric differences as reflected by reaction time. Federation of American Societies for Experimental Biology Proceedings, 1970, 29, 658.

Glencross, D. J. Control of skilled movements. Psychological Bulletin, 1977, 84 (1), 14-22.

Glencross, D. J., & Oldfield, S. R. The use of ischemic nerve block procedures in the investigation of the sensory control of movements. Biological Psychology, 1975, 2, 165-174.

Glickstein, M. Brain mechanisms in reaction time. Brain Research, 1972, 40, 33-37.

Goldman-Rakic, P. S., & Schwartz, M. L. Interdigitation of contralateral and ipsilateral columnar projections to frontal association cortex in primates. Science, 1982, 216, 755-757.

Goldstein, M. N., Joynt, R. J., & Hartley, R. B. The long-term effects of callosal sectioning. Archives of Neurology, 1975, 32, 52-53.

Gordon, H. W. Comparison of ipsilateral and contralateral auditory pathways in callosum-sectioned patients by use of a response-time technique. Neuropsychologia, 1975, 13, 9-18.

Gordon, H. W. Right hemisphere comprehension of verbs in patients with complete forebrain commissurotomy: Use of the dichotic method and manual performance. Brain and Language, 1980, 11, 76-86.

Grafstein, B. Organization of callosal connections in suprasylvian gyrus of the cat. Journal of Neurophysiology, 1959, 22, 504-575.

Grafstein, B. Postnatal development of the transcallosal evoked response in the cerebral cortex of the cat. Journal of Neurophysiology, 1963, 26, 79-99.

Graham, F. K., Ernhart, C. B., Craft, M., & Berman, P. W. Brain injury in the preschool child: Some developmental considerations. Psychological Monographs: General and Applied, 1963, 77 (10), 1-33.

Green, P. Defective interhemispheric transfer in schizophrenia. Journal of Abnormal Psychology, 1978, 87, 472-480.

Gross, C. G., Bender, D. B., & Mishkin, M. Contribution of the corpus callosum and the anterior commissure to visual activation of inferior temporal neurons. Brain Research, 1977, 131, 227-239.

Haaxma, R., & Kuypers, H. G. J. M. Intrahemispheric cortical connexions and visual guidance of hand and finger movements in the rhesus monkey. Brain, 1975, 98, 239-260.

Halsband, U., & Passingham, R. The role of premotor and parietal cortex in the direction of action. Brain Research, 1982, 240, 368-372.

Hamsher, K., & Benton, A. L. The reliability of reaction of time determinations. Cortex, 1977, 13, 306-310.

Harnad, S., & Doty, R. W. Introductory overview. In Lateralization in the Nervous System, S. Harnad, R. W. Doty, L. Goldstein, J. Jaynes, & G. Krauthamer (Eds.), New York: Academic Press, 1977.

Harris, L. J., & Carr, T. N. Implications of differences between perceptual systems for the analysis of hemispheric specialization. The Behavioural and Brain Sciences, 1981, 4, 71-72.

Harvey, Jr. L. O. Single representation of the visual midline in humans. Neuropsychologia, 1978, 16, 601-610.

Hatta, T., Yamamoto, M., Kawabata, Y., & Tsutui, K. Development of hemisphere specialization for tactile recognition in normal children. Cortex, 1981, 17, 611-616.

Hiscock, M., & Kinsbourne, M. Asymmetry of verbal-manual time sharing in children: A follow-up study. Neuropsychologia, 1980, 18, 151-162.

Holtzman, J. D., Sidtis, J. J., Volpe, B. T., Wilson, D. H., & Gazzaniga, M. S. Dissociation of spatial information for stimulus localization and the control of attention. Brain, 1981, 104, 861-872.

Humphries, P. Personal Communication, 1982.

Ingram, D. Cerebral speech lateralization in young children. Neuropsychologia, 1975a, 13, 103-105.

Ingram, D. Motor asymmetries in young children. Neuropsychologia, 1975b, 13, 95-102.

Innocenti, G. M. Development of interhemispheric cortical connections. Neurosciences Research Program Bulletin, 1982, 20 (4), 532-540.

Ishiko, N., Hanamori, T., & Murayama, N. Spatial distrbution of somatosensory responses evoked by tapping the tongue and finger in man. Electroencephalography and Clinical Neurophysiology, 1980, 50, 1-10.

Isseroff, A., Carmon, A., & Nachshon, I. Dissociation of hemifield reaction time differences from verbal stimulus directionality. Journal of Experimental Psychology, 1974, 103 (1), 145-149.

Jeeves, M. A. Psychological studies of three cases of congenital agenesis of the corpus callosum. In Functions of the Corpus Callosum, E. G. Ettlinger (Ed.), Churchill: London, 1965.

Jeeves, M. A. A comparison of interhemispheric transmission times in acallosals and normals. Psychonomic Science, 1969, 16, 245-246.

Jeeves, M. A. Hemisphere differences in response rates to visual stimuli in children. Psychonomic Science, 1972, 27, 201-203.

Jeeves, M. A. Some limits to interhemispheric integration in cases of callosal agenesis and partial commissurotomy. In Structure and Function of Cerebral Commissures, I. S. Russell, M. W., van Hof., & G. Berlucchi, (Eds.), London: Macmillan, 1979.

Jeeves, M. A., & Dixon, N. F. Hemisphere differences in response rates to visual stimuli. Psychonomic Science, 1970, 20, 249-251.

Jensen, A. R. Bias in Mental Testing. New York: The Free Press, 1980.

Jones, B., & Anuza, T. Sex differences in cerebral lateralization in 3- and 4-year old children. Neuropsycholoiga, 1982, 20 (3), 347-350.

Jones, E. G. Development of connectivity in the cerebral cortex. In Studies in Developmental Neurobiology. W. M. Cowan (Ed.), New York: Oxford University Press, 1981.

Jones, E. G., & Hendry, S. H. C. Distribution of callosal fibres around the hand representations in monkey somatic sensory cortex. Neurosciences Letters, 1980, 19, 167-172.

Jones, G. H., & Miller, J. J. Functional tests of the corpus callosum in schizophrenia. British Journal of Psychiatry, 1981, 139, 553-557.

Joseph, R. The neuropsychology of development: Hemispheric laterality, limbic language, and hte origin of thought. Journal of Clinical Psychology (Special Monograph Supplement), 1982, 38 (1), 4-34.

Kershner, J., Thomae, R., & Callaway, R. Nonverbal fixation control in young chilaren induces a left-field advantage in digit recall. Neuropsychologia, 1977, 15, 569-576.

Kinsbourne, M. Latency of uncrossed and of crossed reaction in callosal agenesis. Neuropsychologia, 1971, 9, 471-473.

Kinsbourne, M. The control of attention by interaction between the cerebral hemispheres. In Attention and Performance IV, S. Kornblum (Ed.), New York: Academic Press, 1973.

Kinsbourne, M. The mechanism of hemispheric control of the lateral gradient of attention. In Attention and Performances V., P. M. A. Rabbitt, & S. Dornic (Eds.), New York: Academic Press, 1975.

Kinsbourne, M., & Fisher, M. Latency of uncrossed and of crossed reaction in callosal agenesis. Neuropsychologia, 1971, 9, 471-473.

Kinsbourne, M., & Hiscock, M. Does cerebral dominance develop? In Language Development and Neurological Theory, S. J. Segalowitz and F. A. Gruber (Eds.), New York: Academic Press, 1977.

Kleinman, K. M., Carron, R., Cloninger, L., & Halvachs, P. A comparison of interhemispheric transmission times as measured by verbal and manual reaction-time. International Journal of Neurosciences, 1976, 6, 285-288.

Knox, C., & Kimura, D. Cerebral processing of nonverbal sounds in boys and girls. Neuropsychologia, 1970, 8, 227-237.

Kraft, R. H., Mitchell, O. R., Languis, M. L., & Wheatley, G. H. Hemispheric asymmetries during six-to-eight-year-olds performance on Piagetian conservation and reading tasks. Neuropsychologia, 1980, 18, 637-643.

Kreuter, C., Kinsbourne, M., & Trevarthen, C. Are deconnected cerebral hemispheres independent channels? A preliminary study of the effect of unilateral loading on bilateral finger tapping. Neuropsychologia, 1972, 10, 453-461.

Kuypers, H. G. J. M., & Brinkman, J. Precentral projections to different parts of the spinal intermediate zone in the rhesus monkey. Brain Research, 1970, 24, 29-48.

LaMotte, R. H., & Mountcastle, V. B. Capacities of humans and monkeys to discriminate between vibratory stimuli of different frequency and amplitude: a correlation between neural events and psychophysical measurements. Journal of Neurophysiology, 1975, 38, 539-559.

Landis, T., Regard, M., & Serrat, A. Iconic reading in a case of alexia without agraphia caused by a brain tumor: A tachistoscopic study. Brain and Language, 1980, 11, 45-53.

Laszlo, J. I. The performance of a simple motor task with kinaesthetic sense loss. Quarterly Journal of Experimental Psychology, 1966, 18, 1-8.

Lawrence, D. G., & Hopkins, D. A. The development of motor control in the rhesus monkey: Evidence concerning the role of corticomotorneuronal connections. Brain, 1976, 99, 235-254.

Lawrence, D. G., & Hopkins, D. A. The development of motor control in the rhesus monkey: Evidence concerning the role of corticomotoneuronal connections. Brain, 1977, 100, 87-104.

Lawrence, D. G., & Kuypers, H. G. J. M. The functional organization of the motor system in the monkey. I. The effects of bilateral pyramidal lesions. II. The effects of lesions of the descending brain-stem pathways. Brain, 1968, 1, 1-14, 15-36.

Lecours, A. R. Myelogenetic correlates of the development of speech and language. In Foundations of Language Development. A Multidisciplinary Approach. E. Lenneberg & E. Lenneberg (Eds.), New York: Academic Press, 1975.

LeDoux, J. E., Risse, G. L., Springer, S. P., Wilson, D. H., & Gazzaniga, M. S. Cognition and commissurotomy. Brain, 1977, 100, 87-104.

LeDoux, J. E., Wilson, D. H., & Gazzaniga, M. S. Manipulo-spatial aspects of cerebral lateralization: Clues to the origin of lateralization. Neuropsychologia, 1977, 15, 743-750.

LeDoux, J. E., Wilson, D. H., & Gazzaniga, M. S. Block design performance following callosal sectioning. Archives of Neurology, 1978, 35, 506-508.

Lefford, A., Birch, H. G., & Green, G. The perceptual and cognitive bases for finger localization and selective finger movement in preschool children. Child Development, 1974, 451, 335-343.

Levy, J. Is cerebral asymmetry of function a dynamic process? Implications for specifying degree of lateral differentiation. Neuropsychologia, 1983, 2 (1), 3-11.

Luria, A. R., & Simernitskaya, E. G. Interhemispheric relations and the functions of the minor hemisphere. Neuropsychologia, 1977, 15, 175-178.

Luttenberg, J. Contribution to the fetal ontogenesis of the corpus callosum in man. III. Myelinination in the corpus callosum. Folia Morph., 1966, 14, 192-199.

Maddess, R. J. Reaction time to hemiretinal stimulation. Neuropsychologia, 1975, 13, 213-218.

Marshall, J. C., Caplan, D., & Holmes, J. M. The measure of laterality. Neuropsychologia, 1975, 13, 315-321.

Matsunami, K., & Hamada, I. Characteristics of the ipsilateral movement related neurons in the motor cortex of the monkey. Brain Research, 1981, 204, 22-42.

Maxwell, J. Unpublished Dissertation. 1981.

MacKay, D. G. The problems of flexibility, fluency, and speed-accuracy trade-off in skilled behaviour. Psychological Review, 1982, 89 (5), 483-506.

McKeever, W. F. On laterality research and dichotomania. The Behavioural and Brain Sciences, 1981, 4, 73-74.

McKeever, W. F., & Gill, K. M. Interhemispheric transfer time for visual stimulus information as a function of the retinal locus of stimulation. Psychonomic Science, 1972, 26, 308-310.

McKeever, W. F., Gill, K. M., & Van Deventer, A. D. Letter versus dot stimuli as tools for "splitting the normal brain with reaction time". Quarterly Journal of Experimental Psychology, 1975, 27, 363-373.

McKeever, W. F., & Hoff, A. L. Evidence of a possible isolation of left hemisphere visual and motor areas in sinistrals employing an inverted handwriting posture. Neuropsychologia, 1979, 17, 445-455.

McKeever, W. F., & Huling, M. D. Lateral dominance in tachistoscopic word recognition performances obtained with simultaneous bilateral input. Neuropsychologia, 1971a, 9, 15-20.

McKeever, W. F., & Huling, M. D. Bilateral tachistoscopic word recognition as a function of hemisphere stimulated and interhemispheric transfer time. Neuropsychologia, 1971b, 9, 281-288.

McKeever, W. F., Larrabee, G. J., Sullivan, K. F., Johnson, H. J., Furguson, S., & Rayport, M. Uimanual tactile anonid consequent to corpus callosotomy: Reduction of anomic deficit under hypnosis. <u>Neuropsychologia</u>, 1981, <u>19</u> (2), 179-190.

Meerwaldt, J. D. Disturbances of spatial perception in a patient with agenesis of the corpus callosum. <u>Neuropsychologia</u>, 1983, <u>21</u> (2), 161-165.

Milner, A. D. Simple reaction times to lateralized visual stimuli in a case of callosal agenesis. <u>Neuropsychologia</u>, 1982, <u>20</u> (4), 411-419.

Milner, A. D., & Jeeves, M. A. A review of behavioural studies of agenesis of the corpus callosum. In <u>Structure and Function of Cerebral Commissures</u>. I. S. Russell, M. W. Van Hof, & G. Berlucchi (Eds.), London: MacMillan, 1979.

Milner, A. D., & Jeeves, M. A. The functions of the corpus callosum in infancy and adulthood. <u>The Behavioural and Brain Sciences</u>, 1981, <u>4</u>, 30-32.

Milner, A. D., Jeeves, M. A., Ratcliff, P. J., & Cunnison, J. Interference effects of verbal and spatial tasks on simple visual reaction time. <u>Neuropsychologia</u>, 1982, <u>20</u> (5), 591-595.

Milner, A. D., & Lines, C. R. Interhemispheric pathways in simple reaction time to lateralized light flash. <u>Neuropsychologia</u>, 1982, <u>20</u> (2), 171-179.

Milner, B., Taylor, L., & Sperry, R. W. Lateralized suppression of dichotically presented digits after commissural section in man. <u>Science</u>, 1968, <u>161</u>, 184-186.

Mishkin, M. Analogous neural models for tactual and visual learning. Neuropsychologia, 1979, 17, 139-151.

Moberg, E. The role of cutaneous afferents in position sense, kinaesthesia, and motor function of the hand. Brain, 1983, 106, 1-19.

Molfese, D. L., Freeman, R. B., & Palermo, D. S. The ontogeny of brain lateralization for speech and nonspeech stimuli. Brain and Language, 1975, 2, 356-368.

Moscovitch, M., & Catlin, J. Interhemispheric transmission of information: Measurement in normal man. Psychonomic Science, 1970, 18 (4), 211-213.

Moscovitch, M., & Smith, L. C. Differences in neural organization between individuals with inverted and noninverted handwriting postures. Science, 1979, 205, 710-713.

Moskatova, A. K. Reaction time of simple motor responses to tactile stimuli. Voprosy Psikhologiè, 1966, 12 (2), 68-74.

Muram, D., & Carmon, A. Behavioural properties of somatosensory-motor interhemispheric transfer. Journal of Experimental Psychology, 1972, 94 (2), 225-230.

Olbrich, R. Reaction time in brain-damaged and normal subjects to variable preparatory intervals. The Journal of Nervous and Mental Disease, 1972, 155 (5), 356-362.

O'Leary, D. S. A developmental study of interhemispheric transfer in children aged five to ten. Child Development, 1980, 51, 743-750.

O'Regan, J. K., & Lévy-Schoen, A. Integrating visual information from successive fixations; Does transaccadic fusion exist? Vision Research, 983, 23 (8), 765-768.

Ornstein, R., Herron, J., Johnstone, J., & Swencionis, C. Differential right hemisphere involvement in two reading tasks. Psychophysiology, 1979, 16 (4), 398-401.

Orton, S. T. Reading, Writing, and Speech Problems in Children. New York: Chapman and Hall, 1937.

Pachella, R. G. The interpretation of reaction time information-processing research. In Human Information Processing, B. H. Kantowitz (Ed.), Toronto: J. Wiley & Sons, 1974.

Pandya, D., & Vignolo, L. Intra- and interhemispheric projections of the precentral, premotor and arcuate areas in the rhesus monkey. Brain Research, 1971, 26, 217-233.

Persson, V. G. Untersuchungen bei drei fallen nit angeborenum Balkenmangel. Psychiatry, Neurology and Medical Psychology, 1970, 22, 448-455.

Peters, M. RT to tactile stimuli presented ipsi- and contralaterally to the responding hand. Quarterly Journal of Experimental Psychology, 1983, 35A, 397-410.

Pettigrew, J. D. The effect of visual experience on the development of stimulus specificity by kitten cortical neurons. Journal of Physiology, 1974, 237, 49-74.

Piaget, J. Origins of Intelligence in Children. New York: International Universities Press, 1952.

Poffenberger, A. T. Reaction time to retinal stimulation with special reference to the time lost in conduction through nerve centres. Archives of Psychology, 1912, 23, 1-73.

Poggio, G. F., & Mountcastle, V. B. A study of the functional contributions of the lemniscal and spinothalamic systems to somatic sensibility. Central nervous mechanisms in pain. Johns Hopkins Hospital Bulletin, 1960, 106, 266-316.

Poggio, G. F., & Mountcastle, V. B. The functional properties of ventrobasal thalamic neurons studied in anesthetized monkeys. Journal of Neurophysiology, 1963, 26, 775-806.

Posner, M. J., Lewis, J. L., & Conrad, C. Component processis in reading: A performance analysis. In Language by Ear and Eye, J. F. Kavanagh, & I. G. Mattingly (Eds.), Cambridge, Mass.: MIT Press, 1972.

Powell, T. P. S. Certain aspects of the intrinsic organization of cerebral cortex. In Brain mechanisms of Perceptual Awareness and Purposeful Behaviour. O. Pompeiano & C. A. Marson, (Eds.), New York: Raven Press, 1981.

Preilowski, B. F. Possible contribution of the anterior forebrain commissures to bilateral motor coordination. Neuropsychologia, 1972, 10, 267-277.

Provins, K. A. Sensory factors in the voluntary application of pressure. Quarterly Journal of Experimental Psychology, 1957, 9, 28-41.

Puccetti, R. The case for mental duality: Evidence from split-brain data and other considerations. The Behavioural and Brain Sciences, 1981, 4, 93-123.

Rasmussen, T. Localization of normal function. In K. J. Zulch, O. Creutzfeldt, & G. C. Galbraith (Eds.): Cerebral Localization, New York: Springer-Verlag, 1975.

Ray, W. J., Morell, M., & Frediani, A. W. Sex differences and lateral specilization of hemispheric functioning. Neuropsychological, 1976, 14, 391-394.

Rocha-Miranda, C. F., Bender, D. B., Gross, C. G., & Mishkin, M. Visual activation of neurons in inferotemporal cortex depends on striate cortex and forebrain commissures. Journal of Neurophysiology, 975, 38, 475-491.

Reed, H. B. C., Reitan, R. M., & Klove, H. Influence of cerebral lesions on psychological test performances of older children. Journal of Consulting Psychology, 1965, 29 (3), 247-251.

Reitan, R. M. Sensorimotor functions in brain-damaged and normal children of early school age. Perceptual and Motor Skills, 1971, 33, 655-664.

Reitan, R. M. Psychological effects of cerebral lesions in children of early school age. In Clinical Neuropsychology: Current Status and Applications. V. H. Winston and Sons, Washington, D. C., 1974.

Reynolds, D. McQ, & Jeeves, M. A. Further studies of crossed and uncrossed pathway responding in callosal agenesis - reply to Kinsbourne and Fisher. Neuropsychologia, 1974, 12, 287-290.

Reynolds, D. McQ, & Jeeves, M. A. A developmental study of hemisphere specialization for alphabetical stimuli. Cortex, 1978, 14, 259-267.

Richardson, J. T. E. How to measure laterality. Neuropsychologia, 1976, 14, 135-136.

Risse, G. L., LeDoux, J., Springer, S. P., Wilson, D. H., & Gazzaniga, M. S. The anterior commissure in man: Functional variation in a multisensory system. Neuropsychologia, 1978, 16, 23-31.

Rizzolatti, G., Bertoloni, G., & Buchtel, H. A. Interference of concomitant motor and verbal tasks on simple reaction time: A hemispheric difference. Neuropsychologia, 1979, 17, 323-330.

Rizzolatti, G., & Buchtel, H. A. Hemispheric superiority in reaction time to faces: A sex difference. Cortex, 1977, 13, 300-305.

Roland, P. E., Larsen, B., Lassen, N. A., & Skinhoj, E. Supplementary motor area and other cortical areas in organization of voluntary movements in man. Journal of Neurophysiology, 1980, 43 (1), 118-136.

Rothwell, J. C., Traub, M. M., Day, B. L., Obeso, J. A., Thomas, P. K., & Marsden, C. D. Manual motor performance in a deafferented man. Brain, 1982, 105, 515-542.

Rourke, B. P., & Czudner, A. Age differences in auditory reaction time of "brain damaged" and normal children under regular and irregular preparatory interval conditions. Journal of Experimental Child Psychology, 1972, 14, 372-378.

Rubens, A. B., Geschwind, N., Mahowald, M. W., & Mastri, A. Postraumatic cerebral hemisphere disconnection syndrome. Archives of Neurology, 1977, 34, 750-755.

Rudel, R. G., Teuber, H.-L., & Twitchell, T. E. Levels of impairment of sensori-motor functions in children with early brain damage. Neuropsychologia, 1974, 12, 95-108.

Rugg, M. D., & Beaumont, J. G. Interhemispheric asymmetries int he visual evoked response: Effects of stimulus lateralization and task. Biological Psychology, 1978, 6, 283-292.

Salamy, A. Commissural transmission: Maturational changes in humans. Science, 1978, 200, 1409-1411.

Salamy, A., Fenn, C. B., & Bronshvag, M. Ontogenesis of human brainstem evoked potential amplitude. Developmental Psychobiology, 1979, 12 (5), 519-526.

Sauerwein, H., & Lassonde, M. C. Intra- and interhemispheric processing of visual information in callosal agenesis. Neuropsychologia, 1983, 21 (2), 167-171.

Sauerwein, H. C., Lassonde, M. C., Cardu, B., & Geoffroy, G. Interhemispheric integration of sensory and motor funcitons in agenesis of the corpus callosum. Neuropsychologia, 1981, 19 (3), 445-454.

Satz, P., Bakker, D. J., Teunissen, J., Goebel, R., & Van Der Vlugt, H. Developmental parameters of the ear asymmetry: A multivariate approach. Brain and Language, 1975, 2, 171-185.

Schwartz, M. L., & Goldman-Rakic, P. S. Single cortical neurons have axon collaterals to ipsilateral and contralateral cortex in fetal and adult primates. Nature, 1982, 299, 154-155.

Sechzer, J. A., Folstein, S. E., Geiger, E. H., & Mervis, D. F. Effects of neonatal hemispheric disconnection in Kittens. In Structure and Function of Cerebral Commissures. I. Steele Russell, M. W. van Hoff & G. Berlucchi (Eds.), 1977.

Seggie, J., & Berry, M. Ontogeny of interhemispheric evoked potentials in the rat: Significance of myelination of the corpus callosum. Experimental Neurology, 1972, 35, 215-232.

Selnes, O. A. The corpus callosum: Some anatomical and functional considerations with special reference to language. Brain and Language, 1974, 1, 111-139.

Semmes, J. Hemispheric specialization: A possible clue to mechanisms. Neuropsychologia, 1968, 6, 11-26.

Sergent, J. Basic determinants in visual-field effects with special reference to the Hannay et al (1981) study. Brain and Language, 1982, 16, 158-164.

Sidtis, J. J., Volpé, B. T., Holtzman, J. D., Wilson, D. H., & Gazzaniga, M. S. Cognitive interaction after staged callosal section: Evidence for transfer of semantic activation. Science, 1981, 212, 344-346.

Simon, J. R., Hinrichs, J. V., & Craft, J. L. Auditory S-R compatibility: reaction time as a function of ear-hand correspondence and ear-response-location correspondence. Journal of Experimental Psychology, 1970, 86, 97-102.

Simon, J. R. Effect of ear stimulated on reaction time and movement time. Journal of Experimental Psychology, 1968, 78, 344-346.

Smith, F. O. An experimental study of the reaction time of the cerebral hemispheres in relation to handedness and eyedness. Journal of Experimental Psychology, 1938, 22, 75-83.

Smith, K. U. Bilateral integrative action of the cerebral cortex in man in verbal association and sensorimotor coordination. Journal of Experimental Psychology, 1947, 37 (5), 367-377.

Smith, L. C., & Moscovitch, M. Writing posture, hemispheric control of movement and cerebral dominance in individual with inverted and noninverted postures during writing. Neuropsychologia, 1979, 17, 637-644.

Sparks, R., & Geschwind, N. Dichotic listening in man after section of neocortical commissures. Cortex, 1968, 4, 3-16.

Sperry, R. W. Cerebral organization and behaviour. Science, 1961, 133, 1749-1757.

Sperry, R. W., Gazzaniga, M. S., & Bogen, J. F. Interhemispheric relationships: the neocortical commissures, syndromes of their disconnection. In Handbook of Clinical Neurology (Vol. 4), P. J. Vinken, & G. W. Bruyn (Eds.), Amsterdam: North Holland Publishing Company, 1962.

Springer, S. P., & Gazzaniga, M. S. Dichotic testing of aprtial and complete split main subjects. Neuropsychologia, 1975, 13, 341-346.

Stevens, D. A., Boydstun, J. A., Ackerman, P. T., & Dykman, R. A. Reaction time, implusivity, and autonomic ability in children with minimal brain dysfunction. Proceedings, 76th Annual Convention, American Psychological Association, 1968, 367-368.

Stone, M. A. Measures of laterality and spurious correlation. Neuropsychologia, 1980, 18, 339-345.

Stuss, D. T., Benson, D. F., Kaplan, E. F., Weir, W. S., Naesser, M. A., Lieberman, I., & Ferrill, D. The involvement of orbitofrontal cerebrum in cognitive tasks. Neuropsychologia, 1983, 21 (3), 235-248.

Sugishita, M., Toyokura, Y., Yoshioka, M., & Yamada, R. Unilateral agraphia after section of the posterior half of the truncus of the corpus callosum. Brain and Language, 1980, 9, 215-225.

Swanson, J. M., & Ledlow, A. Unilateral input, attention and performance in RT experiments. Paper presented at American Psychological Association Meeting, 1974, New Orbans.

Swanson, J., Ledlow, A., & Kinsbourne, M. Lateral asymmetries revealed by simple reaction time. In Asymmetrical Function of the Brain, M. Kinsbourne (Ed.), New York: Cambridge University Press, 1978.

Swadlow, H. A., Geschwind, N., & Waxman, S. G. Commissural transmission in humans. Science, 1979, 204 (4), 530-537.

Swadlow, H. A., & Waxman, S. G. Ultrastructure and conduction propoerties of visual callosal axons of the rabbit. In Structure and Function of Cerebral Commissures. I. Steele-Russell, M. Van Hof, and G. Berlucchi (Eds.). London: MacMillan, 1979.

Tallal, P. Temporal processing as related to hemispheric specialization for speech perception in normal and language impaired populations. The Behavioural and Brain Sciences, 1981, 4, 77-78.

Tanji, J., Taniguchi, K., & Saga, T. Supplementary motor area: Neuronal response to motor instructions. Journal of Neurophysiology, 1980, 43 (1), 60-

Teitelbaum, H., Sharpless, S. K., & Byck, R. Role of somato-sensory cortex in interhemispheric transfer of tactile habits. Journal of Comparative Physiology and Psychology, 1968, 66, 623-632.

Tomasch, J.. size, distribution and number of fibres int he human corpus callosum. Anatomical Research, 1954, 119, 119-136.

Twitchell, T. E. Reflex mechanisms and the development of prehension. In Mechanisms of Motor Skill Development. K. J. Connoly (Ed.) London: Academic Press, 1970.

Umilta, C., Rizzolatti, G., Marzi, C. A., Zamboni, G., Franzini, C., Camarda, R., & Berlucchi, G. Hemispheric differences int he discrimination of line orientation. Neuropsychologia, 1974, 12, 165-174.

Van Essen, D. C., Newsome, W. T., & Bixby, J. L. The pattern of interhemispheric connections and its relationship to extrastriate visual areas in the macaque monkey. The Journal of Neuroscience, 1982, 2 (3), 265-283.

Vaughan, H. G., Costa, L. D., & Gilden, L. The functional relation of visual evoked response and reaction time to stimulus intensity. Vision Research, 1966, 6, 645-656.

Vellutino, F. R., Bentley, W. L., & Philips, F. Inter- versus intra-hemispheric learning in dyslexic and normal readers. Developmental Medicine and Child Neurology, 1978, 20, 71-80.

Verrillo, R. T. Vibrotactile subjective magnitude as a function of hand preference. Neuropsychologia, 1983, 21 (4), 383-395.

Villaverde, J. M. De 1919 Beitrag zur entwicklung sgeschichte des Balkens. Cited by Selnes, 1974.

Volpé, B. T., Sidtis, J. J., Holtzman, J. D., Wilson, D. H., & Gazzaniga, M. S. Cortical mechanisms involved in praxis: Observations following partial and complete section of the corpus callosum in man. Neurology, 1982, 32, 645-650.

Volpe, J. J. Neurology of the Newborn. Toronto: W. B. Saunders, 1981.

Wada, J., Clark, R., & Hamm, A. Cerebral hemispheric asymmetry in humans. Archives of Neurology, 1975, 32, 239-246.

Wall, P. D. Habituation and post-tetanic potentiation in the spinal cord. In Short term changes in Neural Activity and behaviour. G. Horn, & R. A. Hinde (Eds.), Cambridge: Cambridge University Press, 1970.

Wallace, R. J. S-R compatibility and the idea of a response code. Journal of Experimental Psychology, 1971, 88, 354-360.

Warrington, E. K., & Pratt, R. T. C. The significance of laterality effects. Journal of Neurology, Neurosurgery, and Psychiatry, 1981, 44, 193-196.

Wiggins, R. C. Myelin development and nutritional insufficiency. Brain Research Reviews, 1982, 4, 151-175.

Willis, W. D. Jr., & Grossman, R. G. Medical Neurobiology. C. V. Mosby, 1977.

Wise, S. P., & Jones, E. G. The organization and postnatal development of the commissural projection of the somatic sensory cortex of the rat. Journal of Comparative Neurology, 1976, 168, 313-343.

Witelson, S. F. Neural and cognitive correlates of developmental dyslexia: Age and sex differences. In Psychopathology and Brain Dysfunction, G. Shagass, S. Gershon, & A. J. Friedhoff (Eds.), New York: Raven Press, 1977.

Witelson, S. F., & Pallie, W. Left hemisphere specialization for language in the newborn: Neuroanatomical evidence of asymmetry. Brain, 1973, 96, 641-646.

Wolff, P. H., & Hurwitz, I. Sex differences in finger tapping: A developmental study. Neuropsychologia, 1976, 14, 35-41.

Woods, B. T. The restricted effects of right-hemisphere lesions after age one; Wechsler test data. Neuropsychologia, 1980, 18, 65-70.

Wolpaw, J. R., & Penry, J. K. Hemispheric differences in the auditory evoked potential. Electroencephalography and Clinical Neurophysiology, 1977, 43, 99-102.

Yakolev, P. I. Morphological criteria of growth and maturation of the nervous system in man. Research Publications Association for Research in Nervous and Mental Disease, 1962, 39, 3-46.

Yakovlev, P. I., & Lecours, A.-R. The myelogenetic cycles of reginal maturation of the brain. In Reginal Development of the Brain in Early Life, A. Minkowski (Ed.), F. A. Davis, Philadelphia, 1967.

Young, A. W., & Ellis, H. D. An experimental investigation of developmental differences in ability to recognize faces presented to the left and right cerebral hemispheres. Neuropsychologia, 1976, 14, 495-498.

Zaidel, E. A. A technique for presenting lateralized visual input with prolonged exposure. Vision Research, 1975, 15, 283-289.

Zaidel, E. Auditory vocabulary of the right hemisphere following main bisection on hemide cortication. Cortex, 1976, 12, 191-211.

Zaidel, D., & Sperry, R. W. Some long-term motor effects of cerebral commissurotomy in man. Neuropsychologia, 1977, 15, 193-204.

Zaidel, E., & Peters, A. M. Phonological encoding and ideographic reading by the disconnected right hemisphere: Two case studies. Brain and Language, 1981, 14, 205-234.

Zaidel, E., Zaidel, D. W., & Sperry, R. W. Left and right intelligence: Case studies of Raven's Progressive Matrices following brain bisection and hemidecortication. Cortex, 1981, 17, 167-186.

Zangwill, O. L. Cerebral Dominance and its relation to psychological funciton. C. C. Thomas, Springfield, Ill., 1960.

Zihl, J., & Von Cramon, D. The contribution of the 'second' visual system to directed visual attention in man. Brain, 1977, 102, 835-856.