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PERFORMANCE OF A TACTUAL DISCRIMINATION TASK BY SECOND, FOURTH, SIXTH, AND EIGHTH GRADE STUDENTS UNDER TWO CONDITIONS OF HEMISPHERIC INFORMATION PROCESSING

The Ohio State University

Ph.D. 1982

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PERFORMANCE OF A TACTUAL DISCRIMINATION TASK
BY SECOND, FOURTH, SIXTH, AND EIGHTH GRADE
STUDENTS UNDER TWO CONDITIONS OF HEMISPHERIC INFORMATION PROCESSING

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Deborah Anita Wolfe, B.A., B.A.M., M.A.

* * * * *

The Ohio State University

1982

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CHAPTER I

INTRODUCTION

Knowledge of the brain has been accumulating as far back as the fifth century B.C. Quantity and quality of brain research has progressed immensely since the time of the ancient Egyptians. For instance, the Egyptians had so little respect for the brain that they scooped it from the nostrils of the dead; considering it unnecessary baggage for the long voyage to resurrection (Groves & Schlesinger, 1979). Today, a plethora of facts exists concerning the brain. According to Groves and Schlesinger (1979):

In this age of radical experimentalism, virtually every species of molecule in the brain has been weighed and measured, every nucleus has been probed, tickled with electrical current, perfused with exotic chemicals, frozen, burned, cut, homogenized, fixed, stained, extracted, and subjected to every insult that the brain itself can contrive. The results are in libraries carefully catalogued and weighing down the stacks. But every new fact recorded reminds us of the conceptual poverty of our field. (pp. 2-3)

The more that is discovered, the greater the need to discover more. Though each discovery reveals unsuspected mysteries of the brain, little is really known. There is an abundance of clues, and yet there is a sense of missing pieces.
Hemispheric lateralization, the concept that one cerebral hemisphere differs from the other with regard to function, has been widely investigated. The validity of the concept of hemispheric lateralization has been continuously challenged by such theorists as Johnson, Cole, Bowers, Foiles, Nikaido, Patrick, and Woliver (1979). They believe that the two hemispheres do not have distinctly different functions in neurologically intact organisms. Instead, they maintain that there is a difference in relative degree of involvement of the hemispheres in different tasks.

The acquisition of all movement behavior involves the close integration of the sensory and the motor systems of the body. Among the least investigated sensory factors influencing the acquisition and learning of motor skills is tactual information processing. When stimuli impinge upon the skin during motor skill acquisition, touch or haptic information processing is involved. The role that such haptic information processing plays in motor skill acquisition needs to be examined and understood. The lack of knowledge concerning haptic information processing is reflected in the need for continued research within the areas of hemispheric specialization and hemispheric lateralization.

Quantifying information from each modality that is processed by the brain by specific regions in the cerebral
hemispheres is called hemispheric specialization. At the present time more evidence exists to support the notion of left hemispheric specialization than right hemispheric specialization. The concurrent tasks experimental paradigm has become quite popular in the experimental quest to discover functional differences between the hemispheres. In this paradigm, a subject performs two tasks simultaneously. Much of the relevant or recent neuropsychological research utilizing the concurrent tasks paradigm has concentrated on vocal-manual interference during a concurrent task paradigm. Much less information is available concerning tactual information processing. Only a limited body of research exists on tactual information processing during simultaneous performance of two tasks. Developmental studies, cross-sectional or longitudinal, are few in number. Research on sex differences in tactual information processing is scarce.

Statement of the Problem

The present study was designed to further investigate tactual information processing and the nature of hemispheric specialization in children. In this study, seven-through fourteen-year-old right-handed children were first asked to perform a haptic task that involved matching nonsense figures made of wood. Afterward, they were asked to
perform a second task which consisted of this same original haptic matching task performed concurrently with a digits backward task. The digits backward task required a child to listen to a series of numbers delivered either to their right or left ear over headphones and to respond to each of the numbers by subtracting "one" from the number heard and saying this number aloud. The purpose of the study was to determine how children perform a task of simple tactual information alone as opposed to a task of both tactual and auditory information presented simultaneously. The auditory information was presented to either the right or the left ear.

Gescheider, Sager, and Ruffolo (1975) found that relatively efficient haptic and auditory information processing occurred when pairs of simple stimuli were presented simultaneously to the skin and ears. In this experiment, subjects were asked to perform two simple perceptual tasks. The subject detected vibrotactile stimuli and judged to loudness of tones. The results of this experiment supported the hypothesis that subjects can process simple stimuli presented simultaneously to two modalities about as well as when they have to make responses to stimuli in only one modality. In another experiment by Gescheider et al. (1975), the subjects were asked to process complex auditory and tactile information simultaneously. Subjects performed an auditory discrimination task and a tactile discrimination task. Subjects had difficulty maintaining high levels of
performance in both modalities due to the increased cognitive processing. The Gescheider et al. (1975) study supports a theory that cognitive, but not perceptual, processing is disrupted when subjects have difficulty performing two perceptual tasks simultaneously. When demands on cognitive processes were small, auditory and tactile stimuli presented simultaneously could be processed as well as when stimuli are presented to only one of the modalities. Only when subjects performed a task with increased cognitive processing or increased demands on memory did the simultaneous performance of the second task have a disruptive effect. The information in two channels disrupts memory rather than perceptual performance.

The present study was designed to test the Gescheider et al. (1975) theory by having subjects perform a task that required minimal demands on memory followed by simultaneous performance of two tasks, haptic and auditory, that placed greater demands on memory.

The first hypothesis of this study was designed to test whether students exposed to haptic information alone would perform significantly better on a haptic task than those exposed to haptic and auditory information delivered simultaneously.

The model of "hemispheric sharing" promulgated by Kinsbourne and Hicks (1975) stated that there should be greater interference between concurrent activities when both are
programmed by the same hemisphere. Intra-hemispheric processing is the result of two stimuli reaching the same primary receiving hemisphere. Inter-hemispheric processing is the result of two stimuli processed in different primary receiving hemispheres; one stimuli goes into one hemisphere and the other enters the opposite hemisphere. In general, inter-hemispheric processing has in the past been found to be more efficient than intra-hemispheric information processing (Kinsbourne & Cook, 1971). Past research has indicated that intra-hemispheric information processing leads to less efficient processing of information demanded during the performance of concurrent tasks (Kinsbourne & Cook, 1971). Research on inter- and intra-hemispheric information processing presently indicates that the two hemispheres do not have distinctly different functions but that there is a relative degree of joint involvement of the hemispheres in different tasks (Johnson et al., 1979). To explore the manner in which inter- and intra-hemispheric information processing occurs during the performance of a tactual task, children were exposed to four conditions of hemispheric processing in the present study: right hand/right ear (RHRE); right hand/left ear (RHLE); left hand/left ear (LHLE); and left hand/right ear (LHRE).

The second hypothesis of this study was designed to test the hemispheric sharing theory of Kinsbourne and Cook (1971) by utilizing one task that was processed by the right
hemisphere (the haptic task) and a task processed by the left hemisphere (the auditory task). The second hypothesis was designed to test whether inter-hemispheric processing of simultaneously presented haptic and auditory information resulted in better haptic task performance than intra-hemispheric processing of simultaneously presented haptic and auditory information.

The third and fourth hypotheses of the study investigated variables of age and sex. The performance of ten males and ten females from each of four grade levels (i.e., second, fourth, sixth, and eighth grades) were examined in order to investigate age and sex differences in tactual information processing. Research has shown that inter-hemispheric processing is generally less efficient in younger children than in older children (Finlayson, 1976). Females have been found to be generally less lateralized than males (McGlone & Davidson, 1973). Thus, males in the present study may display greater differences between left and right hand performances on the tactual task than will females.

The fifth hypothesis of this study was designed to test whether the left hand performed a haptic task better than the right hand. Most studies have found tactile perception to be superior by the left hand (Gardner, English, Flannery, Hartnett, McCormick, & Wifelmy, 1977; Witelson, 1974; Dodds, 1978; Riege, Metter, & Williams, 1980).
Hypotheses

The hypotheses of this study were:

1. Students exposed to haptic information alone will perform significantly better on a haptic task than those exposed to haptic and auditory information delivered simultaneously.

2. Inter-hemispheric information processing of simultaneously presented auditory and haptic information results in significantly better haptic task performance than intra-hemispheric processing of simultaneously presented auditory and haptic information.

3. Males will perform a haptic information processing task significantly better than females.

4. As grade level increases, performance of a haptic information processing task will improve significantly.

5. Left hand performance on the haptic task will be significantly better than right hand performance.

Basic Assumptions

There are a number of assumptions that underlie this study:

1. Tactual information is predominately processed by the right hemisphere (Rudel, 1974; Gardner et al., 1977; Dodds, 1978).

2. Verbal information is processed predominately by
the left hemisphere (Geffen et al., 1971; Botkin et al., 1977).

3. Most right-handed subjects have a language center in the left hemisphere (Goodglass & Quadfasel, 1954; Milner, Branch & Rasmussen, 1964; Pratt & Warrington, 1972).

4. The right ear has crossed auditory neural projections which lead into the left hemisphere and the left ear has crossed auditory neural projections which lead into the right hemisphere (Kimura, 1967; Rosenzweig, 1951).

5. Fingers utilize mainly contralateral neural pathways as opposed to ipsilateral ones (Brinkman & Kuypers, 1972).

6. The left hemisphere predominately controls movements on the right side of the body and the right hemisphere predominately controls movements on the left side of the body (Brinkman & Kuypers, 1972).

**Definition of Terms**

Cerebral Hemispheres - The outermost portion of the forebrain, consisting of the telencephalon (Cerebral cortex, corpus callosum, basal ganglia, and limbic system). Each half of the telencephalon is called a cerebral hemisphere.

Comissure - A compact bundle of axons lying parallel to one another which originate from neuronal cell bodies in a structure on one side of the central nervous
system and terminate (synapse) in large part in the same structure on the other side of the brain or spinal cord. Commissures, including the corpus callosum, are "two-way streets," carrying axons from right to left and left to right sites in the central nervous system, allowing the two halves of that system to communicate directly with each other.

Concurrent - Two tasks performed at once.

Contralateral Pathways - Neural pathways involving right hand control by the left hemisphere and left hand control by the right hemisphere.

Corpus Callosum - A massive bundle of axons connecting the right and left cerebral cortices. The corpus callosum allows the two halves of the cerebral cortex to communicate directly with one another.

Dichotic Listening - Listening to different auditory signals in each of the two ears.

Digits Backward Task - Subject orally subtracts "one" from a series of numbers heard through headphones.

Haptic Task - The tactual recognition task in which the subject feels one form with one hand for the purpose of matching this form to one of two others located directly below it.

Hemispheric Asymmetry - Used with reference to structural or functional differences between the right and left
cerebral hemispheres.

Hemispheric Dominance - Implies left hemisphere superiority of control over the right hemisphere.

Hemispheric Lateralization - The differentiation of the two cerebral hemispheres with regard to function.

Hemispheric Specialization - Processed information from each modality can be specified or quantified in the hemispheres.

Hemispheric Time-Sharing - Programming two tasks within the same hemisphere.

Ipsilateral Pathways - Pathways from the right hand to the right hemisphere and from the right hemisphere to the right hand as well as pathways from the left hand to the left hemisphere from the left hemisphere to the left hand.

Inter-Hemispheric Processing - Information in two different modalities enter different hemispheres simultaneously.

Intra-Hemispheric Processing - Information in two different modalities are processed in the same hemisphere concurrently.

Myelination - The process by which a myelin sheath forms about an axon or collection of axons.

Ontogeny - Refers to the growth and development of an individual organism as opposed to the evolutionary development of a species.
Students - Right-handed children from the second, fourth, sixth, and eighth grades.

Tactual - The sense of touch; one of a number of somatic (body) sensations.
CHAPTER II
REVIEW OF LITERATURE

The review of literature pertaining to this study will be discussed under six topics: (a) functional organization of the human brain - a historical perspective, (b) hemispheric asymmetry, (c) models of information processing, perceptual asymmetry and attention, (d) variables associated with hemispheric asymmetry, (e) inter- and intra-hemispheric information processing, and (f) tactual information processing.

Functional Organization of the Human Brain -
A Historical Perspective

The human brain may be the most complex object in this "corner of the universe." Two popular concepts, hemispheric dominance and specialization, have dominated our thinking about the functional organization of the human brain during the last century. These two concepts have evolved from the notion of cerebral localization.

Interest in the brain as the possible organ of behavior, sensation, and thought can be traced back to the early Greeks of the fifth century B.C. By the close of the 18th century, brain research had gone from the crude to the mature. "Animal spirits" had been replaced by
the "nerve fluid." At the beginning of the 19th century, the science of cranioscopy or phrenology had developed. Franz Joseph Gall postulated that the brain was the organ of the mind with mental and moral faculties located in specific areas of its surface so that a deficit of each could be detected on the cranium. He divided the skull into compartments, each with its own specific function. Thus, attention was drawn to cerebral localization as interest in the cerebral hemispheres emerged (Clarke & Dewhurst, 1972).

In the 1860's, investigations by Fritsch and Hitzig led to the discovery that the removal of certain areas within the brain of a dog produced a disturbance of motor function in the opposite limbs (Clarke & Dewhursts, 1972). Shortly after the pioneering efforts of Fritsch and Hitzig, a British school of "cortical localizers" was established. They believed that mental and motor functions could be located within the cerebral cortex. David Ferrier and Hughlings Jackson, were both members of this school of thought, and based much of their work on cortical localization concepts.

The cortical localizers were soon opposed by a growing body of researchers who supported the theory of cerebral equipotentiality. These researchers considered that
localization of function was impossible due to massive inter-neural connections. This theory supported the conception that any intact cortical area could execute the functions of other parts of the cortex.

During the 19th century, Karl Lashley also formulated a principle of equipotentiality. The principle of equipotentiality stated that regions of the cerebral cortex were equipotential with respect to the storage or location of memory. During the first half of the 20th century, Lashley found memories were stored in a single place in the cerebral cortex (Groves & Schlesinger, 1979).

Hemispheric Dominance

The concept of hemispheric dominance evolved from work by cerebral localizers. Hemispheric dominance presupposes that all functions are represented in "dominant" and "non-dominant hemispheres." If a conflict arises between the two halves of the brain, the resulting behavior is primed by the language-competent hemisphere (Basso, Bisiach, & Capitani, 1977).

As early as the 1860's, Broca discovered that damage to a specific area of the left half of the brain led to disorder of spoken language. After performing autopsies on several of his aphasia patients, Broca found the brain damage to be confined to the third gyrus of the cerebral
cortex (later named Broca's area). A few years later, Broca studied damage done to a comparable area in the right hemisphere (Groves & Schlesinger, 1979). Destruction of the corresponding areas in the right side of the brain left language abilities intact. This unilateral control of function is referred to as "cerebral dominance." Man is the only mammal in which learned behavior is controlled by one half of the brain (Geschwind, 1972).

In 1935, Kirk was concerned with not only hemispheric equipotentiality but also cerebral dominance. Kirk (1935) was interested in establishing whether there was any evidence of cerebral dominance in the rat. On reexamining Kirk's research, Webster (1977) has found his data to be consistent with contemporary findings, suggesting an asymmetry of hemispheric functioning with polarity by paw preference.

The concept of cerebral dominance was perpetuated by claims of cerebral localization. Efforts to localize language and nonlanguage functions resulted in reports of deficits in auditory comprehension, calculation, general intelligence, reading, writing and other nonlanguage functions. References to the left hemisphere of man as "dominant," "major," and "leading" reflected belief that man's left hemisphere was superior to the right.
The notion of cerebral dominance is still present in recent literature on the neuropsychology of the brain. Brown and Jaffe (1975) hypothesized that cerebral dominance was a continuous process which evolved throughout life. The authors suggested that evidence for continuous lateralization development existed with anatomical hemispheric asymmetries at birth. The right hemisphere can be considered dormant in infancy during visual and acoustic communication of the prelinguistic child. Brown and Jaffe (1975) further pointed out that as the child grew older, in addition to progressive left hemisphere lateralization, there may also be a continuing specification within the left hemispheric speech zone.

Further support for cerebral dominance came from Johnson et al. (1979). Measuring right and left hemisphere efficiency by dichotic memory for numbers, Johnson et al. (1979) supported the notion that right hemispheric abilities (such as spatial ability) shows a real decline with age. Abilities that were more left hemisphere dependent hold up with increased age because the "dominant" hemisphere does not decline in efficiency of information processing.
Hemispheric Specialization

During the 1960's, hemispheric specialization became a popular theory of cognitive function. Hemispheric specialization implies that the right hemisphere in man differs from the left in function. Although the hemispheres of man are bilaterally symmetrical, the notion of cerebral specialization evolved in an effort to allow each hemisphere greater competence for its particular abilities (Fagan-Dubin, 1974). The left cerebral hemisphere is specialized for hand control, language, analytic processes, and certain aspects in memory (Gardner, 1975). The right cerebral hemisphere deals with holistic processes, spatial abilities, and nonverbal ideation (Fagan-Dubin, 1974; McGlone & Kertesz, 1973; McGlone, 1978). Levy (1969) has proposed an existing incompatibility between language, analytic abilities and nonverbal or visuospatial processes within each hemisphere.

Hemispheric specialization implies that each modality can be specified or quantified in the hemispheres. Hemispheric dominance implies left hemisphere superiority of control over the right hemisphere. However, the term hemispheric dominance may preclude the right hemisphere of its true place in the hierarchy of function. Hecaen (1975) and associates share this same idea. They substantiate this
idea by citing people who have had early damage to the left hemisphere with speech transferred to the right hemisphere. However, these patients generally remain right-handed. Thus, it may be possible that speech, under these circumstances, can be transferred and developed in the right hemisphere while preference to the right hand is still maintained.

**Hemispheric Asymmetry**

Hemispheric asymmetry refers to functional or structural differences between right and left cerebral hemispheres.

**Methods of Measurement**

Hemispheric functions in man have been studied in many ways, by evaluating: (a) measurements of regional cerebral blood flow, (b) split-brain preparations, (c) acallosal patients, (d) unilateral carotid amytal injections, (e) EEG, (f) aphasics and brain-injured, (g) evoked potentials, (h) responses to tachistoscopic presentations, (i) unilateral EEG, (j) dichotic listening, and (k) responses to concurrent task paradigms.

**Cerebral blood flow.** Support for hemispheric specialization comes from the research of Risberg, Halsey, Wills, and Wilson (1975). These researchers used xenon inhalation
to show that cerebral blood flow increased 16% in the left hemisphere during verbal information processing. During spatial information processing, blood flow increased 10% to the right hemisphere. They concluded that cerebral blood flow increase in the specialized hemisphere was significantly greater than in the nonspecialized hemisphere.

The use of radioactive tracer techniques to study cerebral blood flow is a more sensitive physiological measure to assess hemispheric specialization. The assumption here is that if one hemisphere, or one restricted area of a hemisphere is involved more intensely with a certain type of information processing, then that area requires more oxygen.

Dabbs and Choo (1980) measured the skin temperature over the ophthalmic branches of the internal carotid arteries in order to index blood-flow to the two sides of the head. Left-right temperature differences were found to discriminate among handedness, two kinds of left-handed people and exceptional verbal or spatial ability.

Split-brain. Some of the pioneers of the split-brain technique are Myers, Sperry, Bogen and Gazzaniga. The split-brain technique involves a surgical procedure in which fibers that connect the two hemispheres are severed. Usually the corpus callosum, the cerebral commissure that
interconnects the left and right half-brains, is cut along with smaller commissures. When the optic chiasm is severed visual input from the right eye is then restricted to the right cerebral hemisphere and vice versa. The first experiments were performed on the cat demonstrating that discriminations trained to one side of the brain leave the other half of the brain naive (Gazzinga, 1977).

Surgical transection is not the only technique available to obtain a split-brain preparation. Various agents can be used to obtain a reversible split brain (Groves & Schlesinger, 1979). The reversible split-brain is a preparation in which one cerebral hemisphere is inactive while the remaining hemisphere remains functional.

"Spreading depression" is the technique used to achieve the preparation. By using a salt solution agent, nervous tissue becomes inactive. Potassium chloride applied directly to the cerebral cortex produces depression of the tissue for several hours. Bures and Buresova (1970) used this technique with rats and found learning and memory for an avoidance task to be localized to a single hemisphere.

The brain may also be split for the purpose of controlling inter-hemispheric spread of epilepsy (Sperry & Gazzaniga, 1967; Sperry, 1974). Severing the callosal fibers in epileptic patients does not cause a dramatic
impairment of function but possible alteration in relative efficiency of function as compared to normals (Jeeves, 1965).

Acallosals. Congenital acallosals are also considered split-brain cases. These subjects display evidence of congenital absence of the corpus callosum. Dennis (1976) found the corpus callosum to have an inhibitory role in the ontogeny of sensation and movement. Lacking an ontogenetic inhibitory callosal action, acallosals have developed a cerebral organization which restricts various aspects of movement and sensation within each hand. Acallosals have also developed an elaboration of ipsilateral pathways to compensate development and limitations of function (Dennis, 1976; Reynolds & Jeeves, 1977).

Sodium amytal infection. Sodium amytal can be infected into the carotid artery of one side of the neck or the other. As a sedative, this drug disturbs the functioning of the cerebral hemisphere on the side it was injected. If the subject's speech was disturbed, speech may be represented in that hemisphere (Kimura, 1973). Lake and Bryden (1976) considered the sodium amytal technique to be very useful in clarifying the probable incidence of left and right cerebral dominance. This technique was also useful in the demonstration of bilateral speech representation.
EEG. The electroencephalogram technique has also been used in attempts to ascertain hemispheric asymmetry (Crowell, Jones, Kapunal, & Nakagawa, 1972; Willis, Wheatley, & Mitchell, 1979; Moore, 1979; Galin, Johnstone, & Herron, 1978). In this method, electrodes are placed on the scalp and the subject is given a task to perform. The potential differences between pairs of electrodes are amplified and recorded. The record obtained is called an EEG and represents changes that occur in the voltage field distribution on the head as a function of time.

Most research of hemispheric asymmetry records alpha waves not beta. The alpha rhythm is a rhythmical pattern responsive to arousal, eye opening and closing, and mental activities. This electrical activity is recorded from the cerebral cortex. There is no electrical activity in subcortical structures (Gardner, 1975).

Gardner (1975) cites the electroencephalogram as an important procedure for evaluation and diagnosis. However, he cautions the researcher on the limitations of the EEG. He cites the following variables that may affect EEG readings: (a) individual variations in age differences, (b) susceptibility to drugs, (c) blood sugar levels, (d) acid-base equilibrium, (e) level of attention or awareness.
A number of investigators have reported suppression of alpha brain-wave frequencies over the hemisphere which is involved in processing specific information (Moore, 1979; Dumas, & Morgan, 1975; Galin & Ellis, 1975; Galin & Ornstein, 1972; Moore & Lang, 1977). Alpha suppression or EEG activation occurs as a function of mental processing. Thus, bilateral alpha activity should be sensitive to hemispheric processing asymmetries (Hirshkowitz, Earle, & Paley, 1978).

In the investigations of Hirshkowitz et al. (1978), EEG recordings were made on subjects who merely had to listen to auditory stimuli. Results indicate the right hemisphere is more active than the left when non-musicians listen to music.

EEG's are also used on the brains of human infants (Crowell et al., 1973; Glaser & Levy, 1965). Crowell et al. (1973) found evidence of dominance in the right hemisphere for rhythmic visual stimuli.

Aphasics, Brain-damaged. Researchers may also study lateralization of function of the cerebral hemispheres by examining aphasics. Aphasias are disorders of language resulting from damage to the brain. There are various kinds of aphasias and each is classified as to prefeominate symp­toms. Lake and Bryden (1976) have found many studies of aphasics to be very unsatisfactory. They are displeased by
studies involving subjects with damage resulting from a penetrating brain wound sustained in World War II. The authors state three biases present in aphasia literature; (a) positive cases are reported while negative ones are not, (b) healthy brain-injured patients are usually male war veterans whereas mixed sex distributions present a higher incidence of brain pathology, and (c) inconsistent reporting of sex and familial sinistrality.

Witelson (1974) also warns of the dangers resulting from generalizations with aphasics and the brain-injured. Incorrect inferences may be drawn to the relevance of the dysfunctioning tissue. These deficits mirror the limitations of the remaining neural tissue rather than function as a damaged area in the intact condition.

The investigator may feel there is involvement of lesioned structures for a particular behavior pattern if a change is seen in behavior. Lesions may be caused by removal or damage to a particular part of the brain. Houston (1976) cites three difficulties occurred in lesion techniques. First of all, destroying a given brain structure does not always mean impairment will be permanent. Thus, the destroyed structure may not be absolutely essential for the task. A second problem with lesion studies concerns the fact that the same lesion may produce different degrees
of impairment along with individual differences. The last difficulty cited by Houston (1976) in using lesion techniques is that damage inflicted to one area may result in a constellation of deficits. It may be possible that the order or pattern in which the damage occurs could determine performance deficits.

Evoked potential. The evoked potential has played an important part in what we know about locations in the brain for visual, auditory, and other modalities. Evoked potentials are surface waves that are elicited by peripheral stimulation. The combined electrical response comes from synaptic potentials from millions of neurons. Evoked potentials have been used to map areas of the brain that respond to particular kinds of stimuli (Groves & Schlesinger, 1979). Controllable evoked potentials can be elicited by a flash of light, a sound, or an electrical stimulus of known voltage and duration (Gardner, 1975). Evoked potentials have been utilized by a number of researchers to explore hemispheric asymmetry (Haaland, 1974; Davis & Wada, 1977; Molfese, Freeman, & Palermo, 1975). It is generally agreed that hemispheric asymmetries in evoked potentials are related to the lateralization of cognitive function. Mayes and Beaumont (1977) cite that complex verbal and nonverbal stimuli produce differentially asymmetric evoked
potentials. Generally, a larger amplitude evoked potential was observed on the left hemisphere when the stimulus was verbal whereas the right hemisphere was affected by non-verbal stimuli (Cohn, 1971).

Tachistoscopic studies. The tachistoscope has been used not only to train people during World War II to identify enemy airplanes from a brief exposure to their pictures, but also to explore hemispheric asymmetries (Basso et al., 1977; Allard & Bryden, 1979; McGlone & Davidson, 1973; Birkett, 1978). The tachistoscopic method involved using printed matter or pictures to be projected onto a screen for a very brief duration. The tachistoscope is basically a film slide projector equipped with a very fast shutter speed exposing the slide for possible 1/100 of a second. The "T-scope" has been used extensively in speed of perception experiments (Sage, 1977). While tachistoscopic studies have been very useful in investigations of cerebral asymmetry of function, Birkett (1978) cited inconsistent results from investigations using the T-scope and nonverbal stimuli. He also suggested and implied that knowing detailed information about task requirements and subjects' strategies may be needed to clarify results derived through tachistoscopic means.
Unilateral electroconvulsive therapy. A more recent technique that affords the opportunity to study hemispheric asymmetry is unilateral electroconvulsive therapy. Electroconvulsive therapy (ECT) is a way of inducing retrograde amnesia or memory loss. The procedure involves a strong electric current which is passed through the brain. Warrington and Pratt (1973) assessed cerebral speech dominance by unilateral ECT. Their findings indicated that females are more likely to have close left-handed relatives while males are more likely to have right-handed relatives.

Dichotic listening. In a dichotic listening paradigm, different acoustic stimuli are presented to the two ears simultaneously while the subject is asked to recall what was heard. Usually pairs of stimuli are presented in rapid succession. Dichotic listening is a technique that has been in existence since the 1950's. Dichotic listening addresses the auditory modality only. Functional auditory asymmetry is inferred when a subject is unable to report the stimuli presented to one ear with as much accuracy as the opposite ear (Cooper & O'Malley, 1975). Most of the research indicates that verbal stimuli are reported with greater accuracy when projected to the left cerebral hemisphere or the right ear (Scott, Hynd, Hunt, & Weed, 1979; Schulman-Galambos, 1977).
Over the past decade, the dichotic listening technique has been evaluated. Kimura (1973) and other researchers favor using this technique to investigate ear asymmetry. Kimura (1961) has shown that dichotic listening results correlate reasonably well with the results of cerebral dominance as determined by intracarotid amyntal injections. Schulman-Galambos (1977) has utilized tests of reliability on dichotic listening performances of elementary and college students. Results indicate that the probability a child would score in the same direction on two halves of the test was 0.90. She indicated that all subjects who were tested on two occasions performed in the same way.

Further evidence in favor of the dichotic listening technique comes from Kimura (1967). She cites that the evidence is "overwhelming" that the asymmetrical functioning of the two halves of the brain for speech is reflected in unequal perception of words presented dichotically to left and right ears. The reliability of dichotic ear asymmetry in normal children was calculated by Bakker, Van der Vlugt, and Claushuis (1978). These researchers found about 80 percent of the subjects preserved their initial ear preference. This percentage is less than the Schulman-Galambos report. However, these reports indicate a favorable
reliability for dichotic listening techniques employed in hemispheric asymmetry.

There is also a growing body of recent literature which is disenchanted with the dichotic listening technique. Lishman and McMeekan (1977) view dichotic listening tests with caution, indicating that they are "no more than indirect and approximate indicators of cerebral dominance." They also view this technique as an indicator of receptive language functions only. Lishman and McMeekan (1977) suggested that neural organization was not reflected as subserving aspects of speech. Searleman (1980) examined the usefulness of a variety of subject variables as predictors of cerebral organization for language. In the multiple regression analyses, very little variance could be explained from measures calculated on all subjects. Searleman (1980) indicated that this may be a signification of the inadequacy of dichotic listening to accurately assess language lateralization. Searleman (1980) suggested using other measures of hemispheric specialization such as the EEG or tachistoscope. Satz (1977) was also displeased with conclusions based on dichotic listening technique. He cited the crux of the problem as coming from assumptions concerning a relationship between ear asymmetry and speech-brain lateralization. Satz (1977) explicated that
inductive inferences made on individual subjects to classify them into hemispheric dominant groups may be a reckless assumption. Using a Baysean analysis, inductive inferences were examined about hemispheric dominance based on dichotic listening measures. The probability of right-sided speech, given a left ear advantage was very low ($p = .10$). Thus, when subjects display a left ear advantage in a dichotic verbal task, the probability of misclassification is 90 percent. Satz (1977) cautions the use of dichotic listening due to measurement error, test reliability, and validity.

Further evidence exists indicating that dichotic ear difference is a poor index for the functional asymmetry between the cerebral hemispheres (Teng, 1981). Teng (1981) demonstrates that using dichotic ear advantage as an index for hemispheric dominance is "not well founded on either logical or empirical grounds." Not only is there a variation in degree and direction of ear advantage due to variations in input asymmetry, but also the results of dichotic ear differences have little predictive value, with low retest reliabilities. Along with individual variations in cerebral anatomy, some individuals may have a reversed dominance of the ipsilateral over the contralateral transmission (Whitaker & Selnas, 1976; Damasio, Lima, & Damasio,
Teng (1981) concludes that each dichotic listening test may tap only limited aspects of information processing. Thus, she suggests that no dichotic listening test should join the basis for conclusions on lateralizations of function.

The validity of dichotic listening tests may be lowered due to the factor of ethnology. Scott et al. (1979) suggest that cerebral function for written Japanese to be less fully lateralized in Japanese subjects. Their investigation was to expand knowledge of lateralization of function to include the Navajo Indians. Scott et al. (1979) found that the Navajo subjects demonstrated a left ear advantage compared to the traditional right ear effect with Anglo subjects. Thus, different ethnic groups may be predisposed toward developmental variations in neuropsychological asymmetries. The characteristics of a language may contribute to the developing asymmetry.

**Concurrent tasks.** An alternative means of measuring functional asymmetries exists with concurrent task paradigms. By using a concurrent task paradigm, Kinsbourne and Cook (1971) required adult subjects to talk while balancing a dowel rod on the tip of the right or left index finger. Speaking decreased right-hand scores on balancing duration, but not left-hand scores. Hicks (1975) replicated this study to find similar results.
Hiscock and Kinsbourne (1978) also have employed a dual-task technique in pursuing questions about hemispheric specialization. The authors cited that while most of the knowledge about hemispheric functioning came from dichotic listening and tachistoscopic task paradigms, the dual-task technique was distinguished from other methods for two reasons. First of all, in a dual-task technique the subject produced the words. In a perceptual task, the verbal nature must be inferred from characteristics of stimuli. Thus, less control over the information processing was provided in perceptual tasks (e.g., dichotic listening) as opposed to subject-production tasks.

The concurrent task paradigm was further distinguished from other techniques in that the dual task technique minimized extraneous variables such as attention. Hiscock and Kinsbourne (1979) suggested that in a dichotic listening situation perceptual asymmetries can be influenced by such factors as mental set, strategy, and volitional shifts of attention. The continuous nature of a task in the dual-task paradigm minimizes these attention problems. Thus, attentional biases should be less than the perceptual tasks, in which attention may be focused to one side or the other.
Questionable Nature of Laterality Measurement

While most researchers would agree that hemispheric lateralization can be measured, there are a few recent studies which cast doubt on this subject (Colbourn, 1978; McFarland & Ashton, 1975). Colbourn (1978) concluded that laterality cannot be measured quantitatively as some authors have implied. He explained that outcomes on laterality measures usually yield three kinds of outcomes: a left side advantage, a right side advantage, or no advantage on either side. This brings up the question as to when an "advantage" is a real advantage or rather a statistical effect. These three basic patterns of lateralization make it difficult to compare different individuals or groups. Colbourn (1978) thus regarded the use of between-subject comparisons of laterality with caution. He stated that there was presently an over estimation of the capacity of current laterality paradigms which may be accounted for by a lack of strong theory and understanding of hemispheric processes.

McFarland and Ashton (1975) have found laterality studies to be plagued by: (a) poor psychological methodology; (b) lack of careful specification of stimulus parameters; and (c) exclusive use of left hemisphere dependent measures; for instance verbal activity alone as used
by Kinsbourne and Cook (1971) does not assess laterality effects. Stone (1980) discusses the problem of correlating various measures of laterality and total accuracy. He has found many of the correlations to have non-zero expected values. Stone (1980) discusses the dangers of using laterality measures in hypothesis testing.

Thus, caution should be employed with conclusions and generalizations concerning laterality measures and results. However, that does not preclude the usage of laterality measures. Rather, an awareness of these factors should be incorporated into the researchers' investigations.

**Hemispheric Specialization**

The topic of hemispheric specialization will be discussed under eight sections: (a) spatial processing, (b) verbal processing, (c) sequential processing, (d) global-local processing, (e) motor processing, (f) musical processing, (g) nonverbal processing, and (h) visuospatial processing.

**Spatial processing.** The right hemisphere is believed to be responsible for spatial processing (Gardner, 1975; Galin et al., 1978; Durnford & Kimura, 1971; Fontenot & Benton, 1972). However, both hemispheres may be responsible for some aspects of spatial orientation (Ratcliff & Newcombe, 1973). Hecaen (1975) and commandes
stated that more emphasis should be placed on detecting processing strategies used by subjects to solve problems rather than use the verbal-spatial dichotomy of hemispheric asymmetry.

Due to an increase in right hand scores with the perception of nonsense shapes, Witelson (1974) suggested the possibility of the left hemisphere being more efficient in spatial processing. Although she considered this view to be unlikely, she suggested that the extent of participation of each of the two hemispheres in processing a stimulus depended on the modality components within each stimulus.

Another study suggesting left hemisphere involvement in spatial processing comes from Gardner et al. (1977). They suggested that the right hemisphere was the primary but not exclusive processor of spatial-form information Nebes (1974) suggested that on some spatial tasks, right and left hemispheres may be equally competent, though they may use different strategies. Ornstein, Johnstone, Herron, & Swencionis (1980) described a model that explained the difference between the hemispheres as not a preference of input or output type, but of processing strategy. Ornstein et al. (1980) explained that if analytical processing was more a capacity of the left hemisphere than the right, a spatial task might be processed by the left hemisphere. Thus, the
type of information processing may determine which hemisphere is dominant.

Some attempt has been made to isolate the area of the brain responsible for spatial processing. De Renzi, Faglioni, and Previdi (1977) found a dominant role in the posterior region of the right hemisphere in subserving spatial memory.

**Verbal processing.** Vocal production of any type requires a large contribution from the left hemisphere (Hicks, 1975; Gardner, 1975; Broadbent & Gregory, 1964). In right-handed subjects, there is a right ear superiority in dichotic listening tasks employing verbal stimuli such as words, digits and consonants (Kimura, 1967).

Left hemisphere specialization for language is thought to first occur between the ages of three and five (Geffen, 1976). After this age span, the right hemisphere gradually performs less of the language functions. Geffen (1976) concurs that, after the age of five, the effects of right lesions are the same as those in adults.

Zaidel (1976) has extrapolated that the right hemisphere may be dormant for speech. He postulates that right hemisphere competence for speech can not be released as long as the integrity of the left hemisphere is maintained. Gazzaniga and Sperry (1967) found evidence of right hemispheric control of speech in split-brain patients.
during their investigation from which they concluded that the disconnected right hemisphere comprehends language surprisingly well.

Although symbols may be learned and used by many animals, language is characteristically a human achievement. Animals may use sounds and gestures, but they lack syntactical organization. Although the specialization of the left hemisphere for language is well established, language cannot be said to be "located" in either the right or left hemisphere solely (Gardner, 1975; Zaidel, 1976; Gazzaniga & Sperry, 1967). While damage to the "language area" in children results in aphasias, children recover due to language mechanisms in the right hemisphere. Aphasias from similar lesions in adults are often permanent.

Broca named the third frontal gyrus of the left cerebral hemisphere as the speech center. Lesions of this area interfere with the motor aspects of language (Gardner, 1975). A patient with Broca's aphasia has speech which is slow, labored, grammatically incorrect, and telegraphic. While writing may be severely impaired, spoken and written comprehension is unimpaired. Further complicating the issue, was the discovery of different types of language disability with lesions surrounding Broca's area. In 1874, Wernicke encountered a group of aphasics who were capable of speech, but who made meaningless sentences. These patients were
found to have lesions in the first gyrus of the left temporal lobe (Groves & Schlesinger, 1979). Damage to Wernicke's area (near Broca's area) caused loss of comprehension of the spoken word (Gardner, 1975). Speech was rapid and well-articulated. However, writing was defective and speech was without content. Gardner (1975) stated that lesions in similar areas of the right hemisphere had no effect upon language. Groves and Schlesinger (1979) concluded that there appeared no single area which when damaged was responsible for all types of language disorders.

Levy and Reid (1976) have proposed a relationship between handwriting style and the language dominant hemisphere. Most dextral and sinistral people have left hemispheric representation for language. Most right-handed individuals hold the right hand noninverted in writing. However, right-handers in whom the right hemisphere was specialized for language seemed to display an inverted style. Left-handed people have a similar relationship in handwriting style. Due to motor projections, inverted writing style would reveal that the language-dominant hemisphere is ipsilateral with the writing hand.

**Sequential processing.** Sequencing can be defined as an ability to process two or more stimulus events in the order of occurrence (Kim, Royer, Bonstelle, & Boller, 1980). Some evidence indicated that the left hemisphere is dominant.
for sequential processing whether the stimuli are verbal or nonverbal (Cohen, 1973; Fontenot & Benton, 1972). Research also indicates that sequential-manual activities are processed in the left hemisphere (Kimura & Archibald, 1974; Lomas & Kimura, 1976; Nachshon & Carmon, 1975).

Until recently, sequencing ability was assumed to rely on processing mechanisms within the left cerebral hemisphere (Kim et al., 1980). Using tasks similar to those used in studies of sequencing ability, De Renzi et al. (1977) examined the relationship of short term memory for verbal and nonverbal stimuli. Right hemisphere lesion patients performed worse on nonverbal sequencing than the left hemisphere lesion patients. De Renzi et al. (1977) concluded that the left hemisphere may be associated with verbal (sequential) material, while the right hemisphere is associated with nonverbal (sequential) stimuli.

Kim (1976) had similar results to the De Renzi et al. (1977) study. Kim (1976) compared aphasics, right hemisphere lesioned patients, and normal control subjects on verbal sequencing tasks. Both aphasics and right hemisphere lesion patients were impaired in sequencing verbal stimuli as compared to normal subjects. Kim et al. (1980) explored the laterality effect on performance of verbal and nonverbal sequencing tasks on lesioned patients. They formulated a rule of "material-specific laterality of hemispheric
asymmetry." They concluded that the left hemisphere was associated with verbal sequencing ability while the right hemisphere was associated with nonverbal sequencing ability.

Lomas (1980) suggested that the left hemisphere's motor control was not concerned with sequencing, but contributed to posture changes that were relevant to a sequence of movements. Thus, Lomas (1980) proposed that sequencing per se was not specifically under left hemisphere control.

Global-local processing. Evidence reported in normal right-handed adults indicated evidence that processing of local aspects of a stimulus was more efficient in the left hemisphere, while global aspects may be better handled by the right hemisphere (Levy-Agresti & Sperry, 1968; Atkinson & Egeth, 1973). Martin (1979) demonstrated that while local aspects of a stimulus are more efficiently processed in the left hemisphere, the global aspects are not strongly lateralized. Having used stimuli which were linguistic in nature, Martin (1979) indicated this may be a salient factor in determining lateralization. In studies involving global and local attributes, components should not differ in complexity, familiarity or recognizability so that the whole can be predicted from the elements. Using the Stroop test, Martin (1979) made sure the local and global aspects of the stimulus were of similar conflicting nature, so
that interference incurred would be an indicator of processing type.

Ornstein et al. (1980) found whole-whole matching to be processed primarily by the right hemisphere, while part-whole matching is processed by the left hemisphere. Nebes (1978) describes an approach of "preferred strategy" to explain global versus local processing as follows:

This division of the two hemispheres according to the functions they perform rather than by their preferred input or output has led several investigators...to propose a model of hemispheric action in which the minor hemisphere is seen to organize and treat data in terms of complex wholes, being in effect a synthesizer with a predisposition for viewing the total rather than the part. The left hemisphere in this model sequentially analyzes input, abstracting out the relevant details to which it associates verbal symbols in order to manipulate and store the data more efficiently. (pp. 131-132)

**Motor processing.** Motor programming or motor function is controlled by one cerebral hemisphere, usually the left (Taylor & Heilman, 1980; Kimura & Archibald, 1974; Gardner, 1975). The control resides in the association cortex rather than the motor cortex. Clinical evidence of motor control can be seen from apraxics (Gardner, 1975). An apraxia is the inability to perform a purposeful or voluntary movement, when there is no paralysis. Gardner (1975) has found that apraxias result when the association cortex of the dominant hemisphere is destroyed. Destruction of different
parts of the association cortex may cause various deviations in movement patterns.

Taylor and Heilman (1980) have found support for the concept of left-hemispheric dominance for motor programming in right-handers. They have developed two hypotheses with implications for novel performance of motor acts involving left-hemisphere motor dominance. Their first hypothesis suggests that new skills are acquired more rapidly by the right hand than the left due to direct motor connections from the right hand to the left hemisphere. Information coming from the left hand must cross the corpus callosum before being processed by the left hemisphere, thus a less efficient procedure. The second hypothesis suggested states that there will be greater transfer of skills from the left hand to the right than vice versa.

Musical processing. The right hemisphere is responsible for remembering musical tones (Bogen & Gordon, 1971; Bradshaw, Nettleton, & Geffen, 1971). However, more recent research suggests that music abilities are not as lateralized as earlier studies have indicated. Johnson and Kozma (1977) suggest that it may be possible for different components of music to be processed in different hemispheres, the melodic component in the right and rhythm in the left.

Craig (1979) explored the relationship between cerebral dominance as assumed by handedness and the perception of
the octave illusion. The octave illusion is an illusion based on oscillating octave pitch pattern. In this experiment, one ear received a sequence of tones (high-low-high-low...), while the opposing ear received an opposing pattern (low-high-low-high...). A subject was reported to have heard the illusion if the pattern described was a sequence of single tones which alternated between the right and left ears. Craig (1979) found that increased musical training results in a decrease in the perception of the illusion. The decrease in the illusion perception was attributed to subjects with three or more years of musical training. These subjects had experience with diligent listening to tonal stimuli and some theoretical musical background.

Music may be processed by the right hemisphere in non-musicians or in the left hemisphere in musicians. Gates and Bradshaw (1977) have found differential laterality effects in processing musical information to be a function of subjects' training or adopted strategies. Although the left hemisphere has control of temporal order and rhythm, Gates and Bradshaw (1977) maintain that one hemisphere should not be regarded as "dominant" for music, but rather each interacts with each other. In an earlier study (1975), Gates and Bradshaw supported the notion that musical
performance depends largely upon the coordinated and independent activity of the two hands.

**Nonverbal processing.** Nonverbal or environmental sounds are more dependent on the right hemisphere and are more accurately identified by the left ear (Knox & Kimura, 1970; Spinnler & Vignolo, 1966; Spreen, Benton, Fincham, 1965). Knox and Kimura (1970) investigated the cerebral processing of nonverbal sounds in boys and girls. Environmental sounds such as dog barking, brushing teeth, clock ticking, car starting, and water pouring were presented dichotically. Results indicated that nonverbal stimuli (environmental sounds) were more accurately identified with the left ear in children.

**Visuospatial processing.** Right hemisphere superiority in processing visuospatial information has been found in normal right-handed persons (Kimura & Durnford, 1974; Berlucci, Brizzolaca, Marzi, Rizzolatti, & Umilta, 1979; Riege, Metter, & Williams, 1980). McGlone and Kertesz (1973) assessed language and visuospatial abilities in males and females with left or right cerebral damage. Results from visuospatial testing were worse in the right than left hemisphere damaged group. Birkett (1978) found no lateralization of visuospatial function with right-handed males performing dot location and delayed form recognition.
tasks. Birkett (1978) concluded that knowledge concerning subjects' processing strategies was needed.

Models of Information Processing, Perceptual Asymmetry and Attention

The topic of models of information processing, perceptual asymmetry and attention will be discussed under two sections: (a) general models of information processing, (b) models of perceptual asymmetry.

General Models of Information Processing

A number of general models of human information processing exist which offer explanations of attention and time-sharing (the simultaneous processing of two tasks) that are relevant to an understanding of hemispheric asymmetry. The first model to be examined is Broadbent's filter theory which is a relatively amorphous limited capacity channel model (Kantowitz & Knight, 1974). Singer (1975) described Broadbent's theory as an attentional theory. He stated that an individual is selective in what he taskes in from the environment. There is a "filter" at the entrance of the nervous system that permits some classes of stimuli to pass but not others. Stimuli that are particularly intense or that are novel are given priority of selection. Kantowitz and Knight (1974) suggest that one of the problems
with this theory was the inability to specify the locus of limited-channel effects.

A second model of general information processing is Kahneman's variable-allocation-capacity model (Kahneman, 1973). In his model, Kahneman described total capacity of information processing as increasing slower than the capacity flowing to the primary task. As total capacity increased, there was a decrease in space capacity. Kahneman (1973) argued against the limited capacity channel model.

Information processing models provide the framework for examining limitations of attention, perceptions, and memory. Welford (1968) has formulated a model which was mainly concerned with how a stimulus is perceived and translated into action, with reference to short- and long-term storage. He emphasized three major mechanisms needed for information processing: (a) perceptual mechanism, which perceived and identified information sent from the sense organs; (b) translation mechanism, which decided the choice of attention; and (c) the effector mechanism, which coordinated and phased the action.

Kinsbourne and Hicks (1975) described single and multi-channel models as, "metaphors derived from the perspective of the communications engineer and do not necessarily do justice to the organization of biological systems." (p. 346) Broadbent's model, Kahneman's model, and information
processing models are very general information processing models. Thus, three models of perceptual asymmetry and attention will be discussed that can be more directly applied to hemispheric processing.

Models of Perceptual Asymmetry

One of the first models of perceptual asymmetry was proposed by Kimura (1961, 1966). She found the superiority of the right side of the body for verbal material to be the result of access of the right ear which connects to the left hemisphere. In most people, the left hemisphere is more specialized for the processing of language and, therefore, the right ear would favor verbal input. The left ear favors nonverbal input. All of this is made possible by contralateral pathways between the ears and cortex which may occlude activity in the ipsilateral pathways. Kimura has performed most of her research using dichotic listening paradigms. Support for her theory is contained in a number of studies (Geffen, 1976; Geffner & Dorman, 1976; Broadbent & Gregory, 1964). Other studies demonstrating ear asymmetries with monaurally-presented stimuli have suggested that Kimura's theory may need to be revised (Bakker, 1969; Catlin, Vanderveer, & Teicher, 1976; Fry, 1974).

Kinsbourne and Hicks (1975) have proposed a general model for the operation of interference effects in a dual
task paradigm. They emphasize that each human has a limited amount of functional cerebral space that is a highly linked neural network. The programming of a continuous task involves a cerebral locus, at which point by spread of activation, the cerebral space becomes occupied. A concurrent task will require a locus within the same space. The distance between the foci depends on the localization of function that each task requires. The closer the foci are to each other, the more interference is likely to occur. The greater the distance between foci, the better the individual can run off two programs simultaneously. If the foci are functionally remote from each other, unrelated concurrent motor programs can be run efficiently. Kinsbourne and Hick's model is referred to as the "functional distance model."

Kinsbourne and Cook (1971) had subjects balance a dowel rod on the right and left index finger while speaking and then remain silent. They found that a manual skill executed concurrently with a verbal cognitive task may be enhanced if the skill is performed with the left hand and yet impaired when the right hand is used. The facilitation effect explained within the realm of the functional distance model, is that there was no time-sharing occurring with the manual and verbal skills during left hand involvement. Rather, each
of the concurrent tasks was under the control of a different hemisphere. Thus, possible interference was reduced improving the functional efficiency of each hemisphere.

A corollary to the functional distance model exists in that, although the functional cerebral space is fixed, a highly automatized (highly practiced skill) task will lift limitation of capacity because the automatized task involves very limited cortical area.

Kinsbourne and Cook (1971) proposed a model of "hemispheric sharing" or the need to program both performances in the same hemisphere. Intra-hemispheric competition should produce more disturbance of performance than inter-hemispheric competition. In other words, there should be greater interference between concurrent activities when both are programmed by the same hemisphere.

McFarland and Ashton (1975) have criticized the study of Kinsbourne and Cook (1971). They asserted that the investigators made no comparison between the control task and the spatial condition (dowel balancing). Also, the control condition did not ensure that the subjects were not silently rehearsing verbally. Subjects were instructed to maintain a "blank" mind under the control condition. McFarland and Ashton (1975) cite that processing of extraneous spatial information probably occurred because subjects
could view their manual performance. Thus, the enhancement of the right-hand effect could be explained.

Kinsbourne's functional distance model is also referred to as a model of "perceptual asymmetry" and a model for the "operation of interference effects in dual task performance." A significant body of research exists which support Kinsbourne's theory (Allard & Bryden, 1979; Hicks, Bradshaw, Kinsbourne, & Feigin, 1978; Gardner et al., 1977; Kinsbourne & Cook, 1971; McFarland & Ashton, 1978; Dalby, 1980).

There have been two interesting studies involving hypotheses concerning hemispheric asymmetries (Heilman & Van Dan Abell, 1979; Smith, Chu, & Edmonston, 1977). Heilman and Van den Abell (1979) have proposed an interesting hypothesis concerning hemispheric asymmetries. To determine whether the right hemisphere dominates activation, subjects were given lateralized warning stimuli followed by central reaction time stimuli. The authors proposed that the right hemisphere can activate for the left hemisphere better than the left hemisphere can activate the right hemisphere. The results of this study support the hypothesis that the right hemisphere dominates activation. Smith et al. (1977) have recently proposed a hypothesis concerning interference effects/attention during performance of concurrent tasks. They believe that hemispheric dominance does
not imply superior processing power, but rather the left hemisphere may signify a lower threshold of arousal in specific areas by particular stimuli. This may be accompanied by reciprocal inhibition of homologous part of the opposite hemisphere. Using a concurrent task paradigm, Smith et al. (1977) presented music into one ear or the other during a unilateral haptic matching task. While haptic perception of the left hand generally surpasses that of the right, results indicated that simultaneously playing music into the left ear reverses this superiority in hand performance. Music played into the left ear is said to occupy the right hemisphere's attention, "disengaging" it from the left hemisphere, permitting a greater proficiency of the right hand. They propose that when the right hemisphere is unoccupied, ipsilaterally conducted tactual information activates attentional mechanisms of the right hemisphere with consequent interruption of the left hemisphere. There has been little support from other studies for this hypothesis basically due to a lack of research on haptic processing.

**Variables Associated with Hemispheric Asymmetry**

The variables associated with hemispheric asymmetry will be discussed under two topics: (a) handedness, and (b) sex and age differences.
Handedness

The handedness topic will be divided into two sections: (a) handedness groups, and (b) handedness and cerebral organization.

Handedness groups. Handedness has been found to influence hemispheric functioning in several studies (Milstein, Small, Malloy, & Small, 1979; Finlayson, 1976; Thomas & Campos, 1978). Thus, determination of handedness with a subject pool must precede implementation of research. Basically there are two categories of handedness: those who are lateralized and others who are amilateralized. Lateralized subjects are designated "right-handers" or "left-handers." Finlayson (1976) has determined an interesting relationship with right-handed children. Through performance of motor tasks a relationship between hands was established. Finlayson (1976) demonstrates that in right-handed children the left hand functions generally at about 90% of the level of the right hand. Reitan (1974) suggests that this relationship could possibly serve as a basis for considering the differential functional efficiency of the two sides of the body.

Additional variability can be found in amilerals (subjects who display mixed preference on a handedness questionnaire). Flowers (1975) contends that ambilateral
subjects perform as if they have two nonpreferred hands. Poor performance of ambilateral subjects has been supported in the literature (Harris, 1975; Silverman, Adevai, & McGough, 1966). Todor and Doane (1978) have divided ambilaterals into two groups as assessed by relative manual performance: (a) ambidextrals, whose performance with either hand is equal to that of the dominant hand in lateralized subjects, and (b) ambisinistrals, who exhibit poor performance with both hands. Todor and Doane (1978) hypothesized that low performing ambisinistrals would exhibit less hemispheric specialization of function than the high performance of the ambidextrals. Results of their level attained by each hand on a given motor task to determine which hand achieves the better performance (Benton, Meyers, & Polder, 1962). Still another method includes assessing handedness by a Fitts reciprocal tapping task (Todor & Doane, 1978). In this method, the subject alternately taps two adjacent targets with a handheld stylus. The number of "hits" and "errors" are recorded and used in a handedness index formula. The final score is compared with arbitrary cut-off scores which place the subject into a numerical category.

A handedness questionnaire can indicate a large between-subject variability. Humphrey (1951) investigated handedness by having subjects state their handedness. He then
gave subjects questionnaires on various activities and hand preference used. While there was some variability between right-handed subjects, the variability was greater for the self-reported-left-handers. Humphrey (1951) found some left-handers to indicate even more right-hand preferences than the average right-hander.

The reliability of the handedness questionnaire has been investigated. Hicks and Kinsbourne (1978) cite that subjects tested a month later displayed 11.2% disagreement on items for left-handers and 4.2% for right-handers.

Benton, Varney, and Hamsher (1962) studied right-handers and left-handers who claimed to strong in handedness. Subjects performed various tasks. Results indicated that among the right-handers, 72% showed strong right-handed superiority, 16% showed slight, and 12% showed no difference between hands or left-handedness. Left-handers showed 55% left-hand superiority, 30% showed no difference between the hands, and 15% displayed right-hand superiority.

Acquisition of handedness is often thought to be socially determined. There is little doubt that explicit social attitudes and overt parental training can affect handedness. Leiber and Axelrod (1981) expect modeling handedness within the family to be reflected in 'degree' of handedness rather than 'incidence.' Incidental learning
should be expressed in strength of hand preference, rather than a switching from one category to another. Leiber and Axelrod (1981) state that the presence of right-handers in the family should make a right-hander more right-handed and vice versa. Their finding, that family sinistrality was associated with large increases in the incidence of nondextrality but with very small changes in the degree of handedness, suggests that intra-familial learning is a negligible factor in handedness.

**Handedness and cerebral organization.** One of the facts used to predict the cerebral make-up of an individual for language processing is handedness (Searleman, 1980). Left hemispheric dominance for language is not found in all individuals. While a great majority of right-handers show left hemisphere dominance for language, this appears in only two-thirds to three-quarters of left-handers (Lishman & McMeekan, 1977). Lishman and McMeekan (1977) indicate that dominance for language functions may be less securely established in left-handers and ambidexters than in right-handers. Techniques to assess the hemisphere dominant for language, have yielded an estimate of 98-99% left cerebral dominance for speech among right-handers (Goodglass & Quadfasel, 1954; Milner, Branch, & Rasmussen, 1964; Pratt & Warrington, 1972). Warrington and Pratt (1973) estimate right cerebral dominance for speech among left-handers to be
about 25%. Goodglass and Quadfasel (1954) have a higher estimate for this group, 47%. Although the relationship between handedness and hemispheric asymmetry may be difficult to ascertain exactly, agreement should be made that the two are related.

There is evidence that familial history of sinistrality may obscure the relationship between handedness and cerebral lateralization (Lake & Bryden, 1976; Hecaen & Sanguet, 1971). Hecaen and Sanguet (1981) found few left-handers without familial sinistrality to show reading disturbances following right-sided lesions. Left-handers with familial sinistrality were more likely to show reading disturbances following lesions to either hemisphere. Searleman (1980) found no evidence to indicate familial history was a main effect for language lateralization. Familial history of sinistrality is a controversial subject variable within handedness. Along with familial history of sinistrality, many other factors such as multiple genetic influences, cultural pressures, sex, and the effects of minimal brain damage all contribute to the complex subject of handedness. Neuropsychological research should attempt to make assessment of handedness to eliminate the possibility of this extraneous variable contaminating results and limiting generalization.
Sex and Age Differences

In order to assess sex differences within hemispheric asymmetry, a number of topics will be discussed: (a) organization of the central nervous system by sexual hormones; (b) postnatal brain development; (c) developmental trends in hemispheric asymmetry; (d) literature of children concerning sex differences within hemispheric asymmetry; (e) adult literature concerning sex differences in hemispheric functions or asymmetry. All of these topics are essential to study sex differences and hemispheric asymmetry.

Hormonal "organization" within the central nervous system. Regulation of all bodily activities including behavior can be conceived as being controlled and regulated by the nervous system and the endocrine system. Sexual differentiation occurs by hormonal control. Human beings possess the genetic endowment which determines the genetic sex of the fetus (Groves & Schlesinger, 1979). During the fifth week of development, the fetus' sex will be determined. Groves and Schlesinger (1978) state that information from the Y chromosome (from the XY genetic constitution) stimulates the "indifferent gonad" during the fifth week to transform into a fetal testis. No sexual development takes place during the fifth week if the genetic constitution is XX. Instead, at about the twelfth week, the indifferent
gonad changes into a ovary. Thus, if the fetus is to develop in the masculine direction, certain hormones must be present during a relatively short "critical period."

Some of the initial research on this topic was performed on guinea pigs and rats (Phoenix, Goy, Gerall, & Young, 1959; Grady & Phoenix, 1963). Phoenix et al. (1959) injected pregnant guinea pigs with the male gonadal hormone testosterone. Female offspring of the mothers treated with testosterone exhibited certain aspects of male sexual behavior. Grady and Phoenix (1963) castrated neonatal rats to study later sexual behavior. If the surgery was done before ten days of age, these animals displayed aspects of female sexual behavior. Thus, the absence or presence of testosterone at "critical periods" of fetal development may leave both males and females to display feminine behaviors. Sexual hormones have an "organizing" effect on the brain in that they mediate sexual behaviors.

Neuropsychologically research contains abundant evidence of behavioral differences between the sexes. In addition to evidence for differences between male and females in reproductive and related activities, sexual behaviors can be modified by gonadal hormones at critical periods in development. Thus, it would not be surprising if neural structures subserving sex-typical behaviors were
to differ in males and females (Goldman, Crawford, Stokes, Galkin, Rosvold, 1974).

**Postnatal brain development.** The human brain will increase about two and one-half times in length from birth to adulthood (Kinsbourne & Smith, 1974). The brain of the newborn is comparatively large in proportion to body size: the brain comprises 12% of the newborn infant's body weight, but 2% of that of the adult (Peiper, 1963). The brain will weigh approximately 300 grams at birth, increasing to about 1250 to 1500 grams in adults (Reinis & Goldman, 1980). Reinis and Goldman (1980) stated that the brain grew rapidly over the first four years, at which point, the brain was 80% of adult weight. By 8 years, the brain was 90% that of adult weight. By age 16, the brain was adult size. The infant's brain seemed to be complete since the heart, lungs, kidneys, and liver were functional. However, the most important and largest portion of the brain, the cerebral hemispheres, have not begun to function (Peiper, 1963). Even the lower parts of the brain are not functioning fully. Peiper (1963) stated that movements were not regulated by the cerebral cortex. Uncoordinated movements can be traced to lack of regulation of the pyramidal tracts which are not inhibited by the corpus striatum.

During the first days of life, muscles of the infant are atonic. This may be due to the lack of function within
the cortex of the cerebral hemispheres. Peiper (1963) postulates that hypertonia of muscles is caused by the lower centers being more burdened by invading centripetal stimulation than later when part of the stimuli can be diverted to the cortex. He also describes the senses of the newborn as being functionally intact at birth. All sensory nerves can transmit excitation through the brain. The reflex arc does not rely on the cerebral hemispheres, but passes through the thalamus opticus and the pallidum. Although functional at birth, the eye and ear senses do not operate at functional capacity.

Conol (1963) studied the development of the human cerebral cortex during the first month of life. The following is a summary of his findings:

1. Maturation of internal pyramidal layer especially in the region of the trunk, shoulder, and arm.
2. Nerve cells decrease in number and increase in size.
3. Dendrites and axons increase in size.
4. The number of spines increases in dendrites.
5. Axons of Golgi II cells form a mesh of fine fibers in all layers throughout the cortex.
6. The size and number of exogenous fibers increase.
Kinsbourne and Smith (1974) have found postnatal brain growth to be caused by the extension of dendrites and the proliferation of connecting axons. Cortical cells develop elaborate dendrites. New nerve cells are produced in the cerebral hemispheres and cerebellum. Kinsbourne and Smith (1974) state that the new nerve cells result in the "appearance of interstitial microneurones which may have a role in modification of circuits in later stages of development." (Kinsbourne and Smith, 1974, p. 230).

The brain of the newborn infant is histologically immature. Myelination has only developed to a minor degree and in some places not at all (Peiper, 1963). Myelination begins with the phylogenetically older regions. At birth, the nerve fibers within the cerebral cortex are not myelinated (Reinis & Goldman, 1980). The visual, auditory and somesthetic areas, become myelinated before the motor cortex. Around puberty, ages 13-16, association areas become fully myelinated.

Berkoff and Fox (1972) have described some of the general features of myelination in humans. They describe myelination as occurring in waves or pulses, but not at a uniform time. In general, myelination first occurs close to the cell body and proceeds to the terminal portion of the nerve. Myelination of tracts occurs in the order of their importance. For instance, myelination
occurs prenatally in various tracts of the spinal cord. Myelination of cortical gray matter is thought to continue past puberty into adulthood. Myelination of tracts to convey sensory information of tactile, proprioceptive, auditory, and gustatory stimuli begins in utero. Although absence of myelin does not mean absence of function, an increase in the amount of myelin has been correlated with an increase in functional capacity (Fox, 1971).

Yakovlev and Lecours (1967) have found the hemispheres and brain stem to exhibit three zones which mature at contrasting rates. The "median zone," consisting of the hypothalamus and midline reticular nuclei of the thalamus, is concerned with regulating metabolic and reproductive functions. Maturation in this area may take two to three decades. The "paramedian zone" (cingulum, limbic cortex, basal ganglia) governs innate motor patterns and matures at puberty. The "supralimbic cerebral cortex zone" consists of the commissural and association systems. Maturation of this zone extends through maturity to old age. This kind of research supports the hypothesis that cerebral dominance is not a state but a process that continues through life (Brown & Jaffe, 1975).

Brain growth can also be assessed indirectly by malnutrition studies. Severe restriction of protein and/or calorie intake in early life may permanently influence
growth and maturation of the brain. Brazier (1975) cites that among the changes documented when severe malnutrition occurs during phases of rapid brain development are reduced brain weight, decreased myelination, decreased brain cell number, smaller neurons, and decreased cortical thickness. If malnutrition is imposed after cell division has ceased, reduction in brain cell size is reversible with corrected nutrition.

Thus, the preceding discussion concerning postnatal brain growth supports the hypothesis that laterality of cerebral function is probably a maturational process. Most of this process may be completed by puberty, but a continuation into adulthood is also possible.

**Anatomical differences within the brain.** There may be an anatomical asymmetry in human cerebral hemispheres. Witelson and Pallie (1973) have found a marked anatomical asymmetry in human neonate brains in the planum temporale in the left and right hemispheres. The authors have found these differences to be proportional to that of the adult's planum temporale. They have discovered a larger planum temporale on the left than on the right in newborns. Molfese et al. (1975) conclude that some components of the language system may be operational in infants during the first months of life.
Corballis and Morgan (1978) suggested that cerebral asymmetry favored a more rapid development of the left side than the right. These authors have found a number of animals having organs which were more developed on the left than on the right side of the body. These differences increased with the age of the animal. Within the human brain, a larger asymmetry occurred in the adult brain than in the infant brain.

Larroche (1977) has measured human adult hemispheres. The left hemisphere was found to be slightly longer than the right in about 50% of the cases. In the remaining 50%, the right hemisphere is longer than the left. The relationship between hemispheric asymmetry and hemispheric size and shape is unknown.

Wada, Clarke, and Hamm (1975) examined the brains of 100 fetuses. Their results indicated that 90% were larger on the left side in the areas of the frontal and temporal speech zone. Springer and Searleman (1978) supported the notion that the presence of anatomical asymmetries at the fetal stage may be significant in the processing of speech and language in later life. Thus, such anatomical symmetries give support to the notion that functional manifestations may not simply be the result of postnatal experience.
Development perspective of functional asymmetries and information processing. Left hemispheric specialization for language is thought to occur at an early age. Schulman-Galambo (1977) supports the hypothesis that the left hemisphere is predisposed for the processing of language at birth. In an experiment, children in kindergarten through fifth grade and college students listened to a three-pair dichotic words tape. There was a developmental increase in overall accuracy through third grade. The right ear advantage did not change with age.

Evidence for left hemispheric specialization for speech has also been found in infants ages 3 weeks to 4 months (Entus, 1975; Best & Glanville, 1976). Measures used for these experiments included recovery from habituation of high amplitude sucking and heart deceleration. Molfese et al. (1975) reported that auditorily evoked responses in infants one week of age are greater in amplitude over the left hemisphere for speech stimuli, while non-speech stimuli produced larger amplitude responses over the right hemisphere.

Geffen (1976) stated that left hemisphere specialization for language is thought to occur between the ages three and five years. The right hemisphere is then thought to gradually perform less language functions until puberty. Results of her experiment indicated that in a dichotic
listening paradigm, the left hemisphere is specialized for the analysis of speech signals at age five years. Kimura (1967) found speech functions to be represented in the left hemisphere as early as age four in a dichotic listening paradigm.

Further evidence for cerebral lateralization in young children comes from Piazza (1977). Piazza (1977) found evidence of cerebral lateralization in children of three, four and five years of age. A right ear advantage was found for verbal stimuli and a left ear advantage was discovered for nonverbal stimuli. Ingram (1975) also found a right ear superiority on a dichotic listening task for children aged three years. She suggests that the left hemisphere is specialized for speech functions by this age. She also cites that a right ear superiority for speech can be found in Japanese children at age three years and at four years in Canadian children.

Piazza (1977) also found evidence of sequential lateralization of function in children aged three, four, and five years. Using a finger tapping experiment with a secondary task, results indicated a right finger lower tapping rate when the secondary task was left hemisphere (verbal). Kinsbourne and McMurray (1975) found evidence of sequential lateralization in children five years of age. Lower finger
tapping rates were observed on the right than on the left when simultaneously involved in verbal tasks.

Lateralization of right hemispheric functions can also be found in children's literature. Brown and Jaffe (1975) have found that the right hemisphere can be considered dormant in infancy for visual and acoustic communication. Crowell et al. (1973) found the right hemisphere to develop sensitivity before the left hemisphere to photic driving with neonates. The authors conclude the results are evidence of dominance in the right hemisphere for rhythmic visual stimuli.

Tomlinson-Keasey and Kelly (1979) found right hemispheric specialization for words to be associated with lower levels of language skills in third graders. However, every few seventh graders showed right hemispheric specialization for words. The authors concluded that the results reflected the changing nature of hemispheric specialization for words from third to seventh grade. Perhaps the results indicate that there is a developmental change in the hemispheric specialization for words.

While evidence for development of hemispheric asymmetries exists, developmental changes in the speed of information processing also exist. Surwillo (1977) found decision time or speed of information processing to vary
systematically with age. This researcher cites that evidence is abundant that reaction time is longer in children than in adults and decreases systematically during the developmental years.

Todor (1975) implies that developmental differences accrued on a motor task may be the result of mental space not being large enough for them to integrate the required number of schemes. Applying Pascal-Leon's neo-Piagetian model of learning and development to motor tasks, Todor equated development with the age-related process of growth in mental space and learning with change and growth in the repertoire of schemes.

What is the effect of aging on hemispheric specialization? Borod and Goodglass (1980) used dichotic listening on adults between 24 and 79 years. While overall scores declined with age, there was no interaction between age and the degree of right ear advantage for verbal material and left ear advantage for melodies. Borod and Goodglass (1980) attributed the results of age-related cognitive decline to uniform deterioration of cerebral cortical function. Johnson et al. (1979) assessed right and left hemispheric efficiency by using dichotic memory for numbers. Using a sample of older adults, right hemisphere efficiency was found to drop off sharply with age, while
left hemisphere efficiency did not show a significant decline.

Future research on aging and hemispheric specialization might be aided by the use of more sensitive physiological measures. A new type of EEG, the magnetoencephalograph, assesses a more restricted, narrower area of CNS function than the EEG. The use of radioactive tracer techniques to study cerebral blood flow, though quite expensive, holds a great deal of promise for investigating CNS activity related to perception and cognition.

**Sex differences and hemispheric asymmetry.** Sex-dependent hemispheric specialization has been reported in children as well as adults. McGlone (1978) reported that there was much controversy in literature having to do with children regarding which sex may be more asymmetrically organized for the different functions. She cited several explanations for the lack of consistency in the developmental literature. First of all, there was difficulty in obtaining reliable and valid measures of brain asymmetry using dichotic listening and tachistoscopic techniques. Secondly, there may be differences between boys and girls in rate of brain maturation (Conel, 1963; Goldman, Crawford, Stokes, Galkin, & Rosvold, 1974). McGlone (1978) also stated that verbal, spatial and sensori-motor systems may develop at differing rates with respect to each other as well as sexual differences.
She concludes that the rate of neural or sexual maturation, which differs between the sexes, may be related, in a complicated fashion, to hemispheric specialization before and after puberty.

Hiscock and Kinsbourne (1978) found no sex differences in performance asymmetry when speech lateralization was assessed on children between the ages of three and twelve years using a dual task procedure. The researchers cite instances of sex differences in children in dichotic listening tasks. However, they presume that the dual task technique requires a different set of strategies than does dichotic listening. Therefore, it is suggested that failure to find sex differences in dichotic listening.

The preceding studies should serve to remind the researcher to be cautious when exploring relationships between sex differences and hemispheric specialization. Factors such as reliability of techniques to assess hemispheric specialization, rate in both sexes of neural and physical maturation, and handedness should be controlled as well as possible in order to prevent extraneous variables from adversely influencing findings.

Sexual differences in hemispheric functioning are common among children. Sexual differences were found in children performing a sequential task (Wolff & Hurwitz, 1976). In this study, right-handed elementary school
children were instructed to tap in time to a metronome. The children tapped more steadily with the right than left hand at every age from six through eleven years. Girls tapped with greater stability than boys, with manual asymmetry favoring the right hand of girls as opposed to boys. Wolff and Hurwitz (1976) concluded that sex differences of manual asymmetry performance decreased rapidly at 12 years. Denckla (1976) found a similar manual asymmetry decrease in normal right-handed children, but found the decrease at an earlier age. Wolff and Hurwitz (1976) and Denckla (1976) concluded that manual asymmetry for motor sequencing skills was probably established earlier in girls than in boys. Sapir (1966) reported that during preschool years, girls were developmentally ahead of boys in perceptual-motor skills. Sapir (1966) suggested that sex differences in sequencing tasks may be anticipated.

Sexual differences in hemispheric specialization for speech have also been found. Kimura (1967) stated that boys may lag behind girls in the development of left-hemisphere dominance for speech. Geffner and Dorman (1976) suggested that females at the age of four years, do indeed perform differently than males on dichotic listening tasks. These researchers found an absence of an overall right ear advantage in four-year-old females. Rudel, Denckla, and Spalten (1974) demonstrated that girls developed more slowly
in the performance of left-sided (right-hemisphere-dependent) tasks and that girls depend more than boys on left hemisphere mediation.

Buffery (1971) used techniques of tachistoscopic presentations and dichotic listening to assess lateralization in children. He demonstrated a sex difference in the rate and degree of lateralization of spatial and linguistic functions. Buffery (1971) concludes that the results support the theory that functional asymmetry is initiated and influenced by innate structural asymmetry.

Knox and Kimura (1970) investigated cerebral processing of nonverbal sounds in boys and girls. Boys correctly identified significantly more dichotic nonverbal sounds than did girls. Knox and Kimura (1970) concluded that male superiority on a nonverbal task was also found with nondichotic presentation to children between two and five years of age. The researchers suggest that the superior performance of boys on the nonverbal sound task cannot be attributed to superior ability in labeling or verbal strategy. There also cannot be a basis for differential experience of boys and girls with the environmental sounds. Thus, since both spatial and nonverbal auditory perception is subserved primarily by the right hemisphere, and since males significantly perform better than females on these tasks, the right hemisphere may not
function identically in males and females (Knox & Kimura, 1970). Males may have greater right hemisphere lateralization of these functions than females.

Grossi, Matarese, and Orsini (1980) confirmed their own findings of an earlier study by finding a significantly better performance by male children on a spatial span task. A sex difference was also found on a verbal span task among children.

Sex-dependent behavioral effects of cerebral cortical lesions have been elicited in the developing rhesus monkey (Goldman et al., 1974). These researchers removed the orbital prefrontal cortex of the infant monkey. Male rhesus monkeys were impaired on behavioral tests at 2½ months of age whereas similar deficits were not detected in females with comparable lesions until fifteen to eighteen months of age. Thus, regions of the neocortex may be sexually dimorphic in nonhuman primates. The researchers suggest that maturation of a cortical region in the primate brain proceeds at different rates in males and females. Thus, this study gives support to the hypothesis that lateralization of function may be maturational with completion near puberty.

Adult literature concerning sex differences in hemispheric functioning. Many researchers have proposed a greater lateralization of function in males (Lansdell, 1962; McGlone & Davidson, 1973; McGlone & Kertesz, 1973;
Hannay & Malone, 1976). While some studies have failed to find significant sex differences (Hiscock & Kinsbourne, 1978; Benton, Varney, & Hamsher, 1978), those that do find sex difference findings do generally report that females show less lateralization. Wolff et al. (1977) concluded that since women showed smaller differences between hands than did men on a rhythmic tapping task, female adults may be less completely lateralized than males in verbal and visuospatial processing. However, left-handed females performed much like males on the sequential skill. Wolff et al. (1977) found that the less extensive asymmetry in the performance of right-handed women on motor sequencing was due to their greater facility of tapping with the left, but not with the right hand (sequencing is generally considered a left hemisphere right hand task).

Dalby (1980) stated that while most studies have shown sex differences suggesting that females are less lateralized with regard to verbal and/or spatial processing, his study found females to lack lateralized manual interference during one of his spatial conditions. He concluded that this may only be suggestive of the possibility that females were less lateralized than men.

Searleman (1980) pointed out that while many investigators have reported finding sex differences in language lateralization (Lake & Bryden, 1976; Springer & Searleman,
In 1978, these sex differences have been used as evidence that females are less lateralized than males. Evidence that females are less hemispherically specialized than right-handed men comes from lesion data (McGlone & Kertesz, 1973), dichotic listening data (Knox & Kimura, 1970; Lake & Bryden, 1976), dot enumeration (McGlone & Davidson, 1973), and tachistoscopic tasks (Erlichman, 1971).

Johnson and Kozma (1977) had subjects balance a dowel rod on the right ear or left index finger while speaking, while remaining silent, and while humming a melody. They concluded that unimpaired right-hand performance in verbalizing females suggests that language function is less clearly lateralized in females than males. While significant music effects were not obtained, an interesting music effect in terms of direction was obtained. Johnson and Kozma (1977) found worsened right performance in males, while left-hand performance slightly improved. Music had no effect on the performance of either hand in females. The researchers suggest that hemispheric specialization is less clearly defined in females.

Kimura (1973) suggests that right hemisphere specialization is more pronounced in males than females. This difference can often be explained by females using more verbal strategies during information processing. Moore (1979) found support for the observation that females may
process linguistic and non-linguistic information employing strategies different than males.

Lake and Bryden (1976) have called studies dealing with sex differences in dichotic listening to be "virtually unanimous" in showing greater laterality effects in men than in women. These researchers imply that right-handed males are more likely to be right ear superior than right-handed females. Lake and Bryden (1976) cite that the pattern in left-handers is less clear, but that men show a greater asymmetry than women.

Kail and Siegel (1978) presented arrays of digits to the left or right visual field of men and women. Differences in recall of digits was found for men but not for women. These investigators concluded that specialization of the left hemisphere for processing verbal information seemed greater in men than in women.

In addition to the fact that sequential processing tasks, use of dichotic listening paradigms, and those using other techniques have suggested females are less lateralized than males in left hemispheric processing, females also appear to be less lateralized than men with tasks employing the right hemisphere.

McGlone (1978) studied verbal and nonverbal intellectual abilities in lesioned males and females. Her findings indicated that only men in the sample showed specifically
verbal deficits after left hemisphere damage or nonverbal deficits after right hemisphere damage. Women's deficits were less specific and severe than men, thus supporting the idea of greater functional brain asymmetry in the adult male than female for verbal and nonverbal processes.

McGlone and Davidson (1973) found females showed poorer spatial ability when compared to men on a dot enumeration test. They suggested that visual, nonverbal cerebral dominance may be more right hemisphere dependent in males than females. They further imply that females employ a left hemisphere processing strategy when performing a visuospatial activity. McGlone and Kertesz (1973) cited a growing amount of evidence suggesting that sex may affect the lateralization of visuospatial skills. They suggested that hemispheric specialization of the right hemisphere for nonverbal function may be advantageous in efficiency of processing and that males have this neural organization more often than females. McGlone and Kertesz (1973) supported the idea that females tended to employ left hemisphere verbal strategies more often than men. Their results suggested sex differences in the asymmetrical neural processing of spatial material. Spatial impairment was greatest in males with right hemisphere lesions, suggesting the right hemisphere may be more specialized for spatial processing in men than in women.
Elias and Kinsbourne (1974) also agreed that women rely on verbal coding strategies in processing nonverbal tasks. However, they pointed out that their data do not imply male superiority in information processing tasks involving nonverbal mediation are genetically influenced. In their study, two age groups were used (63-77) and (23-33). Although men were equally proficient at verbal and nonverbal matching, young women were less proficient in nonverbal tasks. This condition was amplified in elderly women.

Davidoff (1977) used a paradigm involving detection of dots in the visual field. He found men to be superior over women in this task. He attributed this finding to males not being more lateralized on spatial tasks but to differing maturation rates between the sexes.

Milstein et al. (1979) have found greater utilization and development of right hemisphere mechanisms in males than females. Schweitzer and Chacko (1980) used lateral eye movements (LEM) to identify patterns of cerebral lateralization. They found that females produced significantly more R-LEM, indicating a preferential use of left hemisphere mechanisms when initiating reflective thought. Emotional and spatial stimuli were found to be less lateralized in females within the right hemisphere.

Reaction time studies have evidenced a sex difference in efficiency of hemispheric processing. Rizzolatti and
Buchtel (1977) found males to have faster reaction times to faces when stimuli were presented to the right hemisphere as compared to females' performances. They suggested that for judgments of brief and immediate exposure, a lateralized mechanism specialized for faces can be activated only in males. Low and Rebert (1978) also used a reaction time paradigm and found a sex difference when females differed from males in left intra-hemispheric coordination of reading-related areas and the precentral motor regions. The researchers concluded that this sex difference may have been a function of task difficulty.

Taylor and Heilman (1980) measured subjects during acquisition and cross hand transfer of a complex key pressing skill. They found evidence for left hemisphere motor dominance in normal right-handed males but not for females. Taylor and Heilman (1980) interpreted this sex difference as the result of females having less established motor dominance than males.

Thus, much of the literature describes men as being more lateralized than women in left and right hemispheric processing. Possibly women use verbal strategies to a greater extent than men, thus resulting in a less efficient performance. Women may rely on a greater integration of both hemispheres than men.
Inter- and Intra-Hemispheric Time-Sharing

Inter-hemispheric information processing occurs when information in two different modalities enter different hemispheres simultaneously. Intra-hemispheric information processing occurs when information in two different modalities are processed in the same hemisphere concurrently. Much of the literature involving inter- and intra-hemispheric time-sharing involves assumptions regarding contralateral and ipsilateral pathways. Brinkman and Kuypers (1972) supported the view that each half of the brain "steers" independent movements of arm, hand and fingers contralaterally, but gross arm movements ipsilaterally. Having performed research on split-brain monkeys, Brinkman and Kuypers (1972) indicated that while the arm may be controlled by both contralateral (pathways involving right hand control by left hemisphere and left hand control by the right hemisphere) pathways and ipsilateral (pathways from the right hand to the right hemisphere and from the left hand to the left hemisphere) pathways. Due to the fact that fingers utilize contralateral pathways, much research involved in cerebral lateralization will use the fingers in a manual task rather than the whole arm (Kinsbourne and McMurray, 1975; Kinsbourne & Cook, 1971; Hiscock & Kinsbourne, 1978). Roy and Hodgson (1977) used an arm positioning task and a thumb positioning task in an
effort to localize positions in space. When the thumbs were used, a clear difference between the hands in localizing positions in space was most evident as opposed to the arm positioning task. Thus, research that is assessing cerebral lateralization through motor performance often involves fingers to ensure usage of contralateral pathways.

The corpus callosum is involved in inter-hemispheric processing. An understanding of this structure may provide insight into inter- and intra-hemispheric processing. Myelination of the commissures is not complete at birth but continues to develop into puberty (Conel, 1941; Conel, 1967). Hewitt (1962) found the corpus callosum to be thinner in neonates than in adults. He also found the rostrum of the corpus callosum was not completely developed. He also discovered that the splenium was continuing to develop. Late maturation of the cerebral commissures and the interconnections to the association cortices, may leave these areas open to environmental influences, according to Kinsbourne and Smith (1975). These researchers suggest that functional hemispheric specialization is the result of slow postnatal development of asymmetric control within association cortex regions. Cerebral lateralization requires intact commissures to integrate information. Sperry (1969) found patients whose corpus callosum had not grown evidenced no cerebral lateralization. Thus, as the corpus callosum
matures and myelinates along with other commissures, there is increasing interaction between the two hemispheres.

Dennis (1976) described two distinct mechanisms by which information regarding one hand can become accessible to the hemisphere on the one side of the body. Inter-hemispheric processing involves transferring information from one half of the brain to the other by way of neocortical commissures which give the crossed motor pathways of one hemisphere half access to the afferent systems in the other hemisphere. The second process described by Dennis (1976) was intra-hemispheric processing which involves an exchange of information within a hemisphere between crossed and uncrossed pathways from opposing limbs.

**Developmental Neuroanatomy**

Infants have very poorly developed hemispheric commissures along with poorly developed interconnections of cortical tissues. However, infants do not behave like split-brains (Kinsbourne & Smith, 1974). Crowell et al. (1973) found evidence of unilateral driving by using EEG's from the hemispheres of newborns. They interpret unilateral driving as evidence of a lack of inter-hemispheric integration. Joseph, Lesevre, Dreyfus-Brisac, and Resmond (1975) have shown that there was a general lack of inter-hemispheric processing in newborn infants. They also
found a slight tendency for prematures to have better inter- and intra-hemispheric relationships than full term newborn infants.

The corpus callosum is a large bundle of fibers that serve to connect the two cortical hemispheres. Within the adult brain, the corpus callosum, which is the largest nerve tract in the brain, transmits information bearing on sensory receptive and sensory integrative processes (Myers, 1965). Gazzaniga (1977) discovered that inter-hemispheric exchange of information was totally disrupted following commisurotomy. Visual, tactual, auditory, proprioceptive, and olfactory information was processed and dealt with in only one hemisphere. Gazzaniga (1977) reported that the bisected brain can simultaneously perform certain double tasks better than the intact brain. This may be the result of reduced interference between the cerebral hemispheres. However, the extent to which inter-hemispheric interference may limit performance in everyday functioning remains unknown (Johnson & Kozma, 1977).

Geffen, Bradshaw, and Wallace (1971) suggested that crossing the callosum may result in information loss producing laterality differences. Anzola, Bertoloni, Buchtel, and Rizzolatti (1977) cited that inter-hemispheric nervous circuits were slower because of transfer of information from
one hemisphere to the other. This delay in transmission between hemispheres, on the order of a few milli-seconds, is due to the conduction time of large fibers of the corpus callosum.

Reynolds and Jeeves (1977) found a congenital acallosal (arrested development of the corpus callosum) to have increased reliance on ipsilateral pathways instead of using inter-hemispheric routes. This results in less efficient motor coordination.

Wolff et al. (1977) found a sex difference in manual asymmetry for motor sequencing. They concluded that earlier physical maturation is related to more efficient inter-hemispheric control for motor sequences.

**Hemispheric Time-Sharing**

Most individuals have difficulty simultaneously performing two tasks. Kinsbourne and McMurray (1975) state that when both activities are programmed in the same cerebral hemisphere, the time shared performances will be inferior to those found when an activity is processed by one hemisphere or the other. Many studies have used the time-sharing paradigms (Kinsbourne & McMurray, 1975; McFarland & Ashton, 1975; Kinsbourne & Cook, 1971; Johnson & Kozma, 1977; Hicks, 1975, Dalby, 1980; Hiscock & Kinsbourne, 1978; Piazza, 1977; Green, 1977; Summers &
The results of most of these studies support the Kinsbourne and Cook (1971) model that postulated greater interference between concurrent activities when both tasks are programmed by the same hemisphere. Within these studies, intra-hemispheric time-sharing produced more interference and disruption of performance than inter-hemispheric time-sharing.

Kinsbourne and Cook (1971) had subjects speak while balancing a dowel rod on the left or right index finger. Speaking impaired right-sided performance (intra-hemispheric time-sharing) but enhanced the left side performance (inter-hemispheric processing). Hicks (1975) replicated Kinsbourne and Cook's experiment. He found concurrent verbalization to shorten right but not left hand balancing. Dalby (1980) considered research on right-hemispheric overloading to be less consistent. The results of the above two studies confirm that possibility.

Time-sharing paradigms have elicited similar results in children as compared with adults. Hiscock and Kinsbourne (1978) found talking to disrupt right-hand tapping more than it disrupted left-hand tapping children between the age of three and twelve years. Piazza (1977) found reciting to disproportionately reduce tapping on the right
(intra-hemispheric interference) while humming disproportionately reduced tapping on the left finger (intra-hemispheric interference) in children of 3 through 5 years of age.

Besides verbal and motor tasks, time-sharing effects have also been found for motor and spatial tasks. Dalby (1980) discovered spatial tasks interfered more with left (intra-hemispheric interference) than with right hand performance. McFarland and Ashton (1978) found the left hand was impaired compared to the right by concurrent visuospatial tasks. These studies also support the theory of Kinsbourne and Cook (1971).

Inter- and intra-hemispheric processing have been further elaborated upon in two other studies. Guiard and Requin (1971) tested the hypothesis that the sharing of the informational load between the cerebral hemispheres increased overall capacity of the brain. Their results showed that inter-hemispheric sharing of signals, as well as inter-hemispheric sharing of responses caused an improvement in overall processing capacity. Lomas (1980) demonstrated that speaking competed selectively with right hand performance of a unimanual task. He explained that interference effects cannot be attributed to processing within the same hemisphere, but rather they occur in functioning overlapping systems within that hemisphere.
He stated that intra-hemispheric competition from speaking was present only for certain kinds of motor tasks. Lomas (1980) opposed the theory of Kinsbourne and suggested that the inability to obtain lateralized interference with right hemisphere tasks suggests this is a left hemisphere phenomenon.

Time-sharing effects can also be achieved using other tasks besides verbal, nonverbal, and manual tasks. Botkin, Schmaltz, and Lamb (1977) had subjects perform a digits backward task while simultaneously performing a hole steadiness task. The results supported Kinsbourne and Cook's hemispheric time-sharing model (1971) in that subjects performed significantly better with their left arm on a digits backward task while simultaneously performing a hole steadiness task than with their right arm.

The Kinsbourne and Cook model (1971) of hemispheric time-sharing has received much support throughout the literature. In general, intra-hemispheric competition causes more disruption to performance than inter-hemispheric competition. The notion of functionally overlapping systems is consistent with the Kinsbourne and Cook model (1971), with limited amounts of functional cerebral space available. Much of the time-sharing literature deals with manual and verbal/nonverbal tasks. Less information is
available on time-sharing with the right hemisphere. Also, developmental studies are lacking in both left and right hemisphere time-sharing studies.

**Tactual Information Processing**

Very little information exists in the research today concerning hemispheric specialization of perceptual functions having do to with the tactual modality (Gardner et al., 1977; Dodds, 1978). While more research has been directed to the functions of the left hemisphere, probably due to the cerebral dominance theory, not as much information is present about right hemispheric functioning. Dalby (1980) states that left hemisphere time-sharing studies have been well documented, but research concerning right hemisphere overloading is less consistent. He concludes that there may be more variability in spatial neural programs as opposed to verbal neural programs.

**Neuroanatomy**

Tactile (touch) stimulation is possible in utero (Reinis & Goldman, 1980; Berkoff & Fox, 1972). The tracts conveying tactile stimuli may be partially myelinated in the fetus at 6 months (Langworthy, 1933).

Before reviewing research on tactual processing, the neuroanatomy that allows for tactual perception should be discussed. Gardner (1975) has explained the "general
sense" of touch and the neuroanatomy involved. He stated that when the skin was lightly stroked, the area that was felt or localized was called a "touch spot." Simultaneously, two spots can be distinguished which was called "two-point discrimination." Although the skin contained many receptors, only a few can be related to sensation: mechanoreceptors, thermoreceptors, and nociceptive receptors. Gardner explained that the parent fibers of receptors enter the spinal cord via dorsal roots and the brain stem via cranial nerves. Before entering the spinal cord, the larger fibers of the dorsal roots collect into the medial division. These fibers divide into descending, local and ascending branches. Ascending fibers reach the medulla oblongata. These fibers are also called the lemniscal system or pathways. The lemniscal system includes fast conducting fibers in the skin, subcutaneous tissues, joints, and ligaments which are involved in touch, pressure, vibration, and movement. Tactile sensations are represented predominantly on opposite sides of the brain (Groves & Schlesinger, 1979; Kimura, 1973). Kimura (1973) stated that the tactual and motor systems of the brain were almost completely crossed to that sensory information from the right side of the body travels to the left side of the brain, and vice versa. The corpus callosum and other commissures provided connections between the two halves of the brain. The posterior body
region of the corpus callosum transmits information which relates to tactual discrimination learning (Ettlinger, 1965). In split-brain patients, tactile information reaching one hemisphere may not influence the other (Groves & Schlesinger, 1979).

Miskin (1979) proposed a sequential neural model for touch (see Figure 1). He described hypothetical pathways for tactual learning as follows:

Sensory information from the right hand during tactual learning activates, in succession, the left primary sensory area (SI), the left secondary sensory area (SII), and the left medial temporal (MT) and ventral frontal (VF) limbic areas. In addition, by virtue of transcallosal connections crossing from the left SI to the right SII (either directly or indirectly through a relay in the left SII, or both), sensory information from the right hand also activates, in succession, the right SII and the right ventromedial limbic areas. (p. 144)

Mishkin (1979) discussed the pivotal link in his model to be the secondary sensory area (SII). Garcha and Ettlinger (1980) removed the SII cortex of monkeys and found them to display tactile learning disorders.

Animal Research

Passingham and Ettlinger (1972) cited that impairments on tactile discrimination learning tasks can be evident from monkeys with ablations of the frontal association cortex. The results of their study indicated that the orbital surface contains the focus of the deficit on
Figure 1. Hypothetical pathways for tactual learning. (From Miskin, 1979)
tactile discrimination learning tasks in monkeys with frontal lesions.

During a commissurotomy, various parts of the corpus callosum and commissures can be sectioned. Manzoni, Hunter, Maccabe, and Ettlinger (1973) assessed intermanual tactile transfer skills in monkeys with varying degrees of commissures present. Almost no transfer occurred on combined division of the corpus callosum, posterior commissure and massa intermedia. Their findings suggested that, without the corpus callosum, the massa intermedia supports tactile transfer more effectively than does the posterior commissure.

**Human Pathology**

Commissurotomitized subjects are capable of reading a passage out loud while blindly sorting objects by tactual means with the left hand (Franco, 1977). However, the same subjects could not read while sorting with the right hand. Two tasks cannot be processed at the same time by one or the other hemisphere. Franco (1977) suggests independent processing takes place in each hemisphere, thus sharing attention. Thus, inter-hemispheric processing of tactual information may not be possible with commissurotomitized subjects (Gazzaniga, 1977).

Total agenesis of the corpus callosum results in a deficit in tactile cross-localization according to the
findings of Reynolds and Jeeves (1977). They employed a task with a congenital acallosal subject which involved the finger of one hand being touched while the thumb of the other hand was required to indicate which finger had done the touching. Reynolds and Jeeves saw no deficit with this subject in the ability to tactually cross-identify objects. The authors suggest the subject's increased use of ipsilateral pathways may account for these findings. Dennis (1976) found that congenital acallosals could make tactile discriminations with either hand, but that neither hand could identify the locus of a tactile stimulus or perform independent finger movements. He demonstrated that these subjects can identify stimulus characteristics such as letters, objects, and shapes, but they cannot find the locus of touch. The author suggested that brain has separate mechanisms for localization and discrimination.

Milner and Taylor (1972) tested for delayed matching of tactile patterns on patients with complete midline sections of the inter-hemispheric commissures. In most of these patients, the left hand was superior to the right for the tactile pattern task that required subjects to keep wire figures in memory.

Blind people read Braille more efficiently with the fingers of the left hand than they do with the fingers of
the right hand (Rudel, Denckla, & Spalten, 1974; Hermelin & O'Connor, 1971). Hermelin and O'Connor (1971) found this effect to be more marked for the middle finger than the index finger.

Dodds (1978) found a consistent right hemisphere advantage from results of blindfolded subjects performing a tactual recognition task. A right hemisphere advantage was also discovered in subjects aged 20-84 years on a task involving memory of non-meaningful wire shapes (Riege et al., 1980). The interesting result of this study is that right hemisphere superiority was considerably reduced in the older group (60-84). No other studies of age differences in tactual recognition were found in a review of the literature.

**Tactual Information Processing and Time-Sharing**

Before the 1974 study of Witelson, very few studies existed concerning tactual processing in intact individuals. The research before this date consisted of brain damaged subjects who had yielded a right hemisphere advantage in tactual tests of tactual-visual matching of geometrical forms, nonsense wire shapes, and perception of tactile stimulation and direction (De Renzi & Scotti, 1969; Fontenot & Benton, 1971; Milner & Taylor, 1972). Witelson (1974) presented subjects with pairs of different tactile
nonsense shapes (one to each hand, simultaneously). Subjects then pointed to the correct response from a display in front of them. Stimuli presented to the left hand were more accurately recognized visually than those shapes to the opposite hand. The right hand needs callosal transmission from the left hemisphere which manifests in less efficient processing. Witelson stated that the asymmetry present in this study depended on a dichotomous testing situation.

Witelson (1974) also found hemispheric asymmetry in nonlinguistic tactual perception of boys age 6 years. The test involving dichotomous presentation of pairs of letters to the two hands, indicated that there was no significant effect between hands. Nachshon and Carmon (1975) suggested that this finding may be due to subjects using either of two strategies, verbal or spatial encoding.

Gardner et al. (1977) used a tactual task similar to Witelson's to test right-handed, left-handed, and ambidextrous subjects. Subjects were found to recognize significantly more shapes with the left hand, regardless of handedness. This study supported the attentional model of Kinsbourne.

by these authors to be tactile-visual, thus, crossmodal in nature. They suggest that the crossmodal nature of these tasks may account for their results. Benton, Varney, and Hamsher (1978) used a unimodal matching task of two tactile stimuli without reference to a visual standard. A left-hand superiority was found using the unimanual tactile matching task.

Time-sharing studies with tactual processing have been used with other tasks besides nonverbal symbols and nonsense wire-shapes. Gardner and Ward (1979) found shorter response latencies and greater accuracy when subjects responded with the same hand on the same side that felt the relevant one of two simultaneously presented nonsense shapes. They attributed the results to "S-R compatibility." In other words, responding to a stimulus on the right was faster if done with the hand on the right. Anzola et al. (1977) would interpret these results in terms of ipsilateral responses being mediated by intra-hemispheric circuits, which are faster than contralateral responses.

While most studies have found tactile perception to be superior by the left hand, Smith et al. (1977) found the reverse to be true. Simultaneously playing music into the left ear while performing a haptic discrimination task, creates right-hand superiority. In this condition of right
hand-left ear, intra-hemispheric interference is created, a condition which usually causes more interference than inter-hemispheric processing. The authors suggest that the left cerebral hemisphere has full haptic perception, which is subject to right hemisphere interference unless the attention of the right hemisphere is engaged by contra-lateral stimulation.

The use of music as a secondary task in the Smith et al. (1977) study may not be the best idea. As discussed earlier, music may be processed in different hemispheres depending on musical training.

Beaumont (1981) designed a study similar to Witelson (1974) and Smith et al. (1977). Using Witelson's design for the tactile task, three conditions of no music, music to the left ear, and music to the right ear were used concurrently. Beaumont (1981) did not get the same findings as Smith et al. (1977). The author found a left hand advantage in the no-music condition. This experiment also involved pointing, which may have influenced the results. This study gives support to the functional cerebral space model of Kinsbourne and Hicks.

Beaton (1979) performed two experiments using the effects of a visual monitoring task on a concurrently performed manual sorting task (of sorting nuts and bolts).
The visual monitoring task was affected depending on which hand was performing the more difficult of two simultaneous sorting tasks.

**Sex and Age Differences**

Rudel et al. (1974) found that girls develop more slowly in the performance of right hemisphere tasks. In their experiment, children aged seven through fourteen years were taught to read Braille letters by palpation.

Witelson (1976) used a dichaptic task with boys and girls between six and thirteen years of age. Boys showed evidence of right hemispheric specialization as early as age six years. Girls showed bilateral representation from ages six through thirteen years.

Dichaptic tasks were used with third graders in a study by Klein and Rosenfield (1981). Results of this study indicate a significant right hemisphere advantage for both boys and girls. Although not significant, boys did perform better than girls on this dichaptic task.

A sex difference was found on measurement of tactual pressure thresholds in children (Ghent, 1961). Girls were found to show an adult pattern of greater sensitivity on the non-preferred hand by age six years, whereas boys did not exhibit this pattern until age eleven.
Smith et al. (1977) demonstrated that females significantly outperformed males on the haptic discrimination task. In this study of Smith et al. (1977), subjects performed a haptic discrimination task while concurrently listening to music.

More research has been performed concerning the functions of the left hemisphere rather than the right hemisphere. Most of the literature on tactual processing has evolved over the last 10 years. Time-sharing studies have mainly employed tactual-visual tasks. However, cross-modality appears to be a factor in this research. Very little information is present on sexual differences in tactual processing. Little research and inconsistent findings concerning sexual differences in boys and girls during tactual processing indicate a need for more research in this area. One of the purposes of the present study was to ascertain whether subjects could process simple stimuli to two modalities as well as can be processed by one modality. This idea tests the theory of Gescheider et al. (1975) that when demands on cognitive processes are increased, the simultaneous performance of a second task has a disruptive effect to performance. Tactual information processing by inter- and intra-hemispheric routes will also be explored. Variables of sex and age were also of interest in this study. Through this study, more information will
signals will be available concerning information processes of tactual stimulation.
CHAPTER III

PROCEDURES

This chapter describes the manner in which subjects were selected for study, the nature of the research design employed, a definition of the experimental variables examined, a description of the tasks employed as well as a rationale for their use, directions that were given to subjects, and the manner in which the data were treated.

Subjects

The subjects of this study were 80 boys and girls selected from the second, fourth, sixth, and eighth grades in the Newark Public School System during the Winter of 1982. The students from the eighth grade were selected from three out of the four possible physical education classes. The elementary students were selected from regular classroom settings. Students ranged in age from seven through fourteen years old.

Permission to undertake the study was granted by the Committee on Human Subjects, The Ohio State University. The letter of permission is contained in Appendix A (see Appendix A, Human Subject Review Committee Response). A letter explaining the nature of the study and a consent
form was sent to the parents of every second, fourth, sixth, and eighth grade student at three elementary schools and one junior high in the Newark Public Schools before the study began (see Appendix B, Correspondence to Parents). Only children for whom consent forms were signed and returned were permitted to participate in the study. Nearly 100 consent forms were sent to parents to obtain 20 eighth grade students. In each of grades 2, 4, and 6, approximately 30 consent forms were sent to parents in each grade to obtain 20 students per grade. After the conclusion of the study, a letter of appreciation was sent to parents (see Appendix B, Correspondence to Parents).

All students in the second, fourth, sixth grades from three elementary schools and all students in three out of the four physical education classes in the eighth grade of one junior high in the Newark Public School System were given a handedness questionnaire. The questionnaires were administered the same day as the consent forms. Only students who were determined to be right-handed based on the results of the questionnaire participated in the study.

The predetermined minimum number of students selected from each grade was seven girls and seven boys. The maximum number of students was fifteen girls and fifteen boys. This predetermined minimum and maximum number of students was determined before the study commenced because of the
anticipated low percentage of parental agreement and the limitation of acquiring only right-handed subjects which would make the subject pool smaller. If the minimum number of subjects could not be reached at one school, then more subjects would be selected from another school in the district. If more than the maximum number of students was obtained, then subjects would be divided into strata of boys and girls for each grade level and random selection would take place.

**Research Design**

This study utilized a one-group repeated trial design: \(X_1^{O_1} X_2^{O_2} O_2\). Kerlinger (1973) explained that, as the name indicates, one group was given different treatments at different times. Each subject was given two tests. The first test consisted of a haptic task with 12 trials, each of 15 seconds duration. The second test was given one minute later and involved the simultaneous performance of a haptic task and a digits backward task. The second test consisted of 12 trials, each of 15 seconds duration. Thus, each subject was administered a total of 24 task trials in the present study.

Before the first test, two practice trials were given. Before the second test, two practice trials were taken. Hence, the experiment lasted approximately 18 minutes for each subject.
According to Kerlinger (1972), history, maturation, and sensitization are possible threats to internal validity in this repeated trials design. History may be a threat in this design in that many events may occur between the first and second tests. The longer the $0_1 - 0_2$ time lapse, the more change-producing events may occur in addition to the treatment of the experimenter to jeopardize internal validity. Such effects may produce an $0_1 - 0_2$ change confusable with the effect of the treatment. This threat was minimized in this experiment by only allowing one minute between the first and second test.

Another variable that may pose a potential threat to internal validity was maturation. Maturation refers to the psychological processes which operate as a function of time. For instance, subjects may become older, hungrier, more tired, or more bored over time. To control for this variable, all of the trials within the first test and the second test were randomized as to shape, left or right hand, and left or right ear. In addition, an attempt was made to minimize the length of the experiment by using 15-second intervals and an overall length of 18 minutes to minimize this threat.

Another potential threat to internal validity within this design was sensitization. The first test may create
a "pretest sensitization" effect producing an interaction between the first test and the experimentally manipulated variable. This threat was minimized in the present study due to the nature of the first test. The first test was not a stimulus to change behavior but rather a passive record of behavior.

Kerlinger (1972) does not consider this design to have any threats to external validity. Campbell and Stanley (1963) consider the interaction of testing and treatment, interaction of selection and treatment, and reactive arrangements to be threats to the internal validity of a time-series design. The interaction of testing and treatment is a threat which involves the effect of the pretest on treatment. Interaction of selection and treatment refers to subjects volunteering to participate in an experiment which may cause a less representative selection of subjects. Reactive arrangements refer to the artificiality of an experimental setting. This may affect subject awareness during the experiment.

**Experimental Variables**

The independent variables used in this study were hand, sex, grade level, modality and hemispheric information processing conditions. The first three variables were attribute variables. Modality and hemispheric information processing conditions were active variables.
Both the right and left hands were examined within the hand variable. Both male and female subjects were examined within the sex independent variable. Second, fourth, sixth, and eighth graders were examined within the grade level variable. The modality variable had two levels. The first level was the haptic test. The second level of modality was the haptic and auditory test. Hemispheric processing conditions had two levels; inter-hemispheric processing (RHLE and LHRE) and intra-hemispheric processing (RHRE and LHLE).

The dependent variables were the scores on the haptic task and the digits backward task tallied as the number correct. To score the haptic task, an "A" or "B" (under each one of the three nonsense shapes) was recorded after the subject indicated his/her choice. A score of "1" was awarded for every correct answer. If the subject was unable to select an answer, a check mark was placed on the scoring sheet and was counted as an error.

To score the simultaneous performance of the haptic task and the digits backward task, each oral response by the subject was recorded by the experimenter. There were two single digit numbers for the experimenter to record on each trial with the second and fourth graders and two double digit numbers to record for the sixth and eighth graders for each trial. While the numbers were recorded,
the digits were not analyzed with hand performance because
the digits task was considered secondary and much of the
data derived from auditory input to the ears appears inconsis­
tent in the research. The analysis of the digit scores
was considered beyond the scope of this study, but the
scores were recorded. If this data warrants further
analysis, then investigation at a later time will ensue.

Task Description

This section will discuss the handedness questionnaire,
the haptic task, the concurrent performance of the haptic
task and digits backward task, and the validity and reli­
ability of techniques used.

Handedness Questionnaire

The handedness questionnaire (see Appendix C, Handed­
ess Questionnaire) was administered to the second, fourth,
sixth, and eighth grades from three elementary schools and
one junior high school. Students were to provide their
name and sex in the right hand column. There were 14
questions concerning which hand was used for items such as
drawing, throwing, and writing. The students checked one
of six boxes: "always use left hand," "usually use left
hand," "use both equally," "usually use right hand,
"always use right hand," and "don't know." The handedness
questionnaire was administered to the second, fourth,
sixth and eighth graders by the experimenter.
The handedness questionnaire was used because only right-handed subjects were needed for the study. The questionnaire is a combination of the Crovitz-Zener Test (Crovitz & Zener, 1962) and the Edinburgh Handedness Inventory or the Oldfield Test (Oldfield, 1971). Bryden (1977) recommended the shortened versions of these two tests asserting that both are reliable and valid in assessing handedness. Each item was scored on a scale from 0 to 5, with the strong right-handed response given a score of "1." The "don't know" column was given total scores ranging from 60 (extremely left-handed) to 14 (extremely right-handed). Only right-handed students were used to minimize any extraneous variance relating to handedness and cerebral organization. Students who did not make check marks in the "always use the left hand," "usually used left hand," "use both equally," were subjects in the experiment. If a student responded to a majority of the items with a "don't know," the subject was not used.

The Haptic Task

Tactual perception of pattern, number, direction, and shape involves the right hemisphere more than the left hemisphere (Rudel, 1974; Gardner et al., 1977). A nonlinguistic haptic task was used to minimize any possible tendency for linguistic mediation (Witelson, 1974; Witelson, 1976;
Nachshon & Carmon, 1975). The haptic task selected was similar to the tasks used by Dodds (1978) and Milner and Taylor (1972). In front of each subject was a large cardboard box, 23 X 20 X 23 inches, positioned between the subject and the experimenter, open end toward the experimenter thus preventing the subject from seeing the stimuli (see Figure 2). Hence, the visual modality was not used. The box had two openings near the base which allowed for placement of the hands of the subjects onto a display board with wooden figures. The openings were made 3 inches from the sides of the box. Each opening was 5 X 3½ inches.

The wooden figures on the display board were 1½ X 2 X ½ inch pieces constructed from balsa wood. Eight shapes were used as models for the 84 pieces used in the experiment. The shapes were painted with white enamel to prevent splinters. The shapes were mounted on a piece of cardboard 11 X 7 inches. Only one shape was mounted at the top of the board. One inch below this shape, two other shapes were mounted, one of which was identical to the top shape. The shapes were rotated on each display board in different orientations using 90 degree, 180 degree, and 270 degree angles to that the top figure on the tray would be different for the 32 trials. Subjects used their thumb and fingers to perform the haptic task, the subject and the
Figure 2. The subject and experimenter in the testing situation.
experimenter were given headphones to wear. By use of the headphones, the time increments could be controlled. Figure 3 is a diagram indicating the time increments that the subject had to respond to during which verbal information was presented through the headphones. During the first 10 seconds, the experimenter told the subject which hand to use. The "Begin" signal was heard through the headphones and was projected to both ears. At this signal, the subject dropped his/her designated hand to the bottom of the box and began feeling the top shape on the display board. (Two practice trials had been given before the 16 trials began so that the subject would not have to search for the wooden shapes.) The subject had 15 seconds to match the top form with one of the two shapes. At the "Stop" signal (input to both ears through the headphones), the subject kept his/her hand on the form that matched the top form. If the subject could not find the form, then the hand was to be raised off the wooden shapes. The subjects were asked not to guess. If the subject selected one of the two shapes and kept his/her hand on one of them, the signal to retract the hand through the hole was the display board being moved from the hand. The subject was to place his/her hand on the selected form even if the selection occurred before the "Stop" signal. The display
Figure 3. Diagram of sound information going into headphones during haptic task performance.
board was removed by a helper after the subject had selected one of the two shapes. There were 12 trials in the first test.

The only function of the helper was to place the boards in front of the subject and to remove the boards after each trial.

The two practice trials used different combinations of forms than were present on the 24 trays.

To score the haptic task, the letters "A" and "B" were placed below each of the two bottom wooden forms from which the subject was to select. The experimenter recorded the letter that corresponded to the choice of the subject. A score of "1" was recorded for each correct answer. Scores for the haptic task ranged from 0-12.

The Concurrent Performance of the Haptic Task and Digits Backward Task

The digits backward task was selected as an appropriate task to engage the left hemisphere. Research has indicated that verbal stimuli such as digits are predominately analyzed by the left hemisphere (Geffen et al., 1971; Botkin, Schmaltz, & Lamb, 1977). This secondary task required the subject to count backwards by one from each number heard from a random set of prerecorded numbers. Fourteen trials with the "Begin" and "Stop" commands were recorded on the tape followed by 14 more trials of the same "Begin" and "Stop"
random numbers in between the commands. The voice recorded was female and not the voice of the experimenter. These numbers were played over headphones and presented either to the right or left ear depending on the experimental condition. The numbers were evenly distributed in the 10-second trial interval. The second and fourth graders responded to a series of two, single digit numbers (2-9) for each trial. Sixth and eighth graders responded to two numbers (2-99) in a series for each trial. The difference in numbers per trial between grades was designed to account for developmental changes in performing this skill. The volume of the tape recorder was kept constant, at a normal speaking voice level.

The concurrent performance of the haptic task and the digits backward task was performed one minute after the haptic task alone. Again, both the experimenter and the subject wore headphones. There were 12 trials utilizing the same time increments as in the haptic task alone. Two practice trials were given to each subject. In the first 10 seconds, the experimenter instructed the subject as to which hand to use and also flipped a toggle switch directing the auditory input of the randomized digits to each ear. At the "Begin" signal, the subject dropped his/her hand to the bottom of the box and performed the haptic task. While performing the haptic task, the subject orally
responded to the digits which were either randomly projected to the right ear or to the left ear in a randomly selected prearranged set. A toggle switch controlled by the experimenter, directed the auditory input into the right or left ear. At the "Stop" signal the subject selected the haptic form.

The experimenter could determine which one of the two switches to flip by following a score sheet for each subject which listed which ear and hand to use on each trial. To insure the subject received appropriate auditory input, the experimenter also had on a set of headphones so that it was possible to monitor the auditory input. The experimenter recorded both the haptic form selection (A or B) and the digit responses by the subject.

A pilot study, utilizing 12 students ranging in age from six to twenty-four years, was conducted. The number of digits selected for the 15-second trial intervals was based on the results of this pilot study. The language used for the directions to the subjects was also determined by the results of the pilot study.

The Validity and Reliability of Techniques Used

The technique of palpating shapes in the haptic task of this study has validity because this technique has been used by other researchers who have obtained similar right hemisphere advantage results when subjects palpated shapes.
Researchers (Gardner et al., 1977; Witelson, 1974; Witelson, 1976) have found that subjects display a right hemisphere advantage when tactually processing shapes. Due to the simple scoring procedure by the experimenter, reliability of scorers should be high, but was not established for the present study.

The wooden nonsense forms used were of identical design to those used in the Witelson studies (1974; 1976) and are nonlinguistic in form rather than linguistic in order to keep the task as much as possible a right hemisphere function. Witelson (1974, 1976) found nonlinguistic haptic forms were more accurately identified with the left hand than the right hand. Using the stimuli of Witelson, Gardner et al. (1977) found greater accuracy for shapes felt with the left hand than the right hand. Thus, the shapes appear to measure what they are supposed to measure. Reliability of measurements using these nonlinguistic stimuli is not well-established.

There is little or no literature on the validity of using the digits backward task. However, scorer reliability should be high due to the simplicity of tabulation of scores. Though the digits backward task is a novel task, the literature substantiates its use. Dichotic listening tasks involving digits with children and adults have been used extensively in research (Geffen, 1976; Knox & Kimura, 1970;
Directions to the Subjects

The subject was seated in a small room with the experimenter and the helper. At each school, the experiment took place in a similar room. The noise was kept constant in each setting. Students were not tested during a time when a bell could ring. Students were tested primarily between the hours of 12:30 and 3:30 p.m. Eighth grade students were tested during study halls and elementary students were tested during music, physical education, and art periods.

The directions to each subject were as follows:

"You are about to participate in a study. It has two parts. The first part you will be using your hands in matching shapes. In the second part of the experiment, you still do two things at once: you will do the same matching and some arithmetic."

"Place both your hands in the box. Lift your hands off the bottom of the box. Drop your right hand. You should feel three wooden shapes all glued to a piece of cardboard. Take your fingers and run them around the edges of the shapes. Find the two shapes that match each other and tell me by pointing which two are the same." (The Experimenter then shows the subject a simple tray.)
"You will have headphones on during the entire experiment. When you hear a 'Begin' signal, drop your hand and feel the shapes as fast as you can. Find the two shapes that are the same. At the 'Stop' signal, keep your hand over the shape that matches the top shape. Do you have any questions? We will now do 14 trials."

(The Experimenter tells the subject, "You only missed a couple," or "You did a very good job.") After the first task...

"Now for the second part of the experiment. You will hear a 'Begin' signal followed by two numbers like 87, 66 followed by a 'Stop' signal. After each number you hear, subtract (or take away) one and give me the answers right away. So if you hear 88, you'll respond by saying 87. At the same time, you will be doing the same task you just did. In other words, you will be doing two things at once. Do you have any questions?"

After the second task, praise is given. "One of the reasons we are doing this experiment is to find out the role of touch in sports. It is hard to throw a football or dribble a basketball without being able to feel it. We really don't know very much about this sense. Thank you for participating in my study."
Data Analysis

The data were treated with two separate factorial analyses of variance (Ott, 1977). In the first analysis the independent variables were modality (two levels: haptic and haptic-auditory), sex (two levels: male and female), grade (four levels: second, fourth, sixth, eighth), and hand (two levels: right and left). The dependent variable measured was performance on the haptic matching task. In the second analysis the independent variables were hemispheric information processing (two levels: inter- and intra-hemispheric information processing), sex (two levels: male and female), and grade (four levels: second, fourth, sixth, eighth). The dependent variable measured was performance on the haptic matching task. In both analysis all factors were crossed.

The Duncan's New Multiple Range Test was used to locate significant differences within main effects if they proved significant. The Duncan's Test was used because it was a less conservative test for comparisons with respect to type I error (Winer, 1971). The acceptable a priori level of significance was .05.

The analysis of variance data were treated with MD 08V computer program using Statistical Analysis System (SAS Institute, Inc., 1979).
CHAPTER IV
RESULTS

Haptic information processing was assessed examining the performance of 80 children. Having selected only right-handed students by using a handedness questionnaire, 20 students were selected from each of four grade levels (i.e., second, fourth, sixth, and eighth) in the Newark Public School System. Of the twenty students selected from each grade, 10 were males and 10 were females. Each student first performed a haptic task. This was followed by simultaneously performed haptic and auditory tasks. For the haptic task, each subject had 15 seconds, for each of 28 trials, in which to identify which two out of the three haptic forms were identical. Afterward, each subject performed the haptic matching task while subtracting one from each number heard through headphones. The haptic matching performances were statistically analyzed using two different factorial analyses of variance. The a priori level of significance was set at the .05 level.

Four cases were excluded from the second grade sample and one case from the fourth grade sample due to an inability of subjects to understand task directions. Raw scores, means, and standard deviations for all subjects and all
tasks are presented in Appendix D.

The data collected in this study were treated with two factorial analyses of variance. In the first analysis of variance of (see Table 1), modality (two levels: haptic and haptic/auditory), sex (two levels: male and female), grade (four levels: second, fourth, sixth, eighth), and hand (two levels: right and left) were the factors analyzed. Haptic performance was the dependent measure for the first analysis of variance. In the second analysis of variance (see Table 2), hemispheric information processing conditions (two levels: inter-hemispheric/intra-hemispheric information processing), sex (two levels: male and female), and grade (four levels: second, fourth, sixth, eighth) were the factors analyzed. In both analyses of variance all factors were crossed.

In the first analysis of variance (see Table 1), the main effects of grade, hand, and modality were found to be significant at the .05 alpha level. Both of the within-cell variances were found to be significant beyond the .05 alpha level. In the first within-cell variance, the difference must lie within the variable grade level. In the second within-cell variance, the differences would lie within hand and modality. No other main effects or interaction effects proved significant. In the second analysis of variance (see Table 2) the main effect of grade and the
Table 1
Analysis of Variance Summary Table Involving the Independent Variable of Modality

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F-Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>26.784</td>
<td>3</td>
<td>8.928</td>
<td>9.16*</td>
</tr>
<tr>
<td>Sex</td>
<td>1.128</td>
<td>1</td>
<td>1.128</td>
<td>1.16</td>
</tr>
<tr>
<td>Grade X Sex</td>
<td>5.584</td>
<td>3</td>
<td>1.861</td>
<td>1.91</td>
</tr>
<tr>
<td>Within Cell Variation</td>
<td>286.435</td>
<td>72</td>
<td>3.728</td>
<td>3.83*</td>
</tr>
<tr>
<td>Modality</td>
<td>38.503</td>
<td>1</td>
<td>38.503</td>
<td>39.51*</td>
</tr>
<tr>
<td>Hand</td>
<td>12.403</td>
<td>1</td>
<td>13.403</td>
<td>12.73*</td>
</tr>
<tr>
<td>Hand X Modality</td>
<td>0.378</td>
<td>1</td>
<td>0.378</td>
<td>0.39</td>
</tr>
<tr>
<td>Grade X Modality</td>
<td>2.659</td>
<td>3</td>
<td>0.886</td>
<td>0.91</td>
</tr>
<tr>
<td>Sex X Modality</td>
<td>0.378</td>
<td>1</td>
<td>0.378</td>
<td>0.39</td>
</tr>
<tr>
<td>Grade X Hand</td>
<td>1.759</td>
<td>3</td>
<td>0.586</td>
<td>0.60</td>
</tr>
<tr>
<td>Sex X Hand</td>
<td>0.078</td>
<td>1</td>
<td>0.078</td>
<td>0.08</td>
</tr>
<tr>
<td>Grade X Sex X Hand X Mod.</td>
<td>2.734</td>
<td>3</td>
<td>0.911</td>
<td>0.94</td>
</tr>
<tr>
<td>Grade X Sex X Mod.</td>
<td>1.384</td>
<td>3</td>
<td>0.461</td>
<td>0.48</td>
</tr>
<tr>
<td>Grade X Sex X Hand</td>
<td>6.484</td>
<td>3</td>
<td>2.161</td>
<td>2.24</td>
</tr>
<tr>
<td>Grade X Hand X Mod.</td>
<td>2.234</td>
<td>3</td>
<td>0.745</td>
<td>0.76</td>
</tr>
<tr>
<td>Sex X Hand X Mod.</td>
<td>0.078</td>
<td>1</td>
<td>0.078</td>
<td>0.08</td>
</tr>
<tr>
<td>Within Cell Variation</td>
<td>208.675</td>
<td>216</td>
<td>3.602</td>
<td>3.73*</td>
</tr>
<tr>
<td>Total</td>
<td>579.672</td>
<td>319</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at the .05 level.
Table 2
Analysis of Variance Summary Table
Involving the Independent Variable of Hemispheric Information Processing

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F-Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>16.450</td>
<td>3</td>
<td>5.483</td>
<td>7.47*</td>
</tr>
<tr>
<td>Sex</td>
<td>0.200</td>
<td>1</td>
<td>0.200</td>
<td>0.27</td>
</tr>
<tr>
<td>Hemispheric Processing</td>
<td>0.000</td>
<td>1</td>
<td>0.000</td>
<td>0.00</td>
</tr>
<tr>
<td>Grade X Sex</td>
<td>11.500</td>
<td>3</td>
<td>3.833</td>
<td>5.22*</td>
</tr>
<tr>
<td>Grade X Hem. Processing</td>
<td>0.000</td>
<td>3</td>
<td>0.000</td>
<td>0.00</td>
</tr>
<tr>
<td>Sex X Hem. Processing</td>
<td>0.000</td>
<td>1</td>
<td>0.000</td>
<td>0.00</td>
</tr>
<tr>
<td>Grade X Sex X Hem. Pro.</td>
<td>0.000</td>
<td>3</td>
<td>0.000</td>
<td>0.00</td>
</tr>
<tr>
<td>Within Cell Variation</td>
<td>527.800</td>
<td>304</td>
<td>1.736</td>
<td>1.08</td>
</tr>
<tr>
<td>Total</td>
<td>555.950</td>
<td>319</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at the .05 level.
two-way interaction effect of grade and sex were significant at the .05 level. No other main effects or interaction effects proved significant.

The hypotheses of this study were:

1. Students exposed to information delivered through one modality (haptic) will perform significantly better on a haptic matching task than those exposed to information delivered through two modalities (haptic and auditory).

2. Inter-hemispheric information processing (RHLE and LHRE) results in significantly better haptic task performance than intra-hemispheric processing (LHLE and RHRE).

3. Males will perform a haptic matching task significantly better than females.

4. As grade level increases, haptic matching task performance will improve significantly.

5. The left hand will produce significantly better haptic performance scores than the right hand.

The first null hypothesis, that students exposed to information delivered through one modality (haptic) will perform a haptic matching discrimination task the same as those exposed to information from two modalities (haptic and auditory), was not supported. Therefore, the hypothesis of students exposed to information delivered through one modality (haptic) will perform significantly better on a haptic matching task than those exposed to information
delivered through two modalities (haptic and auditory) was supported. In the first analysis of variance the treatment main effect was significant at the .05 level indicating that students exposed to haptic information alone performed significantly better on a haptic task than students exposed to both haptic and auditory information.

The second null hypothesis, that inter-hemispheric information processing conditions (RHLE and LHRE) will result in the same performance on a haptic task as will intra-hemispheric information processing (LHLE and RHRE) was not supported. Therefore, the research hypothesis that inter-hemispheric information processing (RHLE and LHRE) results in significantly better haptic task performance than intra-hemispheric processing (LHLE and RHRE) was not supported. In the second analysis there was not a statistically significant difference in haptic performance as a result of inter- or intra-hemispheric information processing conditions in this study.

Although inter-hemispheric information processing was not found to be significantly better than intra-hemispheric information processing, the inter-hemispheric mean scores tended to be higher across all grades than intra-hemispheric mean scores.

The third null hypothesis, that males will perform the same as females on a haptic discrimination task was
supported. Therefore, the research hypothesis that males will perform a haptic matching task significantly better than females was not supported. The sex main effect in both analyses of variance did not prove significant.

Although sex did not prove to be a statistically significant main effect, males did tend to process intra-hemispheric information more efficiently than females during grades four through six. This may be attributed to the notion that females have more bilateral representation within the cerebral hemispheres from ages six through thirteen.

The fourth null hypothesis, that performance on the haptic discrimination task will not improve as grade level increases, was not supported. Therefore, the research hypothesis that as grade level increases, haptic matching task performance will improve significantly was supported. In both analyses of variance, the grade level main effect proved significant at the .05 level. The Duncan's Multiple Range Test was applied to grade level in order to locate significant differences among age groups for the two analyses. The results are summarized in Tables 3 and 4. The results of both the Duncan tests indicated that grades 8 and 6 did not perform significantly differently from one another and that grades 4 and 2 did not perform significantly differently from one another. However, grades 2 and 4
Table 3
Duncan's Multiple Range Test for Grade Level
Main Effect Found in the First Analysis of Variance

<table>
<thead>
<tr>
<th>Grade</th>
<th>n</th>
<th>Mean</th>
<th>Significance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>80</td>
<td>4.74</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
<td>4.53</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>4.09</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>4.08</td>
<td>B</td>
</tr>
</tbody>
</table>

*Comparisons with the same letter are not significantly different at the .05 alpha level.
### Table 4

**Duncan's Multiple Range Test for Grade Level Main Effect Found in the Second Analysis of Variance**

<table>
<thead>
<tr>
<th>Grade</th>
<th>n</th>
<th>Mean</th>
<th>Significance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>80</td>
<td>4.25</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
<td>4.22</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>3.82</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>3.75</td>
<td>B</td>
</tr>
</tbody>
</table>

*Comparisons with the same letter are not significantly different at the .05 alpha level.*
differed from grades 6 and 8 in that students in grades 6 and 8 performed significantly better than students in the former two grades.

Haptic information processing in the present study increased in efficiency as grade level increased. The haptic information processing probably continues to develop in efficiency as the child matures. The ability of children to process information in two modalities also increases in efficiency as the child continues to mature physically and neurologically.

The fifth null hypothesis, that performance on a haptic task by the right or left hand will be the same, was not supported by the results of the first analysis of variance. Therefore, the research hypothesis that the left hand will produce significantly better haptic performance scores than the right hand was supported. The left hand performance was significantly better than that of the right hand performance.

Second grade children showed evidence of right hemispheric specialization in the present study. Both boys and girls performed significantly better with the left hand than the right hand during haptic performance. The left hand performance is thought to result in hemispheric information processing of haptic information which is more efficient than that of the right hand in right-handed
individuals because of the contralateral pathways leading to the right hemisphere (which is the hemisphere in which spatial information is predominately processed).

In the second analysis of variance, the grade by sex interaction proved significant at the .05 alpha level. This interaction is graphically represented in Figure 4. Figure 4 illustrates hemispheric processing scores plotted by grade level and sex. Between grades 2 and 4, the converging lines illustrate that there was disordinal interaction. Hemispheric processing scores of females decreased between grades 2 and 4 while hemispheric processing scores increased for males between the same grades. Between grades 4 and 6, the performances of males paralleled those of females with males performing better than females with regard to haptic scores. Between grades 6 and 8, there is disordinal interaction (crossing of lines); while hemispheric processing scores increased for females, male hemispheric processing scores decreased.

The fifth null hypothesis, that the left hand will produce the same haptic performance scores as the right hand, was not supported by the results of the first analysis. The hand main effect proved significant in the first factorial analysis of variance, favoring the left hand (see Table 1). Haptic information is believed to be processed predominately by the right hemisphere (Witelson,
Figure 4. Grade X sex interaction effect for the second analysis of variance.
1974). Thus, the result that the left hand in right-handed individuals would be superior to the right hand in processing haptic information was not unexpected.
Eighty children from grades 2, 4, 6, and 8 were selected from three elementary schools and one junior high in the Newark Public School System to assess haptic information processing. Ten consenting males and ten consenting females were selected from each grade. A handedness questionnaire was administered to obtain only right-handed subjects. Each student was given a haptic test followed by a haptic and auditory test. The haptic test involved three nonsense forms on a board which were out of view of the subject. The trays of nonsense forms were placed inside a large box while the student was seated with hands outside the box. The student had to identify which of the two forms matched each other. There were twelve 15 second trials in which the student was to identify shapes. The second test was administered one minute after the first test. While the subject performed the same haptic test, the subject responded orally, subtracting one from a series of numbers heard over headphones. Two numbers were heard during the 15 second intervals. The maximum number of digits heard over the headphones was determined by the
pilot test. In a pilot investigation, the use of more than two digits in the 15-second interval did not allow the subject enough time to perform the subtraction on each figure. During the second test, information in two modalities, touch and audition, was involved.

The study was a one-group repeated measures design. Two factorial analyses of variance were used to analyze the data. These analyses were performed to test five hypotheses:

1. Students exposed to information delivered through one modality (haptic) will perform significantly better on a haptic task than those exposed to information delivered through two modalities (haptic and auditory).

2. Inter-hemispheric information processing (RHLE, LHRE) will result in significantly better haptic task performance than intra-hemispheric information processing (LHLE, RHRE).

3. Males will perform a haptic information processing task significantly better than females.

4. As grade increases, performance on a haptic information task will improve significantly.

5. The left hand will produce significantly better haptic performance scores than the right hand.

In the first analysis, the main effects for grade level, modality, and hand were significant beyond the .05 alpha level in the analysis of variance in which haptic performance was the dependent variable and modality, grade
level, sex, and hand were the independent variables. Using the Duncan's Multiple Range Test to locate significant differences, grades 2 and 4 scored significantly lower than grades 6 and 8. Haptic performance for the first test was significantly better than the haptic performance on the second test. Left hand performance proved significantly better than the right hand during haptic task performance.

In the second analysis, the main effect of grade level and the interaction effect of grade level and sex during inter- and intra-hemispheric information processing were significant beyond the .05 alpha level in the analysis of variance in which haptic performance was the dependent variable and hemispheric information processing, grade level, and sex were the independent variables. The Duncan's Multiple Range Test was used to locate significant differences in the main effect of grade level. Haptic performances of grades 6 and 8 were found to be significantly better during inter- and intra-hemispheric information processing than grades 2 and 4.

Examination of the grade X sex interaction effect indicated that male haptic performance scores increased while female haptic performance scores decreased between grades 2 and 4. Between grades 4 and 6, male and female haptic performance increased. Between grades 6 and 8,
male haptic performance scores decreased while female haptic performance scores increased.

Although inter-hemispheric information processing scores were not significantly better than intra-hemispheric processing scores, the mean scores for inter-hemispheric information processing were higher than the mean scores for intra-hemispheric information processing in grades 2 - 8.

Null hypotheses 1, 4, and 5 were not supported, while null hypotheses 2 and 3 were supported.

Conclusions

Within the framework of this investigation, the following conclusions are justified:

1. Students perform a haptic task significantly better when exposed to haptic information only as compared to processing haptic and auditory information simultaneously.

2. Haptic performance during inter-hemispheric information processing was not significantly better than haptic performance during intra-hemispheric information processing.

3. As grade level increased, students performed significantly better both during the haptic task performance and the haptic/auditory task performance. Sixth and eighth graders perform a haptic discrimination task better than second and fourth graders.
4. The left hand is associated with better haptic performance than the right hand in right-handed children.

5. Males were not significantly better than females during both haptic task performance and haptic/auditory performance.

Implications

Gescheider, Sager, and Ruffolo (1975) have found results which supported the hypothesis that subjects can process simple stimuli presented simultaneously to two modalities about as well as when they can process stimuli in only one modality. Their results indicate that when the demands on cognitive processes are small, auditory and tactile stimuli presented simultaneously can be processed as well as when stimuli are presented in only one modality. However, there is a certain amount of uncertainty in quantifying the degree of demand placed on cognitive processing. In this study the digits backward task required cognitive processing which involved activities such as rehearsal, coding, and short-term memory store. Because the task in the present study involved a limited amount of memory, the simultaneous performance of the second task produced the disruptive effect. The present study supports the findings of the Gescheider, Sager, and Ruffolo (1975) study in that, when one of the two simultaneous tasks requires a large amount of cognitive processing, it becomes
difficult for subjects to maintain high levels of performance in both modalities.

Performing two tasks at once may be less efficient than performing one task if cognitive demands are placed on one of the tasks. For example, if a person is typing a paper, it is very likely that music or television may not hinder the performance of the typist because of limited cognitive demands these secondary stimuli impose. If someone begins a conversation with a typist, the cognitive demands of the conversation may produce a decrement in typing performance.

According to Kinsbourne and Cook (1971), intra-hemispheric competition causes more disruption to performance than inter-hemispheric competition. Inter-hemispheric information processing was not significantly better than intra-hemispheric information processing in the present study.

Although sex did not prove to be a statistically significant main effect, males did tend to process intra-hemispheric information more efficiently than females during grades 4 - 6. This may be attributed to the notion that females have more bilateral representation within the cerebral hemispheres from ages 6 - 13.

There is the possibility that sex differences arise in processing visual or visual-spatial information (Witelson,
1974) rather than information processing purely in the tactual modality. This study suggests that information processing within the tactual modality alone, produces no sex differences.

Second grade children showed evidence of right hemispheric specialization in the present study. Both boys and girls performed significantly better with the left hand than the right hand during both the first and second haptic tests. The left hand is thought to process haptic information more efficiently than the right hand in right-handed individuals because of the contralateral pathways leading to the right hemisphere (which is the hemisphere in which spatial information is predominately processed).

Haptic information processing in the present study increased in efficiency as grade level increased. The haptic information processing probably continues to develop in efficiency as the child matures. The ability of children to process information in two modalities also increases in efficiency as the child continues to mature physically and neurologically.

The left hand was significantly better than the right hand during haptic task performance. The hand proved significant in the first four factor factorial analysis of variance, favoring the left hand (see Table 1). Since haptic information is believed to be processed predominately
by the right hemisphere, the result that the left hand in right-handed individuals would be superior to the right hand in processing haptic information was not unexpected.

There are several implications that can be drawn from the results of this study. While a student studies in a study hall where music has been piped into the room, the increased cognitive demands of processing popular music along with completing homework may produce a disruptive effect on the homework completion.

Another implication that can be drawn from this data concerns the classroom teacher. As a student takes a test, noise level should be kept to a minimum. For instance, if during a test, other students are participating in recess such that the noise of the playground can be heard during the test, then the auditory input may cause some disruption of test performance.

An implication for tennis players can also be drawn from this data. If an audience is allowed to talk during a tennis match, the auditory stimuli may increase the cognitive processing of the situation resulting in disruptive tennis performance.

**Need for Further Study**

The following recommendations for further study are based upon information gained from the present investigation. The present study attempted to examine the efficiency of
information processing in the haptic modality alone compared to information processing in two modalities (haptic and auditory). Several recommendations for further study have been suggested in the hope that their investigation might lead to further understanding of the process of haptic information processing.

One of the recommendations is to repeat the present study using more subjects. Increased confidence in the results of the study may result by increasing the sample size or by replication of the study.

The study could also be repeated using only one or two grade levels. This would create a less complicated design. However, the study could even be repeated using more grade levels.

The study could be repeated using adults. The literature of tactual information processing in older and aged adults is as inconsistent in findings in literature of children. There is also a need to explore tactual information processing in adults of later years.

Different socioeconomic groups may be utilized in further studies of tactual information processing. At present there is no literature on this subject.

The study may also be repeated using left-handed subjects or using learning disabled children. The
difficulty of using these groups is to ascertain the cerebral make-up of these individuals.
APPENDIX A

HUMAN SUBJECT REVIEW COMMITTEE RESPONSE
APPENDIX A

OHIO STATE UNIVERSITY
Social & Behavioral Sciences
Human Subject Review Committee
Research involving Human Subjects

PROTOCOL NO. B103027
ORIGINAL REVIEW
CONTINUING REVIEW
FIVE-YEAR REVIEW

ACTION OF THE REVIEW COMMITTEE

With regard to the employment of human subjects in the proposed research entitled:

A DEVELOPMENTAL PERSPECTIVE OF TACTUAL PROCESSING DURING THE SIMULTANEOUS PERFORMANCE OF TWO TASKS

is listed as the principal investigator.

Jacqueline Herkowitz, Deborah A. Wolfe

Health, Physical Education & Recreation

The Social and Behavioral Sciences Review Committee has taken the following action:

☑ Approved
☐ Disapproved
☐ Approved with conditions *cons * ☐ Waiver of Written Consent Granted

* Conditions stated by the Committee have been met by the Investigator and, therefore the protocol is approved.

It is the responsibility of the principal investigator to retain a copy of each signed consent form for at least four (4) years beyond the termination of the subject's participation in the proposed activity. Should the principal investigator leave the University, signed consent forms are to be transferred to the Human Subject Review Committee for the required retention period. This application has been approved for the period of one year. You are reminded that you must promptly report any problems to the Review Committee, and that no procedural changes may be made without prior review and approval. You are also reminded that the identity of the research participants must be kept confidential.

Date: NOV 13 1981
Signed: LDS

CC: Original - Investigator
Ftie

MS-0250 (Rev. 7/81)
Winter, 1982

Dear Parents:

I am a graduate student at Ohio State University and I am currently working on a Ph.D. degree in Physical Education. For my dissertation I am studying tactual information processing or the ability to touch. The research study is being supervised by my adviser, Dr. Jacqueline Herkowitz. I have been working with the principal and the superintendent and they have invited me to conduct my research study at your child's school. The teachers have offered tremendous cooperation and support. We are anxious to have your child participate in the study.

Let me describe what the experience will be like for your child. The child will perform 2 tests. During the first test, the child will feel an object which has been placed in a box out of his/her sight. The child must then pick that same shape out of a presentation of three forms. The test involves absolutely no risks. The second test has the child perform 2 tasks at once. The child will feel an object while performing a simple math skill. The math skill involves subtracting one from a series of numbers heard over headphones. Neither task involves any risk. Your child will attain knowledge as to what a scientific experiment is all about.

After reading the description of the study, I hope you will agree to let your child participate in the activities. If you have any questions concerning the experiment, you may contact me at 344-9527. You may also contact my advisor Jacqueline Herkowitz at O.S.U. (422-2255) if you have any questions. Please sign the consent form and return it to your child's teacher by Monday, Jan. 11.

Thank you for your cooperation.

Sincerely,

Deborah A. Wolfe
APPENDIX B

CORRESPONDENCE TO PARENTS

CONSENT FORM

I consent to allow my child ____________________ (Name) to participate in the research study conducted by Deborah A. Wolfe for her dissertation work and supervised by Dr. Jacqueline Herkowitz. The nature and general purpose of the research procedure has been explained to me. I understand that any further inquiries I make concerning this procedure will be answered. I understand that test scores will be kept anonymous and that my child will not be identified in any way. Finally, I understand that I am free to withdraw my consent and discontinue my child's participation at any time following the notification of the project director, Deborah A. Wolfe.

Deborah A. Wolfe
Investigator

Signature of Parent

Date

Dr. Jacqueline Herkowitz
Supervisor
Dear Parents,

Thank you for allowing your child to participate in my research study. Your child has contributed greatly to the success of the study.

Although it is too early to draw conclusions from the study, I will be in touch with the Principal of your school and will inform them of the results.

Again, thank you for allowing your child to participate in my study.

Sincerely,

Deborah A. Wolfe
APPENDIX C

HANDEDNESS QUESTIONNAIRE
APPENDIX C

HANDEDNESS QUESTIONNAIRE

Name_________________________

Sex_________________________

Please check one of six boxes at the right as to which hand you use with the following items.

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<td>7) Glass when drinking</td>
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<td>8) Untwisting a bottle cap (not the hand holding the bottle)</td>
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### APPENDIX C
### HANDEDNESS QUESTIONNAIRE

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APPENDIX D

RAW DATA
APPENDIX D

Table 5

Raw Data for T1, R1, L, T2, R2, L2, RHLE, RHLE, RHRE, LHLE, RL, and RR

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T1 = The total right and left hand correct responses from the haptic task.
R1 = The number of correct haptic responses by the right hand during haptic task performance.
L1 = The number of correct haptic responses by the left hand during haptic task performance.
T2 = The total right and left hand correct responses from the haptic and auditory task.
R2 = The number of correct haptic responses by the right hand during the haptic and auditory task.
L2 = The number or correct haptic responses by the left hand during the haptic and auditory task.
RHLE = Right hand/left ear
RHRE = Right hand/right ear
Table 5 -- Continued

LHLE = Left hand/left ear
LHRE = Left hand/right ear
RL = Inter-hemispheric information processing
RR = Intra-hemispheric information processing
**APPENDIX D**

**Table 6**

Mean, Standard Deviation, Range and Variance for Tl, Rl, Ll, T2, R2, L2, RL, and RR

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| R1       | 3.900 | 1.449 | 4.000 | 2.100 |
| L1       | 5.000 | 0.943 | 3.000 | 0.889 |
| T2       | 8.000 | 2.309 | 6.000 | 5.333 |
| R2       | 3.600 | 1.578 | 5.000 | 2.489 |
| L2       | 4.400 | 1.075 | 3.000 | 1.156 |
| RL       | 3.900 | 1.853 | 5.000 | 3.433 |
| RR       | 4.100 | 0.994 | 3.000 | 0.989 |</p>
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APPENDIX E

EIGHT SHAPES
APPENDIX E

EIGHT SHAPES
APPENDIX F

SAMPLE ROTATION DURING THE SECOND TEST OF TACTUAL AND AUDITORY TASK PERFORMANCE
Sample Rotation During the Second Test of Haptic and Auditory Task Performance

Order of Trials:

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Total 14 trials.

The first two trials were practice trials.

RHLE, LHRE, RHRE, LHLE were used three times during haptic/auditory test.
APPENDIX G

SCORING SHEET
### APPENDIX G

**SCORING SHEET**

<table>
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<th>Name ______________________</th>
<th>Sex __________</th>
<th>Grade Level ______</th>
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#### T1
1) Practice R [ ] 2) Practice L [ ]
3) R [ ] 4) L [ ] 5) R [ ] 6) L [ ] 7) R [ ] 8) L [ ]
9) R [ ]

#### T2
1) Practice RHLE [ ] 2) Practice LHLE [ ]
3) RHLE [ ] 4) LHRE [ ] 5) [ ]
6) LHLE [ ] 7) LHRE [ ] 8) [ ]
9) LHLE [ ] 10) RHLE [ ] 11) [ ]
12) LHLE [ ] 13) RHLE [ ] 14) [ ]
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