EDUCATION AND CEREBRAL ASYMMETRIES

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SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY

AT DALHOUSIE UNIVERSITY

October 1984

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ABSTRACT

The present study is an attempt to synthesize the findings related to higher psychological functions obtained from brain research especially in the area of split-brain studies and highlight their implications for education. An awareness of these significant findings among educators as well as parents is essential for a full development of mental potentialities of our youngsters, who are going to be the citizens of tomorrow.

Split-brain research has pointed out the different functions of the two hemispheres of the brain. More specifically, the left hemisphere is considered to be responsible for verbal, analytic and linear functions, whereas the right hemisphere is specialized for visuospatial, synthetic and emotional abilities of the human mental domain. In reality there is some overlapping between the two. The main difference between the two hemispheres lies in the mode of processing stimuli - the left utilizes a verbal mode and the right a nonverbal mode. The difference between the two hemispheres is more in terms of the degree of input from each of the hemispheres in a particular mental function. Hence, both make important contributions in various higher mental functions.

Each learner is unique in terms of his mental potentials. Teaching is the process of stimulating each learner's potentials and helps him develop his potentials to the fullest. The present educational system, however, is largely left-hemisphere dominant both in terms of subject-matter as well as in terms of the method of teaching. The results are reflected in the growing number of children falling behind the expected rate of learning because of their inability to cope with the pressures exerted by a technocratic society. Hence, there is a strong need for a reexamination of the present left-oriented educational system. A holistic approach to education might provide balance to all learners (left-oriented or right-oriented).

Stimulation of both modes of processing stimuli among all learners would give equal opportunity to develop and utilize their capabilities fully. The emphasis is to create a shift towards a balanced whole brain education. This balanced approach does not necessarily demand a change in the contents of the curriculum. In fact, the initial change requires a shift in the method of teaching from left hemisphere-oriented to a balanced method utilizing both left and right cerebral hemispheres.

ACKNOWLEDGEMENTS

I wish to express my deep gratitude and sincere thanks to my supervisor, Dr. R. Puccetti, for his constant guidance and encouragement throughout the completion of this thesis.

I am thankful to Margaret Odell for doing a splendid job in typing the thesis.

Last but not least, I am grateful to the Canadian Commonwealth Scholarship and Fellowship Committee as well as Dalhousie University for their financial assistance.

Chapter I

Introduction

The present thesis deals with a review of split-brain studies of animals, humans and the asymmetrical functions of the two hemispheres of the brain. Finally, an attempt to extend the implications of these studies to possible curricular changes that will address the development of the cognitive capacities of the mute right hemisphere of children will be made. The field of neuroscience is still in its infancy - but is progressing at a tremendous pace in uncovering the mysteries of the human brain. The sensory and motor functions of the human brain are well understood. But the mechanics of higher mental functions such as thinking, learning and memory are yet to be understood fully (Doty, 1974; Teyler, 1977, 1978). Since the brain is so complex and differentiated, research on the relationship between the brain and mental functions becomes all the more difficult. It acts as an instrument that directs and regulates human behaviour. Though neuroscience has made great progress in unlocking the incredibly complex secrets of the brain, the unlocking of one door has led to another more fascinating door. For neuroscientists, the challenge is to explore the house (brain) without disturbing the occupant (individual). A slight error of the neurosurgeon's knife in brain surgery might be disastrous for the individual - a permanent loss of a sensory/motor or mental function and sometimes even resulting in death. Therefore, neuroscientists are forced to attempt initial investigations on animal brains.

A brief description of the gradual development of the brain and its progressive differentiation into various zones across mammalian evolution seems appropriate before taking up phenomena of "split-brain" or "cerebral asymmetry" which is the subject of the present thesis. On the phylogenetic scale, a comparison of brains of four mammals (rat, cat, monkey and man) indicates that changes in the brain are limited by and large to the cerebral cortex which is largely involved in higher cognitive functions in man (Teyler, 1977; Thompson, 1975). Probably this is the reason that the cortex has undergone a great deal of development across phylogeny. The cerebral cortex is considered to be the most recent evolutionary development of the vertebrate nervous system. An examination of successively more complex mammals shows a fairly regular increase in the size of the cortex. This increase is largely evident in fissures or folding of the cortical surface. The development of fissures has allowed a tremendous increase in the amount of cortex without conscipuous enlargement of the rigid skull casing in man. The basic organization of the cortical sensory and motor areas does not seem to differ markedly from rat to man. The relative amount of association cortex (cortex that is neither sensory nor motor but is assumed to be involved in higher complex psychological functions) increases sharply as seen in Fig. 1.1 (Thompson, 1975). It has been estimated that more than three-quarters of the total amount of cerebral cortex in the human brain lies within fissures.

Though the basic features of brain organization are present at birth, the human brain undergoes tremendous growth in neural processes, synaptic formation and myelin sheath formation until puberty. These processes can be profoundly affected by the organism's environment. Thus, the wiring of the brain is completed as a result of the

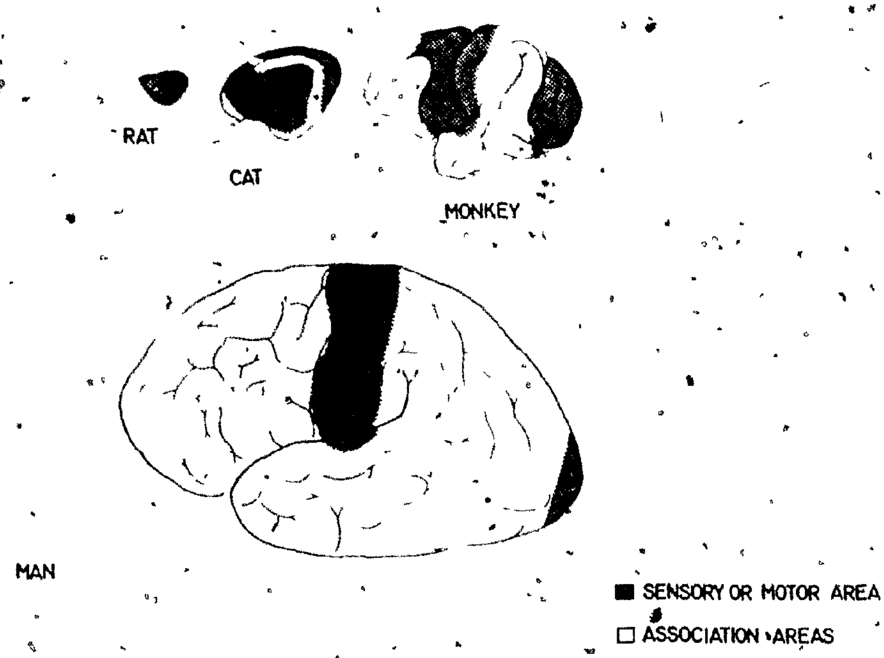


Fig. 1.1

(From Thompson, 1975)

interaction of genetic blueprints and environmental influences. Furthermore, Teyler (1978) comments:

> ... brain processes present at birth will degenerate if the environmental stimulation necessary to activate them is withheld. It appears that the genetic contribution provides a framework which, if not used, will disappear, but which is capable of further development given the optimal environmental stimulation (p. 27).

In the latter part of the nineteenth century, the cerebral cortex became a subject of great interest. In 1861, the French surgeon Paul Broca discovered that speech is impaired when damage occurs to a small area of the cortex low along the side of the frontal lobe known as Broca's motor speech area. Thus, the evidence for cortical localization was noted. Four years later, Broca observed that the effect occurred only when the left side of the cortex was damaged and this paved the way for further investigations (Watson, 1981). A series of investigations followed and another important finding was reported by Wernicke. He described another area on the left side of the brain located around the junction of the temporal and parietal lobes that came to be known as Wernicke's receptive speech area where lesions may result in language difficulties (Watson, 1981). Damage to this area was found to affect comprehension but not the ability to articulate speech. With these important discoveries began the era of strict localization of mental functions in the brain. The idea behind the strict localization theory was that for each function a corresponding area in the brain can be found. However, soon it became evident that though the left side of the brain served as the control center for the right side of the body and vice versa, the same did not hold true for complex mental functions.

Higher mental functions are regulated by an integrated effort of two or more differentiated areas of the cortex (Luria, 1966a, b; Vygotsky, 1952). Man's cerebral cortex shows an extreme degree of differentiation into regions and fields as compared to the simple undifferentiated cortex of the lower mammals. The progressive differentiation of the cortex across mammalian evolution is clearly shown in Fig. 1.2 (Luria, 1966b). In the lower mammals, only a few of the principal analyzer zones (visual, auditory, cutaneokinesthetic), although not yet differentiated internally into fields and only very vaguely distinguished from each other, is evident. At higher stages of evolution, however, the nuclear zones of the analyzers are more clearly distinguished and differentiated into central and secondary fields. Simultaneous to this differentiation, there is an increasing tendency for one area to extend into another, resulting in overlapping zones or areas. This overlapping explains the involvement of more than one area of the brain in any complex mental task.

The cerebral cortex consists of two hemispheres that are exactly alike in appearance and contain identical control centers for sensory and motor activities of the body (Sperry, 1961, 1964) as seen in Fig. 1.3. In the normal brain, the two are connected via a thick bundle of nerve fibers known as the corpus callosum and thus the brain is seen as an integrated whole. The two hemispheres have clearcut roles with regard to the sensory and motor functions of the body. The left hemisphere controls the right side of the body and the right hemisphere controls the functions of the left side of the body. But when it comes to the regulation of higher psychological functions, the two hemispheres do not have clearcut roles. Largely the two work

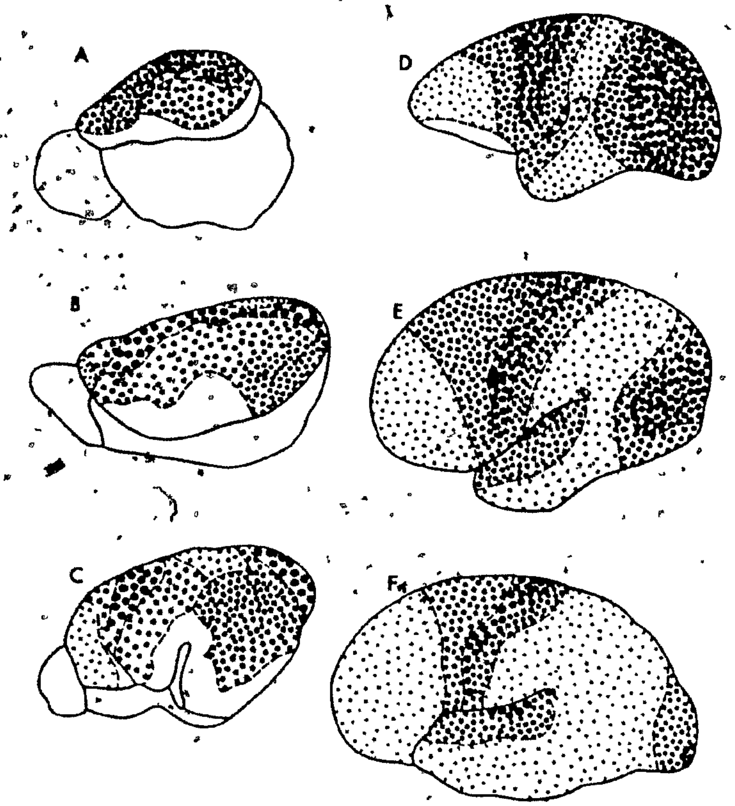


Fig. 1.2

(From Luria, 1966b)

Progressive differentiation of the regions and fields of the cerebral cortex. (A) Brain of the hedgehog. (B) Brain of the rat. (C) Brain of the dog. (D) Brain of a lower ape. (E) Brain of a higher ape. (F) Human brain. The large dots denote the primary (central) fields of the nuclear zones; the middle-sized dots denote the peripheral (secondary) fields of the nuclear zones; the small dots denote the tertiary fields (overlapping zones).

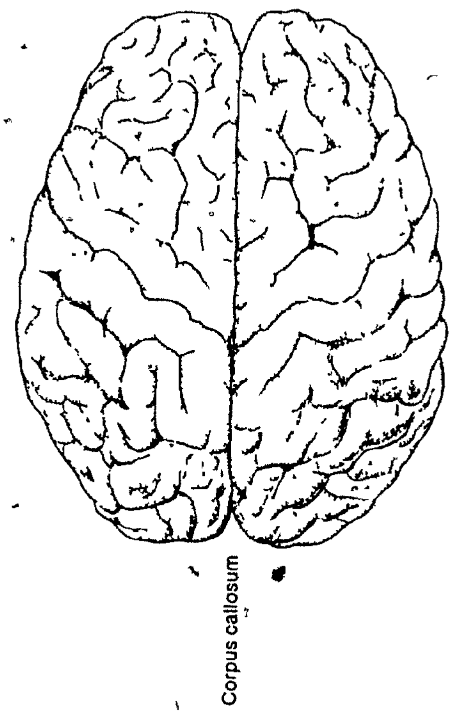


Fig. 1.3

(From Ornstein, 1977)

in harmony and integrate information received in the two hemispheres. Until about the year 1950, the corpus callosum was considered to be the largest and most useless among all the brain structures. Then in the early 1950's, Sperry and his collaborators discovered the phenomenon of split-brain in animals and the important role of the corpus callosum became evident (Myers, 1955, 1956; Myers and Sperry, 1953). Results from a number of experiments on cats and monkeys indicated that the corpus callosum was instrumental in laying down a duplicate image of the learnt task in the opposite hemisphere. Soon other experiments followed both on animals and on humans (operated for medical reasons) and a gradual progress in understanding mental functions began.

Initial disconnection of the two hemispheres did not indicate any change in the animal's or individual's behaviour. Soon a complete functional independence of the separated hemispheres was noted (Geschwind and Kaplan, 1962; Sperry et al., 1956; Stamm and Sperry, 1957). Each of the disconnected hemispheres developed its own chain of learning and memory experiences with no connection between the two at all. Furthermore, the two hemispheres could be trained simultaneously to perform diametrically opposed activities (Myers, 1962). These findings raised questions about the role of the corpus callosum in the normal brain. With continued efforts of neuroscientists, it can now be safely concluded that the corpus callosum has an important function in integrating information from the left and right hemispheres to maintain unity in the behaviour of the normal animal or individual.

Research work since the 1960's in the neurosciences has uncovered a great deal of the mysteries of the brain. The specialization of the two hemispheres in different functions has been emphasized. It is a well established fact that control centers for language are located in the left hemisphere of right-handed individuals. Most left-handed individuals have their language control centers in the right hemisphere. The left hemisphere, however, due to its major control over linguistic, analytic, mathematical and logical capabilities has received much more attention not only in research work but also in education. The right hemisphere was largely ignored by researchers until the early 1970's when it started gaining popularity in research work. The right hemisphere's holistic, visuospatial ability is now being given considerable attention. Gradually, its major characteristics are being discovered. It tends to take the major lead in integrating or synthesizing information, in the act of creativity and musical tasks. Its intuitive powers have been realized by great scientists in the process of their scientific discoveries. The right hemisphere's approach utilizes visual imagery and sometimes dreams in processing a particular task. Visual imagery, dreams, etc. are often associated with the domain of abnormal behaviour and, thus, are not readily acceptable in our present society. Though children tend to utilize visual images in their early years of life, these are gradually de-emphasized in the process of being educated.

In the present technocratic society, left hemispheric functions have largely taken control over individuals. Western society is heavily dominated by linear logic. Rational linear thinking has affected individuals' minds. Anything that fails to fit in the S-R formula is rejected by investigators for further study. Since the right hemisphere's visual imagery and intuitive ability cannot be explained in terms of the S-R formula, educators do not find it necessary to stimulate these abilities in the schools. Learning to read and write is considered to be important as long as the methods employed to teach incorporates the whole brain. However, this is not the case. The human brain's capacity has been underestimated and is clearly reflected in the present educational systems. Thus, Hart (1978) rightly refers to schools as "brain-antagonistic":

> We are obsessed by "logic", usually meaning ... tight, step-by-step, ordered, sequential effort ... But the human brain has little use for logic of this kind. It is a computer of incredible power and subtlety, but far more analog than digital. It works not by precision but probabilistically by great numbers of often rough or even vague approximations (p. 394).

With advances in brain research more specifically in the field of split-brain, it is now evident that the human brain's potential is much more than just left hemispheric abilities. Complex mental tasks are accomplished by a coordinated functioning of both the hemispheres. Hence, it is time for educators to reexamine the present half-brain teaching in the schools. It is essential to shift their focus from verbal rationality and attempt to utilize the findings from the neurosciences. The need for change in the educational system seems necessary considering the widening discrepancy between learners' potentials and methods of curriculum presentation. Each learner is unique in terms of his potentials. Teaching, then, in large part, is the process of stimulating each learner's potential and helping him to construct appropriate mental elaborations of subject matter, concepts and behaviour to be learned (Wittrock, 1981). Environmental stimulation, especially education, can have important input in helping these learners develop their potentials to the fullest. Hence, it becomes all the more important to see that all learners get an equal opportunity to develop and utilize their abilities fully.

The increasing number of children being classified as "slow learners" has become a common feature in the schools. Instead of looking for external causes for such a widespread calamity, educators are quick in finding faults with the child. This seems to be the easier solution. The reason for such a hasty judgement is a reflection of left hemispheric dominance which is obsessed with logic and dilemmas of win/lose and right/wrong. What is the result of such a left hemispheric approach to education? Who is affected? These questions are of great concern for society's future. Each individual brain is capable of handling incredible amounts of information each in its own way. The general consensus is that there are two ways of handling information - the left hemispheric mode of processing and the right hemispheric mode of processing. This being the case, the current trend in education seems to be ignoring one mode of processing which represents one half of the brain. Therefore, there appears to be a strong need for examining the features of this neglected partner in the brain and then attempt to find ways to reinforce its development. The discoveries about the specialization of the two hemispheres of the brain seem to offer new ideas for enhancing learning in the schools. Briefly, a comparison of the important features of the two hemispheres is presented by Edwards (1979):

L-Mode	R-Mode
Verbal: Using words to name, describe, define.	Nonverbal: Awareness of things, but minimal connection with words.
Analytic: Figuring things out step-by-step and part-by-part.	Synthetic: Putting things together to form wholes.
Symbolic: Using a symbol to stand for something ... the sign + stands for the process of addition.	Concrete: Relating to things as they are, at the present moment.
Abstract: Taking out a small bit of information and using it to represent the whole thing.	Analogic: Seeing likeness between things; understanding metaphoric relationships.
Temporal: Keeping track of time, sequencing one thing after another: Doing first things first, second things second, etc.	Nontemporal: Without a sense of time.
Rational: Drawing conclusions based on reason and facts.	Nonrational: Not requiring a basis of reason or facts; willingness to suspend judgement.
Digital: Using numbers as in counting.	Spatial: Seeing where things are in relation to other things, and how parts go together to form a whole.
Logical: Drawing conclusions based on logic: one thing following another in logical order - for example, a mathematical theorem or a well-stated argument.	Intuitive: Making maps of insight, often based on incomplete patterns, hunches, feelings, or visual images.
Linear: Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion.	Holistic: Seeing whole things all at once; perceiving the overall patterns and structures often leading to divergent conclusions (p. 40).

Considering the tremendous advances in the understanding of complex mental functions based on split-brain research, the present thesis is an attempt to synthesize these important findings and highlight their important implications for education. This would certainly create an awareness of the importance of split-brain findings among educators in the present society. This awareness or consciousness of the functioning of the normal brain is essential if the present left hemisphere-oriented society is to provide equal learning opportunities for all learners. The existing educational curriculum is not doing justice to all learners; that is evident in the growing number of children having problems in the schools. We have had enough of "testing" which has led to "labelling" children. What is needed now is to devise ways to promote learning in all children, keeping in mind the diversities of normal brain functioning.

The present thesis begins with studies related to the discovery of the split-brain phenomenon, first in animals and later in humans. The studies on animal split-brains are treated separately. The work on split-brain animals has contributed a great deal in undertaking split-brain operations on humans. Findings of split-brain studies on animals became the starting point for neuroscience researchers to probe the split-brain in humans. Further, the similarity between the two brain structures makes the task of investigating somewhat easier.

The following chapter deals with studies on split-brain humans. The effects of corpus callosum section on the behaviour of individuals becomes apparent. The findings of these studies led to the discovery of the specific features of the two disconnected hemispheres of the brain which is dealt with at length.

The next chapter takes into account the normal functioning of the brain under the heading "Cerebral Asymmetry". A number of non-invasive techniques have been developed to investigate the functions of the two hemispheres that are connected via the corpus callosum in the normal human brain. Some important differences between the two hemispheres are related to task, mode of processing stimuli, sex and handedness. Findings from such studies seem to provide evidence for the validity of split-brain findings. In other words, a greater understanding of the specific features of the two hemispheres in the normal brain is gained.

The second last chapter, "Educational Implications of Cerebral Asymmetry", takes into account the findings from preceding chapters and discusses its implications for a holistic approach to education in which each learner gets the opportunity to actualize his full potentials. The aim is to create a shift from half-brain education to a balanced whole-brain education. In the last chapter, a brief summary of the chapters, together with its important implications for education, is presented.

A final cautionary note should be added to this introduction. As the Table of Contents clearly suggests, this thesis explores the biological basis for learning abilities in human beings, and argues from the results that one whole side of the brain in normal children is at present insufficiently exploited in our schools. From this it should not be inferred that the author holds to any kind of biological determinism in educational philosophy, or favours rigid categorization of children on a biological basis. I am well aware of the strength of objections against such simplistic, sweeping claims made by social critics of current pedagogy. If anything, my intention is to provide means for enhancing cognitive potentialities all normal children already possess, by making fellow educators more aware of those potentialities than they have been hitherto.

Chapter II

Split-Brain Studies of Animals

The split-brain phenomenon, which arises as a result of sectioning of a large bundle of nerve fibers called the corpus callosum and other forebrain commissures, became a special field of interest not only in the field of medicine but also in the social sciences, philosophy, psychology and education since the 1950's. The corpus callosum is the principal connecting link between the two hemispheres of the brain. The control centers of the brain including the cortical areas are found in matched pairs, right and left mirror mates. With respect to the structural and functional capacity, the two halves of the mammalian brain appear to be twins, each with a complete set of centers for the control of sensory and motor activities of the body (Sperry, 1961, 1964). Each hemisphere of the brain is mainly associated with the functioning of the opposite side of the body. In other words, the left hemisphere controls the functions of the right side of the body and the right hemisphere controls the functions of the left side of the body. However, anatomically, the two hemispheres are linked together via a large bundle of nerve fibers known as the corpus callosum and hence the two hemispheres function as a single organ.

In the present century between 1900 and 1950, the corpus callosum had acquired a notable reputation for being the largest and most useless among all the brain structures (Sperry, 1962). Sperry (1962) reminds us about some of the comments made with respect to the function of the corpus callosum. About 1940 Warren McCulloch remarked that the only observed function of this structure appears to be that of helping in the transmission of epileptic attacks from one to the other side of the body. Again, even after 10 years or so, Lashley believed that the main function of the corpus callosum was more of a mechanical one, that is, to keep the two hemispheres from sagging.

The situation, however, changed considerably with the rise of the modern era of study of callosal function which began with the development of tests to measure behaviour in the split-brain animal. Bremer (1956) characterized the new role of the corpus callosum: "It is now obvious that the functioning of the corpus callosum is associated with the highest and most elaborative activities of the brain." In fact, it was the findings obtained through animal split-brains that shed some light on the functions of the corpus callosum. Earlier, a complete surgical section of the callosum for medical reasons in human patients had failed to produce any noticeable change in the patients' behaviours. More specifically, practic and graphic employment of both sides of the body was found to be well preserved. Even in cases of pure agenesis of the callosum, bodily functions seemed to be normal. The animal studies from the beginning confirmed the earlier clinical observations in few humans that complete section of the callosum produces no observable disturbance of ordinary behaviour. Callosum-sectioned cats and monkeys were indistinguishable from their normal mates under most testing and training conditions. The animals seemed to remain alert and curious and maintained fair to good muscular coordination. They were able to perceive, learn, and remember as much as normal animals do. Hence, all these findings led to a further mystery regarding the functions of this structure of the brain.

The first convincing demonstration of the important function of the corpus callosum came from the experiments of Myers (1955, 1956) and Myers and Sperry (1953). All these experiments were conducted to investigate the role of the corpus callosum in interocular transfer in the cat. The concept of interocular transfer implies that the two hemispheres of the brain work in an integrated manner. The implication is that any task learned is accessible to both the hemispheres through the great cerebral commissure or the corpus callosum. To test the phenomenon of interocular transfer required the development of special surgical techniques, training and testing procedures.

It is a well established fact that there is a bilateral projection of the afferent fibers in mammals. Hence, in order to study interaction between the two sides of the brain, the crossed optic fibers are destroyed by a midline section of the optic chiasma. In the absence of the crossed fibers, the patterns of stimulation from each eye are transmitted entirely to the ipsilateral brain-halves by the remaining uncrossed fibers. Once the surgical procedure was completed, the cats were trained for form discrimination tasks (e.g. circle versus square) with a mask covering one eye. After overtraining, the mask was moved to the trained eye and then performance with the untrained eye was tested. Results indicated a positive transfer. Sperry (1958) and Downer (1958) have reported that either the callosum or the chiasm section alone was unable to disrupt interocular transfer of learned visual discrimination in monkeys. However, in cases where both the optic chiasma and the callosum was sectioned, cats and monkeys were unable to perform visual pattern discriminations with the untrained eye. Again if the corpus callosum was cut after training with one eye had been completed, learning did transfer and the cat was able to perform the task with the untrained eye equally well. If, after training with the callosum intact, the cortex on the trained side was ablated, transfer still occurred to the second eye (Myers and Sperry, 1958). In a nutshell, the callosum was found to be instrumental in laying down a duplicate image of the learnt task in the contralateral hemisphere.

Furthermore, sectioning the corpus callosum and studying separately the functioning of the two halves of the brain has contributed a great deal in the understanding of mental functions. As Sperry (1961) has rightly said:

> One obvious advantage of the split-brain preparation lies in the factor of built-in controls within the spare hemisphere, controls for all sorts of experiments ranging from short-term studies on innate organization to studies on the long-term effects of early experience on adult behavior. These controls are not only of the homozygous, identical-twin type but are equated also for almost all experientially derived organization implanted up to the time of splitting (p. 1753).

Soon a functional independence of the two hemispheres was observed in the split-brain animal. Sperry et al. (1956) attempted to compare the monocular learning of a series of visual discriminations with the relearning of the same discriminations through the other untrained eye in six cats who had their chiasm and callosum both severed. The purpose of the experiment was to determine whether learning with the second eye would be facilitated by the original learning with the first eye. Results indicated no significant saving in the relearning scores with the exception of one case in which savings occurred but this was found to be as a result of incomplete section of the optic chiasm. In all other cases, the discrimination tasks were relearned with the opposite untrained eye at rates similar to the original learning with the first eye. Hence, it was concluded that visual learning and memory occurred independently in the left and the right hemisphere.

In another experiment on cats involving a pedal-pressing apparatus, Stamm and Sperry (1957) provide further evidence regarding functional independence of the separated hemispheres. The experiment was conducted with respect to somesthetic learning and memory involving touch and pressure discriminations on the surface of the forepaw. There were two groups of cats, one with intact callosum and the other with the sectioned callosum. Results demonstrated a transfer of not only discriminations but also of simple motor patterns acquired in learning to operate the pedals smoothly to the second paw in normal cats. However, no transfer was observed in the callosum-sectioned cats. Also, a statistical comparison of the learning curves for the first and second paws showed a complete absence of transfer of learning from one to the other cerebral hemisphere. Learning an entirely different response with the second paw occurred as easily as relearning the original response. Paired learning curves are given for one of the four animals studied along with the statement that the learning curve for one cerebral hemisphere is markedly similar to the relearning curve for the other hemisphere. Thus Stamm and Sperry (1957) comment:

> The relearning curves (for corpus callosum sectioned cats) then followed the course of the curves for the first paw. The marked agreement between the two curves of each task was evident in the majority of discriminations of the other three cats (p. 140).

While reviewing the literature on interhemispheric transfer in split-brains, one does come across a few cases in which a high-level of transfer effect has been noted. Sperry (1958) reports a case of high degree of intermanual transfer of somesthetic discriminations in a chiasm-sectioned and callosum-sectioned monkey. Earlier, Smith (1952) had noted indications of intermanual transfer involving a stylus-maze task in callosum-sectioned humans. Due to these scattered conflicting results, Glickstein and Sperry (1960) attempted to gain further clarification regarding intermanual transfer following section of the corpus callosum. Results of the majority of tests were in line with those obtained by Stamm and Sperry (1957). Callosum-section was successful in blocking transfer of the task learned from one hand to the other hand. However, a good deal of transfer was observed in a small minority of tests. In situations where training of the second hand was the opposite of that with the first hand, good transfer of the reversed training back to the first hand was observed among the controls, but was consistently absent throughout the experimental group. The general testing procedure of reaching out and feeling the two test objects before selecting one transferred consistently in the split-brain group, whereas the specific pattern of finger movements used in testing failed to transfer.

Despite the fact that results were varied, it was emphasized that the evidence of intermanual transfer is not in itself any contradiction of the more general conclusion that section of the callosum and anterior commissure effectively divides the learning and memory processes of the two hemispheres. Even where somesthetic discrimination transfers, the learning process of each hemisphere presumably proceeds independently in the absence of the neocortical commissures.

It was noted that after the corpus callosum was sectioned, each of the disconnected hemispheres developed its own private chain of learning and memory experiences that have no connection whatsoever with the opposite hemisphere. Also, not only did learning remain lateralized to the hemisphere receiving the critical sensory stimulation, but the two hemispheres could be trained simultaneously to perform diametrically opposed tasks (Myers, 1962). The learning of diametrically opposed discriminations have been performed concurrently by switching from eye to eye every few trials during the training period by the split-brain animals. Results have indicated no sign of interference between the two processes of learning (Sperry, 1958, 1961). These findings have been confirmed in monkeys as well with regard to visual learning and memory. Soon after the confirmation of the split-brain monkeys' ability to learn contradictory discriminations concurrently with the two hemispheres, the question arose as to whether concurrent learning of reverse tasks could proceed simultaneously. Thus, to investigate this question, Trevarthen (1960, 1962) conducted experiments on split-brain monkeys with the aid of a specially designed apparatus with an optical system of light-polarizing filters through which disconnected hemispheres could be made to perceive two different objects occupying the same position in space concurrently (Fig. 2.1). Under such conditions where one or the other of two stimulus panels is selectively activated in a series of trial-and-error responses, one hemisphere perceives itself to be receiving rewards for selecting, for example, circles and avoiding crosses and the other at the same time with the same responses finds itself being rewarded conversely for avoiding circles and selecting crosses. In this type of situation, the animal works with one particular hand, and the hemisphere controlling it tends to learn more rapidly as compared to the other passive one. Learning was considered to be complete when a reliable criterion of learning set by the experimenter had been attained. Then the performance of each eye was tested separately. In addition, cerebral dominance can be shifted by compelling the animal to use the untrained hand after learning has taken place, and by limiting vision to the more passive hemisphere. Thus, the overall results indicated that the animal could learn with the second hemisphere the opposite of what was being learned with the first hemisphere at the same time without any interference. Further evidence of lack

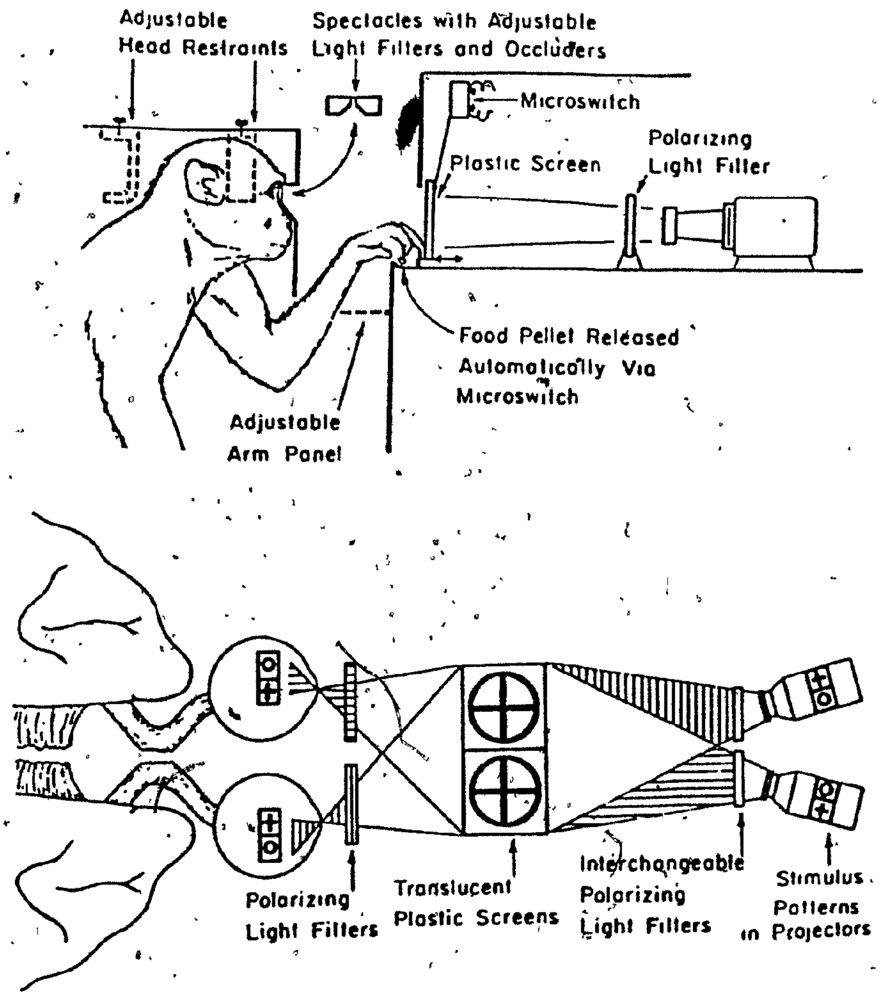


Fig. 2.1

(From Trevarthen, 1962)

of cross communication between the two separated hemispheres was noted in the inability of the split-brain animal to integrate sensory information projected simultaneously partly to one and partly to the other hemisphere (Sperry and Green, 1964).

An important characteristic of the split-brains is their bilateral predominance, each with its full complement of control centers over the brain stem and spinal cord and, hence, each is capable to a large degree of taking over and governing the total behaviour of the body (Sperry, 1961). It has been observed that with one hemisphere damaged, the cat, monkey and even man seems to get along quite well and most of the central nervous functions are maintained. In the case of the split-brain with both hemispheres present, even though one hemisphere is strongly dominant or in total control of the higher functions, the other continues to contribute much to generalized background functions (Sperry, 1961). As long as there is unity in the lower centers of the brain, there is no interference in the simultaneous use of the two separated hemispheres. Further the split-brain preparation serves as an ideal approach for studying the functions of each hemisphere because the two separated hemispheres of the same animal can be compared directly on the ability to learn and perform the same tasks without the complicating effects of unilateral lesions.

Another advantage of the split-brain technique is that it is possible to functionally compare a unilateral lesion with a symmetrical bilateral ablation (with regard to visual stimulation) when the eye homolateral to the lesion is kept open and the opposite eye sutured shut. When the eye contralateral to the lesion is open and the homolateral eye shut, the animal's behaviour with respect to visual stimuli is like the one in its preoperative state. Therefore, this suggests that it can be possible in effect to remove brain tissue and replace it by opening and closing the appropriate eye (Downer, 1961).

While investigating inter-hemispheric transfer of visual discrimination tasks in monkeys, Downer (1961) noted that transfer of monocularly learned visual discrimination tasks did not occur in three animals with mid-sagittal division of optic chiasm, corpus callosum, anterior commissure and that part of the hippocampal commissure lying subjacent to the corpus callosum. However, transfer was evident in a fourth animal in which the anterior commissure was not sectioned while all others were sectioned. Findings were significant in the sense that the role of temporal poles in the transfer of visual gnostic behaviour became evident. The anterior commissure is the major connecting link between the temporal poles. Hence, in order to investigate the role of temporal lobes, Downer (1962) conducted a dramatic experiment in which he combined a split-brain technique with a unilateral temporal lobectomy in a monkey that had previously completed a visual discrimination training sequence, following mid-sagittal division of the optic chiasma, corpus callosum, and part of the hippocampal commissure. After the recovery period, the eye projecting to the side of the temporal pole lesion was left open, and the opposite eyelid was sutured shut. A remarkable change in the animal's behaviour was noted. The animal was unable to differentiate between edible and non-edible objects merely by visual cues and spent some time sniffing and biting before actually eating or rejecting them. Changes in emotional behaviour were noted too. The animal exhibited the normal wild and aggressive behaviour at the sight of humans before the temporal pole removal. However, following the temporal pole removal, the animal showed no aggressive behaviour but rather became calm and quiet. Again, when the eye projecting to the side of the temporal pole removal was closed and the other eye opened, an abrupt change in behaviour resulted. The animal was back to its preoperative state of aggressive behaviour. These findings demonstrated the intimate relationship between the primary visual system and the temporal lobe of the same hemisphere, especially the subjacent amygdala.

Results of an experiment on monkeys by Ettlinger (1959) are similar to the above. He found that animals that had both their tract and temporal lesions on the same side were consistently superior in their visual learning task as compared to other animals that were forced to use a transcallosal system. Hence, Mishkin (1962) concludes that the interconnections of visual mechanisms within a hemisphere are more important and efficient as compared to connections between the two hemispheres.

Results of studies on split-brain cats and monkeys on visuomotor coordination are many and varied. Contralateral motor projections or decussation is a well-known neurophysiological fact, corroborated by a great deal of anatomical evidence. Nevertheless, there are ipsilateral projections as well (Voneida, 1963). The primary visual area is isolated from the primary motor area when cerebral commissures and optic chiasm have been sectioned in monkeys. Obviously the question arises: How does visuomotor coordination take place in the split-brain animal? Some findings on split-brain monkeys and cats indicate little or no coordinational deficits (Bossom and Hamilton, 1963; Myers and Sperry, 1962; Schrier and Sperry, 1959). On the other hand, some other studies point towards serious impairments of visual-motor coordination (Downer, 1959; Gazzaniga, 1963, 1964).

The first published studies were by Downer (1959) who reported serious deficits in ipsilateral eye-hand coordination caused by midline section of the corpus callosum, anterior commissure and optic chiasm in monkeys. Vision limited to one eye was poor at directing and controlling the ipsilateral arm and always produced limb preferences for the contralateral arm. Impairments were so severe that all monkeys neglected almost completely the homolateral arm. Even when forced to use the ipsilateral arm, few, if any, responses were emitted. Sometimes groping movements occurred but without any visual direction.

The expected preference for the forelimb controlled from the hemisphere that receives the visual input becomes evident under specially designed testing conditions, such as those obtainable through the training apparatus designed by Trevarthen (1960). He provides clear-cut differences in the learning curves obtained in pairing the ipsilateral and contralateral forelimbs with a particular eye that points out basic differences in the neural mechanisms for the two combinations. With regard to the ipsilateral forelimb, the reaction time becomes lengthened and learning slowed down and erratic in nature. The tendency for split-brain monkeys to prefer the contralateral arm has been noted (Trevarthen, 1962) though not as invariably as that reported by Downer (1959).

On the contrary, Schrier and Sperry (1959) noted that visual input into one hemisphere directed either the homolateral or the contralateral paw with equal facility. They concluded that either direct control by the homolateral motor fibers or a subcortical integrating center was involved. Similarly, Bossom and Hamilton (1963) conducted an experiment to determine whether a change in direction of reaching produced by adaptation to a prism covering one eye would transfer to an unexposed contralateral eye. The optic chiasm, corpus callosum, anterior, posterior, hippocampal, and habenular commissures were severed in all the animals.

They observed no homolateral impairment or contralateral arm preference in the split-brain monkey. On an analysis of the results, Bossom and Hamilton (1963) conclude:

> Interocular transfer of the prism adaptation demonstrates interhemispheric communication, and without the possibility of new pathways being forced into use by lesions in visual or motor cortex. The more extensive midline surgery ... further restricts the localization of the paths or centers involved in visuomotor coordination. Further research is necessary to determine how the cortical motor areas involved participate in the acquisition and the maintenance of visuomotor coordination (p. 774).

Hence the question remains: How does one disconnected hemisphere direct and control the ipsilateral arm? In order to gain some insight into the phenomenon of visuomotor integration in split-brain monkeys, Gazzaniga (1966) made an attempt to determine the neural mechanisms underlying ipsilateral eye-hand coordination. Massive cortical lesions involving the removal of almost the whole frontal lobe and some of the parietal cortex was performed in four split-brain monkeys. When these animals were tested for visual discrimination tasks they were able to perform the tasks using the lesioned hemisphere and the homolateral limb. Further results pointed out that the responding arm was not in any way directly controlled by visual processes of the homolateral hemisphere. Analysis of the data indicated that integrity of the contralateral motor cortex was essential for good homolateral eye-hand movements due to the fact that the unlesioned intact hemisphere could not possibly control the paralyzed homolateral limb. Also, since the lesioned hemisphere could hardly process any information, if any, from the homolateral arm, it became very difficult to imagine how the lesioned hemisphere alone could direct and control the homolateral arm. All these observations lead to the conclusion that the mechanisms of ipsilateral eye-hand movement is determined somehow by the main sensory-motor mechanisms of the contralateral hemisphere.

On an examination of the anatomy of the cerebral hemisphere, it becomes evident that these can also exchange information in the reticular formations of the upper and lower brain stem. In Gazzaniga's (1970) words: "... there are several pathways through which an ipsilateral visual-motor response could be mediated." Hence, in order to test this notion, he carried out a deep midline surgery extended down to include the medulla in the monkey. When tested, the animals were able to perform visuo-motor tasks with ipsilateral eye-hand combinations. In fact, their responses became far better in the second to fourth months after surgery than in the first. Though slight errors were often made in reaching, such as missing the visual target by an inch or so, their responses were always in the right direction.

The possible technique employed by the split-brain animal in making ipsilateral eye-hand responses has been called by Gazzaniga (1970) the "cross-cuing mechanism". The general idea behind this is that hemisphere A can set up hemisphere B to respond correctly through a number of ways. However, each way requires hemisphere B to act in response to a cue made available to it in the peripheral apparatus by hemisphere A. The crossover of information here does not take place via the central neural channels. Instead, it transfers by one hemisphere taking note of cues made available to it by the overt bodily-systemic changes executed by the other hemisphere. This notion of "cross-cuing" mechanism was based on a series of observations of several split-brain monkeys in a slow motion film. These animals with varying lesions and midline disconnections were filmed while retrieving food morsels presented to them. In general, one eye was covered with an opaque contact lens and the ipsilateral hand was restrained. With this arrangement, the animal was set free to use one hand only and to see only through the ipsilateral eye. Gross observation in this kind of task did not reveal any possible strategy that might have been used in making successful ipsilateral eye-hand responses.

It was only through observations in a slow-motion film that the mechanism of cross-cuing was discovered. When a food morsel was held out in a particular part of the visual field, the monkey would scan the visual field until the object came into focus. Then it would fixate the object, orienting it with eye, head, and neck movements, all in a line. Once this was achieved, the animal would reach out with the homolateral arm to the relevant point in the space. In fact, it was noted that while reaching, several monkeys closed their eyes. Thus, Gazzaniga (1970) comments:

> The seeing hemisphere takes note of the point in space to be obtained, fixates on the point, thereby allowing the nonseeing hemisphere's ability to read off eye, head, and neck position by means of nonvisual proprioceptive systems. With this information input held at a constant level, the blind hemisphere can either itself decide to reach to the point in space, using the readily controllable contralateral arm; or the seeing hemisphere, by some kind of peripheral jerk or grunt, or the like, could signal the blind hemisphere to go when ready (p. 48).

Thus, it can be seen that emphasis was being shifted from the corpus callosum to the extracallosal pathways in investigations of interocular transfer. Meikle and Sechzer (1960) observed that split-brain cats with mid-sagittal section of the optic chiasm and corpus callosum were able to transfer interocularly simple brightness discrimination tasks. Results strongly suggested that an extracallosal pathway is responsible for communication between the two hemispheres in brightness discrimination tasks. However, the same cats failed to transfer pattern discrimination tasks. Thus, in an attempt to determine whether there are extracallosal pathways that could mediate interocular transfer of pattern discrimination, Sechzer (1964) conducted an experiment on split-brain cats with section of the chiasm and the corpus callosum using two kinds of motivational approach. Considering the fact that all earlier studies had utilized food-approach motivation, he decided to include in his experiment another motivational approach namely, shock-avoidance motivation. Each cat learned a pattern discrimination under both food-approach and shock-avoidance motivation. The same split-brain cats that failed to transfer a learned pattern discrimination from one eye to the other under food-approach motivation were tested under shock-avoidance condition. Results indicates significant interocular transfer of pattern discrimination under shock-avoidance condition. Hence, it appears interocular transfer of pattern discrimination is greatly influenced by the method of training procedure employed.

High level of interocular transfer of pattern discrimination under shock-avoidance motivation illustrated that bilateral interaction of a complex visual function can occur even after both the corpus callosum and the optic chiasm have been sectioned. Thus, it is evident that transfer in the above case is mediated by an extracallosal, subcortical pathway which is activated by shock-avoidance and not by food-approach motivation. Although these findings indicate that an extracallosal commissure is responsible for connecting the two cerebral hemispheres, no specific anatomical pathway has been determined (Sechzer, 1964). However, earlier there had been some indication that probably a multisynaptic, subcortical system is involved in interhemispheric communication after section of the corpus callosum (Rutledge and Kennedy, 1960). They conducted experiments on cats in which one hemisphere was stimulated and electrical response of the opposite hemisphere was recorded. Interhemispheric communication was noted. Based on his observations, Sechzer (1964) concludes:

> ... the confluence of pain and visual pathways known to occur in the superior colliculi and adjacent tegmentum may be essential to the interocular transfer of pattern discrimination in split-brain cats, trained under shock-avoidance motivation (p. 83).

From the above, it is apparent that there are a number of neural pathways involved in the interocular transfer of pattern discrimination. There is an extracallosal, subcortical pathway involved in the process of interaction between the two hemispheres. However, the exact location of such a pathway is yet to be determined.

Sechzer (1970) has provided further insight into the phenomenon of interhemispheric transfer in split-brain cats. He noted that split-brain cats trained with one hemisphere at a time needed more than twice as many trials to reach criterion as compared to normal or commissurotomized cats tested with both disconnected hemispheres participating. On an analysis of the findings, it was concluded that learning time is normal when interhemispheric transfer succeeds and on the contrary, learning time is lengthened when interhemispheric transfer fails to occur.

In order to test the generality of the split-brain phenomenon, Teitelbaum (1971) conducted an experiment on rats using a different sense modality. The corpus callosum, hippocampal commissure and anterior commissure were severed in the rat and olfactory input was lateralized by blocking one nostril at a time. Despite the fact that the study was successful in producing a deficit in interhemispheric transfer in the rat, it could not be determined whether the anterior commissure was solely responsible for such a deficit in transfer. This was due to unavoidable partial damage to the corpus callosum in all cases. However, results were fruitful in the sense that it became evident that odor can be used as a stimulus in studies of interhemispheric transfer. Also, the laboratory rat proved to be an ideal subject for the investigation of split-brain phenomena. Furthermore, results indicated an independent functioning of the two hemispheres when tested with olfactory stimuli in the split-brain situation.

A number of experimental findings in the split-brain literature have demonstrated that although learning and memory may proceed independently when the corpus callosum has been sectioned, they do not do so normally in each hemisphere. When interaction and cooperation cannot occur between the two hemispheres, learning is markedly prolonged and retention is impaired (Meikle, 1964; Meikle and Sechzer, 1960; Meikle et al., 1962; Robinson and Voneida, 1970; Sechzer, 1964, 1965, 1968, 1970; Teitelbaum, 1971).

It is abundantly clear that the corpus callosum plays a major role in the processes of learning and memory. It serves as a link through which stored memory traces are accessible to each of the hemispheres. Also, it controls the formation of memory traces in such a manner that they are imprinted in only one hemisphere instead of in both. This mechanism of duality aids in doubling the mnemonic storage capacity of the brain. It has been found that the existence of an intact corpus callosum in the monkey during learning does not necessarily result in the laying down of a double set of memory traces in the two hemispheres. Gazzaniga (1963) conducted an experiment on three pigtail monkeys to determine the effects of commissurotomy on a preoperatively learned visual discrimination task. These animals were trained and tested in an apparatus that allowed the experiments to control eye and hand use. Also, it produced a minimum restriction of the visual field and hand movement or both. Preoperative training permitted free use of both eyes with equalized use of right and left hands by forced alternation every twenty or forty trials. The stimuli were equated for brightness and were shifted from right to left on a pseudo-random basis. After the animals had learned the discrimination task and were performing at high level with each of the four eye-hand combinations, a complete section of the corpus callosum, anterior commissure and midline section of the optic chiasm was performed. Then these animals were tested on the preoperatively learned discrimination tasks. On the basis of their performance it became evident that the cortical engrams are localized predominantly or entirely in one hemisphere. When needed by the other hemisphere, the stored information is transferred via the corpus callosum.

Experiments with amydgalectomized macaques have demonstrated that they are unable to recognize danger visually. The normal monkeys exhibit a fleeing response at the slightest approach of man whereas the amydgalectomized subjects tend to appraoch the outstretched human hand just to sniff at it. This is a permanent condition and therefore it has been concluded that the amygdala has an essential role in the monkey's visual recognition of fearful objects (Doty et al., 1973; Doty, 1975). Earlier, Downer (1961) found that the amygdala in one hemisphere could communicate through the corpus callosum with the visual system in the other hemisphere to arouse fear. In order to gain more clarity on the subject, Doty et al. (1973) conducted an experiment with the splenium ensnared in monkeys. On one side the optic tract was cut, leaving that hemisphere blind, and the amygdala was removed on the contralateral visual side, thus making it incapable of motivational interpretations of visual inputs. As long as the splenium was left intact these monkeys exhibited a fleeing response at human approach. But the moment the splenium was transected by pulling the snare, the fleeing response disappeared.

It thus becomes evident that the visual cortex of one hemisphere, which is capable of seeing but lacks the amygdala for interpreting the importance of the stimulation, could somehow communicate with the contralateral amygdala on the blind side via the splenium. This obviously implies that the splenium is responsible for unifying the conscious experience of the monkey. However, when it comes to determining the nature and direction of intercommunications between visual and motivational systems, little is firmly known. As Doty, Sr. and Overman, Jr. (1977) comment:

> A priori, it would seem reasonable that the visual system should encode and abstract patterns from the input and transmit them continually across the splenium into the contralateral temporal lobe. How the amygdala "recognizes" a pattern as significant, or instructs the visual system to do so, goes directly to the heart of one of the most difficult and important problems of neurophysiology (p. 81).

In addition, it was noted that in monkeys with sectioned optic chiasm, the hemisphere which initially learned a maze with five choice points had no advantage over the contralateral hemisphere as long as the splenium was intact. However, when the snare was pulled, thus completing the separation of the forebrain commissures, the originally trained hemisphere was fully capable of guiding the monkey through the maze. But the less trained hemisphere showed considerable confusion for one or more traverses of the maze.

Also, a comparison of the mnemonic role of splenium versus anterior commissure was made. On the basis of their findings, Doty et al. (1973) concluded:

> Thus, the splenial system upon excitation of one hemisphere merely "reads out" the engram, which has remained in the "trained" hemisphere and has not been transferred into the "untrained" hemisphere; whereas the anterior commissure is able to induce the formation of an engram in the "untrained" hemisphere ... achievement of unilateral engrams with bihemispheric, transcallosal access to them effectively doubles the mnemonic storage capacity of the brain (p. 726).

From the above it becomes clear that unilateral storage of memory has been emphasized. The anterior commissure and the splenium of the corpus callosum have different roles to play in the phenomenon of interhemispheric transfer. The experiments of Doty and his co-workers involved a two-stage commissurotomy technique in which one of the two could be sectioned and the other ensnared for instant sectioning after the animal had learned a response to direct unilateral stimulation of the striate cortex. With either commissure intact during the unilateral training the monkeys were able to perform the response to initial stimulation of the untrained side. Thus, either commissure alone could subserve interhemispheric transfer. However, after the second stage of commissurotomy had been completed, the animals' response varied in accordance with the commissure which had been intact during training. If the anterior commissure had remained intact, then the animal continued to respond to stimulation from either side. On the contrary, with the splenium intact the monkey responded only to the trained side. Hence, Doty concluded that the anterior commissure is responsible for establishing a memory for learning in both hemispheres - a bilateral engram, whereas the splenium affects interhemispheric transfer by establishing a unilateral memory trace (homolateral to the side of stimulation) and making it accessible to the other side. Thus, with complete sectioning, communication is lost.

In a nutshell, regarding the anterior commissure, the results demonstrate bilaterality and therefore are in agreement with the results obtained by other investigators (Butler, 1968; Ebner and Myers, 1962; Hamilton, 1977; Myers, 1961) using natural visual stimuli. But when it comes to the role of splenium, it is in contradiction with the bilaterality effect for it does not allow memory formation in the untrained hemisphere. Hamilton (1977) concluded, based on his observations on monkeys, that normal as well as split-brain monkeys store memories bilaterally. The cerebral commissures help in establishing a duplicate memory in the untrained hemisphere. Results of experiments conducted by Hamilton (1977) lend support to the hypothesis that with lateralized input bilateral memories are formed when either or both the anterior commissure and the splenium are intact during the training session. It was also noted that memory traces are stronger in the trained hemisphere as compared to the untrained one. Butler (1968) noted good duplicate memory traces in the untrained hemisphere in monkeys trained after transections of the optic chiasm and the anterior commissure and tested with their brains split. Similarly, Ebner and Myers (1962) found bilateral memory traces for tactile discriminations trained through one hand.

The contradictory findings in the liaterature do require further investigations taking into account factors such as the amount of overtraining in the learning task and the time lapse between the transection of the commissural pathways and testing. These factors may have some role in establishing memories in the hemispheres. At this stage it is difficult to estimate their input in learning and memory.

On the basis of an overall review of the experiments on split-brain animals it can be safely concluded that these studies have definitely provided a sound basis for investigating mental functions in humans. Not only that, animal split-brains would continue to serve as a foundation for the discovery of the secrets of the human brain. Due to the similarities in the structure between the mammalian brains the neuroscientists have the advantage of variability in experimentation. The complex and intricate structure of the human brain imposes definite limits in terms of surgical procedures involved in investigating the mental domain. Since higher psychological functions are complex in nature and are dependent upon a coordinated functioning of various cortical zones (Vygotsky, 1952; Luria, 1966a, b), a slip of the neurosurgeon's knife could result in an irreparable damage to the human brain. Therefore, animal studies are an essential part of brain research in humans. In fact, the achievements made in the understanding of the human brain and mental functions have been largely possible due to experiments on animal split-brains.

Further, it is abundantly clear now that the large bundle of nerve fibers called the corpus callosum (once considered to be useless) has a very important role to play in the functioning of the mental domain. In the literature there are mainly two points of view with regard to its function. According to one point of view, the corpus callosum is responsible for integrating the information of the two cerebral hemispheres.

The other point of view regards it as responsible for laying down bilateral memory traces in the two hemispheres. Upon analysis it appears that neither is incorrect nor contradictory. The corpus callosum definitely has an integrative function within the range of specialized abilities because the two hemispheres in the normal brain work as a single organ. Information from the two hemispheres are integrated for a unified perception. The normal animal functions as a unified whole. Further, due to bilateral sensory projections information is transmitted to both the cerebral hemispheres and unified via the corpus callosum. Hence, there is no doubt now that the corpus callosum is important in the normal functioning of the animal as well as in the human being. To sum up, the sectioning of the corpus callosum has definitely contributed to the understanding of much of the mental functions. Also, results of experiments on split-brain animals have led to the exploration of the psychological functions in the human brain. Although tremendous advances have been made in terms of understanding the brain, still much more needs to be understood. This could only be achieved by continued investigations of animal split-brains as well as human split-brains.

Chapter III

Split-Brain Studies of Humans

The corpus callosum is the largest single bundle of nerve fibers which directly connects the two cerebral hemispheres. It forms the principal of "the cerebral commissures" which also include the anterior commissure, the hippocampal commissure and, for some 65% of us, the massa intermedia (Bogen, 1979). Due to its physical prominence in brain structure, researchers in the field of neuroscience have been interested in its study from the time when serious anatomical descriptions were being made. Further, the necessity of sectioning the corpus callosum in some human patients for therapeutic reasons provided the opportunity for serious investigations of its functions in the normal human brain. In fact, speculation about its functions was facilitated even prior to the discovery of concepts of cerebral lateralization and dominance. As Joynt (1974) points out, although in recent years clinicians have correlated callosal lesions with neurological impairments, they have not been able to pinpoint the exact nature of their relationship. Hence, it has been rightly said that "... the corpus callosum has a long heritage of anatomical description, functional speculations, and clinical correlations" (Joynt, 1974).

Looking back into callosal history, prior to the beginning of the 1940's, one finds that most of the reports regarding cases of commissurotomy include large series devoted to changes in the mental state and very little is mentioned about the aspects of the so called "deconnection syndrome". It was only in the later 1930's and early 1940's that the corpus callosum received renewed interest from Van Wagenen, Akelaitis and their colleagues at Rochester, New York. A. J. Akelaitis appears to have been the first person to undertake the operation of commissurotomy and has reported about some two dozen such patients between the years 1942 and 1945. Partial or complete callosal sections were performed on patients of longstanding epilepsy acquired in early life. These patients were critical cases to the understanding of callosal functions. After the operation, all these patients were carefully examined by the psychologist, K. U. Smith. Results of both neurological and psychological examinations as a whole did not indicate any consistent deficits that could be reliably attributed to commissurotomy.

Smith and Akelaitis (1942) on the basis of their observations of human patients before and after the section of the corpus callosum attempted to describe possible relationships existing between laterality or sidedness in behaviour and neural activity mediated by the corpus callosum. The terms "sidedness" and "laterality" in behaviour refer to a basic neurological and psychological aspect of bilateral motor coordination. There is ample evidence that the regulation of movement in all motor functions demands a preferential role of one side of the brain over the other. In fact, this experiment on the effects of partial and complete section of the corpus callosum on motor organization further provided an opportunity to evaluate directly the general notion of cerebral dominance. The results were discussed under two main headings: (i) the initial effects of the operation on representative motor skills and (ii) laterality in behaviour after section of the corpus callosum as evident from the performance test results.

On a careful examination of patients soon after recovery from anesthesia, Smith and Akelaitis (1942) concluded:

> There was no indication in the patients in whom recovery from the operation was not complicated by signs of organic lesion to the brain in addition to section of the corpus callosum that common tasks of eating, dressing, locomotion, etc.,were seriously disturbed by the operation, except possibly for some slowing of the speed of reaction ... observations indicate clearly that disturbances of unilateral and bilateral motor skills occur infrequently after section of the corpus callosum. Those cases in which such disturbances were noted were complicated by the presence of pathologic conditions not directly dependent on the callosal section (p. 528-529).

Hence, it can be seen that all the evidences obtained by Smith and Akelaitis (1942) indicated no significant changes in the patients' overall behaviour. Further observations of laterality in behaviour of the patient before and after the sectioning of the corpus callosum revealed little or no shifts at all. Shifts in laterality in a few cases noted by the investigators resulted only after extensive sampling and statistical treatment of observations in over 100 different performances. Also, the measured shifts in laterality were found to be only temporary. The relevant facts from the data has been summarized by Smith and Akelaitis (1942):

> Temporary instability in laterality of function appears in some patients after section of the corpus callosum. Right-sided persons may not be affected at all, even though the section is complete ... patients having any marked degree of left-sidedness (i.e., left-sided and ambidextrous persons) are affected more seriously than right-sided patients. After section of the corpus callosum, mean decrease and mean increase in laterality are about equal in right-sided persons, but mean decrease is more than double mean increase in patients with notable degrees of left-sidedness. After some two or three months the laterality status of the patients is readjusted, so that the preoperative laterality is approximated ... Different aspects of motor organization are unequally affected by the operation. Eyedness and writing habits generally are not modified at all. Performances involving bimanual eye-hand coordination, unimanual tool using and manipulation and general body orientation are changed most by the operation. When the results in all the cases for all different types of performance are averaged, decreases in

> laterality exceed increases. This decrease is accounted for entirely in terms of the greater tendency toward ambidexterity after operation among persons possessing preoperatively mixed dominance or left sidedness (p. 540-541).

Akelaitis (1941a, b, 1943, 1944) observed no change in the postoperative findings regarding stereognosis; personality; visual, auditory or tactile gnosis; language function; and size, object, letter and colour discriminative ability in the field of vision. Bridgman and Smith (1945) found no change in binocular depth perception and in the ability to maintain and recover fusion in response to diplopia producing stimuli in the same group of patients. Further, it was noted that dyspraxia did not occur unless one of the hemispheres had been damaged preoperatively. However, some minor defects in the patients were noted but due to their fragmentary and transient nature, they were largely ignored. Patients experienced some difficulties in coordinating actions of both hands, but these could not be assessed accurately (Akelaitis, 1944-45). Due to negative findings, it was concluded that information from the two hemispheres integrated either through the forebrain or subcortically. In a nutshell, results obtained by Akelaitis and his colleagues were largely negative in the sense that no definite function could be attributed to the corpus callosum itself. It is often said that negative findings are obtained due to inappropriate or insensitive testing procedures. Probably this was the case with the findings of Akelaitis and his collaborators.

It was only around the early 1950's that Ronald E. Myers and R. W. Sperry, then at the University of Chicago, made a surprising discovery: When the large bundle of nerve fibers called the corpus callosum was sectioned, thus disconnecting the two cerebral hemispheres, each hemisphere functioned independently as if it were a complete brain. The experiment was first conducted on a cat in which not only the corpus callosum but the optic chiasm was also sectioned so that visual information from one eye did not transfer when the animal was tested with the other eye open and the original eye sutured shut. In fact, the animal did not demonstrate any recognition of the problem and had to learn the problem from the beginning utilizing the other half of the brain. This and similar findings obtained from other animal studies introduced entirely new questions in the study of mental functions in the human brain. All questions were mainly directed to the role of the corpus callosum in the intact human brain. One of the major questions was: To what extent were the two separated hemispheres independent in terms of their mental functions? Hence, in order to probe into the characteristics of the disconnected hemispheres, Sperry and his colleagues conducted a wide-ranging series of animal studies at the California Institute of Technology throughout the 1950's.

Knowledge obtained from experiments on split-brain laboratory animals had generated the possibility of discovering a hemisphere-disconnection syndrome in human patients. Geschwind and Kaplan (1962) while looking for disconnection symptoms in a patient with cerebral neoplasm and callosal infarction observed that although he was able to write clearly with his right hand, he was also able to write "aphasically" with his left hand too. However, the patient was surprised when he looked at what he had written with his left hand. In other words, his left hemisphere remained ignorant of the functions of the right hemisphere. Further, an object placed in his left hand was handled properly and was picked out merely by touch, however, it could not be named. Even feeling the object with his right hand did not help in retrieving the object.

Thus, Geschwind and Kaplan (1962) comment:

> .... he behaved as if his two cerebral hemispheres were functioning nearly autonomously. Thus, we found that so long as we confined stimulation and response within the same hemisphere, the patient showed correct performance (p. 683).

On the other hand, the patient responded incorrectly when the stimulus was presented to one hemisphere and the response was demanded from the other. These observations led the two investigators to conclude that the patient's hemispheres were disconnected due to a lesion in the corpus callosum. Their conclusion was later confirmed by autopsy. In addition, a sample of the large variety of studies with the split-brain has been beautifully described by Sperry (1964). On an analysis of the results of these varied studies, Sperry (1964) concludes:

> Work with the split-brain has enabled us to pinpoint various centers of specific brain activity, has suggested new concepts and new lines of thought and has opened up a wealth of new possibilities for investigating the mysteries of the mind (p. 52).

Results of experimental studies on animals were quite encouraging in the sense that sectioning of the corpus callosum did not seriously impair mental functions. Hence, it paved the way for the neurosurgeons to perform this operation on patients suffering from uncontrollable epileptic seizures. The purpose was to limit the seizure to one hemisphere. Remarkable success occurred in that the epileptic attacks disappeared altogether, including the unilateral ones. The operations were performed by Bogen and Vogel of the California College of Medicine. Mental investigations were carried out by Sperry and his collaborators. The first patient was a 48-year old war veteran, who underwent the operation which consisted of sectioning of the corpus callosum and other commissural structures connecting the two cerebral hemispheres (Bogen and Vogel, 1962). Since then the operation has been performed on a number of other human patients with thorough investigations over a long period using many testing procedures. One of the most striking features observed was that the operation did not produce any noticeable change in the patient's temperament, personality or general intelligence. Close and careful observation, however, started revealing some changes in the patient's daily behaviour. Despite the fact that spontaneous coordination of the whole body generally remained normal after cerebral commissurotomy, some discoordinated involuntary movements of the limbs, comparable to those described in split-brain monkeys, were noted in varying degrees with different patients. Even though episodes of dissociated voluntary activity of the two hands or transitory silence of one limb while the other is active are frequent, bimanual coordination is maintained to a high degree, especially in well-learned automatic performance (Smith and Akelaitis, 1942; Akelaitis, 1944; Gazzaniga, et al., 1962, 1967; Trevarthen and Sperry, 1973). As Gazzaniga (1967) reports:

> ... it could be seen that in moving about and responding to sensory stimuli the patients favored the right side of the body, which is controlled by the dominant left half of the brain. For a considerable period after the operation the left side of the body rarely showed spontaneous activity, and the patient generally did not respond to stimulation of that side: when he brushed against something with his left side he did not notice that he had done so, and when an object was placed in his left hand he generally denied its presence (p. 24).

Further, specific tests revealed the main characteristics of the split-brains. One of these tests investigated responses to visual stimulation. Spots of light were flashed (tenth of a second) in a row across the board, while the patient fixed his gaze on a central point on the board. Flashing of the lights covered the whole visual field including the right and the left half of the visual field. When asked to report what he had seen, the patient replied that he had seen lights flashed in the right half of the visual field. However, when lights were flashed only on the left half of the field, the patient reported that he had not seen any lights at all. This was obviously due to the well known physiological fact that stimulations from the senses (with the exception of olfactory sense) are projected to the contralateral side of the brain. Therefore, stimulations from the right side of the visual field are projected to the left 'speaking' hemisphere and stimulations from the left are transmitted to the right hemisphere, which does not possess linguistic capabilities. But when the opportunity was given, the right hemisphere dominated and the patient was able to point with his hand when lights were flashed in the left visual field (Gazzaniga, 1967).

The above findings made it amply clear that the right hemisphere is equally important in perception as the left. It is due to the location of speech centers in the left hemisphere that verbal response is controlled by it. Tests of the patient's ability to recognize objects by touch gave similar general findings. When the object was held in the left hand, the patient could not report verbally but was able to match with a similar object in a collection of various objects. Soon it was realized that in addition to the inputs received from the opposite side of the body, each hemisphere received some inputs from the homolateral side too. This homolateral input is mainly responsible for "cuing in" the hemisphere about the presence or absence of stimulation and in transmitting overall information about the location of the stimulus on the body surface. However, it is unable to relay information about the exact nature of the stimulus.

With respect to motor control in the split-brain patients, test results indicated that the left hemisphere exercised normal control over the right hand but was considerably poorer at controlling the left hand. Likewise, the right hemisphere had full control over the left hand but not over the right hand. When a conflicting situation arose and the two hemispheres were dictating varied movements for the same hand, the contralateral hemisphere dominated over the ipsilateral half of the brain. On the whole, the motor findings in the human split-brain patients were in line with those observed in split-brain monkeys.

To investigate the mental functions of the human split-brain, two different techniques were employed: one visual and the other tactile. Results of both tests indicated in general that when information was transmitted to the left hemisphere, the patients were able to handle it both verbally and in writing; whereas, when information was directed to the right hemisphere, the patient was unable to respond verbally or in writing. A picture presented to the right hemisphere produced either a blind guess or no verbal response at all. In contrast, when information was transmitted to the right hemisphere and nonverbal responses were required, the capacity for accurate performance was noted. In fact, other test results indicated that the right hemisphere possesses a certain degree of language comprehension (Gazzaniga, 1967). In a particular interesting experiment conducted by Gazzaniga (1967):

> ... the word "heart" was flashed across the center of the visual field, with the "he" portion to the left of the center and "art" to the right ... the patients would say they had seen "art" - the portion projected to the left brain hemisphere (which is responsible for speech). Curiously, when after "heart" had been flashed in the same way, the patients were asked to point with the left hand to one of the two cards - "art" or "he" - to identify the word they had seen, they invariably pointed to "he" ... both hemispheres had simultaneously observed the portions of the word

> available to them and that in this particular case the right hemisphere, when it had had the opportunity to express itself, had prevailed over the left (p. 26).

Thus, it can be seen that the right hemisphere is not completely devoid of linguistic capabilities. In a case of left hemispherectomy, Smith (1966) found that mental functions such as speaking, reading, writing, and understanding language showed continuous improvement in the first seven months after hemispherectomy. Although there are individual differences he concludes that hemispheric functions seem to differ quantitatively and not qualitatively. The right hemisphere seems to possess a considerable capacity even in the adult to organize linguistic capabilities. However, the upper limit of linguistic abilities in each hemisphere varies from individual to individual (Gazzaniga, 1967). Further, it has been established that in early childhood the two hemispheres are equipotential. In instances where damage occurs to one of them, the other is able to take over its functions. Speech is developed and maintained in the intact hemisphere (Basser, 1962). This indicates the plasticity of the human brain in early childhood. The maturation of the human brain is a lengthy process and it is during this process that later on mental capabilities become differentiated in the two hemispheres. Consequently, each hemisphere assumes responsibility for specific mental functions. The dominance of the left hemisphere is particularly related to its linguistic functions which is one of the unique characteristics of man. Yet examination of right hemispheric functions through specialized tests demonstrates the superiority of the right over the left in certain specialized functions. Tests, for example, have shown that the left hand was capable of arranging blocks to match a pictured design and of drawing a three dimensional cube, whereas the right hand, without any instructions from the right hemisphere, was incapable of performing either of these tasks. Interestingly however, it was noted that although the patients could not perform with the right hand, they were capable of matching a test stimulus to the correct design when it appeared among five similar patterns presented in their right visual field. Therefore, the dominant left hemisphere is capable of differentiating between correct and incorrect stimuli (Gazzaniga, 1967).

In fact, in certain mental processes, the right hemisphere is at par with the left. It is independently capable of generating an emotional response. In one of a series of experiments on emotional reactions along with a number of ordinary objects, a picture of a nude woman was flashed suddenly. The patient was amused regardless of whether the picture was presented to the right or the left hemisphere. When it was flashed to the left hemisphere, the patient laughed and verbally reported that it was nude. However, later when it was presented to the right hemisphere she reported seeing nothing, but immediately a sly smile spread over her face and she began to chuckle. When asked why was she laughing, she replied, "I don't know ... nothing ... oh - that funny machine." Despite the fact that the right hemisphere was not able to describe what she had seen, it was capable of eliciting an emotional response similar to the one evoked by the left hemisphere.

So far, all evidence points towards the independent functioning of the two cerebral hemispheres in a split-brain situation. This obviously leads to another question: Are two brains capable of handling double the information handled by one whole brain? Studies on split-brain monkeys have indicated that they can handle twice as much information as a normal monkey. Human split-brain patients have been observed to carry out two tasks as fast as a normal person can do one. All evidences thus support the phenomenon of "two independent spheres of consciousness within a single cranium". The phenomenon of consciousness in the split-brain has led to a great deal of controversy among researchers in the social sciences as well as the neurosciences. Here it seems appropriate to deal first with various features of the two separated hemispheres in the split-brain and then take up the question of consciousness.

The surgical sectioning of the forebrain commissures produces some changes in the visual perception in man (Sperry, 1970). The visual image on its way to the brain is split down in the middle: one half is transmitted to the right hemisphere and the other half to the left hemisphere. The question then arises: How do the two separate cortical fields get united and the patient perceives a single visual image? Since the neocortical commissures have already been sectioned, there is obviously some other connecting link between the two cerebral hemispheres. (Sperry, 1970) attempts to investigate the possible link involved in uniting the two separated visual images. Initially, after the period of recovery from surgery, no change in behaviour was noted as far as vision was concerned. These patients did not report any peculiarities in their visual experience. With the aid of specially designed tests, serious abnormalities were observed in these patients. In these tests, visual stimulation was controlled, divided and directed separately to the right and left hemispheres. Under such conditions, the patients appeared to see objects through "two quite separate and distinct perceiving systems, one in each hemisphere and neither having any conscious connection with the other". Test results indicate a lack of perceptual transfer between the right and left halves of the visual field. These patients were able to name and describe objects presented in the right visual field but failed to do so when presented to the left visual field. On the contrary, when the testing procedure required a non-verbal response, then the patient was able to point or pick out the correct stimulus from among several other objects even though he verbally denied having seen it. Furthermore, when the collection of objects was lined up in front of the subject, the subject was able to point to the correct object with either hand with the aid of bilateral orientational cues and due to considerable homolateral as well as contralateral motor control in each hemisphere. However, when the test objects are presented behind the screen and the correct object has to be identified by touch only, then the left hand must be used with the left visual field and the right hand with the right visual field. Thus, crossed interhemispheric combinations do not occur and the same is true for perceptual associations that involve visual and auditory or visual and olfactory stimuli, although in the case of olfaction input is homolateral (Gordon and Sperry, 1969; Milner, Taylor and Sperry, 1968).

An important point to be noted in connection with the disconnected hemispheres is that the major hemisphere (usually the left) or the talking hemisphere does not remain in contact with the minor (right) hemisphere. In other words, it has no knowledge of the perceptual experiences of the right hemisphere and therefore when the major hemisphere does the talking, it is speaking for itself. The speaking hemisphere can only guess about the other hemisphere's activity. Also, it has been noted that two tasks could be performed with the two hands working simultaneously. A separate goal object to search for is presented to each hemisphere simultaneously. This is usually done by flashing pictures of the goal objects to each visual half field, or by naming the objects through auditory instructions via earphones with different dichotic input, or by placing the objects in each hand for identification by touch. The two goal objects are then intermingled with other objects and placed behind the screen - out of view. While searching for the goal object, each hand comes up with the right choice. Often one hand comes across the object that the other hand is looking for. When this occurs, the object is merely rejected and the search continues for its own goal object. It is like two people are searching for their own goal objects without any communication between the two. Of course other auditory cues, including speech, have to be controlled. The findings related to the disconnected hemispheres have been summarized schematically by Sperry (1970) in Fig. 3.1. Based on these findings, Sperry (1970) concludes:

> ....each of the disconnected hemispheres has its own private sensations and perceptions, and also its own private images and memory, as well as its own mental associations, ideas, and other gnostic experiences. Recent observations on the emotional reactions evoked by pleasant and unpleasant olfactory stimuli suggest that the related feelings and emotions also may be included as being lateralized in man by forebrain commissurotomy (p. 127-129).

Evidences in support of the simultaneous independent functioning of the two cerebral hemispheres are numerous. Hence, one is back to the original question of locating the connecting link between the two hemispheres that unite the visual images of both hemispheres, thereby producing a single unified image. A recent study of the agenesis of the corpus callosum has further puzzled researchers about the unifying link. Saul and Sperry (1968) administered a series of perceptual and related tests on a 19-year old girl who was diagnosed to have a complete congenital absence of the corpus callosum. The purpose of these tests was to detect right-left cross-integrational deficits. The entire battery of

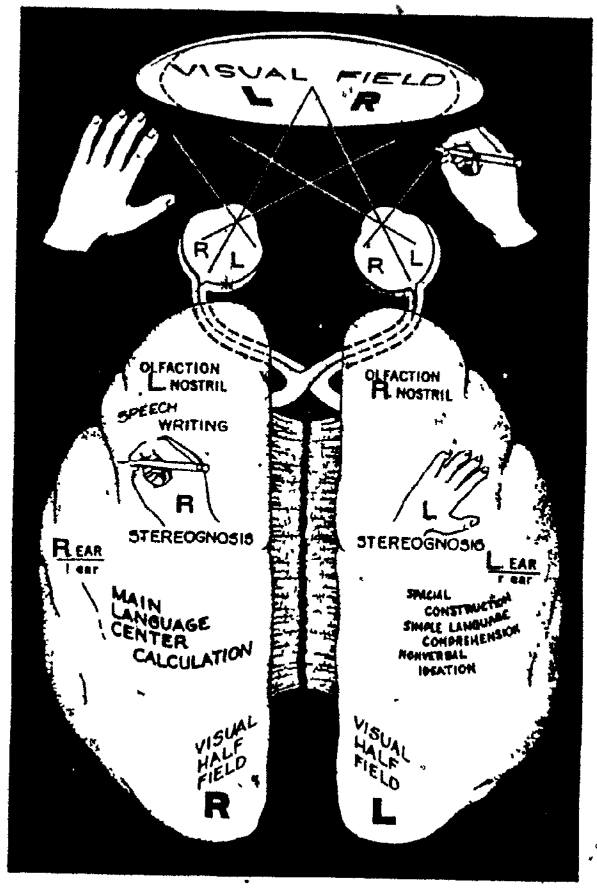


Fig. 3.1

(From Sperry, 1970)

tests developed primarily for detecting basic cross-integrational deficits in the commissurotomy patients were administered to the girl with agenesis of the corpus callosum. Her performance throughout the testing was basically like normal controls. None of the impairments noted in the commissurotomy patients 4 to 7 years after surgery was evident. This obviously reflects the functional plasticity of the nervous system especially during the growing period. Even when visual inputs were restricted to either half of the visual field, she was able to read the whole word without any difficulty. In other words, inputs from right and left visual fields were integrated into a unified whole just like it gets integrated in normal subjects. The only explanation for her so-called normal performance thus far provided is the presence of a slightly enlarged anterior commissure in the brain. However, the high level of performance demonstrated suggests that the anterior commissure alone could not be responsible for such a high degree of integration. Therefore, according to Sperry (1970):

> The most promising explanation ... at present is in terms of a developmental elaboration, reinforced by function of the ipsilateral sensory, motor and associated systems of the brain. These ipsilateral systems normally are weak by comparison with the main contralateral systems, but they are known to be potentiated by conditions like brain damage at birth (p. 133).

Thus, the human brain possesses a remarkable ability to compensate (neurally and/or functionally) for agenesis of the corpus callosum, though it is not yet clearly explainable how such remarkable functions of the human brain are carried out in the absence of the callosum. After reviewing behavioural studies of agenesis of the corpus callosum, Milner and Jeeves (1979) conclude:

> It has been securely established ... that this huge forebrain commissure is normally active in a variety of cognitive, perceptual and motor processes. Yet there is only minimal loss of efficiency in such processes in individuals lacking this pathway. Near-intact behaviour is ensured in these patients by virtue of the immature brain's capacity to reprogramme its development subsequent to an earlier developmental error, making use both of alternative neural structures and of behavioural skills which modify its own inputs. Evidence (both structural and behavioural) nevertheless suggests that there are limits to the amount of compensation, of whatever kind, that can occur. In particular, it seems that an absent corpus callosum cannot be compensated for where cross-mapping of fine-grain sensory information, in vision, or in touch, is necessary. For these, callosal communication seems indispensable (p. 443).

Higher mental functions that are associated with cerebral dominance and lateral specialization of the brain are affected in the absence of the corpus callosum. These unique functions especially require a coordinated functioning of various qualitatively specialized mental faculties of both right and left sides of the brain. The deficits noted in more general, complex and abstract mental functions could result due to either an underdeveloped minor hemisphere because of an extra pressure of having to share with the functions of the other hemisphere, or lack of full coordination between the two hemispheres. Also, the same deficits are noted in an exaggerated form in commissurotomy patients. These patients obtain average scores on verbal left hemispheric functions. In other words, the lateralized functions remain normal, but the nonlateralized, holistic functions of the right hemisphere are markedly impaired in commissurotomy patients (Sperry, 1970). Hence, Sperry (1970) has rightly said: "No doubt remains today that two hemispheres are 'good for you' and that two hemispheres united are better than two hemispheres divided."

The overall behaviour of patients after the recovery period (from commissurotomy) seems to be normal. His personality and behaviour in terms of social interaction remain unchanged. However, when specially designed tests are administered, the entire picture of the patient changes. A general testing unit used extensively to test commissurotomy patients is given in Fig. 3.2 The subject is seated at a table on which an adjustable screen is placed in front of the subject. This screen prevents the subject from seeing his hands, the test items on the table, the tester and other equipment used for testing purposes. In addition, the screen is equipped with a white glass viewing window for the back projection of 2x2 slides in an automatic projector with a mechanical shutter for brief tachistoscopic presentation of stimuli. This testing unit permits the experimenter to exercise greater control in terms of presenting visual stimuli to either one of the two hemispheres or both by asking the subject to fix his gaze on a specific point on the viewing shield. Pictures of objects are presented to the right and left halves of the subject's visual field via exposure times of 1/10 sec. or less. The brief exposure time does not leave room for scanning movement of the eyes and hence stimuli presented to a given half-field cannot be projected to the wrong hemisphere. Visual stimuli presented to the right side of the vertical midline are transmitted to the left hemisphere and vice versa. As far as the right visual field is concerned, there seems to be no problem in naming and describing the object or material by the commissurotomized patient. When a visual stimulus is presented to the left visual field, the subject is unable to identify the object verbally. This is obviously due to linguistic functions being situated in the left hemsiphere. However, when exposure time is

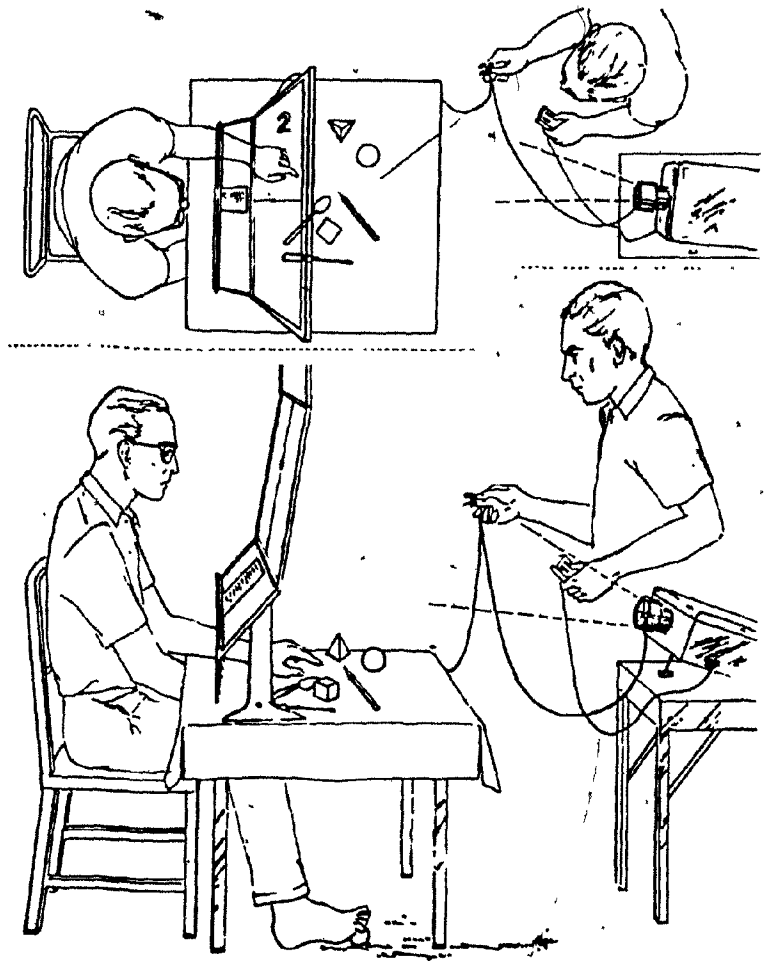


Fig. 3.2

(From Sperry, Gazzaniga and Bogen, 1969) increased, the stimulus is identified due to rapid eye movements that bring the stimulus to the right half field. The story is very different when the subject is required to identify the stimulus using simple manual or other non-verbal responses (Sperry, Gazzaniga and Bogen, 1969).

An analysis of test results of these patients point to an independent functioning of the two visual half-fields. In other words, stimuli perceived in one hemisphere are not perceived and stored in the other disconnected hemisphere. It appears as if there are two separate brains in the commissurotomized patient and each one has its own sphere of sensations, perceptions and memories - short-term and long-term. Also, only one, usually the left, hemisphere is capable of communicating what it perceives through speech or writing. All evidence indicates that the commissures do have an important role to play in terms of integrating information from the two hemispheres in the normal person (Sperry, Gazzaniga and Bogen, 1969). This is true with not only visual information but also somesthetic information. Further, it has been noted that both hemispheres are capable of bilateral recognition and retention of auditory perceptions. Tasks that involve intermodal association are completed successfully only when sensory and related informations are all transmitted to the same hemisphere. Cross-integrations between oppositely lateralized visual and somesthetic inputs are not possible in the commissurotomized patient (Sperry, Gazzaniga and Bogen, 1969).

The fact that the two hemispheres are capable of independent functioning poses a question: Do the two hemispheres get into conflicting situations in the commissurotomized patient? It has been noted that conflicts do occur in the early months of postoperative recovery (Bogen, 1979; Sperry, 1966; Wilson et al., 1977; Zaidel, 1973). Sperry (1966) reports about a patient who exhibited interhemispheric conflicts in his early postrecovery period. He was observed by his wife to sometimes pull up his trousers with one hand and push them down with the other while dressing, or after tying the belt of his robe with help from his left hand to the right, the left would immediately untie it again. In one particular situation, the patient's left hand tried to push away his wife, while the right hand was beckoning her. These instances have been explained by Sperry as conflicts between "willpower-right" and "willpower-left". Similarly, a patient was observed pushing a plate away with one hand and getting it with the other, just to have it pushed away again (Zaidel, 1973). Bogen (1979) reports about other instances of inter-manual conflicts in almost all commissurotomized patients in the early postoperative period. A physiotherapist reports of a patient: "You should have seen Rocky yesterday - one hand was buttoning up his shirt and the other hand was coming along right behind it undoing the buttons!" However, such behaviour soon subsides, probably because of other unifying mechanisms that take over the commissural function. Hence, the patient appears normal in his behaviour under ordinary conditions. As Sperry (1968) comments:

> ... the fact that these two separate mental spheres have only one body, so they always get dragged to the same places, meet the same people, and see and do the same things all the time and thus are bound to have a great overlap of common, almost identical, experience. Just the unity of the optic image - and even after chiasm section in animal experiments, the conjugate movements of the eyes - means that both hemispheres automatically center on, focus on, and hence probably attend to, the same items in the visual field all the time. Through sensory feedback a unifying body schema is imposed in each hemisphere with common components that similarly condition in parallel many processes of perception and motor action onto a common base (p. 728).

Since evidence for right hemispheric linguistic abilities are largely obtained from studies of clinical cases, care should be taken in generalizing to the normal population (Searleman, 1977). The clinical group comprises patients each of whom are unique and differ in such relevant variables as age, intelligence, motivation, and education. Not only that, even the treatment varies from case to case. As Kinsbourne (1974) has rightly said:

> Split-brain patients are notoriously different from one another, to an extent which makes it rarely justifiable to report them as a group. Their data must be analyzed and reported individually (p. 262).

Hence, any generalization to the normal population would be a rough estimation unless and until a large normal population is tested. However, the split-brain cases do and have provided the bases for further inquiry in the normals utilizing modern techniques such as dichotic listening tests.

The functional plasticity of the developing cerebral hemispheres have been noted in children who have undergone hemispherectomy for the treatment of infantile hemiplegia. Hemispherectomies performed in the early years of life, regardless of initial handedness or hemisphere removed, do not hinder normal language development in almost 99% of the cases (Searleman, 1977). Therefore, investigators have often regarded the two hemispheres as equipotential in the early years of life for the development of language (Basser, 1962; Zangwill, 1960).

Speech and writing appear to be maintained at a normal level in the commissurotomized patient under ordinary conditions. The testing procedures required to determine linguistic capabilities of the right hemisphere involve nonverbal responses (Gazzaniga and Sperry, 1967). When stimulation is restricted to one half of the visual field then only limitations of speech and writing abilities are noted. Visual or tactile stimulation to the left half fail to elicit a verbal or written response. These observations further strengthen the conclusion that speech and writing in the split-brain patients are entirely located in the left hemisphere and thus the right hemisphere remains mute and agraphic (Sperry, Gazzaniga and Bogen, 1969). However there is some evidence that the right contributes to some extent in reading and writing in commissurotomized patients. In a patient after left hemispherectomy, Smith (1966) noted that functions such as reading, writing, speaking and understanding language were not entirely lost and showed continuous improvement. Hence he concluded that hemispheric functions differ quantitatively and not qualitatively. The ability to sing and verbal comprehension was also noted which suggested that the right hemisphere does play an important role in these functions.

An important point regarding linguistic ability has been pointed out by Searleman (1977). He points out that there are two aspects of language, namely, production and comprehension of speech. There is a difference between the two. As far as the production aspect is concerned, the left hemisphere takes the lead. However, the right is no less competent in terms of comprehension of language when the opportunity is given. In fact, it appears that failure to distinguish between the two aspects of language have largely contributed to earlier remarks in the literature that the right hemisphere is "mute" or "word-blind" or "word-deaf" (Geschwind, 1965a, b).

Comprehension of both spoken and written words are carried out by the minor hemisphere and expressed non-verbally. Auditory comprehension of language was evident in the ability of patients to pick out with the left hand the object named aloud by the tester from a collection of objects. Words like cylinder, coin, scissors, etc. were comprehended by the right hemisphere particularly when these objects were described in an indirect way like "something to cut with" instead of "scissors". Due to the fact that tactual recognition with the left hand is a right hemispheric function, it could be implied that verbal instruction and description is understood by the right hemisphere and hence the task is completed. Thus, the right hemisphere does have a moderate vocabulary of its own too, though the major left hemisphere might help the minor one with feedback effects, or some facilitative techniques (Sperry, Gazzaniga and Bogen, 1969). Comprehension of written words in the minor hemisphere was demonstrated in the split-brain patient. When a printed word was flashed to the left half visual field, the subject was able to pick out the corresponding object from a collection of objects by feeling them with the left hand behind the screen. Further investigations of the linguistic capacity of the right hemisphere of split-brain patients have been carried out (Gazzaniga, 1970). It was noted that some of the split-brain patients possessed a limited linguistic ability in the right hemisphere. They were able to recognize simple nouns, for example, when the word "spoon" was flashed to the right hemisphere, these patients were able to identify and pick out a spoon with their left hand behind the screen. Though comprehension of nouns was evident through both auditory and visual modalities, little or no evidence for response to verbal commands were found. Even the simplest verbs were outside the limits of the right hemisphere. It could not comprehend at all (Gazzaniga, 1970).

In order to interrogate deeper into the upper limits of semantic and syntactic structure in the right hemisphere, Gazzaniga and Hillyard (1971) administered tests on split-brain patients. Based on their analyses, they conclude that the right hemisphere is unable to tie the subject and the object through a verb and hence to respond to verbal commands. It is efficient mainly in comprehending nouns. Gazzaniga and Hillyard (1971) comment:

> The extent and nature of verbal structure processing in the right hemisphere remain unknown, but it conceivably has become locked in an infantile mode, wherein only simple naming is possible and "no" is the most deeply entrenched concept. These two aspects may be among the most elementary components of logic and/or language, both ontogenetically and perhaps phylogenetically (p. 277).

In addition to the quantitative difference in the capacity of the two hemispheres as noted earlier by Smith (1966), there is a basic qualitative difference in the manner the two cerebral hemispheres process the same information under the same conditions of sensory input and motor response. Thus, there are two modes of mental functioning that are mutually opposing (Levy, 1969; Levy-Agresti and Sperry, 1968). In order to investigate this, Levy et al. (1972) conducted a study in which the two sensory images perceived in right and left hemispheres are arranged to be different and conflicting. A series of visual stimuli in a facial recognition test were split down in the middle and then recombined and joined at the middle to construct composite right-left chimeras as given in Fig. 3.3. These chimeric photographs are then flashed to the subject while his gaze is centered. Since the two hemispheres are disconnected, each is completely unaware of the dissimilarity in the chimeric figures. Hence, the two hemispheres see two different things at the same place and time. This, of course, is never accepted by the normal brain. The two competing perceptual figures joined in the

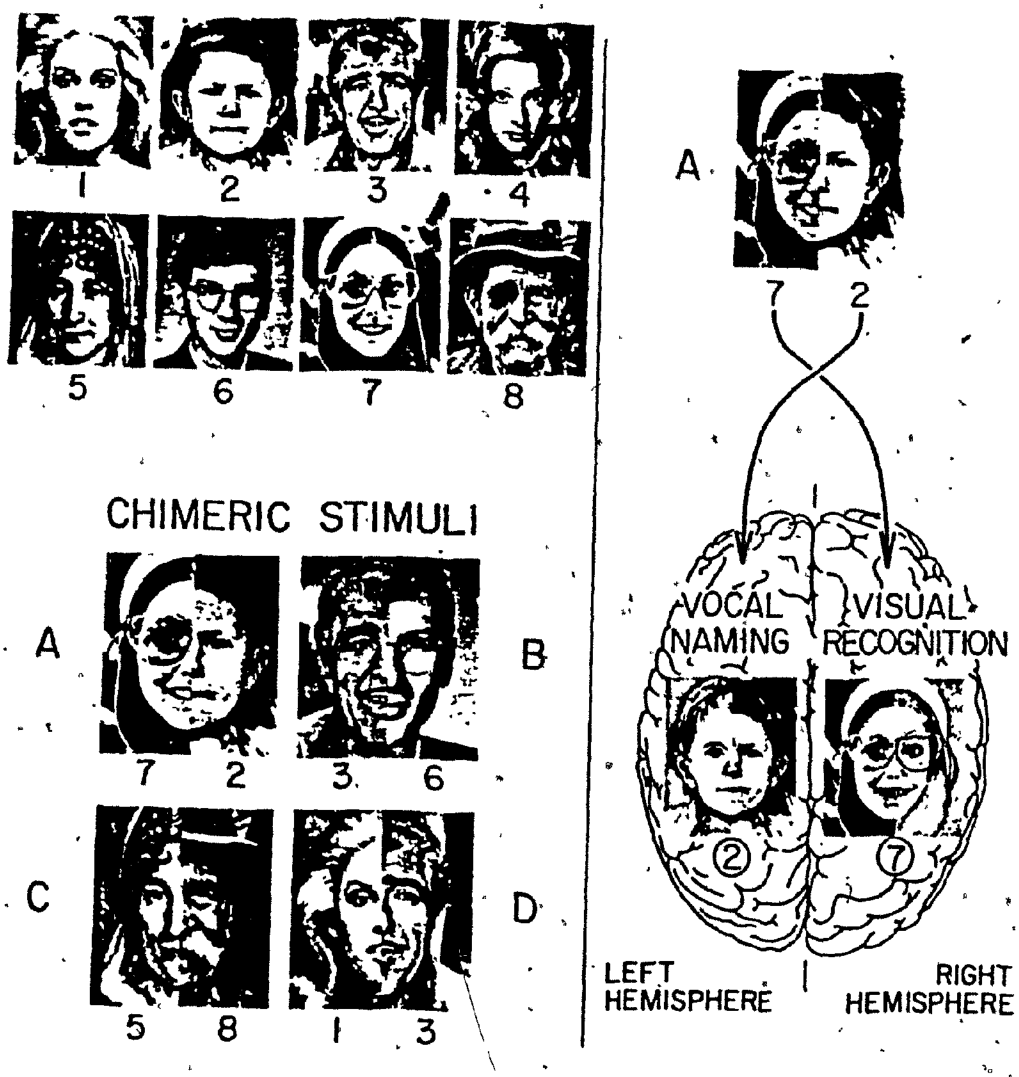


Fig. 3.3

(From Levy et al., 1972)

middle and projected to the right and left sides of the brain provide an opportunity to observe which side of the brain dominates in responding. The response can be either verbal or pointing with the left hand. When patients were tested on these chimeric figures, the left hemisphere dominated when a verbal response was required and the right dominated when nonverbal response was expected.

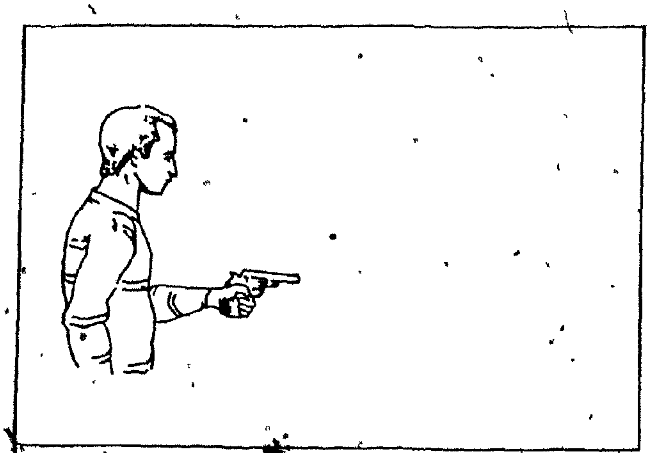
Another study was conducted by Levy and Trevarthen (1977) utilizing the same procedure of split chimeric stimuli in order to investigate differences between the two hemispheres in terms of processing elementary linguistic ability. Three tests of visual recognition, semantic decoding and phonetic similarity were administered to four commissurotomy patients. On the whole, the right hemisphere assumed dominance on the visual recognition tasks where no semantic or phonetic analysis was involved. On semantic tasks, where written words had to be matched to pictures, the left hemisphere gained control, though the right hemisphere was also found to be competent at these tasks. The left hemisphere strongly dominated the right on the test of phonetic similarity or rhyming. Hence, on the basis of their results, Levy and Trevarthen (1977) conclude that "the two hemispheres are basically differentiated with respect to their generative, constructive capacities in language ..."

Furthermore, investigations of a particular case P.S. have demonstrated a wide range of linguistic capabilities in the right hemisphere (Gazzaniga, LeDoux and Wilson, 1977; Gazzaniga et al., 1979). Linguistic capabilities of each disconnected hemisphere were examined in P.S. who is a right-handed male. Results of investigations in 1977 demonstrated rich linguistic skills in each of the so-called "two brains". Both hemispheres were capable of processing nouns, verbs, rhymes and antonyms.

The most distinguishing feature, however, was the right hemisphere's ability to respond verbally through writing and by selecting and arranging letters in a word. The case of P.S. is special in the sense that the extent of linguistic representation in the right hemisphere is more than that noted in other split-brain patients earlier. However, due to the limited number of observations in patients with various case histories, it becomes very difficult to make judgements about language processing in the normal brain. As Gazzaniga, LeDoux and Wilson (1977) rightly state:

> ... split-brain results probably reflect neuroplasticity during early development.. It is generally believed that language develops in both cerebral hemispheres, to some unknown extent, with the process eventually consolidating in the left for most right-handers ...
>
> The variable existence of some linguistic skills in the absence of other linguistic skills in the right hemisphere of split-brain patients demonstrates that different linguistic functions can develop and exist independent of the other functions. Written expression can exist independently of the capacity to produce speech, and neither speech nor writing is a necessary prerequisite for the various comprehensive skills, which may exist together or separately (p. 1146).

Continued investigations of P.S. have shown that the right hemisphere is capable of verbal ability in response to stimuli exposed in his left visual field (Gazzaniga et al., 1979). Verbal responses to complex pictures presented to the two visual fields separately varied in content. An example of a complex picture and the different verbal responses given by P.S. to this and other complex pictures are given in Fig. 3.4 The contents of his responses to the left and right visual presentation varied. The left hemisphere gave an accurate description of the scene. The right hemisphere at first described the idea accurately, but further explanation, although detailed, had no



Right hemisphere stimulus	*Verbal response*
(A piece of) layer cake	'Cake . . . it was a whole vanilla cake with chocolate icing, silverware is there too'.
Exploding firecracker	'Smoke . . . coming out of a chimney, it's a small house'.
Man, shearing sheep	'Man . . . he is walking through the woods'.
Couple dancing	'Some guys . . . working on building together'.
Man with gun	'Gun . . . hold-up . . . he has a gun and is holding up a bank teller, a counter separates them'

Left hemisphere stimulus	*Verbal response*
Christmas tree	'A Christmas tree standing alone'.
Fat man, sweating	'Man—big and fat'.
Man with gun	'Guy with a gun'.

Fig. 3.4

(From Gazzaniga et al., 1979)

relation to the content of those pictures. Initially, the verbal ability in the right hemisphere of P.S. was attributed to the interhemispheric visual transfer through his anterior commissure which had been left intact. But with additional tests requiring 'same-different' judgements when the two stimuli were presented simultaneously through the left and right visual fields separately, the visual interhemispheric transfer hypothesis was rejected in the case of P.S.

Hence, several experiments were conducted to explore the nature of verbal ability in the right hemisphere of P.S. with reference to visual field stimuli. His responses as a whole indicate that his right hemisphere is unique and appears to be in the process of continuing development (Gazzaniga et al., 1979).

In a very recent study, P.S. has shown that interhemispheric communication with reference to language occurs between the left and right hemispheres without any overt voicing movements (Gazzaniga et al., 1982). However, it is not yet clear how such transfer occurred. As Gazzaniga (1983) comments: "It is not yet clear whether such transfer relies on midbrain and brain stem systems or afferent information provided by the speech musculature." He maintains that various manifestations of linguistic capabilities in the right hemisphere of split-brain patients are results of early damage to critical areas of the left hemisphere which prompted the other hemisphere to take over its functions. This is supported by the fact that the small sample of split-brain patients who have shown evidence of linguistic ability in the right hemisphere have suffered damage to their critical area in the left hemisphere in early childhood. I agree with Levy's (1983) statement that "... whether a hemisphere is passive or dominant depends on the nature of task demands, with the left hemisphere passive in some circumstances and the right hemisphere in others." In fact, this has been generally agreed upon in the split-brain literature. On a review of split-brain literature in terms of right hemispheric linguistic ability, Gazzaniga (1983) concludes that the performance of right hemispheres with little linguistic ability is limited to simple matching tasks, whereas others (like in the case of P.S.) are much more capable. However, with increased advances in neuropsychology and more sophisticated techniques, much more is likely to be revealed about the "two brains". Thus, Gazzaniga (1983) rightly comments:

> As neurospychology moves toward a more complete understanding of brain laterality, the contribution of each hemisphere to the expression of specialized skills and the role language plays in such expression will continue to be clarified through future research (p. 548).

Thus, it can be seen that the right minor hemisphere does possess some linguistic comprehension which becomes evident only under specific testing conditions. Under ordinary normal conditions, the dominant left hemisphere takes the lead and therefore no limitations on the two hemispheres are noted. The commissurotomized patient appears normal in his day to day behaviour.

Calculation or arithmetical performance is organized mainly in the left hemisphere. Tests that limit the stimulation to the left visual field or the left hand reveal that the capacity for calculation is almost negligible in the right hemisphere. Very simple tasks like matching numbers or in adding one to numbers below ten can be completed successfully when stimulation is restricted to the left field. The split-brain patients fail on tasks requiring addition or subtraction of two or higher numbers and multiplication and division (Sperry, Gazzaniga and Bogen, 1969).

With regard to motor functions in commissurotomized patients, no long-term basic deficits were noted as long as the combinations were left hemisphere-right hand and minor hemisphere-left hand. However, after commissurotomy there was some tendency to use the left hand less than normal in the ordinary situation. The left hand was brought into action through much effort and stimulation. On the whole, motor symptoms were particularly obvious in those activities in which a hemisphere was expected to guide movement of the homolateral extremities. Gradually, after several months the majority of the patients were able to make a variety of hand and finger postures to verbal instructions with either hand. They were even able to write with their left hand if free shoulder movement was permitted, though the writing was not as good as that of the right hand. One of these patients, L.B., was able to write with his left hand using finger and wrist movement alone (Sperry, Gazzaniga and Bogen, 1969).

Thus, an overall picture of the patients' behaviour in the ordinary situation undermines the capabilities of the right hemisphere. However, when tests require the right hemisphere to express its experience and understanding through nonverbal responses, it appears quite efficient in performing the task. Therefore, Sperry, Gazzaniga and Bogen (1969) rightly conclude that the right hemisphere possesses "conscious awareness and intellect at a level characteristically human with fairly high order mental processes including abstract thinking and reasoning." The minor hemisphere has been found to be effective in handling intermodal transfer tasks between vision, touch, hearing and other modalities. A solution learned through auditory stimulation, as an example, is easily transfered into vision or touch, and vice versa. This level of transfer is far beyond that achieved by subhuman primates with a whole intact brain. Right hemisphere performances also include associations for things that match together like paper and pencil, nut and bolt, etc. Hence, it can be clearly seen that the right hemisphere is not a dumb and mute hemisphere as it appears in ordinary behaviour. Although it fails in verbal expression, it does match it with nonverbal means. Not only that, the minor hemisphere excels the major left hemisphere in certain functions like emotional sensitivity and spatial conceptions.

In the split-brain literature, it is noted that different terms have often been used to describe different perceptual organizations in the two hemispheres such as symbolic vs. visual-spatial (Zangwill, 1961), analytic vs. gestalt (Levy-Agresti and Sperry, 1968), associational vs. apperceptive (deRenzi, Scotti and Spinnler, 1969) and propositional vs. appositional (Bogen, 1969). It is interesting to note however that all these terms basically imply the same meaning in terms of the functions assigned to each hemisphere. As Nebes (1974) has beautifully put it:

> ... they all assign to the major hemisphere the tasks of sequentially analyzing sensory input, abstracting out the relevant details, and attaching verbal labels, while the right hemisphere attends to the overall configuration of the stimulus situation, synthesizing the fragmentary chunks of perceptual data received from sampling of the sensory surround into a meaningful percept of the environment. The right hemisphere is thus viewed as giving spatial context to the detailed analysis carried out by the major hemisphere (p. 156).

Though the left hemisphere has received much more attention due to its linguistic and mathematical abilities, the right hemisphere's functional superiority in some instances have been noted. It has been found to be superior to the left hemisphere in the construction of block designs, and in copying and drawing test figures such as a house (Bogen and Gazzaniga, 1965; Bogen, 1969).

In order to compare spatial abilities of the two hemispheres, Nebes conducted three experiments on human split-brain patients. The tasks in these experiments consisted of perceiving the relationship between the parts of a stimulus and the whole. In the first experiment, Nebes (1971) used the task of part-whole operation at the most basic level. The subjects were merely asked to estimate from visual or somesthetic examination of an arc, the size of the complete circle to which it belonged. Since all stimuli were either arcs or circles, stimuli complexity was at a minimum level. The stimuli consisted of three different inner diameters of ring: 1½, 1¼ and 1 inch. Each ring had a set of a complete ring and four arcs of 280°, 180°, 120° and 80°. These stimuli were presented to the subjects through three different procedures: somesthetic-visual, visual-somesthetic and somesthetic-somesthetic as shown in Fig. 3.5. Two control tests were also administered to assess the patients' ability to match wholes to wholes or parts to parts. The overall results indicated the left hand superiority in completing the tasks on the experimental part-whole matching tasks. The two hands were found to be equally efficient on the control tasks. Thus, it was concluded that the right hemisphere excelled the left in tasks involving part-whole relationships.

In his second experiment, Nebes (1972) introduced more complex stimuli. Instead of the previous presentation of a piece of contour, the whole structure of the stimuli were presented, but in fragments. The patients' task was to perceive the relationship of the pieces of the stimulus to the overall structure of the stimulus. Again comparison of

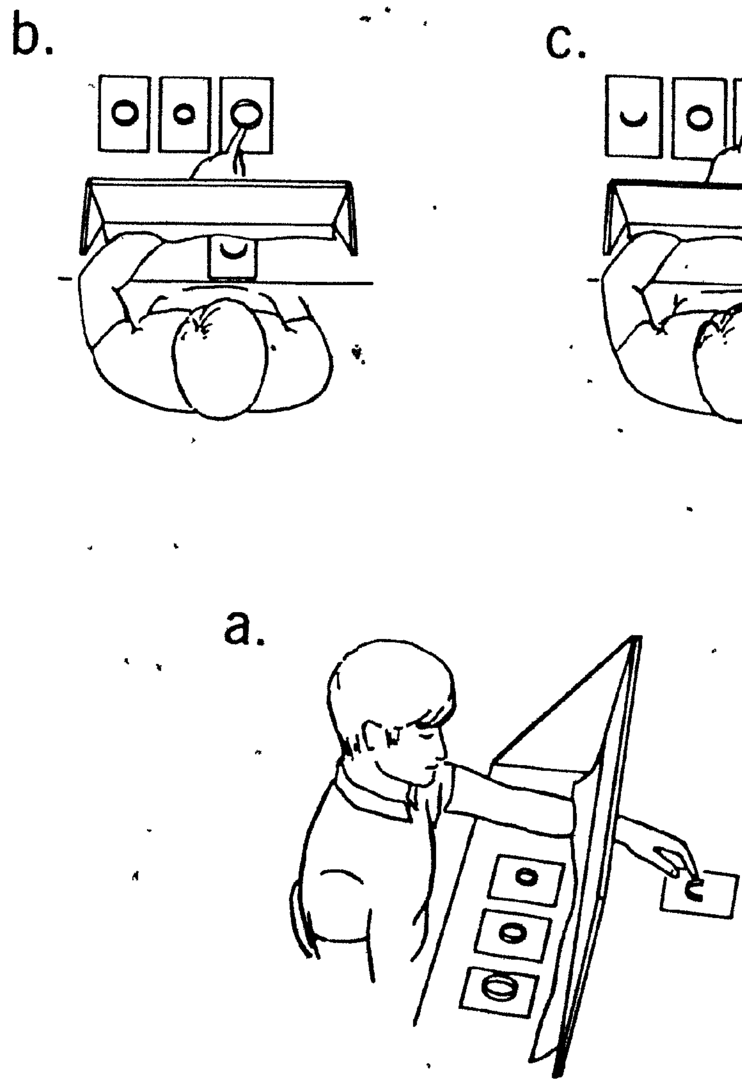


Fig. 3.5

(From Nebes, 1974)

(a) Somesthetic-visual

(b) Visual-somesthetic

(c) Somesthetic-somesthetic

experimental and control results indicated left hand superiority. Obviously, the right hemisphere superceded the left on these tasks. In order to gain further evidence, Nebes (1973) conducted another study in which the part-whole phenomenon was investigated based on Gestalt principles of perceptual organization. The performance of the patients as a whole provided additional support to the right hemisphere superiority in spatial configuration tasks. On the basis of his experimental results, Nebes (1974) summarizes:

> In man ... the principal locus for this part-whole or closure type of process is the right hemisphere, a fact which is consistent with the previously stated models of hemispheric operation. The usefulness of such a perceptual ability is obvious, as it permits the formation of a concept of the structure and organization of the environment without the necessity of subjecting the entire sensory input to a detailed analysis; instead, predictions can be made from the partial data available according to some innate or learned perceptual rules and transformations (p. 163).

Hence, it can be seen that the right hemisphere has an important role in our spatial abilities. As Sperry (1974) states: "... it appears that the minor hemisphere can readily learn and remember such things as spatial relationships and related sorting and assembly tasks."

Under ordinary observation patients who have undergone commissurotomy appear primarily to be dominated by the left hemisphere. Therefore, their right hemispheric capabilities remain hidden, unless specific tests are administered. Largely due to linguistic capabilities, the left hemisphere dominates and the right mute hemisphere remains a silent partner. Lack of verbal expression leaves the minor hemisphere relatively inaccessible to direct investigation. Hence, tests requiring nonverbal means of responses serve as tools for finding out more about this "silent partner". It has been shown that both hemispheres need not necessarily operate together in bringing about an emotional response (Lishman, 1971). The most striking feature is the ability of the right hemisphere to trigger an emotional response to the appropriate stimuli entering it with the left hemisphere being entirely ignorant about the process. Evidence clearly indicates that emotion-provoking stimuli enter the right hemisphere only, and the patient responds with the appropriate emotional reaction. However, the patient is not able to explain his behaviour (Lishman, 1971). An intriguing example related to emotional reactions is described by Sperry and Gazzaniga (in Lishman, 1971):

> The minor hemisphere also shows emotional reactions in response to pin-up shots. For example, one flashes a series of pairs of pictures to right and left visual fields and the subject reads off the names, but only, of course, for those that appear in the right half-field. Into this series of paired presentations of triangles, umbrellas, horses, houses, cigars, and other neutral stimuli one then flashes a vivid pin-up shot of a nude that projects into the minor hemisphere only. At the same time a tree or horse or some such appears on the right side. The subject says, of course, that she saw a horse - with no hesitation. But then you notice that a kind of sneaky grin has begun to spread over the subject's features, and even the tone of voice changes. This emotional effect then carries on through the next several trials. If you ask her what she is grinning at she does not know, and says, "Oh, that light." In this situation recall that the major hemisphere meantime is going along in parallel and is calling the correct names of these objects in the right half-field (p. 183).

Thus, it is abundantly clear that although the patient recognizes that an emotional response has been emitted, she is unable to provide a verbal explanation for its occurrence. Gordon and Sperry (1969) provide additional information concerning emotional reactions in split-brain patients based on their study of olfactory perception. Olfactory perception may be limited to a single hemisphere when stimulation is restricted to a single nostril after the split-brain operation. Hence, odours presented to the right nostril and registering only in the mute hemisphere cannot be verbally identified, though the patient can point out or identify through touch the right associated object. In one particular patient, the affective as well as the olfactory component seemed to be totally limited to one hemisphere. In response to strongly unpleasant odours presented to the right hemisphere, the patient expressed various signs of physical withdrawal from the stimulation. Yet when asked about the stimulus, the patient reported it as "water" because of his inability to smell it. His reasons for withdrawal behaviour were not given, except for saying that it might have been stimulated "unconsciously". Another subject did show some awareness in the left hemisphere when unpleasant odour was presented to the right nostril. However, the awareness was limited to naming the stimulus but usually restricted to choosing any unpleasant odour. Also, differentiation between various unpleasant odours of a particular series was not found to be significantly above the chance level. In a nutshell, the left hemisphere received information about the general affective property of olfactory stimulation to the right nostril, but the more important olfactory component remained under the control of the right hemisphere.

In another situation, when the patient was instructed to abstain from overt responses to distasteful or other stimuli, the unpleasant odours were verbally identified as "water", regardless of the fact that other evidence indicated that the right hemisphere had perceived and identified the odours correctly. Hence, it was confirmed that transfers of even the slightest awareness of the olfactory stimuli to the left hemisphere are dependent upon the feedback from peripheral responses.

Suppression of all peripheral expression of emotion hinders the transfer of information to the left speaking hemisphere. Thus, there is no affective awareness in the left hemisphere. These observations in the commissurbtomized patient certainly point to the importance of the right hemisphere in emotional reactions.

All evidence in the literature so far points towards right hemispheric superiority in processing emotional stimuli. Some of the right hemisphere features make it especially equipped for handling affective stimuli (Ley and Bryden, 1979). Earlier, Semmes (1968) noted that sensory and motor capacities are organized differently in the two hemispheres of brain-injured subjects. These elementary functions are focally represented in the left hemisphere and diffusely in the right. The focal representation involves an integration of similar units and hence specializes in functions that require fine sensorimotor control, such as manual skills and speech. On the other hand, diffuse organization involves an integration of dissimilar units and thus equipped for multimodal integration, such as different spatial abilities. Thus, if it is proposed that an experience of emotion implies an integration of information from both sensory and motor units then the right hemisphere is best suited for dealing with emotional stimuli (Ley and Bryden, 1979). The right hemisphere is often referred to as "holistic" by several investigators (Levy, 1972; Ornstein, 1972). As Ley and Bryden (1979) conclude:

> ... synthetic and integrative characteristics, a holistic and gestalten nature, and imagic associations are three features of processing affective material that would differentially favor right hemispheric mediation of the task (p. 137).

In a nutshell, the right hemisphere possesses distinctive abilities to process stimuli involving visuospatial capabilities and affective material. It has the ability to integrate information from various sources and respond in a holistic manner.

The concept of consciousness remains one of the most intriguing and puzzling ones in the human psychological domain. In fact the controversies surrounding it are mainly due to differences in opinion with regard to its definition and the recent advances in the field of neurosciences. Upon review of the literature in the field, one finds that consciousness has been equated, for example, with subjective experience, language, self-awareness and self-recognition. More broadly, it not only includes 'physical awareness' but the whole realm of complex mental functions in man. The higher psychological functions are highly complex in structure and social in origin (Vygotsky, 1952; Luria, 1966a, b, c, 1970; Luria et al., 1970). With the gradual progress in the field of neurosciences, we have learnt more and more about the intricate nature of the brain. As new facts are revealed, new questions arise about its functions. More specifically, split-brain operations have enabled investigators to explore behavioural phenomena such as consciousness. As Gazzaniga (1972) remarks: "The behavioral consequences of sectioning the cerebral commissures raise fascinating questions about the physical basis of conscious behavior."

By and large, results of split-brain experiments on human patients confirm that normal conscious unity is disrupted after commissurotomy and the patient is left with two minds - mind left and mind right (Gazzaniga, 1970; Sperry, 1966, 1967, 1968, 1974, 1976). The two co-exist as completely separate conscious persons (Gazzaniga, 1972). The two disconnected hemispheres perceive and process stimuli independently. As Sperry (1966) summarizes:

> Everything ... so far indicates that the (split-brain) surgery has left these people with two separate minds, that is, two separate spheres of consciousness. 'What

> is experienced in the right hemisphere seems to be entirely outside the realm of awareness of the left hemisphere. This mental division has been demonstrated in regard to perception, cognition, volition, learning and memory (p. 299).

The behaviour of split-brain patients suggests that capacities for perception, learning, and remembering are duplicated within each cerebral hemisphere (Dimond, 1972). The difference between the two becomes evident in their mode of responding. The left major hemisphere largely responds verbally and the right or the minor hemisphere utilizes non-verbal modes to process stimuli. However, the two hemispheres have not been given equal status by Eccles (1965). He likens the right hemisphere with a computer, capable of complex acts of discrimination, recognition and learning yet devoid of conscious experience. According to him the conscious self is evident in left hemispheric functions. Thus he writes: "the conscious self, with all its linguistic and sophisticated behavioural performance, seems to be represented solely in the dominant hemisphere in these split-brain patients." However, Eccles has made revisions in his views regarding the concept of consciousness (Popper and Eccles, 1977). He does attribute some degree of consciousness to the right hemisphere but considers it as different from self-consciousness. Eccles (1977) concludes:

> Commissurotomy has split the bihemispheric brain into a dominant hemisphere that is exclusively in liaison with the self-conscious mind and controlled by it and a minor hemisphere that carries out many of the performances previously carried out by the intact brain, but it is not under control by the self-conscious mind ... this is quite different from the self-conscious mind of the dominant hemisphere ... (p. 329).

Thus, again it is evident that the right hemisphere is not given credit as an independent entity. Due to the left hemisphere's linguistic capability, it is considered to take the lead in man's higher psychological functions. As Sperry (1974) comments:

> Although some authorities have been reluctant to credit the disconnected minor hemisphere even with being conscious, it is our own interpretation based on a large number and variety of nonverbal tasks, that the minor hemisphere is indeed a conscious system in its own right, perceiving, thinking, remembering, reasoning, willing, and emoting, all at a characteristically human level, and that both the left and the right hemisphere may be conscious simultaneously in different, even in mutually conflicting, mental experiences that run along in parallel (p. 11).

The two hemispheres have been found to demonstrate little if any intermanual transfer of experience for objects felt and show total independence in perceptual awareness for the two visual fields under controlled tests. Though each of the disconnected hemispheres is equipped to perceive the identity of a familiar group of objects, only the left is capable of a comprehensive verbal report. However, the right hemisphere is found to be superior, for example, in dealing with perceptual tasks consisting of unfamiliar shapes (Trevarthen, 1974). Preilowski (1979) attempted to test a certain aspect of consciousness which involved the ability of self-reference by recognizing self-attribution or photograph of oneself in split-brain patients. On an analysis of his results he concludes that it is difficult to deprive the right hemisphere of consciousness just because it cannot talk. This hemisphere is capable of handling a variety of tasks such as perceiving and memorizing without the awareness of the left hemisphere. On an examination of views on the concept of consciousness, it seems clear that now there is largely a consensus between investigators regarding attribution of consciousness to the right hemisphere. The difference of opinion lies in the degree of importance attached to the right hemisphere's consciousness. Of course there is still controversy as to what are the distinctive features of consciousness. In other words, there appear to be controversies surrounding the determining factors of consciousness that attribute greater importance to the left hemisphere. The range of behaviour and psychological processes considered relevant to the demonstration of consciousness is very wide. At one extreme Trevarthen (1974) includes "attention, perceptual selection, spatial coordination, and patterning of voluntary performance", while Kinsbourne (1974) refers to "a particular cognitive style, a manner of attending and responding selectively". According to Gazzaniga (1967) any cognitive function can be included in the realm of consciousness. On the contrary, Eccles (Popper and Eccles, 1977) has been largely concerned with conscious self-awareness while discussing the concept of consciousness.

According to Sperry (1969) conscious awareness is regarded as a dynamic emergent property of brain activity, able to influence neural processes, and hence different from and more than the elements from which it emerges. However, Sperry (1970) feels unable to define in concrete terms the exact organizational process involved in conscious effects. These are a few examples of just how the concept of consciousness has been dealt with in the field of neuropsychology.

The dual anatomical structure of the human brain and the presence of two independent states of consciousness in split-brain patients poses an important question: What is the nature of consciousness in the normal person? More specifically, it can be asked: Does cerebral commissurotomy produce a splitting or doubling of the mind, or is it more correctly considered a 'manoeuver' resulting in a duality existing originally? The idea that one's personal consciousness is of the external world, and one is aware of everything present in the environment, is an illusion. As

Ornstein (1972, 1973, 1977) points out, that awareness or consciousness is selected and limited. The various senses through which an individual gains information involves a selective process. The image on the retina, for example, does not represent an exact copy of the external world, rather it undergoes a scanning and selective process. Even at the most elementary level, visual experience represents a constructive synthesis based on past experiences, expectation, filtering, and tuning. Ornstein (1972, 1973, 1977) distinguishes between two modes of consciousness related to each of the two hemispheres. The specialization of function in each determines the nature of consciousness. Broadly, individuals fall into two categories – one in which persons tend to employ the linear, verbal mode and the other in which they are less verbal and more involved in spatial imagery. Hence, scientists and mathematicians indicate the dominance of verbal-rational mode controlled by the left hemisphere. On the other hand, an artist or a musician points towards the dominance of a non-linear mode controlled by the right hemisphere. However, despite the dominance of one or the other mode in a particular individual, he operates in both modes. In other words, no person functions entirely through one mode. The difference lies in the degree of inclination towards a particular mode of consciousness.

Bogen (1973) too believes in two modes of consciousness originating in the two hemispheres. He refers to the left hemisphere as 'propositional' and the right as 'appositional'. The lateralization of functions have been suggestd by a number of investigators – some even before the split-brain operations were undertaken. Bogen has collected a whole list of dichotomies with lateralization which is given in Fig. 3.6. While discussing the dual nature of the cerebrum, Bogen (1973) concludes:

Dichotomies with Lateralization Suggested

Suggested By	Left Hemisphere	Right Hemisphere
Jackson (1864)	Expression	Perception
Jackson (1874)	Audito-articular	Retino-ocular
Jackson (1876)	Propositionizing	Visual imagery
Weisenberg & McBride (1935)	Linguistic	Visual or kinesthetic
Anderson (1951)	Storage	Executive
Humphrey & Zangwill (1951)	Symbolic or propositional	Visual or imaginative
McFie & Piercy (1952)	Education of relations	Education of correlates
Milner (1958)	Verbal	Perceptual or non-verbal
Semmes, Weinstein, Ghent, Teuber (1960)	Discrete	Diffuse
Zangwill (1961)	Symbolic	Visuospatial
Hécaen, Ajuriaguerra, Angelergues (1963)	Linguistic	Pre-verbal
Bogen and Gazzaniga (1965)	Verbal	Visuospatial
Levy-Agresti and Sperry (1968)	Logical or analytic	Synthetic perceptual
Bogen (1969)	Propositional	Appositional

Fig. 3.6

(From Bogen, 1973)

> Various kinds of evidence, especially from hemispherectomy, have made it clear that one hemisphere is sufficient to sustain a personality or mind. We may then conclude that the individual with two intact hemispheres has the capacity for two distinct minds. This conclusion finds its experimental proof in the split-brain animal whose two hemispheres can be trained to perceive, consider, and act independently. In the human, where propositional thought is typically lateralized to one hemisphere, the other hemisphere evidently specializes in a different mode of thought, which may be called appositional (p. 119).

Furthermore, a variety of related opinions from different sources on duality of mind have been compiled (Bogen, 1973). The list is given in Fig. 3.7. Thus, it can be seen that though terminology has varied from time to time, the notion of two modes of thought has been proposed quite often by psychologists. It is amply clear by now that the two hemispheres are specialized for different functions and the mode of information processing is different too. The right hemisphere works simultaneously through a mode complimentary to that of the ordered sequence of logical thought. According to Ornstein (1973) the activities of the right or "minor" hemisphere along with phenomena termed "mystical" have been largely neglected and devalued in the present technological culture. He feels that the right hemisphere could prove "essential to our personal and cultural survival."

The concept of consciousness has been also referred to as 'bimodal' - the action mode and the receptive mode (Deikman, 1973). The action mode is considered as a state of striving, directed towards the accomplishment of one's personal goals and avoidance of pain arousing stimuli. This mode develops gradually from the early years of life through interaction with the environment. On the other hand, the receptive mode is organized around intake from the environment and aims at

Dichotomies Without Reference to Cerebral Lateralization

Suggested By	Dichotomies	
C. S. Smith	Atomistic	Gross
Price	Analytic or reductionist	Synthetic or concrete
Wilder	Numerical	Geometric
Head	Symbolic or systematic	Perceptual or non-verbal
Goldstein	Abstract	Concrete
Reusch	Digital or discursive	Analogic or eidetic
Bateson & Jackson	Digital	Analogic
J. Z. Young	Abstract	Map-like
Pribram	Digital	Analogic
W. James	Differential	Existential
Spearman	Education of relations	Education of correlates
Hobbes	Directed	Free or unordered
Freud	Secondary process	Primary process
Pavlov	Second signalling	First signalling
Sechenov (Luria)	Successive	Simultaneous
Levi-Strauss	Positive	Mythic
Bruner	Rational	Metaphoric
Akhilananda	Buddhi	Manas
Radhakrishnan	Rational	Integral

Fig. 3.7

(From Bogen, 1973

maximizing this intake. It tends to originate and function maximally in the infantile state. However, the receptive mode tends to be dominated by the progressive development of the action mode. Since language is regarded as the very essence of the action mode, it obviously gains priority. The choice of mode is largely determined by the culture to which an individual belongs. The action mode seems to dominate the consciousness of western civilization. To Deikman the often neglected mode (receptive in his terms) is an essential component of man's highest capabilities and is desperately needed by our present society. Thus Deikman (1973) comments:

> The action mode has ruled our individual lives and our national politics, and the I-It relationship that has provided the base for technical mastery is now the primary obstacle to saving our race. If, however, each person were able to feel an identity with other persons and with his environment, to see himself as part of a large unity, he would have that sense of oneness that supports the selfless actions necessary to ... minimize pollution, and end war. The receptive mode ... is the mode in which this identification - the I-Thou relationship - exists and it may be needed to provide the experiential base for the values and world view now needed so desperately by our society as a whole (p. 85).

According to Hilgard (1977) to limit consciousness to verbal behaviour only is "to deny that the words refer to anything of substantive interest." Mere utterance of words may not fully convey the whole conscious experience. In order to explain consciousness, he takes into account the differential functions of the two cerebral hemispheres. An important point to be taken into account while considering the concept of consciousness is that there is also a layering of the brain in a higher-lower division. Hence, he concludes that divisions of consciousness cannot be explained in terms of hemispheric differences alone. For our present purposes, however, it is not considered necessary to explore further into the higher-lower dimension of the brain.

A distinction has been made between the phenomenal contents of consciousness and the conscious context or consciousness per se (Globus, 1973). Anything that an individual is aware of is considered to fall into the category of phenomenal contents of consciousness. In marked contrast, consciousness per se is independent of the content of awareness and is extremely difficult to convey due to lack of appropriate words. Globus identifies the phenomenal contents of consciousness with the neural events of the brain, while consciousness per se is attributed to an intrinsic organization which takes place within the brain. Hence, consciousness per se is not identified with the neural events of the brain. Various decisions taken by man in his day to day life seem to involve an intrinsic capability of the brain.

From the above it can be seen that the phenomenon of consciousness is very complex in terms of its contents. In fact, this makes it more difficult when dealing with unicity versus duality of consciousness in the normal brain. Duality of consciousness in the split-brain is no more a matter of controversy. Evidence for duality of minds after hemispheric deconnection has not only been obtained from some striking clinical cases and surgical patients but from split-brain experiments too with many different species by a large number of investigators around the world. They all seem to agree unanimously on the independent functioning of the two separated hemispheres (Bogen, 1977). The important conclusion here is that complex continuing functions can occur in both major and minor hemispheres, independent of the definition of consciousness. Lack of verbal report about the mental processes in the right hemisphere does not make it less important. However, it was only after Sperry, Zaidel and Zaidel (1979) had reported evidence of self-recognition and social awareness in the minor hemisphere that the right hemisphere gained added attention and support in favour of an independent state of consciousness comparable to that of the left. It has been demonstrated that self-recognition is an indicator of consciousness. Here it is important to note that although man is the only animal so far with natural symbolic language functions, he is not the only animal possessing self-awareness. Chimpanzees appear to have self-awareness as indicated by their ability to recognize themselves in the mirror (Gallup, Jr., 1970, 1977). Initially when exposed to mirrors, most animals equipped with visual sensitivity respond to their own image as if it were the image of another animal. But after prolonged exposure to mirrors, some animals seem to learn to recognize themselves and cease to respond socially to the image. This is what probably occurs in man. So far chimpanzees and orangutans seem to be the only ones besides man who are capable of self-recognition as demonstrated in the mirror self-recognition tests.

Sperry et al. (1979) in their experiment utilized a special kind of technique in which the patient was fitted with a scleral contact lens on his/her dominant eye. The scleral lens consists of a small optical system with an opaque screen in the focal plane of the visual field of vision. The experimental arrangement is given in Fig. 3.8. This procedure allows the experimenter to restrict the visual input to the desired hemisphere with a prolonged presentation of stimuli to allow free scanning movements of the eyes. Two commissurotomy patients (NG and LB) were chosen for this experiment because they appear to have had the least damage to extracommissural systems. A choice array of 4 to 9 cards containing photographs, pictures and line drawings were,

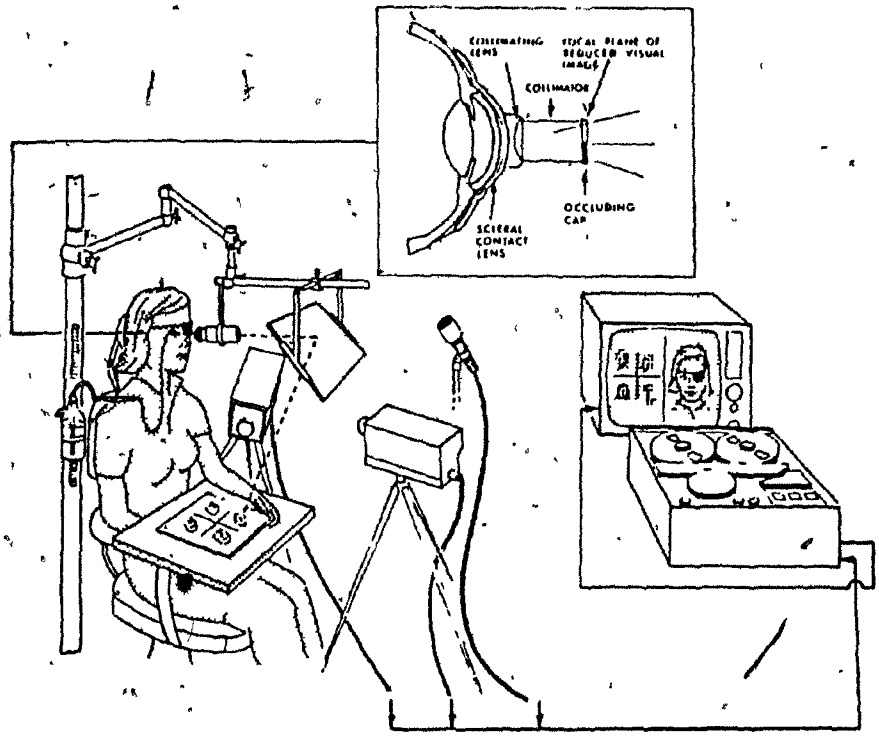


Fig. 3.8

(From Sperry et al., 1979)

presented at a time. Audiovisual tape recordings were made of the subjects' emotional expression and verbal comments. An excerpt from responses given by LB to one of the tests makes it clear that the right hemisphere is capable of social awareness. LB was presented with an array of four pictures of people for examining with the visual input restricted to right hemisphere. He was instructed to point to any picture he recognizes with his left hand. He points to the picture of Hitler and indicates his disapproval with a 'thumbs-down' signal with his left hand. Now the speaking hemisphere is asked to guess whose picture did he see. As reported by Sperry, Zaidel and Zaidel (1979):

> Ex: "That's another 'thumbs-down'?"
> LB: "Guess I'm antisocial." (because this was his third consecutive 'thumbs-down')
> Ex: "Who is it?"
> LB: "GI came to mind. I mean ..." (subject at this point was seen to be tracing letters with the first finger of the left hand on the back of his right hand)
> Ex: "You're writing with your left hand; let's keep the cues out."
> LB: "Sorry about that."
> Ex: "Is it someone you know personally, ... or from entertainment, ... or historical, or ...?"
> LB interrupted and said "Historical."
> Ex: "Recent or ...?"
> LB: "Past."
> Ex: "This country or another country?"
> LB: "Uh-huh-okay."
> Ex: "You're not sure?"
> LB: "Another country, I think."
> Ex: "Prime Minister, king, president, ..., any of them?"
> LB: "Gee", and pondered with accompanying lip movements for several seconds.
> Ex: giving further cues: "Great Britain .... Germany?"
> LB interrupted and said definitely "Germany" and then after a slight pause added "Hitler" (p. 160).

An analysis of the above demonstrates the right hemisphere's capability of identification without the aid of cues from the left hemisphere. This appears to be at par with the ability of the left. In so far as self-recognition and social awareness are indicators of consciousness, there seems to be no doubt that the right hemisphere possesses consciousness. Also it appears to be engaged in analysing the verbal cues. As Sperry et al. (1979) comment: "However to entangle the various alternative possible mechanisms that may be at work will require more analytic data than is currently available." However, this much seems apparently clear: that both the left hemisphere and right hemisphere play important roles in higher mental functions - consciousness. To ignore one or the other is not justified. Under normal conditions the two work in a coordinated manner. According to Ellenberg and Sperry (1980), attention is normally limited to a unitary focus and the cerebral commissures are responsible for keeping the two hemispheres functioning as a single unified attentional system, though the role of the cerebral commissures is still far from being agreed upon among the investigators in the field.

The question of mental duality has gained much attention in the split-brain research, especially with regard to normal individuals with intact commissures. An interesting position in terms of personal identity has been taken by Puccetti (1973, 1976, 1977a, b, 1981) and Bogen (1969) who propose that each hemisphere has a mind of its own, not only after commissurotomy but in the normal intact brain too. According to Puccetti if disconnecting the two hemispheres produces two coconscious minds, and if a right or a left hemispherectomy leaves one conscious person or self, then there must have been two originally in the intact brain. Thus, two coconscious persons exist in the normal brain. His view is opposed to what Sperry (1977) states, that "consciousness and the conscious self (are) normally single and unified, mediated by brain processes that typically involve and span both hemispheres through the commissures." This is based on the view that there is a single mind in the intact brain which becomes two after commissurotomy. Puccetti (1977a) poses an important question: "Which mind or self is the new, additional one? The mind or self based in the left hemisphere, or the mind or self based in the right hemisphere? How does one choose between them?" There appears to be no clearcut answer to it. Puccetti's (1981) claim is that the mind in the normal brain is unitary in its functioning but that there are two of them, each receiving sensory input from the other. Thus, the author feels that it is not a question of unity in functioning that is being disputed, but rather the issue here is of 'one or two minds' in the normal person. At present the issue seems to be far from a solution unless an attempt is made to test Puccetti's (1977b) proposed hypothesis.

On looking back, it seems very difficult to generalize the findings obtained from limited split-brain experiments to the normal human being. Not only that, much more is yet to be learnt about our complicated three and a half pounds of gray matter. However, experiments on normal individuals using EEG techniques and dichotic listening tests might provide some answers to the question of duality of consciousness in the brain. An important achievement has been made to the extent that the long-neglected mute hemisphere has gained much attention in recent years. We are beginning to realize its importance in our mental life. As Robert Ornstein has repeatedly reminded us, its value lies in governing qualities long undervalued by Western culture. As Goleman (1977) quotes, Ornstein's claim is that the right hemisphere could prove "essential to our personal and cultural survival." In summing up, the author is reminded of the phenomena of altered states of consciousness discussed by Tart (1973). Although the concept itself falls outside the scope of this thesis, it is worth noting that in the quest of scientific achievements, (left hemispheric function) we have lost track of ourselves. Hence, Tart (1973) proposes the development of state-specific sciences that might lead us towards gaining real knowledge about ourselves. As Tart (1973) puts it:

> Our immense success in the development of the physical sciences has not been particularly successful in formulating better philosophies of life, or increasing our real knowledge of ourselves. The sciences we have developed to date are not very human sciences. They tell us how to do things, but give us no scientific insights on questions of what to do, what not to do, or why to do things (p. 59-60).

Chapter IV

Cerebral Asymmetry

The discovery of cerebral asymmetry was made in the year 1836 by Marc Dax; though it was not until the latter part of the nineteenth century that it was recognised. On the basis of his experiences with patients suffering from loss of speech (technically known as aphasia) following brain damage, Dax (in Springer and Deutsch, 1981) presented a paper to the medical society meeting in France. The central theme of his paper was that each half of the brain is responsible for different functions. In more than 40 patients with aphasia, Dax observed signs of damage to the left half of the brain. Hence, he concluded speech is controlled by the left hemisphere. He died the following year and his findings remained forgotten until Broca's discovery of fundamental brain asymmetry in 1864. Hence, Broca obtained the credit for being the first person to bring to the attention of the medical community as a whole the asymmetrical feature of the human brain with regard to speech. Also, he was the first to link the asymmetry with hand preference. While emphasizing the importance of the left hemisphere in speech in 1864, Broca remarked:

> I have been struck with the fact that in my first aphemics the lesion always lay not only in the same part of the brain but always the same side - the left. Since then, from many postmortems, the lesion was always left sided. One has also seen many aphemics alive, most of them hemiplegic, and always hemiplegic on the right side. Furthermore, one has seen at autopsy lesions on the right side in patients who had shown no aphemia. It seems from all this that the faculty of articulate language is localized in the left hemisphere or at least that it depends chiefly upon that hemisphere (in Springer and Deutsch, 1981, p. 10).

Thus, the earliest and most convincing evidence of functional asymmetries was obtained from clinical data of patients with brain damage. The study of anatomical asymmetries in the human brain had started in the latter part of the 19th century, but soon got entangled with physiology and cerebral dominance (Bonin, 1962). However, towards the end of the 19th century it became well accepted all over the world that the two hemispheres are very different in their functions, though they appeared grossly symmetrical. The left was referred to as the "dominant hemisphere" due to its control of language and by a curious extrapolation, it also came to be regarded as dominant for all complex cognitive functions. The left hemisphere was considered important in interpreting sensory input and planning and controlling behaviour. The right was regarded as a mere relay station. The right hemisphere was considered to be responsible for controlling elementary sensory and motor functions. Since these were known to be represented in mirror-image fashion in the two hemispheres, the right controlled the left side of the body and the left visual field. The physical symmetry of the two hemispheres were considered in line with the general left-right symmetry of the human body and, hence, the study of anatomical asymmetry did not receive much attention in the medical field. As the concept of cerebral dominance gained popularity, evidence of specialized abilities in the right hemisphere also began to appear. Around the 1860's Hughlings Jackson came to realize that the extreme, one-sided view of the way mental functions were localized in the brain was false. Thus Jackson (1958) writes: "If then, it should be proven by wider experience that the faculty of expression resides in one hemisphere, there is no absurdity in raising the question as to whether perception - its corresponding opposite -

may be seated in the other." However, his views were largely neglected until about the mid-1900's when data from clinical patients with well-lateralized right sided lesions indicated severe spatial and other perceptual disorders (Milner, 1971).

Although clinical data on the asymmetrical function of the human brain have been available in the medical literature for over 100 years, current revival of interest in the two hemispheres of the brain can be traced back to the early 1960's when the phenomenon of the "split-brain" operation was discovered by Sperry and his collaborators. The so-called "split-brain" patients provided the basis for an in-depth exploration of the higher mental functions in the brain. The technique of 'lateralization' of stimuli to one hemisphere was developed. Special apparatus (as discussed in the previous chapter) was developed to restrict detailed sensory information to one hemisphere at a time so that specific features and limitations of the two hemispheres can be noted independently. One simple way to achieve lateralization is to allow a blindfolded patient feel an object with one hand at a time. When the split-brain patient feels the object with his right hand (left hemisphere), he experiences no difficulty in naming the object. However, when allowed to feel with his left hand (right hemisphere), the patient is unable to name the object; although he is capable of retrieving the object from a number of other objects out of sight. Thus, the split-brain studies revealed the two different modes of operation of the two disconnected hemispheres in the same individual.

In the 1930's and 1940's, two highly specialized neurosurgical techniques were developed to investigate hemispheric asymmetry of functions. While engaged in the treatment of epilepsy in patients, Penfield and his associates pioneered removing the brain tissue where abnormal activity was located. However, they were hesitant to undertake cases in which removal of the tissue was found to be very close to the brain area controlling language for they wanted to avoid the risk of substituting aphasia for epilepsy. As Penfield and Roberts (1959) write:

> Twenty-five years ago we were embarking on the treatment of focal epilepsy by radical surgical excision of abnormal areas of brain. In the beginning it was our practice to refuse radical operation upon the dominant hemisphere unless a lesion lay anteriorly in the frontal lobe or posteriorly in the occipital lobe ... we feared that removal of cortex in other parts of this hemisphere would produce aphasia. [The] aphasia literature gave no clear guide as to just what might and what might not be removed with impunity (p. 103).

Obviously, a technique for determining the exact location of the centers controlling speech and language in each patient was urgently needed. Hence, Penfield and his associates developed the technique of mapping these areas with the aid of direct electrical stimulation of the brain before surgery. This method of direct electrical stimulation was not a new procedure for in the early 1900's preliminary work had demonstrated that since the brain itself does not contain pain receptors, it was possible for a patient to remain fully conscious while a neurosurgeon removed a flap of skull under local anesthesia and applied small electrical currents directly to the brain surface. Electrodes could be placed on different points in the brain and, thus, note its effects in the patients' behaviour. It became apparent that electrical stimulation of specific parts of the brain can lead patients to see, hear, smell, or feel in an elementary manner. Stimulation of other parts resulted in involuntary motor responses such as the movement of an arm or leg. Thus, the important contribution of the Montreal Neurological Institute group was in utilizing this technique to locate precisely the centers controlling speech and language in a particular patient. Location of speech and language centers in the left hemisphere is given in Fig. 4.1 by Penfield and Roberts (1959).

The other test utilized to determine different mental functions within each hemisphere was the Wada test. This test temporarily anesthetizes one hemisphere at a time on separate days to find out which one normally controls the ability to speak (Wada and Rasmussen, 1960). A small tube is inserted into the carotid artery on one side of the patient's neck. Sodium amytal is injected into the artery. The carotid artery on each side brings blood to the hemisphere on the same side and, hence, sodium amytal injected into the right artery is carried to the right hemisphere. The effect is that one half of the brain is put to sleep at a time so that the functions of the other awake side are examined. The above two techniques have served as valuable tools in obtaining information about the relationship of handedness to hemispheric asymmetry and also the effects of early damage on asymmetry. It has been determined that the left hemisphere controls speech and language in over 95 percent of all right-handers who have no evidence of early brain damage. The rest have their speech centers in their right hemisphere. However, a majority of left-handers (about 70 percent) too have their speech centers located in the left hemisphere. About 15 percent of left-handers have speech in the right hemisphere and 15 percent or so indicate bilateral speech control (Rasmussen and Milner, 1977).

In a review of hemispheric specialization studies, it is noted that until fairly recent times, investigations into the nature of hemispheric specialization of function have depended largely on examination of

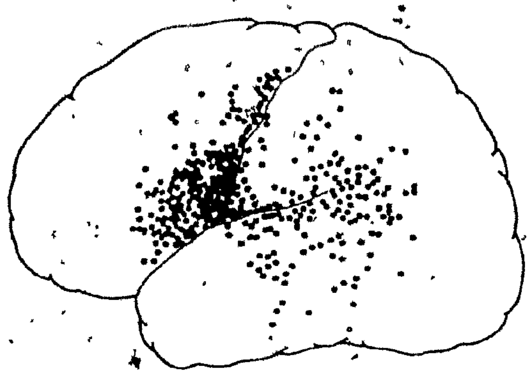


Fig. 4.1

(From Penfield and Roberts, 1959)

Points along the surface of the left hemisphere where electrical stimulation resulted in interference with speech.

behavioural deficits resulting after unilateral cortical injuries such as strokes or surgical excisions (Madden and Nebes, 1980). The most frequently used experimental approach utilizes a comparison of performance on a given task by two groups of patients: one composed of patients with right hemisphere damage and the other with left hemisphere damage. Any difference noted in the performance between the two groups has been interpreted as an underlying difference in the relative contribution of the two hemispheres to the achievement of the same task in normal persons. In other words, if individuals with a lesion in one hemisphere do worse on a task as compared to persons with lesion in the other hemisphere, it is concluded that the first hemisphere must have a more important role in the accomplishment of the given task. As, for example, Benton (1969) points out that since a lesion in the right hemisphere is more likely to produce severe deficits in the comprehension and drawing of maps than a similar lesion in the left hemisphere, it is concluded that the right hemisphere is primarily responsible for comprehension and drawing of maps.

While pathological cases of brain lesions and split-brain patients have generated much of the experimental evidence indicating that the two hemispheres are specialized for different cognitive functions, there are certain limitations to its generalization on normal individuals (Madden and Nebes, 1980). The work with normal individuals has led to a better understanding of the function of the two cerebral hemispheres. Madden and Nebes (1980) discuss some of the factors which force series of limitations on the researcher in accepting uncritically the results obtained from unilateral brain lesion studies. One of the problems is to match two groups of patients with unilateral cortical injuries on all those personal variables, such as age, intelligence, and education which are known to be contributing factors in cognitive performance. Much more difficult and crucial is the matching of the two groups with regard to size and location of the lesion. Various cortical zones within a particular hemisphere have very different functions and, therefore, even a slight variation in the foci of the damage in the left and right lesion groups can lead to a potential confounding of intrahemispheric with interhemispheric differences. Similarly, if the size of the lesions in the two groups is not matched, it cannot give reliable results, as, for example, both hemispheres may contain cortical areas which are in fact equally important for the successful completion of a particular mental act. When performances of two groups of patients having different average extent of unilateral lesions are compared, a poor performance may well be exhibited by the group with the more extensive damage. According to Madden and Nebes (1980), difference in the performance between the two groups "would be based not on any unequal representation of function by the two sides of the brain, however, but solely on the fact that the more extensive the lesion, the greater the probability that it will involve the critical cortical region." Hence, a spurious interpretation could result with regard to the differentiation of functions of the two hemispheres. Another problem encountered in localization of function on the basis of brain damage has been pointed out by Smith (1975). According to him, even a very well localized lesion often has widespread effects due to vascular spasm, edema, and deafferentation, which can influence the performance of the intact hemisphere as well (diaschesis).

The above represents only the methodological problems encountered in matching two groups of patients with unilateral cortical lesions.

However, the most difficult part in such studies involves the interpretation of cognitive deficits following the lesions. Since it is well established that higher mental functions require a coordinated functioning of one or more cortical zones (Luria, 1966a, b), it becomes very difficult to pinpoint cognitive deficits resulting from a particular lesion. The difficulty in making cognitive interpretations based on brain lesions has been rightly explained by Madden and Nebes (1980):

> ... the relative competence of the two hemispheres to carry out a certain mental operation must be inferred from a comparison of the severity of the performance deficits displayed by the two patient groups on a task requiring that operation. The danger in this situation is that performing a particular cognitive task rarely involves a unitary, clearly definable mental operation. All our tests require a variety of mental skills, and patients can therefore fail them for a variety of reasons... The interpretation of brain damage is complicated even further by the fact that a lesion is rarely small and limited to just one anatomical region. Thus a number of different functions may be simultaneously affected, producing not only additive but also interactive effects on cognition and behavior (p. 143).

Semmes (1968) has pointed out another error which often occurs in generalizing about the role of a given hemisphere based on the unilateral brain damage paradigm. According to him, it just might be that both hemispheres are equally important in the execution of a particular cognitive function. But the anatomical organization regarding it may be represented differently in the two hemispheres: focal representation in one hemisphere and diffuse representation in the other. As a consequence, lesion studies could provide evidence which would lead the investigator to infer, incorrectly, that one hemisphere has a more important role than the other in a specific cognitive ability. Hence, a lesion in the diffusely organized hemisphere would obviously produce a mild deficit that would go undetected by crude behavioural techniques, while a lesion in the focally represented hemisphere would result in a severe deficit, thus leading to the inference that this hemisphere is more important in the execution of the cognitive operation in question.

Although some of the above problems are eliminated in the study of patients in whom cerebral commissures have been disconnected or one hemisphere has been temporarily inactivated via sodium amytal injections (Nebes, 1978), investigations of the normal population are needed for a better understanding of hemispheric specialization without any risk of adverse consequences and limitations which might be associated with the use of other techniques in the patient population. Investigations of the functioning of the two hemispheres in the normal population is much more easily accessible compared to the patient population with unilateral brain damage and split-brain surgery. Hence, knowledge obtained through the study of normal individuals regarding hemispheric functions can be considered to be more representative of the normal functioning of the two hemispheres.

Although relative superiority of the left hemisphere in speech functions was generally accepted, it was hardly associated with significant anatomical differences between the two halves of the brain (von Bonin, 1962). Perhaps the most influential observation was by Geschwind and Levitsky (1968), who investigated the structural organization of the two hemispheres with respect to the temporal speech region in a large sample of human brains. In fact, it was their study mainly that brought about a revival of interest in anatomical asymmetry. As Witelson (1980) remarks:

> Within the last decade, the study of anatomical asymmetry between the two cerebral hemispheres of man has been revived after a long interim since its first documentation around the turn of the century. Such study was not pursued at that time as it was thought that the right-left differences that were observed were insufficient to have any functional significance. However, a recent surge of studies has led to further documentation of neuroanatomical asymmetry and, consequently, its functional significance has been considered (p. 80).

Geschwind and Levitsky (1968) examined 100 normal adult human brains obtained at postmortem. The two hemispheres were divided and the upper surface of the temporal lobe was exposed on each side by a cut in the plane of the sylvian fissure. These investigators noted marked anatomical asymmetries between the upper surfaces of the right and left temporal lobes. The planum temporale of the left hemisphere was found to be larger than the homologous region of the right hemisphere in 65 per cent of the brains. Only 11 per cent of the brains showed a larger planum on the right side. The remaining 24 per cent showed no difference. On average, the left planum was found to be one third longer than its right counterpart. This area constitutes the part of the temporal speech cortex, whose importance in speech has been well established. Other left- versus right-sided differences were also observed. The anteroparietal region was larger on the left side, as was the posterioccipital region, while the prefrontal region was found to be larger on the right side. In a nutshell, their study provided an impetus for further studies on the subject of anatomical asymmetry.

Subsequent studies confirmed anatomical asymmetries in newborn and fetal brains (Wada et al., 1975; Witelson, 1977; Witelson and Pallie, 1973). Wada et al. (1975) studied the asymmetry of the temporal planum in 100 infants' brains and 100 adults' brains. An asymmetry in size favouring the left was present in the brain even in the youngest infants' brains studied (19th week of gestation). However, the asymmetries found in the brains of the adults were more extreme than those found in the infants' brains. Another study by Witelson and Pallie (1973) was conducted in order to examine the human temporal lobe for evidence of cerebral asymmetry in the neonatal period, when language or unimanual hand preference related to learning had not begun. Their study made a comparative analysis of adult and neonate brains free from neurological pathology. Anatomical asymmetry in adult samples was found to be similar to those observed by Geschwind and Levitsky (1968). Also, anatomical asymmetry between left and right plana was noted in the neonatal brain samples on all measurements taken. The size of the left-right difference in the neonates was proportionately at least as large as that in the adult sample brains. Thus, Witelson and Pallie (1973) summarize:

> The anatomical data indicate that the human infant is born with or develops very soon after birth a larger area in the left hemisphere in a region ... of significance for language function ... this anatomical asymmetry precedes any learning effects, since the postnatal age of the infants precluded little if any environmental experiences, such as language acquisition or preferred hand usage ... further ... the observed neonatal anatomical asymmetry provides a structural basis for the adult pattern of lateralization of language functions and it is such biological structures, rather than experiential factors, which are the determining factors in predisposing the left hemisphere to become the major hemisphere in mediating language functions (p. 644).

In a nutshell, evidence of neonatal asymmetry indicates a preprogrammed biological capacity to process speech sounds. Eimas et al. (1971) based on results of their study concluded that neonates are cable of discriminating speech sounds along adult phonemic categories at an age when little, if any, learning has occurred. However, Rubens (1977) emphasizes that although these gross asymmetries, at face value, support the notion of an inborn anatomical superiority of the left temporal auditory cortical region, they are also inconsistent with the theory that left cerebral language dominance is based on the superior ability of the left hemisphere to make cross-modal associations (Geschwind, 1965b). Similarly, gross morphological differences in surface area are difficult to interpret with respect to microscopic structural differences (Szentagothai, 1972). For instance, a larger area on one side could be inferred as containing more cells or larger cells, or that there exists a difference in the ratio of cell volume to total tissue volume. In certain areas connectivity may be more important than the total number of cells. Rubens (1977), therefore, concludes: "that sophisticated cytoarchitectural studies designed to correlate interindividual and interhemispheric differences at microscopic and macroscopic levels are the next logical and necessary steps in the investigation of morphological correlates of functional asymmetry."

Another comparative study of modern man, fossil man, and nonhuman primate regarding morphological cerebral asymmetries has been conducted by LeMay (1976). Cerebral asymmetries were noted in modern and fossil man and the great apes. The left occipital pole was found to be often wider and usually protruding more posteriorly than the right and this is known as left occipito-petalia. Also the left lateral ventricle, and particularly the occipital horn, is usually larger than the right. Further, if one frontal pole extends beyond the other, it is usually the right and is known as right fronto-petalia. The left occipito-petalia and right fronto-petalia can be seen in Fig. 4.2.

Fig. 4.2

(From Le May, 1976)

It shows the X-ray of a human brain in which the blood vessels were injected with an opaque substance post-mortem. In addition, it was noted that on X-ray computerized axial tomograms (CT) of the brain, the right frontal lobe and the central portion of the right hemisphere more frequently measure wider than the left. However, the most striking and consistently present cerebral asymmetries found in adult and fetal brains are noted in the region of the posterior end of the sylvian fissures which is generally considered to be very important in linguistic functions (Le May, 1976).

All the anatomical cerebral asymmetry studies discussed so far have involved measurements taken from brains examined post-mortem. Other evidence suggests that it is also possible to investigate asymmetries in the living brain. It is known that the paths of the large blood vessels in the brain reflect the anatomy of the neighbouring brain tissue. In particular, the middle cerebral artery passes through the area in the temporal lobe which is critical to linguistic functions. Therefore, for many years, neurologists have used the technique of cerebral angiography to examine this major blood vessel to determine the nature of the surrounding brain tissues (Springer and Deutsch, 1981). A dye is injected into the internal carotid artery in the neck which flows into the middle cerebral artery and makes it visible on the X-ray of the skull. Le May and Culebras (1972) have observed left-right asymmetries utilizing the technique of cerebral angiography. Their results were similar to those obtained from post-mortem brains.

Another technique used to investigate asymmetry in the living brain is computerized tomography or CT scan. In this procedure, an X-ray source is rotated in a plane around the head and the detectors are continuously engaged in monitoring the intensity of the X-ray beam passing through to the other side. A computer stores this information and later utilizes it to restructure an image of a slice of a brain. The image of any slice of brain is obtained by simply adjusting the angles through which the X-ray passes. A representative CT scan is shown in Fig. 4.3 (Springer and Deutsch, 1981). This technique has often been used to locate exact lesion sites in cases of brain damage.

The techniques of angiography and CT scan are especially useful in investigating the possibility of an existing relationship between cerebral and functional asymmetry. Examinations of post-mortem brains only provide information about anatomical asymmetries and nothing about the kinds of functional asymmetries that may have been present before death. Frequently not even the handedness of individuals is known. Hence, the investigations of living brains are crucial for obtaining detailed information about cerebral and functional asymmetry as a whole. In other words, information about anatomical asymmetries and functional asymmetries can be obtained on the same living brains, thus allowing the investigator to infer the nature of relationship between the two.

Another study by Galaburda et al. (1978) supports the notion of cerebral asymmetry in the human brain. The larger planum temporale on the left is clearly seen in Fig. 4.4(B). Also in the same Fig. (4.4) at the bottom is a computerized axial tomogram of a brain showing hemispheric asymmetry. In fact, there has been an increase in the rate of data collection on anatomical asymmetry and cerebral dominance since the development of computerized tomography techniques. These techniques do not pose any risk to the individuals being studied and hence are very useful in research. Le May (1976) provides us with striking asymmetries

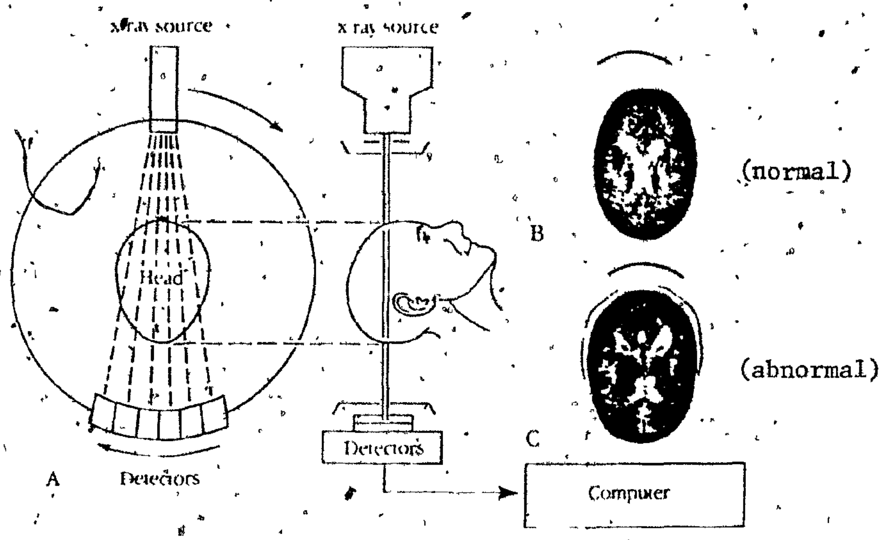


Fig. 4.3

(From Springer and Deutsch, 1981)

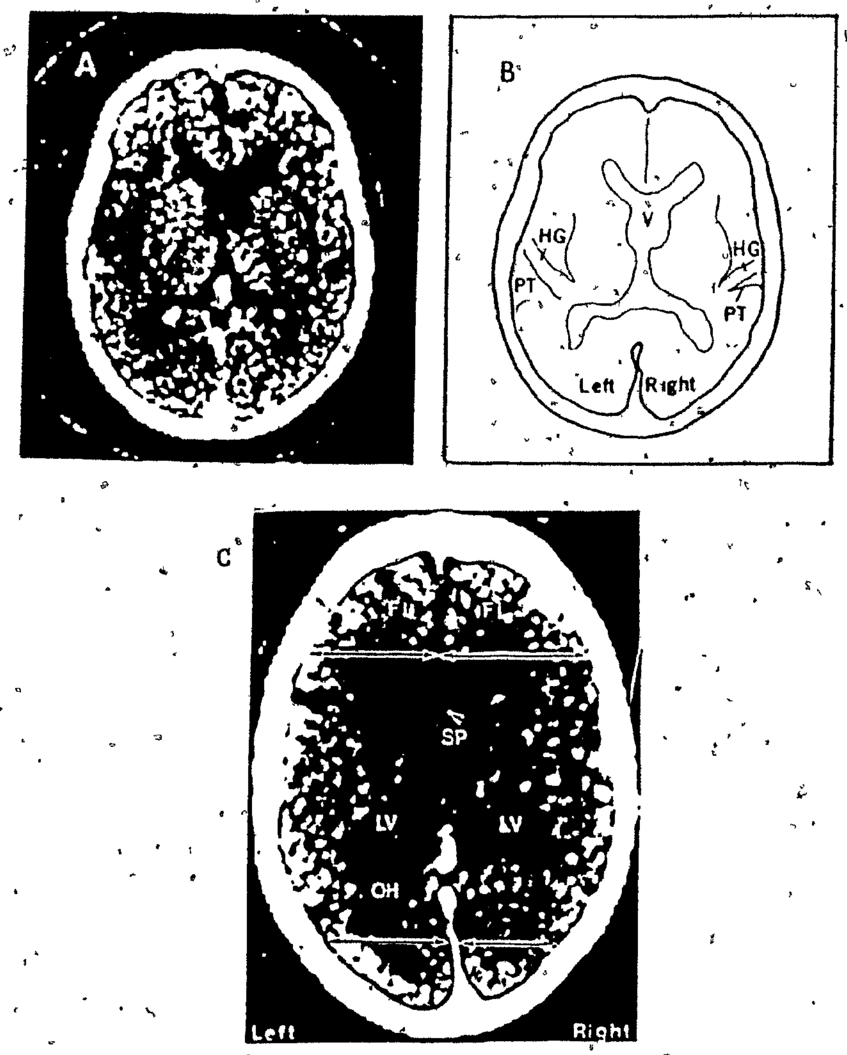


Fig. 4.4

(From Galaburda et al., 1978)

(A) Computerized axial tomogram of a brain showing asymmetry of the planum temporale.

(B) Diagram made from (A) outlining the asymmetry of the planum temporale (PT).

(C) Computerized axial tomogram of a brain showing the usual pattern of hemispheric asymmetry. Note wider right frontal lobe (FL, upper arrows), the wider left occipital lobe (lower arrows) and the more prominent left occipital horn (OH) of the lateral ventricles (LV). (SP) denotes the midline.

in computerized scans that are readily seen and measured. The most striking ones are the presence of a wider left occipital lobe known as left occipital petalia and a wider right frontal lobe referred to as right frontal petalia. It is further noted that a left occipital petalia is almost four times more common than a right occipital petalia in the right-handed. Again in the right-handed, right frontal petalia is nearly nine times more common than a left frontal petalia. In the left-handed, however, these differences are much less evident. The main aim of all these studies related to anatomical cerebral asymmetry is to gain a better understanding of higher human mental functions. A general pattern that emerges in relation to cerebral asymmetry and handedness is summarized by Galaburda et al. (1978):

> (i) brains without a particular asymmetry are more common in the left-handed; (ii) the left-handed are more likely than the right-handed to show the reverse asymmetry, but the extent of the asymmetry is less striking; and (iii) in some cases the asymmetry is in the same direction in the left-handed as in the right-handed, but, again, it is less striking in magnitude (p. 855).

The literature on cerebral asymmetry and handedness consistently indicate that the direction of the asymmetry is correlated with hand-preference. In general, right-handedness is associated with anatomical asymmetry in one direction, and left-handedness with either less anatomical asymmetry or asymmetry in the reverse direction (Witelson, 1980). The first evidence that individuals differ in their laterality pattern came from studies of left-handed neurological patients with damage to their left or right hemisphere (Levy, 1980). Few of the patients developed language disorders after left-hemisphere damage, which is generally true with right-handers. However, some of them were suffering from aphasic symptoms after damage to the right hemisphere, which is extremely rare among right-handers. Also, a substantial proportion of left-handed patients appeared to be at risk for aphasia regardless of left or right hemisphere injury. Thus, Levy (1980) comments:

> ... in a random sample of neurological patients having damage on one side of the brain, no more than 50 percent would be expected to display linguistic disorders if language is strictly unilaterally organized; yet, among left-handers, from some 70 percent to 80 percent develop an initial aphasia that, in a large fraction, is transient. These observations imply that in left-handers, much more frequently than in right-handers, there is a bilateral representation of language. Damage to either side therefore can produce a temporary disruption of function, but with time the intact hemisphere can assume control of processing ... It appears that left-handers not only differ from right-handers but are highly variable among themselves in the degree and direction of lateral asymmetry for speech and possibly for other cognitive functions as well (p. 360).

Thus, it becomes apparent that there exists a relationship between anatomical asymmetry and functional specialization of the two hemispheres. This is a positive step towards gaining further clarity about some of the highly specialized features of the human brain. Only further studies on anatomical asymmetry might be able to shed more light on asymmetrical functions of the brain.

The phenomenon of asymmetrical functions of the brain have been dealt with more extensively in the brain research literature. Studies with split-brain patients have indicated asymmetry with regard to functions of the left and right hemispheres, although in the early studies of split-brain patients, no asymmetry in their behaviour had been noted. However, with the aid of highly specialized techniques, the distinguishing features of the two hemispheres became apparent. Since much has been already discussed on the differing functions of the two hemispheres in the previous chapter, it seems appropriate here to take up studies conducted on normal individuals. The techniques employed in these studies do not pose any harmful effects and hence are often referred to as noninvasive techniques.

The anatomy of the visual system has proved to be very useful in studies of normal functioning of the two hemispheres. When an individual's gaze is fixated on a point in space, stimuli presented to the left of that point are projected onto the right side of the retina in both eyes. From here, information is transmitted to the visual cortex in the right hemisphere via visual fibers that pass through several relay stations. Similarly, stimuli presented to the right of the fixation point are projected to the left side of the retina in both eyes and visual information is transmitted to the left hemisphere. This anatomical organization provides an opportunity for selective presentation of visual stimuli to one hemisphere by restricting the stimulus to one half of the visual field. However, stimulus durations have to be kept very brief (usually less than 200 msec.) because the subject might reflexively divert his eyes toward any stimulus appearing peripheral to his fixation point (Madden and Nebes, 1980). Studies of hemispheric differences in normal individuals utilizing the visual system are helpful in understanding the degree of involvement of the two hemispheres in a particular cognitive operation. As Madden and Nebes (1980) comment:

> ... the ability of a person to carry out some cognitive operations on a stimulus presented to his left visual half-field (LVF) is compared to his ability to process a stimulus presented to his right visual half-field (RVF). Any discrepancy in performance

> between the two fields is assumed to reflect a difference in capacity between the subjects' right and left hemispheres to carry out the task. Performance is measured in terms of either accuracy or reaction time (RT), that is, the time required to make some decision about the stimulus (p. 145).

The concept of lateral asymmetries had been noted by a number of investigators in the 1950's based on the subjects' ability to process stimuli presented to his left visual half-field and right visual half-field with the aid of a tachistoscope (Mishkin and Forgays, 1952; Heron, 1957). These investigators found a right visual field advantage in the recognition of verbal stimuli presented through a tachistoscope. However, these findings were not given much attention at the time and therefore remained largely neglected. It was only after the publication of Kimura's (1961a, b) studies that perceptual asymmetries were regarded as evidences of lateral differences in the brain. In her first study, Kimura (1961a) studied the effects of temporal lobe damage on auditory perception of 71 patients at the Montreal Neurological Institute. A dual-channel tape recorder with stereophonic ear-phones was used to present digits in groups of six in such a way that half the digits went to the left ear and the other half to the right. After each group of six numbers, the subject was asked to report all the numbers he had heard, in any order he wanted. Analysis of results indicated that the left temporal lobe is especially important in the perception of verbal material in the auditory modality. Damage to the left temporal lobe was found to impair the subjects' over-all performance regardless of the ear through which stimuli were presented.

The above study provided the basis for further investigation of the phenomenon of perception of verbal stimuli in patients with epileptogenic lesions of various parts of the brain as well as in normal subjects. Kimura (1961b) concluded:

> Since the right ear was presumably more strongly connected to the left temporal lobe than was the left ear, this finding suggested that verbal material arriving along this pathway had an advantage in being more reliably transmitted to the hemisphere which was dominant for speech representation. It would then follow that, in subjects with speech represented in the right hemisphere, recognition of verbal material arriving in the left ear should be more efficient. [This was the hypothesis set for investigation.] (p. 166).

The patients consisted of two groups: one group of patients had speech represented in the left hemisphere and the other in the right. The technique for presenting stimuli was similar to the one used in the earlier study. The patients' performance was superior when stimuli were presented through the ear contralateral to the dominant hemisphere. Bryden (1963) obtained similar results. In other words, the right ear was found to be more efficient in recognizing verbal material in the left-dominant group and the left ear was superior in the right-dominant group. These results were consistent with the earlier one in that crossed auditory pathways have a stronger influence on auditory perception as compared to the uncrossed ones. Hence, the dominant temporal lobe (left or right as the individual case may be) has the major contribution in the perception of verbal material.

Similarly, in tachistoscopically presented visual material, subjects showed a superior level of performance when the stimulus appeared to the right of a central fixation point in comparison to the left of the fixation point (Bryden and Rainey, 1963). In a later study, Bryden (1965) studied the relationships between tachistoscopic recognition, handedness, and cerebral dominance in 40 normal subjects. In the group, 20 were left-handers and 20 were right-handers with equal number of men and women in each group. Two tests were administered: one consisted of dichotic listening task and the other tachistoscopic recognition. On both tests, right-handers were significantly more correct in recognizing stimuli presented to the right side. The left-handers, on the other hand, did not show any consistent left-right differences. In general, though not very conclusive, results of tachistoscopically presented verbal material supported the findings obtained by Kimura (1961b) that dichotically-presented verbal material is more efficiently analyzed by the dominant hemisphere or 'speech hemisphere'. The lack of consistent relationship between right ear superiority in dichotic listening tasks and right visual field superiority in tachistoscopic recognition could be due to a number of factors in operation. As Bryden (1965) comments:

> First of all, one task is visual while the other is auditory, and there may be some disassociation of later laterality effects in the two modalities. Secondly, in the dichotic listening task, where the numbers are already audible, the major problem is to remember all the material during recall, while the tachistoscopic recognition situation, with its extremely brief exposure duration, is primarily a problem of obtaining enough information to make the proper identification (p. 7).

Thus, the difference in the two modalities employed to present stimuli create different problems for the subject in identifying the material in the two situations. To sum up, the dichotic listening task leads to an output problem and the tachistoscopic recognition task creates an input problem.

A number of other studies have been conducted on normal subjects to investigate the functional asymmetry of the brain. Most of these studies have focused on visual and auditory perception tasks. Kimura (1966) presented verbal and nonverbal stimuli to normal subjects through a tachistoscope in order to find out if there was any difference in the perception of two kinds of material. Various stimuli were presented either to the left or to the right visual half-field on a successive random basis. The sample consisted of twenty-eight right-handed undergraduate students. It was expected that the right visual half-field would be superior in the perception of verbal (alphabetical letters) stimuli and the left visual-half field would supercede the right in dealing with nonverbal (nonsense figures and dots) materials. This is in line with the asymmetrical functions of the two hemispheres which is by now well established in the split-brain literature. Results of this study were significant in that the role of the posterior regions of the brain became evident. It was noted that the left posterior part of the brain has an important contribution in the perception of verbal-conceptual material whereas the corresponding area on the right is involved in some way in the registration of nonverbal materials. Further, it became apparent that differences in function between left and right hemispheres are to a large extent responsible for the greater part of the asymmetry between fields whether visual or auditory (Kimura, 1964, 1966). Kimura (1966) also points out that the method of successive presentation more closely reflects the phenomenon of cerebral asymmetry. With this method left- or right-field superiority is dependent upon the nature of the visual material (verbal or nonverbal). According to her, the method of simultaneous presentation generally shows a left-field superiority regardless of the nature of stimulus. Hence, it reflects the operation of some general scanning mechanism and not hemispheric asymmetry. In other words, the method of successive presentation is a more reliable indicator of cerebral asymmetry.

It is important here to re-emphasize the finding that emerged from the use of dichotic digits tests. When the dichotic digits test was administered to a group of patients with lesions in different parts of the brain, their performance was better through the right ear. The same was observed among the normal group of individuals. More digits were accurately reported from the right ear which lies opposite to the left dominant hemisphere (Kimura, 1961b). It is a well known fact that each ear has connections with the auditory receiving area in each hemisphere. In other words, each ear has direct connections with the homolateral as well as crossed connections with the contralateral hemisphere. However, it has been pointed out repeatedly that crossed connections with the contralateral hemisphere are dominant and, therefore, more effective in perception in comparison to homolateral connections. As Kimura (1967) comments:

> The explanation for the right-ear superiority on the digits test, [in her earlier study, 1961b] then, was that the right ear had better connections with the left hemisphere than did the left ear, and since the left hemisphere was the one in which speech sounds were presumably analyzed, the right-ear sounds had the advantage of having better access to these speech centres (p. 164).

The above obviously leads to the second hypothesis that in case of speech representation in the right hemisphere, the left-ear superiority should occur. This hypothesis has been tested on a small group of patients with right hemisphere dominance in speech as determined by the sodium amytal technique (Wada and Rasmussen, 1960). Results were in line with the hypothesis. In each case, the ear contralateral to the dominant hemisphere obtained the higher score (Kimura, 1961b). Thus, it is clear that ear asymmetry is related to the dominant hemisphere. The asymmetrical functioning of the two hemispheres for speech becomes evident from unequal perception of words presented dichotically to left and right ears. Speech functions are represented predominantly in the left hemisphere in the clinical population as well as in a random group of normal subjects consisting of both right-handers and left-handers (Branch et al., 1964; Bryden, 1965). In such cases, there will always be a right-ear superiority in dichotic listening tasks. Again, it is appropriate to recall that only dichotic presentation technique is a reliable measure of auditory asymmetry (Kimura, 1966, 1967). Kimura (1967) noted a slight trend for right ear superiority under rapid alternating conditions. This is explained in terms of competition between the two ears in the simultaneous presentation which is not present in the monaural presentation. The reason for the importance of competition is probably due to the arrangement of auditory pathways. The arrangement is shown schematically by Kimura (1967) in Fig. 4.5. From the diagram, it appears that there is only a slight increase in the number of fibers coming from the right ear to the left hemisphere as compared to the left ear. However, there is an occlusion mechanism at work at the point of overlap between the two pathways. At the point of overlap (indicated by arrows in the Figure), the contralateral pathways dominate due to partial occlusion of the homolateral impulses.

In addition, she points out a factor of central occlusion - "... when two different speech sounds must compete for overlapping pathways in the dominant hemisphere, the slight advantage of the contralateral input over the ipsilateral may be further enhanced by central

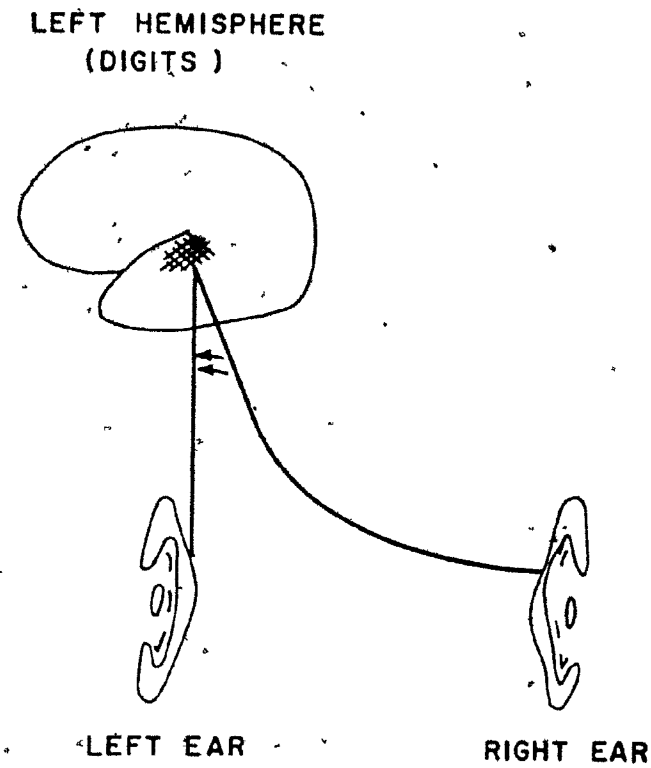


Fig. 4.5

(From Kimura, 1967)

competition." Though dichotic stimulation seems to be a necessary condition for observing perceptual asymmetry, reporting the stimuli from both ears is not. This was observed simply by presenting stimuli to both ears simultaneously, but asking the subject to report from only one ear. The same subjects were presented with the same list of words (reported in the dichotic condition) in a monaural condition and the subjects reported all they could. Results indicated that subjects who reported from the right ear obtained much higher scores than those who reported from the left ear under dichotic conditions. The right-ear superiority, however, is not evident under the monaural condition. It is important to note here that both conditions demand only monaural report. The difference between the two is that under the dichotic presentation, irrelevant words are coming at the other ear. Thus, Kimura (1967) concludes that the right-ear superiority observed here with monaural report "... must reflect a competition between stimulus inputs to the two ears, that is, a perceptual rivalry rather than a response rivalry."

The dichotic technique has been very useful in investigating asymmetrical functions of the two hemispheres utilizing nonverbal auditory stimuli. Spoken digits and words are all primarily dependent upon the left hemisphere for recognition. Certain nonverbal auditory stimuli are processed primarily by the right hemisphere (Kimura, 1967). Since musical abilities have been associated with the right hemisphere, Kimura (1967) devised a melodies task to test if there exists a left-ear superiority in a group of normal subjects. Results indicated a significantly greater number of correct identifications with the left ear as compared to the right ear. The same subjects obtained a higher score for the right ear when digits were presented. Thus, the dichotic test findings from the normal population support the lateralization of functions observed in the patient population. It is the type of stimulus that determines the direction of auditory asymmetry, and the asymmetry in turn reflects the varied functions of the two hemispheres. Kimura (1967) has proposed a neuroanatomical basis for the dual auditory asymmetry which is shown in Fig. 4.6. It shows the connections between each ear and each auditory cortex and also the difference in function between the two auditory hemispheres. The left temporal lobe dominates in the perception of verbal material (digits and words) and the right temporal lobe dominates in the identification of melodies. In addition, another study was conducted to test if familiarity had a role in the identification of melodies. On the basis of her comparative results, Kimura (1967) concluded that melodic patterns regardless of familiarity were recognized by the right hemisphere. In a nutshell, familiarity was not found to be a critical factor in specialization of hemispheric functions.

A series of experiments have been conducted by Kimura (1969) to investigate spatial ability in left and right visual fields. In other words, the purpose was to determine differences, if any, between the performance of left- and right-visual fields in terms of spatial perception. It is well established that visual impulses from the left visual field are transmitted to area 17 in the right hemisphere and visual impulses from the right visual field travel to the corresponding area in the left hemisphere. However, at the same time there is ample evidence for dominance of the left hemisphere in speech functions and dominance of the right hemisphere in visuospatial abilities. In view of the major role of right hemisphere in visuospatial abilities, it was proposed

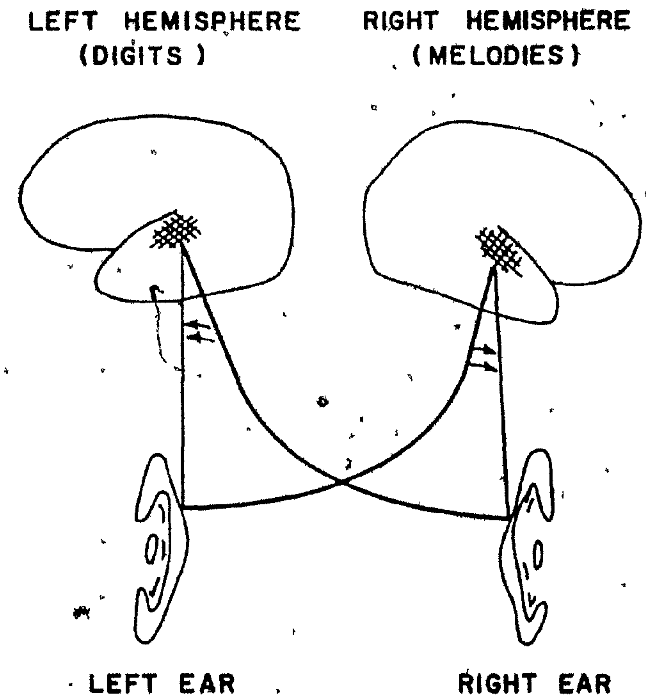


Fig. 4.6

(From Kimura, 1967)

(Kimura, 1969) that stimuli should be more accurately located spatially upon presentation to the left visual field than to the right visual field. Earlier it had been noted that enumeration of groups of dots or geometrical designs were more accurately perceived through the left visual field than through the right (Kimura, 1966). The 1969 series of experiments required the subject to locate the dot on a spatial map depicting all of the lot locations presented. The subjects were right-handed undergraduate males and females. A single dot was presented on each trial through a Gerbrands Harvard Tachistoscope. The subjects' eyes are approximately two feet from the exposure field. A fixation point is set and before each presentation a 'ready' signal is given.

Analysis of results indicated left visual field superiority in the localization of the dot among men under all testing conditions. Women also showed a left visual field superiority on some localization tasks and no difference on other tasks. However, no sex difference was noted on an overall accuracy of performance. The overall left field superiority for dot localization lends support to the dominance of the right posterior region of the brain in visuospatial ability. The absence of left-field superiority in females on some tasks has been interpreted to imply that differentiation of right and left hemispheres with respect to visuospatial ability may be greater in men than in women. In concluding, Kimura (1969) comments: "... a number of unpublished observations from our laboratory support the view that males and females may approach even simple perceptual tasks differently, often related to their differential use of verbal and non-verbal systems" (p. 457). Thus, a sex difference, though limited to just a few tasks, was noted. This study is important in that at least the question of sex difference in visuospatial ability came into discussion which served as impetus to subsequent research on the subject.

A review of studies related to asymmetry in visual perception by White (1969) provides a wide range of literature on the subject. He also makes an attempt to interpret and discuss the implications of reported data and conclusions. Most of the studies on visual perception have utilized two methods of stimulus presentation - bilateral or unilateral set up. In general, with bilateral presentation of random letters, recognition is better from the left visual field (Bryden, 1966; Harcum, 1964). Recall of single random letters is better with the right visual field when presented unilaterally (Bryden, 1966; Bryden and Rainey, 1963). As White (1969) rightly comments:

> Of the implications arising [from relevant studies in the field],... the most important would seem to be that a general interaction exists between hemifield and type of presentation. When rows of letters or digits are presented across the subject's visual field and the subject is given "free report", stimulus elements from the LVF are better recalled than are those from the RVF. When these materials are presented either in the LVF or in the RVF, elements from the RVF tend to have better recall scores (p. 390).

However, according to White (1969), data relating cerebral lateralization to visual field asymmetry are not as clear-cut or as conclusive as are the comparable auditory data from dichotic listening studies. With respect to auditory data, it has been demonstrated that the left temporal lobe dominates the right temporal lobe in the perception of verbal material, whereas the right dominates the left in the perception of nonverbal material. Also, contralateral auditory pathways seem to dominate the homolateral pathways. These conclusions are based upon studies of patients with unilateral temporal lobectomy as well as studies on normal individuals. As far as visual asymmetry studies are concerned, much of the evidence comes from studies of normal subjects only. Also, there exists a major difficulty in assigning the label 'nonverbal' to stimulus materials. Hence, White (1969) concludes: "... a functional asymmetry of the sort observed with various auditory inputs does not seem apparent when visual - verbal and nonverbal - material is used." Nevertheless, studies on visual perception in normal individuals have contributed towards conducting further researches in the field of cerebral asymmetry.

The use of reaction time (RT) as a measure has also been an important contribution to more sensitive observation of lateral asymmetries. Reaction time has been extensively employed in asymmetry studies on normal human subjects (Berlucchi et al., 1971, 1979; Buchtel et al., 1978; Filbey and Gazzaniga, 1969; Geffen et al., 1971; Jeeves and Dixon, 1970; McKeever et al., 1975; Moscovitch, 1972; Moscovitch and Catlin, 1970; Rizzolatti, 1979; Rizzolatti and Buchtel, 1977). Reaction time experiments have helped in understanding the nature and logic of the information-transmission mechanism in the normal intact brain. The importance of the great cerebral commissure (the corpus callosum) has been well established on the basis of split-brain studies on animals and humans (Sperry, 1961, 1964; Gazzaniga, 1967, 1970). It helps in maintaining unity in behaviour in the normal intact brain. Hence, to learn more about the intact brain, one has to rely upon noninvasive techniques such as reaction time and dichotic listening.

Filbey and Gazzaniga (1969) conducted two simple choice-reaction-time experiments and noted that in between 30-40 msec. are required for the transfer of simple visual information across the corpus callosum. Their experiments have been an important impetus to subsequent use of reaction time methods for investigating functional asymmetries of the brain. Their first experiment was based on the knowledge that speech is controlled by the left hemisphere in nearly all right-handed individuals (Penfield and Roberts, 1959; Branch et al., 1964). Thus, their hypothesis for investigation was that vocal report latencies about stimuli presented to the right hemisphere should be longer than for stimuli presented to the left hemisphere. The difference between the reaction times obtained through two modes of stimulus presentation should reflect the time needed for transcallosal transfer. The experimental procedure involved a presentation of a single dot stimuli 1° of visual angle to the left or right of fixation on half the experimental trials and blank fields on the remaining trials. The subjects were required to respond by "yes" or "no" depending upon the presence or absence of the dot. "Yes" and "no" responses were counterbalanced across instructions to respond affirmatively to dots or to blanks. After every trial, subjects were notified of their exact vocal reaction time to that trial. Results obtained from eight female subjects confirmed their hypothesis. The right visual field dot trials were reported a little over 30 msec. faster than left visual field dot trials or blank field trials. A second experiment was performed to replicate the previous experiment on eight right-handed female subjects. The subjects were, however, asked to give a manual response which consisted of moving a lever to the right or left, depending on the stimulus. Results showed no half-field differences in dot detection times, while those to blank field trials took significantly longer than dot trials.

In other words, data indicated an intercortical difference in reaction time during a visual discrimination task. In concluding, Filbey and Gazzaniga (1969) remark:

> ... now that a base time [of about 35 msec.] has been established for callosal transmission in a very simple visual pattern-discrimination task, it remains to be discovered whether or not this callosal transmission time increases with the complexity of the discrimination. The answer ... would give evidence as to the amount of processing that each side of the cortex does on the discrimination task, i.e., whether the callosal transmission is some sort of "go/no-go" message or an elaborate readout of raw visual information (p. 336).

Few studies have been conducted to determine interhemispheric transmission times to visual stimuli (Moscovitch and Catlin, 1970; Jeeves and Dixon, 1970). Moscovitch and Catlin (1970) on analysis of data noted a value in the order of 10 msec. required for information to pass from one hemisphere to the other. They also observed a right-field superiority in speed of verbal recognition of single capital letters presented about 4.2 degrees from the fovea. Jeeves and Dixon (1970) pointed out a right hemisphere superiority as compared to the left hemisphere in processing unstructured visual stimuli when a bright point of light was flashed for 2 msec. at a lateral angle of 70 degrees from the fovea.

As Jeeves and Dixon (1970) summarize: "Visual stimulation going initially to the right hemisphere is responded to faster than stimulation going initially to the left hemisphere" (p. 250). According to them, the time taken to respond (reaction time) depends upon the pathway involved in receiving the stimulation and responding. Four possible pathways have been outlined: (1) right hemisphere receiving the stimulus and left hemisphere directing the response (right hand); (2) right hemisphere receiving the input as well as directing the output (left hand); (3) left hemisphere receiving as well as initiating response (right hand); (4) left hemisphere receiving and right hemisphere directing the response (left hand). Results have been explained in terms of two assumptions. Firstly, the sensory receiving area in the right hemisphere processes visual information faster than the corresponding one in the left hemisphere. Secondly, the motor responding area in the left hemisphere is faster at responding than the corresponding area in the right hemisphere.

Another study by Berlucchi et al. (1971) deals with a comparison of simple reaction times of homolateral and contralateral hand to lateralized visual stimuli. The main purpose of the study was to find out whether there is a delay between reaction times involving homolateral hand-visual hemifield combinations and contralateral hand-visual hemifield combinations. In addition, they were interested in finding out if the distance of the visual stimulus from the vertical meridian of the visual field had some input in the length of the delay period, i.e., the reaction time in the two combinations (homolateral hand-visual hemifield and contralateral hand-visual hemifield). The sample consisted of 14 normal subjects. Results pointed out that visual stimuli presented on one side of the fixation point elicited responses faster from the homolateral hand than from the contralateral hand. In other words, the homolateral hand-visual hemifield combination produced a smaller reaction time than the contralateral combination. A significantly longer reaction time was noted for the contralateral (crossed) combination. The overall average difference between the crossed and uncrossed reaction times was 3.3 msec. in one group of subjects and 2.1

msec. in the other group. This difference between the two reaction times was not affected by the location of the visual stimulus. Thus, Berlucchi et al. (1971) conclude that callosal connections of the visual cortex are not crucially responsible for interhemispheric integration of simple visuomotor tasks. This is in line with the report by Gazzaniga et al. (1967) that each hemisphere is capable of controlling the homolateral hand efficiently in performing very simple visuomotor tasks after forebrain commissurotomy.

A subsequent study by Rizzolatti, Umilta and Berlucchi (1971) in the same journal <u>Brain</u> is related to choice reaction time of the two hands of 24 right handed male students of the University of Bologna to two groups of visual stimuli, presented either to the right or to the left of a central fixation point. Two types of visual stimuli - single capital letters and photographs of faces of unknown persons - were used for the experiment because their recognition appeared to involve respectively a left-hemisphere and a right-hemisphere dominance. The discrimination stimuli used in the experiment are presented in Fig. 4.7. The investigators' aim was to demonstrate a right-field superiority for the speed of response to letters (left hemispheric function) and a left-field dominance for the speed of response to faces (right-hemispheric function). Analysis of data confirmed the dominant role of the left hemisphere for the recognition of single capital letters. Also, a clear evidence of the primary role of the right hemisphere for the identification of faces was noted. Reaction times to letters were significantly shorter when stimuli were presented to the right visual field (transmitted directly to the left hemisphere); whereas reaction times to faces were significantly shorter when the stimuli

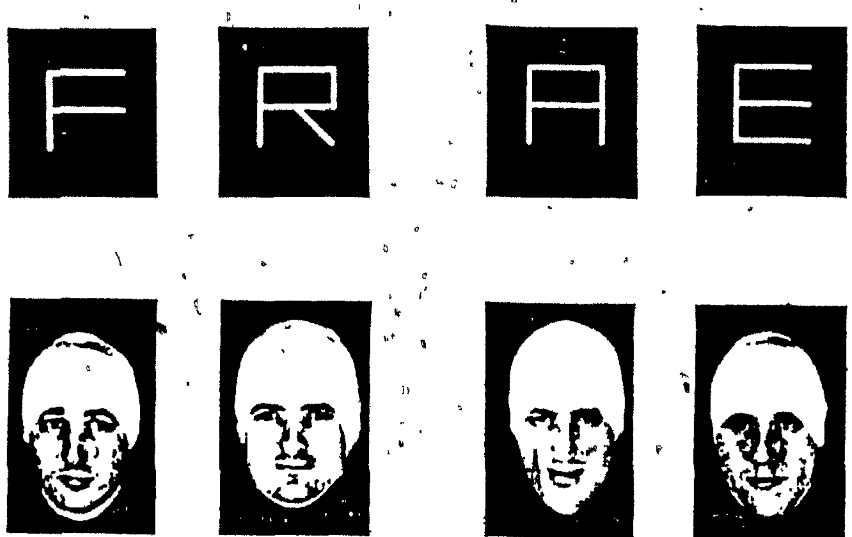


Fig. 4.7

(From Rizzolatti et al., 1971)

were presented in the left visual field (transmitted directly to the right hemisphere). Thus, Rizzolatti, Umilta and Berlucchi (1971) comment:

> ... a hemisphere specialized in the recognition of one particular kind of visual pattern receives its information via a direct sensory route, when the pattern is presented in the contralateral visual field, and through an indirect, interhemispheric route (sensory input to and callosal projections from sensory and associational areas of the other hemisphere) when the pattern is presented in the ipsilateral visual field (p. 438).

This importance of the corpus callosum has been well established from split-brain studies in the transfer of visual information by Sperry (1961, 1968) and others. Results of the above study are consistent with 'material-specific asymmetries' of the cerebral hemispheres. In addition, no significant difference was noted in relation to responding hand or to the interaction of the responding hand and the side of the stimulus. In complex visuomotor tasks, the role of the specialized hemisphere becomes much more important and, therefore, stimuli projected to the specialized hemisphere elicits a faster response than stimuli projected to the non-specialized hemisphere. In other words, when stimuli is projected to the non-specialized hemisphere, information has to cross over to the other specialized hemisphere to be processed and, hence, a longer reaction time is noted. In a nutshell, perceptual asymmetry seems well established.

Experiments involving measurement of reaction time in normal individuals by Geffen et al. (1971, 1972) provide further support to perceptual asymmetry between the two hemispheres. Geffen et al. (1972) investigated hemispheric specialization and noted reaction times for verbal and spatial encoding of visual stimuli. The subjects' reaction time was shorter when stimuli consisting of letter pairs similar in name (Aa) were projected to the left (language) hemisphere. On the other hand, physically identical letter pairs (AA) elicited a shorter reaction time when projected to the right hemisphere via left visual field stimulation. These differences in processing two different kinds of stimuli suggest a dominance of the left hemisphere in processing name matches whereas the right hemisphere takes the lead in processing physically identical items. The differences in the reaction times between visual fields have been explained (Geffen et al., 1971, 1972) in terms of interhemispheric transfer times and less efficient processing of verbal material by the right hemisphere and spatial material by the left hemisphere. The results of the 1972 experiment emphasizes the nature of task in the determination of hemispheric asymmetry. As Geffen et al. (1972) comment:

> ... faster processing of physically identical stimuli when these are directed to the right hemisphere suggests that the type of task is more important than the type of stimulus in determining hemispheric asymmetry. When analysis of visual patterns is required, the right hemisphere is better (p. 30).

A number of experiments on various aspects of visual perception have been conducted on normal subjects to determine the degree of involvement of the two hemispheres. On the basis of their experimental results obtained under the two dimensional situation, Kimura and Durnford (1974) concluded that the right hemisphere plays an important role in spatial location of stimuli. Also, data from experiments on depth perception yielded a left visual field (right hemisphere) superiority (Durnford and Kimura, 1971; Kimura and Durnford, 1974). On the basis of results obtained from normal studies, Kimura and Durnford (1974) conclude:

> ... not only is the right hemisphere of primary importance for complex visuospatial functions, but also for more fundamental perceptual processes. Functions which are basic to visual perception - perception of line orientation, depth perception, rapid scanning of a number of stimuli, and visual point location - were all shown to depend more on right hemisphere activity than on left hemisphere activity (p. 42).

However, experiments related to perception of line orientation have given contradictory results. Kimura and Durnford (1974) obtained left field superiority in line orientation tasks. On the contrary, White (1971), Umilta et al. (1973) noted a right field (left hemisphere) dominance in perception of line orientation tasks. These data are perplexing. In one experiment by Umilta et al. (1973), reaction times were significantly faster to stimuli in the right visual field (left hemisphere). However, in two other similar experiments in which the orientation of the line stimuli was changed to, respectively, 30, 45, 120 and 135 degrees from the vertical in one experiment and 15, 45, or 60 degrees from the vertical in the other experiment, a clear cut evidence of right-hemispheric dominance was noted. These variable findings have been explained by Berlucchi (1974):

> ... these results indicate that the vertical, horizontal, and intermediate orientations are perceived and responded to faster by the left hemisphere exactly because these orientations are easily analyzed and categorized in verbal terms (e.g. vertical, horizontal, tilted to the right, tilted to the left). On the contrary, with the other orientation discriminations, it is difficult to encode the orientation of each particular stimulus by itself, and probably it is necessary to proceed by an internal comparison between the orientation of the present stimulus and those of the other discriminative stimuli. [It is] under these conditions, [that] the superior ability of the right hemisphere in analyzing spatial relationships would emerge and reverse the visual field asymmetry (p. 68).

Thus, there appears to be no doubt in that visual field asymmetry does exist. The controversies surround the dominance of one or the other hemisphere in various tasks. Reaction time as a measure has been useful in investigating the asymmetrical nature of the brain. Buchtel et al. (1978) measured reaction times to facial expression in normals. A preponderance of the experimental evidence in normal subjects points to right hemisphere dominance in processing emotional stimuli. A left-ear (right hemisphere) advantage has been noted in normal subjects in the perception of affective stimuli (Carmon and Nachshon, 1973; King and Kimura, 1972). In the experiment by Buchtel et al. (1978) a lateralized tachistoscopic presentation of frontal photographs of faces (each showing a happy, neutral and sad expression) was made to sixteen normal subjects. The investigators attempted to determine which hemisphere is faster in analyzing the emotion of a facial expression. Results indicated a left visual field (right hemisphere) superiority in the speed of judging a facial expression. On the other hand, responses to the neutral face were faster with right visual field (left hemisphere) presentation. This is interpreted as a superiority of the left hemisphere in resolving ambiguity. In other words, the left hemisphere is faster in making a decision about the nature of ambiguous emotional stimuli (happy or sad). Whereas basic identification of clear-cut emotional tone of the stimuli is made by the left visual field (right hemisphere).

A recent study by Berlucchi et al. (1979) attempts to distinguish the relative importance of two factors, namely discriminability and verbal codability for hemispheric dominance in visuospatial tasks. These investigators have tested the ability of normal subjects to read the time on a clockface tachistoscopically lateralized to the right and left visual fields. It was found that perception of the hands on a clockface was faster when presented to the left visual field. Further, despite Kimura and Durnford"s (1974) claim that vocal reaction time is an inadequate measure for showing the superiority of the right hemisphere (due to left hemispheric bias for vocal output), Berlucchi et al. (1979) have demonstrated a superiority of the left visual field in visuospatial abilities using a vocal reaction time measure. As Berlucchi et al. (1979) comment:

> ... a theoretical analysis of interhemispheric interactions shows that if the processing of a given sensory material is carried out by one particular hemisphere, then the discrimination of that material should be faster when the output is directed to the dominant hemisphere, regardless of whether the final response is produced by that or the opposite hemisphere. If only one hemisphere has access to the output while the other hemisphere is specialized at decoding the input, the channelling of the input into the hemisphere controlling the output should by no means increase the speed of the response, since information would have to be relayed first to the other hemisphere for decoding (p. 199).

Also, a suggestion has been made by Berlucchi et al. (1979) that verbal encoding by the left hemisphere "must" be preceded by a processing of the visual stimulus in the right hemisphere for a complex visuospatial discrimination task (estimating the position of the hands of a clock). Hence, it becomes apparent that both hemispheres are involved in processing complex visuospatial discrimination stimuli. The difference lies in the degree of involvement of each of the hemispheres in a given task. As Luria (1966 a, b) maintains, higher psychological functions are dependent upon a coordinated functioning of various cortical zones. Similarly, Rizzolatti (1979) emphasizes the role of the two hemispheres in discriminative reaction time experiments. The asymmetrical nature of the two hemispheres in terms of their analyzing capabilities must be considered in such experiments. Thus, according to Rizzolatti (1979) "... for a given material, there is one hemisphere which is highly competent and one which is less competent or incompetent in performing the analysis."

It is worth noting that in all the studies (utilizing special testing conditions) on the asymmetrical feature of the two hemispheres, inferences drawn are based on some assumptions that are made in behavioural studies. In a way, these studies are indirect means of drawing inferences about brain activity. Hence, in order to investigate the differing features of the two hemispheres directly, it is appropriate to measure the brain activity itself (Springer and Deutsch, 1981). One way of recording brain activity is done by placing electrodes on the scalp. Brain waves can be recorded at various sites on the head and these can be helpful in studying differences within and between hemispheres. Although patterns of electrical activity (often referred to as 'electroencephalogram" or 'EEG') were being recorded and used for clinical purposes in the earlier part of the century, it was not until the late 1960's that EEG recordings were being used to study asymmetries of the two hemispheres. The use of electrophysiological indices of hemispheric utilization has developed gradually with the increasing interest in the study of specialization of the two hemispheres. The asymmetries of the cerebral hemispheres have been well established from commissurotomized populations (Gazzaniga, 1970; Sperry, 1974) as well as from patients suffering from lesions (Milner, 1974). With the development of specialized techniques for presenting stimuli to one hemisphere at a time in dichotic listening and reaction time experiments, further evidence of hemispheric asymmetry has been obtained (Dimond and Beaumont, 1974).

However, as already pointed out earlier, EEG studies are of potential value because they are free from constraints encountered in experimental psychology studies and therefore provide a more accurate measurement of brain activity during a particular task. Also, these recordings can be taken on the infant population, aphasic patients and other clinical patients who might not be able to respond in the manner required by behavioural tests. Still another advantage is that EEG studies provide an opportunity for continuous measure over time and thus can be used to investigate ongoing brain activity while the subject is engaged in long, complex tasks (Springer and Deutsch, 1981). Nevertheless, a problem encountered in EEG studies is to relate changes in EEG to the occurrence of specific stimulus events. In fact, the complex EEG wave patterns do not seem to vary too much during various kinds of sensory input but, rather, indicate the general arousal level of the brain. But this problem is somewhat overcome by attempts to make the change in response to a particular stimulus obvious. As Springer and Deutsch (1981) point out:

> ... a computer is used to average the waveform records following repeated presentations of the same stimulus. Electrical activity that is random with respect to the stimulus presentation will tend to be cancelled out by this process, while electrical activity occurring in a fixed time relation to the stimulus will emerge as the potential evoked by the stimulus.... The evoked potential consists of a sequence of positive and negative changes from a baseline and typically lasts about 500 milliseconds after the stimulus ends. Each potential can be analyzed in terms of certain components or parameters such as amplitude or latency (the amount of time from the onset of the stimulus to the onset of the activity) (p. 89):

Springer and Deutsch (1981) have provided some examples of typical encephalograms that are shown in Fig. 4.8. Four EEG waveforms represent four different brain states. The nature of the stimulus is one of the factors that determine the exact form of the evoked potential. Evoked potentials vary from one sense modality to another. Auditory evoked potentials, for example, differ from visually evoked potentials. Further, the site of each hemisphere generating maximum activity varies with the type of the stimulus. Few representative evoked potentials to stimuli in different sense modalities are shown in Fig. 4.9 (Springer and Deutsch, 1981). The major concern of investigators in EEG studies on normals is to find out whether there are differences in the evoked potentials obtained from equivalent locations in the two hemispheres. A number of EEG studies have been conducted on the human population (Buchsbaum and Fedio, 1969, 1970; Galin and Ornstein, 1972; Gardiner and Walter, 1977; Matsumiya et al., 1972; McAdam and Whitaker, 1971; Morrell and Salamy, 1971). Electroencephalographic studies' findings have shown hemispheric asymmetry.

Buchsbaum and Fedio (1970) recorded evoked potentials to verbal and nonverbal stimuli from the two hemispheres in normal subjects. The perceptual task consisted of a list of verbal and nonsense material. The method of successive presentation was employed in the experiment. Evoked electrical potentials were recorded simultaneously from the left and right occipital cortex. It was found that verbal material and nonsense patterns produced different evoked response waveforms from the left and right occipital cortex. Recordings from the left hemisphere produced greater differences in evoked response waveform for verbal and nonverbal stimuli in comparison to evoked response waveform

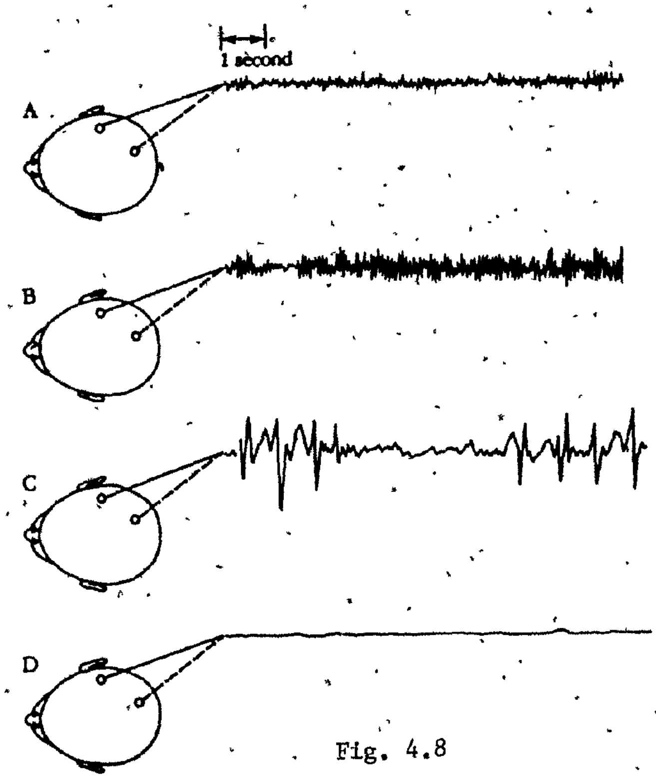


Fig. 4.8

(From Springer and Deutsch, 1981)

A (at rest with eyes open)
B (at rest with eyes shut)
C (the dramatic spiking associated with an epileptic seizure)
D ("brain death" or "cerebral death")

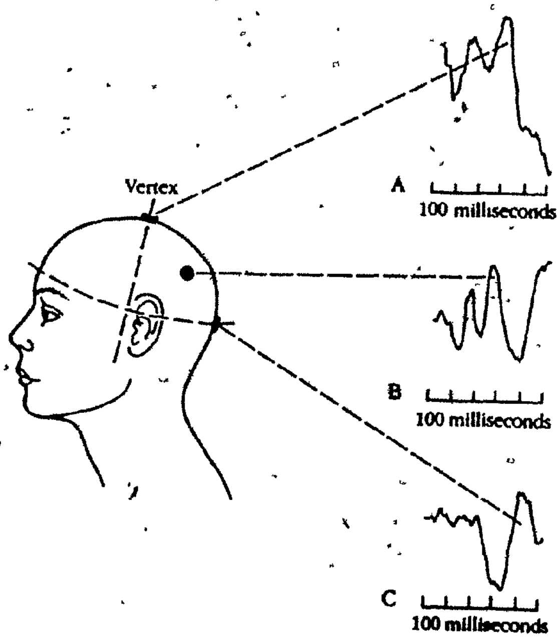


Fig. 4.9

(From Springer and Deutsch, 1981)

A (auditory)
B (somatosensory)
C (visual stimulation)

for the two classes of stimuli in the right. In addition, information transmitted through direct visual pathways to each hemisphere showed greater stability in evoked response activity in relation to evoked response activity from indirect pathways.

Galin and Ornstein (1972) were two of the first investigators to study EEG asymmetry in relation to the nature of the task performed by normal subjects. These investigators emphasize the role of studies of normal subjects in making inferences of lateral specialization of cognitive functions. As Galin and Ornstein (1972) comment:

> Although the "split-brain" work has shown that the verbal and spatial cognitive systems can function independently, there are few studies which attempt to evaluate their interaction in normal people. Our opinion is that in most ordinary activities we simply alternate between cognitive modes rather than integrating them. These modes compliment each other but do not readily substitute for each other. ... Therefore, in a subject performing a verbal or a spatial task, we expected to find electrophysiological signs of differences in activity between the appropriate and inappropriate hemispheres (p. 413).

While the subject was engaged in performing verbal tasks such as writing a letter and spatial tasks such as constructing a memorized geometrical pattern with multicoloured blocks (based on Kohs block design test), electrodes placed on symmetrical positions on the two sides of the head recorded brain activity. Analysis of results indicated characteristic patterns of activity and inactivity at the scalp for the two cognitive modes. Results were analyzed in terms of the ratio of right-hemisphere EEG power (R) to left-hemisphere EEG power (L). The right/left hemisphere power ratio was 1.15 for the spatial task and 1.30 for the verbal task. The amount of electrical energy being produced per unit of time is called EEG power. R/L power ratio was found to be significantly greater in the verbal than in the spatial tasks. Alpha activity was the predominant rhythm in the EEG records. Since alpha rhythms reflect a resting brain state, less alpha rhythms is presumed to reflect the greater involvement of the hemisphere that is predominant in a particular task accomplishment. Galin and Ornstein (1972) noted relatively less alpha activity in the left hemisphere while the subject was engaged in a verbal task as compared to the amount of alpha activity while the subject was performing a spatial task. Similar findings were obtained in studies of activity in the alpha band (Dumas and Morgan, 1975; McKee et al., 1973; Morgan et al., 1971). Thus, the asymmetrical feature of the two cognitive modes in normal subjects was noted. Findings of a later study by Doyle et al. (1974) supported earlier findings. Cognitive mode was found to be reliably reflected in patterns of EEG lateral asymmetry. Hence, Doyle et al. (1974) have rightly concluded:

> ... that EEG analysis can be a powerful method in studies of the brain mechanisms relating to cognition. It is essential, however, to take into account the effects of electrode locus, frequency band, task demands, and the levels of engagement and performance (p. 577).

The role of task demands in EEG analysis of lateral asymmetry as emphasized by Doyle et al. (1974) has been taken into account in a study by Morgan et al. (1974). EEG alpha activity was recorded from the occipital lobes in the left and right hemispheres while subjects were involved in analytic (verbal and numerical) tasks, spatial (imagery) tasks, a music task, and under hypnotic susceptibility state. An alpha laterality score was calculated by obtaining the per cent difference in the amplitude of alpha in the two hemispheres. The laterality score was significantly different between the analytic and spatial tasks.

However, due to the fact that spatial tasks were considered "easier" as compared to analytic or music tasks, the role of task difficulty could not be clearly ascertained. Significantly more total alpha was recorded from the right hemisphere during analytic tasks than during spatial tasks. Two possible explanations have been indicated by Morgan et al. (1974). They are: "(1) ... laterality is a function of task, i.e., analytic tasks are processed primarily in the left hemisphere, spatial tasks in the right; or (2) ... laterality is a function of task difficulty, with those tasks requiring more cognitive work being processed in the left hemisphere, easier tasks in the right." However, a conclusive decision could not be made on the basis of the data available. Also, no differences in laterality were noted between the high and low hypnotizables during hypnosis. If hypnotic stimuli should be "easier" for the hypnotizable subjects than for the non-hypnotizable, the available finding did not support the difficulty hypothesis.

The function of stimulus location in the analysis of visual cortical evoked potential (VEP) has been investigated by Andreassi et al. (1975). Two separate experiments were conducted on normal subjects with no visual system defects other than myopia (corrected to 20/20). The VEP was recorded from left and right occipital hemispheres while stimuli were being presented binocularly. In the first experiment, three stimulus locations were used and in the second experiment seven stimulus locations were used. Results of both experiments indicated that when stimuli were presented in the left visual field, the primary right occipital lobe produced shorter VEP latencies as compared to simultaneous recording of VEP latencies from the secondary left occipital lobe. The opposite latency results were noted when stimuli appeared in the right visual field and the left occipital lobe was functioning as the primary area. In addition, experiment II indicated a tendency of decrease in VEP amplitude with the increase in distance of the stimulus from the fovea. The VEP latency asymmetries have been explained in terms of the angle at which the visual stimulus enter the retinas of the two eyes from various locations. In other words, when the stimulus appears in the right visual field, it falls most directly on the temporal retina of the left eye and the nasal retina of the right eye and, hence, results in a shorter latency of VEP response recorded from the left occipital lobe. Similarly, when the stimulus is presented in the left visual field, it impinges most directly on the temporal retina of the right eye and nasal retina of the left eye, thus producing a shorter VEP latency from the right occipital lobe. On the other hand, when the stimulus appears directly ahead, no differences of VEP latencies occur because the angle of the stimulus for both retinas is similar. These findings are important in the sense that the role of stimulus location becomes apparent. Therefore, Andreassi et al. (1975) point out " ... that researchers must be certain that stimulus location is controlled, and that the stimulus is fixated in a similar manner by all subjects, before firm conclusions regarding VEP asymmetries and behavior can be made."

A rather remarkable cross-hemispheric symmetry of VEP has been reported in normal subjects (Harmony et al., 1973). Recordings were obtained from central, occipital, temporal, centro-occipital and occipito-temporal left and right derivations. Simultaneous recordings were made from homologous derivations. Analysis of homologous pairs of VEPs indicated quite symmetrical VEP at all scalp derivations used in the experiment. On the other hand, other researchers have noted asymmetric evoked potentials with larger amplitude components in the right hemispheres (Bigum et al., 1970; Giannitrapani, 1967; Rhodes et al., 1975; Richlin et al., 1971). Richlin et al. (1971) obtained visual evoked cortical responses that reflected an interhemispheric asymmetry consistent with the nonverbal stimuli employed. The amplitudes of the left hemisphere were lower than those of the right hemisphere. Similarly, a number of other studies have pointed out that evoked response asymmetry is related to lateralization (Buchsbaum and Fedio, 1970; Matsumiya et al., 1972; Morrell and Salamy, 1971; Vella et al., 1972; Wood et al., 1971).

In the experiment by Wood et al. (1971), electrical activity was recorded from temporal and central scalp sites over the left hemisphere as well as from corresponding areas over the right hemisphere while the subject was engaged in two auditory tasks. One task required analysis of acoustic parameters important for making a linguistic distinction, while the other task required analysis of an acoustic parameter which gave no linguistic information at the phoneme level. Evoked potentials from the two tasks were found to differ only at left hemisphere locations. Evoked potentials recorded from the right hemisphere for the two different asks were found to be identical. Thus, their results indicated that different neural events occur in the left hemisphere during analysis of linguistic versus nonlinguistic parameters of the same acoustic signal. In addition, the investigators noted a strong support for the idea that a unilateral neural network is specialized to handle those linguistic processes essential for speech perception.

Similarly, Morrell and Salamy (1971) observed hemispheric asymmetry in electrocortical responses to speech stimuli. Electrocortical responses to natural speech stimuli were recorded from symmetrical sites in the two hemispheres at frontal, Rolandic, and temperoparietal regions. Analysis of data suggested that specialized neural pathways were activated in the left temperoparietal cortex when speech sounds were perceived. The corresponding posterior right cortex indicated specialization for certain types of visual perception. Hence, these electrocortical measures seem to be of considerable value in studying higher mental functions of the brain. Interhemispheric asymmetry in auditory evoked responses to verbal and nonverbal materials was also noted by Matsumiya et al. (1972). However, they concluded that meaningfulness of the subject of the auditory stimulus may be more related to the occurrence of the interhemispheric asymmetry in auditory evoked responses than the mere use of verbal versus nonverbal materials.

Lateral asymmetry in terms of speech and nonspeech stimuli has been further investigated in human infants, children and adults (Molfese et al., 1975). Auditory evoked responses were recorded over temporal regions in both the hemispheres. Results supported earlier findings in that auditory evoked responses from the left hemisphere to speech stimuli were larger in amplitude than right hemisphere auditory evoked responses in all three groups of subjects. As expected, nonspeech stimuli produced larger amplitudes of auditory evoked responses in the right hemisphere. An additional finding that lateral differences to both types of stimuli decreased with age was noted. A possible explanation offered by Molfese et al. (1975) is related to the maturation and the myelination of the corpus callosum and other commissures that interconnect the two cerebral hemispheres. According to them, with increasing myelination and development there will be more interaction between the two cerebral hemispheres and, hence, less lateral differences. One exception is that a decrease in lateralization with age was noted. In contrast to mechanical stimuli and speech syllables, word stimuli produced greater lateralized response in children than in infants and adults. This inconsistency may be due to the meaningfulness of the material (pointed out earlier by Matsumiya et al., 1972) and due to differences in attention between children and adults in the testing situation (Keating and Ruhm, 1971). By now it seems quite clear that asymmetry in the functions of the two hemispheres has been well established.

An important contribution to the study of lateralized cognitive functions, however, has been made by Galin and Ellis (1975). They made a direct comparison of asymmetry of alpha and evoked potentials in the same subjects, performing the same tasks. The EEG alpha asymmetry was manipulated and its effect on superimposed evoked potentials was noted. This was accomplished by allowing the subjects to engage in spatial and verbal tasks, and simultaneously presenting flashes throughout the accomplishment of the task. It was found that both EEG and evoked potential asymmetry measures reflected the hemispheric specialization for the cognitive tasks used in the experiment. They report that changes in evoked potential power and peak-trough amplitudes co-vary with the task-dependent asymmetry of the EEG alpha power. Also, their finding suggests that the hemispheres process even simple stimuli differently depending on their involvement in concurrent activities.

On the contrary, Mayes and Beaumont (1977) found that the nature of the cognitive task had no significant effect on evoked potential asymmetry. In one respect, their results were similar to Galin and Ellis'

(1975) results, for although they do not involve task related changes in evoked potential asymmetries, they do indicate that concurrent cognitive activity affects the way the cerebral hemispheres process even simple stimuli. The discrepancy in the findings of Galin and Ellis (1975) and the present one has been explained by Mayes and Beaumont (1977) in terms of an experimental situation which contains too many uncontrolled factors. Nevertheless, both studies agree on the effect of concurrent cognitive activity in the processing of simple stimuli which could be very useful in the field of psychology.

Electroencephalographic study has also been very useful in localization of language production (McAdam and Whitaker, 1971). In fact, results of their study are the first evidence of localization of language production in the normal human brain. The salient features of the electrical activity preceding language production has been summarized by McAdam and Whitaker (1971):

> First, when electrodes are placed over the inferior frontal sites of the left hemisphere (presumably Broca's area) and of the right hemisphere, larger negative potentials are recorded from the left hemisphere. Second, inferior frontal and precentral potentials show significant differences between hemispheres, which is suggestive evidence for within-hemisphere localization (p. 501-502).

Asymmetry of auditory evoked potentials elicited by linguistic stimuli have been also reported by Thatcher (1977). Asymmetries were found to be generally absent to random dot control stimuli and appeared most clearly to the second words in the synonym, antonym, neutral comparison paradigm. Hence, these findings support the results of earlier studies showing auditory evoked asymmetries with visual and auditory stimuli. These asymmetries were maximal in posterior regions of the brain (occipital, parietal, and posterior temporal) and did not involve lateralized eye movements. However, Thatcher (1977) remarks: "The precise meaning or significance of the asymmetries in terms of language processing is currently unknown."

Hemispheric lateralization has been noted in 6-month-old infants too by recording brain activity from homologous sites over left and right hemispheres during presentations of normal speech and music stimuli (Gardiner and Walter, 1977). In all four infants, interhemispheric differences between the processing of speech and music stimuli were noted. These results with infants are in line with the findings obtained from adult studies and also indicate early differences in lateralization for the processing of speech and music stimuli.

Sex differences in terms of brain asymmetry have been noted. A number of investigators have suggested that men display larger perceptual asymmetries on laterality tests than do females on both spatial and verbal cognitive processes (Baken and Putnam, 1974; Kimura, 1969, 1973; McGlone and Davidson, 1973; McGlone and Kertesz, 1973; Lake and Bryden, 1976; Levy, 1980). This inference has been supported by data on neurological patients that indicate greater symptom differentiation depending upon which hemisphere is damaged in males compared to females. Left hemisphere damage has been found to result in less severe linguistic disorders in women than in men and in greater chance of perceptual disorders. Likewise, right hemisphere damage has a lesser probability of disrupting visuospatial ability in women than in men and a greater chance of disrupting certain logical-verbal functions. In right hemisphere tasks, men tend to have a greater left-visual field superiority for dot location and dot emuneration than women. Also, men surpass females in certain visual-spatial tasks (Harris, 1978; Maccoby and Jacklin, 1974; McGee, 1979; McGlone and Davidson, 1973). Thus, it may be that the right hemisphere is more clearly specialized in males than in females. In contrast, females seem to exhibit greater verbal fluency than males, although Kimura (1973) points out that there is no evidence that adult females show greater asymmetry in speech lateralization than their male counterparts.

A right hemisphere specialization for visuospatial tasks emerges earlier (as early as the age of 6) in boys than in girls (Witelson, 1976). On the contrary, a left hemisphere superiority for verbal and other related cognitive tasks has been sometimes noted to emerge earlier in girls than in boys (Kimura, 1973; Levy, 1980). According to Levy (1980): "Biological differences in the two sexes apparently control hemisphere maturation rates through undetermined mechanisms."

On an examination of literature on sex differences in psychological functions, one encounters a great deal of controversy among research findings. In one instance, males showed a faster reaction time to faces when presented to the right hemisphere in comparison to reaction time obtained from left hemisphere presentation. On the contrary, females showed a total lack of hemispheric difference (Rizzolatti and Buchtel, 1977). McGlone (1981) not only observed sex differences in spatial and verbal tasks but also noted differences in behaviours of the two sexes during spatial and verbal problem solving. In general, females showed a higher frequency of certain types of movement patterns than their male counterparts. On a verbal fluency task, sexual variation in terms of movement patterns did not occur, but vocalizations occurred more often in females than in males. Levy (1980) has beautifully summarized these findings:

> In general males have been found to be superior to females in map reading, three-dimensional visualization, understanding of physical principles, and mathematical reasoning, while females have been found to surpass males in reading skill, verbal fluency, noting of fine visual details, incidental memory (i.e., noting and remembering of aspects of experiences that have no direct bearing on a particular well-structured task), pure associative memory (where a well-structured cognitive framework is not available for the organization of new information), and understanding of social relationships ... In brief, there are some right-hemisphere processes in which males surpass females, others in which the sexes do not differ, and still others in which females surpass males. The same holds with respect to left-hemisphere processes. The smaller degree of asymmetry between the female hemispheres seems to be related to a field-dependent cognitive style which is more prevalent in females than males. The admixture of verbal and perceptual processes within the same hemisphere in females, versus their extreme separation into different hemispheres in males, may play a critical role in the psychological differences in the sexes (p. 368-369).

In addition, Levy (1980) points out that it seems that fetal sex hormones play a significant part in conditioning the differences in the males' and females' brains. In a nutshell, it seems clear that the two sexes do differ in the degree of brain asymmetry. However, a great degree of clarity is yet to be found regarding the causal relationship between hemispheric and psychological differences between the sexes and the causal role of biological versus cultural factors (Levy, 1980).

The technique of measuring blood flow in the cerebral hemispheres has also been used to investigate differences in the activation of the two cerebral hemispheres under various psychological functions. The flow of blood through the tissues of the body varies with the metabolism and activity in those tissues. It has been noted that blood flow, which supplies essential nutrients to the various parts of the body and removes waste products, is very sensitive and responsive to minute changes in cellular activity. In other words, changes in the activity of the various parts of the brain are reflected in the relative amount of blood flowing through those areas. Hence, the technique of measuring blood flow becomes very useful in understanding the roles of different parts of the brain in a particular mental task. A number of blood flow studies have been conducted to study specialization of the two hemispheres (Gur and Reivich, 1980; Lassen et al., 1978; Risberg et al., 1975).

Cerebral blood flow is measured while the subject is made to inhale a special air-xenon mixture with the aid of a special monitoring device. In one study, Risberg et al. (1975) observed that the mean left-hemisphere flow was greater during the verbal analogies task whereas the mean right hemisphere flow was greater during the picture completion task. Also, measurement of regions that contributed the most to the interhemispheric blood flow differences were measured. The largest differences were found in the frontal, fronto-temporal, and parietal regions for the verbal tasks. Differences between corresponding regions of the hemispheres were very small in the resting state.

In a recent study on normal individuals, Gur and Reivich (1980) obtained somewhat similar results. A verbal task led to an increased blood flow in the left hemisphere whereas a spatial task induced only a nonsignificant increase in right-hemisphere blood flow. However, individuals indicating an increased blood flow in the right hemisphere scored better on the spatial task than those indicating either no change in flow or an increased left-hemisphere flow. Thus, it can be seen that people do differ in the degree of activation of the two cerebral hemispheres. In summing up, cerebral flow techniques (though not refined enough at the present to provide accurate information about the deepest regions of the brain) lead a step further in obtaining evidence for cerebral lateralization in human psychological functioning.

At a glance into the literature on cerebral asymmetry of the brain, it becomes clear that evidence for lateralization is abundant. Some controversies do exist but that is only normal in a scientific study. Disagreements open up new areas for research and provide further insight into some of the factors that might have influenced the general inferences drawn on the subject. Data on the asymmetrical nature of the brain have been increasing since the pioneering research on split-brain patients in the 1960's by Nobel Prize winner Roger Sperry and his coworkers. Gradually with the development of dichotic listening, lateralized tachistoscopic presentation and EEG techniques it became possible to explore the functions of the normal brain. The credit goes to Kimura for developing a dichotic listening task in which a headset was used to simultaneously play one melodic pattern to one ear and a different one to the other ear. The subject was then asked to choose the two melodies that he or she had just heard from four melodies that were played one by one to both ears. As we all know that melodies are processed by the right temporal lobe, the subjects' performance was better in choosing the two melodies when presented to the left ear. These results were very encouraging and researchers in the field began exploring the characteristics of the verbal and nonverbal processes in the brain. Similarly, tachistoscopic presentation of visual stimuli contributed a great deal in exploring brain laterality.

Kimura (1973) has suggested that the functions of regions near the striate cortex, the major visual receptor in the hemispheres, are explored with the tachistoscopic tests, whereas the functions of the temporal lobes are explored with the help of auditory dichotic tests. The two taken together have contributed in deriving certain conclusions about the perceptual processes in the normal brain. Thus, Kimura (1973) concludes:

> ... the posterior part of the right hemisphere is involved in the direct analysis of information about the external environment. The parieto-occipital area is particularly critical for the kinds of behavior that are dependent on spatial relations, whereas the temporal region takes part in processing nonspatial stimuli such as melodic patterns and nonsense designs (p. 366).

The major controversy in the laterality issue has often centered around linguistic functions of the brain. In a very recent article in the American Psychologist, Gazzaniga (1983) asserts that in the normal brain, the right hemisphere remains nonlinguistic. It is only in cases of early damage to the critical areas of the left hemisphere that evidence of linguistic functions are found in the right hemisphere. This is attributed to the plasticity of the brain in early years of development. With regard to the behavioural and cognitive characteristics of the nonlinguistic right hemisphere, Gazzaniga (1983) maintains that the right hemisphere is passive and nonresponsive and the limits of its cognitive abilities (when noted in split-brain patients) consists of simple comprehensive skills reflected in simple matching-to-sample tasks. Levy (1983) agrees to the typical nonlinguistic nature of the right hemisphere (except in clinical cases). However, she does not agree with its limited cognitive abilities in cases where evidence is noted. Levy (1983) rightly concludes:

> ... the evidence is overpowering that it is active, responsive, highly intelligent, thinking, conscious, and fully human with respect to its cognitive depth and complexity. The metabolic costs of the right hemisphere are paid because its functions are of central importance. It is large because this is demanded by the intellectual capacities it possesses. It has human intelligence because it evolved as a human brain (p. 541).

The precise limits of the right hemisphere in relation to linguistic functions remains to be determined (Zaidel, 1983). Finn (1983) points out that the layman is baffled by the differing views of the experts in brain research. For some, the right hemisphere is nonresponsive and for some it is not. Others give equal importance to both hemispheres. and still others maintain the view of left hemisphere dominance. There is also the view that two consciousnesses are dancing in almost perfect unison in the normal mind. Thus, the split-brain research keeps on generating new questions about our normal brains.

As already mentioned, noninvasive techniques (dichotic listening, tachistoscopic presentation, EEG and blood flow) have contributed significantly to an understanding of hemispheric asymmetries in psychological functioning. The anatomical asymmetry has also been noted in the normal human brain. However, a great deal remains to be explored. Despite some of the limitations of such techniques, studies employing these noninvasive techniques are expected to continue to unravel parts of the lateralization puzzle. The question remains as to how exactly the brain combines the lateralized functions into a unitary whole-integrated behaviour. While the search for answers to the question continues, one must not forget that individuals differ from each other. As Levy (1980) points out:

> Certain current ideas that all individuals are biologically identical and susceptible to being molded into some "perfect" type is a denial of our mutual interdependencies .... we must value and encourage the differences among us that simultaneously offer the possibilities of self-fulfillment and a stable, noncoercive, and beneficient social organization (p. 374).

The above is a note of caution especially for educators who tend to expect a symmetrical pattern of learning in all their students. Biological inheritance is important in regulating their behaviour, nevertheless each child is unique in terms of his psychological functioning. The educational system often assumes a very important role in developing each learner's psychological capacities to his optimal potential. In case of biologically identical individuals, there would be no significant differences between them. Since this is definitely not the case, one standard curriculum for a particular grade level would not suit the needs of all students in that specific grade.

Hence, the next chapter will be devoted to the subject of educational instruction in relation to neurophysiological research. Based on findings in the preceding chapters, an attempt will be made to suggest possible changes in the present educational system to provide some degree of diversity in the methodology of teaching all students.

Chapter V

Educational Implications of Cerebral Asymmetry

Formal schooling remains an important element of our educational process. It is often viewed as a means to a better, more successful life in our complex modern world. Schools are here and are going to stay around, hence we educators have an important role in devising ways to make the best use of them. We are living in a highly competitive society, where each of us is struggling to get ahead without much regard for those around us. Western society has equated the good life with material consumption at the expense of individuality. The individual's behaviour is controlled and directed through the manipulation of stimuli. The primary concern is how to get people to do what others wish them to. In other words, individuals' lives are directed by others. In the process, one's individuality is lost and the person is deprived of his inner qualities such as imagination and invention. According to Ferguson (1980): "Human nature is neither good nor bad but open to continuous transformation and transcendence. It has only to discover itself." Thus, unless the opportunity and encouragement is given, the individual will not be able to unlock his immense mental capabilities. Even "natural" abilities such as learning to walk or talk need encouragement. If babies are kept in cribs in institutions with nothing to do but stare at the ceiling, they will walk and talk very late, if ever. These capacities have to be released in order to let them develop in interaction with other individual members in the environment. Controls from society have led to a feeling of insecurity among individuals which is reflected in the state of uncertainty rampant in today's society. Hence, energies of North American education should be directed towards creating an individual who is not only a self-centered "private" citizen but also a "public" citizen; as Beals (1981) comments,

> ... one who also is responsible to family, employer, and country, but who also is openly energetic and committed to an active involvement with his fellow man, one who feels a committment to and responsibility for the well-being of those around him, who defines his community in a universal sense rather than in terms of a specific geographic locale (p. 97-98).

Present day society is so heavily dominated by the mass production and perfection and duplication of products and services that these become the standard against which most things seem to be evaluated. This affects our educational system too. Education is directed towards fulfillment of the needs of a mechanized society rather than on an individual's needs. Learning outcomes are measured by the use of standardized tests. Anything which is not observable or measurable is discarded by the educational community. The phenomenon of stimulus-response, cause-effect chain of events in the learning process has become a part and parcel of the educational system in the present temporal society. In other words, the primary goal of education then is to educate individuals to function in a computerized society. In the process, the individual is deprived of his own autonomy; his immense capabilities remain locked within his brain. By now there is sufficient evidence that clearly indicates that human brains do not operate in simple S-R terms but engage in the discovery and creation of meaning. As Combs (1982) comments: "Awake or asleep our brains constantly seek to make sense of inner and outer experience. We are seekers and creators of meaning and the meanings we create determine the ways we behave." Thus, due to the complexity of each human brain, it is all the more important that we do not exercise our control over it. Each brain consisting of more than ten billion neurons and each with as many as fifty thousand synaptic connections is not an easy one to understand. Each has its own limited capacity to handle information at various stages in the course of development of a fully mature brain. Hence, too much pressure and demands put on the child in the school might hinder his total growth process. Young students are often expected to adjust and accommodate experiences beyond their capabilities. In an interview with Goleman, Ashley Montagu (1977) highlights the society's (particularly the school's) disrespect for children:

> ... We require them to follow rigid rules and, in schools particularly, we cause children to learn in ways which are the very antithesis of actual learning. We force them to remember and regurgitate large quantities of rote-remembered facts for certain rituals that we call "examinations", and those who have the highest disgorgitive capacities are considered the most intelligent and the most highly rewarded (p. 461).

Hence, it is high time the goals of education be reexamined. Children have been through enough of learning according to rules and rituals set by 'others'. Modified goals of education must be holistic and human with special emphasis upon helping its young people to actualize their innate mental potentialities. In other words, a comprehensive educational curriculum is needed to facilitate full development of mental capabilities in each child. The need for the development of a holistic approach in the educational system has been pointed out by investigators like Ornstein (1969, 1973, 1977) and Bogen (1975, 1977). Thus, the time for paradigm change has come. Kuhn (1962) has discussed at great length the idea of paradigms, closed systems of belief, scientific enquiry, and membership. A paradigm is a scheme for understanding and explaining certain aspects of reality. Although Kuhn (1962) used the term 'paradigm' in writing about science, it has been widely used in education and in other fields as well. The question of paradigm change or shift arises only when the old paradigm is unable to explain emerging new facts. Thus, a new paradigm emerges which does more than the old paradigm. It predicts more accurately and gives more room for new exploration. According to Kuhn (1962), this change in paradigm is sudden, occurring all at once. The new paradigm demands such a change that members of the old paradigm find it extremely difficult to adopt it. A few may never accept the new one. But gradually, the new paradigm receives recognition by a new generation of thinkers. Ferguson (1980) gives a list of the assumptions linked with the old and the new paradigms of education:

Assumptions of the old paradigm:

1. Emphasis on content, acquiring a body of "right" information, once and for all.
2. Learning as a product, a destination.
3. Hierarchical and authoritarian structure. Rewards conformity, discourages dissent.
4. Relatively rigid structure, prescribed curriculum.
5. ... emphasis on the "appropriate" ages for certain activities, age segregation. Compartmentalized.
6. Priority on performance.
7. Emphasis on external world. Inner experience often considered inappropriate in school setting.
8. Guessing and divergent thinking discouraged.
9. Emphasis on analytical, linear, left-brain thinking.
10. Labeling (remedial, gifted ...) which contributes to self-fulfilling prophecy.
11. Concern with norms.
12. Primary reliance on theoretical, abstract "book knowledge".
13. Classrooms designed for efficiency and convenience.
14. Bureaucratically determined, resistant to community input.

15. Education seen as a social necessity for a certain period of time, to inculcate minimum skills and train for a specific role.
16. Increasing reliance on technology (audiovisual equipment, computers ...) dehumanization.
17. Teacher imparts knowledge ...

Assumptions of the new paradigm:

1. Emphasis on learning how to learn, how to ask good questions, pay attention to the right things ...
2. Learning as a process ...
3. ... encourages autonomy.
4. Relatively flexible structure ...
5. Flexibility and integration of age groupings ...
6. Priority on self-image as the generator of performance.
7. Inner experience seen as context for learning. Use of imagery, storytelling ... "centering" exercises, and exploration of feelings encouraged.
8. Guessing and divergent thinking encouraged as part of the creative process.
9. Strives for whole-brain education ... fusion of the two processes (left-brain/right-brain) emphasized.
10. Labeling used only in minor prescriptive role and not as fixed evaluation (affecting) individual's educational career.
11. Concern with the individual's performance in terms of potential ...
12. Theoretical and abstract knowledge heavily complemented by experiment and experience ...
13. Concern for the environment of learning ...
14. Encourages community input, even community control.
15. Education seen as lifelong process ...
16. Appropriate technology, human relationships between teachers and learners of primary importance.
17. Teacher is learner, too, learning from students (p. 289-291).

From the above, the contradictory nature of the two paradigms of education becomes clear. Our western society is mostly governed by the game of winning/losing, associated with the old paradigm. The problem is that the educators who are involved in education policy making themselves have been educated in the old or traditional method. Many hold degrees from reputable universities where clear analytical, logical methods of thinking and problem-solving are the standard (MacKinnon, 1981). The logical, rational mode is so grounded in their thinking process that they cannot conceive of any other form of thinking. Thus, the educational curriculum tends to be loaded with a one-dimensional approach to learning. Reliance on verbal rationality has led many to believe that this is the only way to gain knowledge. As Maslow (1969) has rightly pointed out: "If the only tool you have is a hammer, you tend to treat everything as if it were a nail." The one-dimensional approach to learning and cognition is perpetuated by a literate culture consisting of educators of the old paradigm group. A classic example of this one-dimensional approach can be seen in the teaching of reading and writing in the early grades. Often children as well as their teachers in the primary grades experience problems. Since many primary grade children enter school without much reading or writing readiness, partly due to lengthy hours in front of the television set in their first five years of life, they experience difficulties in learning to read and write. Television's effect is mainly spatial and holistic, rather than just linguistic. This is contrary to the school expectations. In a nutshell, the present school system is mainly concerned with the verbal rational knowledge. Creative arts and music fall outside the domain of education for the old paradigm group. This occurs as a natural result of ignoring the "unconscious" side of the brain. As Blakeslee (1980) rightly comments:

> ... A sort of academic dream world has been created in which purely left-brain thinkers admire each other's "scholarliness". Many students who earn their Ph.D.'s become so habitually "left-brained" that they are unable to do anything but become "scholars" themselves. The system thus feeds itself and becomes more and more

> scholarly and less and less intuitive ... Most policy makers of primary and secondary education have doctor's degrees. The result is a selection process that eliminates thinkers from high positions in education. People who started out with a good intuitive feel for education often have it "educated out" of them in the process of getting their doctorates (p. 56-57).

This left-brain take-over of higher education affects the field of education right from the elementary level. Unfortunately it is much easier to talk about the drawbacks of the educational system than to do something about them. A real change in the system will only occur when the basic thinking of the whole educational establishment is changed. This can be achieved by creating an awareness of another intuitive mode of thinking in the society, especially in the educational community. It is an extremely difficult task to change their way of thinking overnight but certainly efforts toward it might be fruitful in the long run. Already a paradigm shift has occurred in education. A new emphasis on the holistic mode of thinking is gaining prominence in educational circles. Members of this new paradigm group believe in a holistic approach to education, where both verbal rationality and non-verbal intuitive capacity are given equal importance (Bogen, 1975, 1977; Ornstein, 1972). Ignoring either mode of thinking (verbal or non-verbal) is likely to lead to serious consequences both to the individual in particular and to society at large. Hence, to bring about a change in the current educational system, it is highly important for educational researchers to utilize findings from the field of brain research too. A multiplicity of operations, interpretations, and inferences characterize the complex reality constructed by the human brain. Hence, Sylwester et al. (1981) rightly feels that the educational and medical professions might get much closer by the end of the decade. Since both are concerned with the development and maintenance of a healthy brain and body, they need to interact much more and work together to achieve their common goal.

Recent startling research on brain growth might boost learning in schools. Epstein (1974a, b, 1978, 1979) based on a series of investigations concludes that brain growth is not a smooth, continuous process as assumed for a number of years. Instead the human brain develops in spurts that can be predicted by age. He uses the term "phrenoblysis" (a Greek word) for spurts of growth in brain and mind. "Phreno" means skull or mind, where "blysis" refers to a welling up of matter (1974a). Epstein began his study of brain growth by examining children's brains and investigating large numbers of children's autopsy reports. He plotted his findings on a graph together with children's ages. An analysis of his graph showed increases in brain growth during five chronological age intervals. The five periods of brain growth occurred primarily during the age intervals of three to ten months; two to four years; six to eight years; ten to twelve or thirteen; and fourteen to sixteen or seventeen years. The age intervals between any two growth periods are called plateau periods. The growth process is very slow during the plateau periods. Since it is a well accepted fact that mental growth is related to brain growth, these stages of brain growth deserve special attention in the field of education. Brain growth spurts have been noted in normal children from quite a number of countries (Epstein and Toepfer, Jr., 1978).

Brain growth spurts are accompanied by spurts in mental age and a number of intelligence-associated tests such as tests of memory, vocabulary, or language utilization. Also evidence indicates that brain growth spurts correlate in age with learning capacity. Data have confirmed a peak around the age of eleven years and a very low (near zero) value around age thirteen to thirteen-and-half years of age for "gf" - the fluid intelligence factor (Epstein and Toepfer, Jr., 1978). These brain growth stages do not imply an increase in the number of brain cells. By the age of eighteen months, the child's brain possesses the total number of cells found in an adult human brain. In other words, the total number of brain cells found in an adult human brain is developed by eighteen months of age (Epstein, 1974a, b, 1978, 1979; Epstein and Toepfer, Jr., 1978). During the next four growth periods the human brain increases in weight from 350 grams at birth to about 1400 grams at brain maturity around age 17. The increase in brain growth consists of two components. The first component is one that is proportional to increase in body size. The other refers to an increase in size of the brain cells. The cells shift and branch out to form new patterns. Thus, the complexity of the neural networks increases to handle incoming complex messages from various sense organs.

According to Epstein, brain growth periods may provide the biological basis for Piaget's (1969) four stages of cognitive development. There is no cognitive stage corresponding to the fifth and final brain growth period in Piaget's theory. However, Arlin (1975) has found a fifth Piagetian counterpart. Now the question arises: How can this knowledge of correlated spurts in brain and mental development be used in the field of education? The magnitude of the difference in growth between a plateau and a spurt may be as high as 500% (Hill, 1981). Vygotsky (1974) too noted critical periods of intellectual functioning during which rapid changes occurred in children. According to him, these critical periods occur during the first year of life, then around three years of age, and seven years of age. The age of thirteen is considered as a period of stable growth. After the age of seventeen there is no critical period of intellectual functioning. This is somewhat similar to the brain growth periods laid out by Epstein. To enhance learning in the schools, educators can take maximum benefit from the critical periods of brain and mind growth. Thus, children should be exposed to new problems requiring a higher level of thinking learnt in the preceding growth period. This can be achieved by practice. It reminds me of a simple example of maths. There is a saying that 'the more you practice the better you get at maths'. Stated simply, learning maths definitely implies consolidation of learned principles. Through appropriate guidance and instruction during critical and plateau periods, the child will not only learn more but will also pass through a smooth transition from one growth period to another. Thus, learning problems in a child may very often arise due to undue pressure on learning concepts for which his brain is not ready. This undue pressure at the wrong time may further lead to failure on the part of the child to deal with complex problems later when neural connections have developed. Each growth spurt period thus becomes extremely important for each child's learning process. Information that the child is ready to handle at a particular stage only should be presented. Epstein uses an example involving mathematics to explain the various stages of mental development. Cramer (1981) quotes Epstein:

> When a three or four-year old child first learns something about proportional reasoning, he might understand that the taller a person is, the older that person is. Around age six or seven, a child learns to cut a pie in two or three

> pieces - kids of that age can handle ratios of one-to-one and two-to-one. At approximately age ten or eleven, a child can be taught to handle more sophisticated problems involving ratios of seven-to-two or nine-to-four. Finally, if a child advances through these stages, he might develop late formal reasoning and be able to work with a number of proportions at once - the kind you might need when projecting how different voting groups might split to affect the outcome of an election (in Cramer, 1981, p. 18).

Thus, it can be seen that during critical age periods spurts of brain growth occur which in turn prepare the child for handling complex problems. The possible reason for failure to move to the next stage of cognitive development among a few children might be due to the pressures placed on them by the school system when they are not yet ready to comprehend. To avoid irreparable damage to the child's cognitive development, school education cannot afford to ingore the critical periods of brain growth. Children need to be exposed to new intellectual challenges during brain growth periods (Epstein, 1978, 1979). During the plateau periods, new concepts should not be presented to the child; rather as Epstein (1978) points out:

> The child should be exposed to large amounts of information and to a wide variety of direct experiences with nature, science, people, and work, all from the point of view of enlarging his direct experience base and avoiding much pressure for elaborate inferences about the natures and interrelationships of such experiences. [The plateau period could be utilized] ... for perfecting the long neglected memorization skills involved in the learning of poetry and songs, of the important facts of history, the facts of geography of the nation and of the whole earth, of health science facts, of legal facts ... and so forth ... we could also help children increase their skills in already initiated competencies (p. 364).

The school then assumes a very important role in helping the child to move from one cognitive stage to another as well as guiding him in broadening his experiences with practical knowledge. The level of learning in the child during the brain growth stages can be improved by appropriate stimulation in the schools. As Cramer (1981) comments: "At each stage of growth, movement to a higher level of reasoning is dependent on intensive stimulation that matches the current reasoning ability of the child." Thus, proper stimulation at the proper time is important in cognitive development of the child. During plateau periods, the child could be encouraged to spend his time in consolidating already learnt materials. Furthermore, Epstein (1979) observes that the child cannot handle tasks of the next stage until he reaches his next brain growth period. Webb (1974) observed that the difference between a child with an I.Q. of 160 and the child with an I.Q. of 100 is reflected in the speed at which the new cognitive abilities mature. The child with 160 I.Q. can master a particular cognitive task within a few months, whereas the child with an I.Q. of 100 can take two years. However, the child with the 160 I.Q. will not be able to move to problems requiring more complex reasoning until he enters the next growth spurt. Hence, cognitive development is dependent upon brain growth periods of the child no matter what his I.Q. (160 or 100).

It is interesting to note that two plateau periods, age 4 to 6, where most standard Head Start programs were targeted, and 12-14, when most students are in the first two years of junior high school, may be responsible for some problems educators have had (Hill, 1981). A comparative study of early childhood intervention programs was undertaken by Hunt (1975). He found that six programs that covered the age two- to four-years period were much more successful than the standard program. The age factor (growth period) becomes important in the effectiveness of such programs. The period of 12-14 years (characterized by slow brain growth) has much more negative effect on the later growth period if pressurised to handle increasingly complex input (not suited to the student's thinking capacity) (Epstein and Toepfer, Jr., 1978). It ultimately leads to a "turning off" stage and the student cannot develop new challenging cognitive skills. In other words, this last plateau period (12-14 years) before the onset of the last brain growth period (14-16+) is a rather sensitive one in terms of future high school education. Hence, the junior high school programs need to abandon the mass introduction of new cognitive materials to students who do not have such readiness and present cognitive information matched with the existing skill level of students. This would lead to a smooth transition to the next higher brain growth period.

To put the brain growth-spurt theory into practice in public schools, first of all a testing program is required to determine each child's cognitive development. This would help in grouping children by the kind of thinking of which they are capable and teachers can then match instruction accordingly. One accurate and fairly simple test has been developed by Michael Shayer (Cramer, 1981). This test consists of 25 questions that focus on a single mental behaviour and enables a teacher to determine the child's reasoning level. This kind of test has much more value than an I.Q. test. I.Q. measures only the capacity of the child. The teacher's concern would be to find out the way the child can best be reached at a given age level. This is the main theme of Epstein's view of education in the schools. The plateau periods could be utilized effectively without disrupting future development of cognitive ability. Epstein examined school curriculums in junior high schools and came to the conclusion that a large number of children remained left out of the learning process. The majority of materials demanded some kind of formal or abstract thinking which were suited to only 12 per cent of the children. As Epstein (in Cramer, 1981) remarks: "... the junior high school is the sick man of the educational system ... We have been asking kids to sit through classes using a language that contains concepts they can't possibly understand." Thus, a massive re-education program taking into account various levels of thinking abilities of children is essential both for parents and teachers.

Epstein himself remains active in the field of education in schools. Several years ago he got permission of the school in Poughkeepsie, N.Y. to try out an experiment on junior high school kids (in the midst of a plateau period). He took them out of school twice a week and let them work (in day care facilities and in nursing homes) at tasks that would aid them to consolidate their education and emotional skills (Cramer, 1981). Though the experiment was not a controlled scientific one, the effort was very successful. As Epstein noted: "We were able to reduce the mismatch of what the kids were asked to do in school and what they were able to assimilate, and we were able to reinforce what they had learned with their work twice a week." (in Cramer, 1981). Epstein has also been involved in teacher-training courses in Lexington and Needham, Mass. These courses were designed to create an awareness of the brain growth theory and the concept of cognitive level matching among teachers. Response from school authorities in Needham and Lexington has been very encouraging. As an assistant superintendent for curriculum in Lexington noted: "Now teachers can be aware that some kids who are bright about some things and slow at others simply haven't made a transition. Teachers can observe student behavior and tailor their classroom material and homework assignments to fit the needs of particular kids" (in Cramer, 1981). In summing up, it is clear that school curricula can definitely help or hinder cognitive development in children. The teacher's efforts together with the appropriate learning materials are crucial to an optimum level of learning in children. Hence, a great deal of effort is needed on the part of educators in order to facilitate learning in the school.

The field of split-brain research has led to a new direction in education. Tremendous advances in this field have shed new light on the understanding of complex psychological functions. Stated most simply, it is now clear that the brain is double, in the sense that each half-brain can function independently in a manner of its own.

Two major implications can be drawn from split-brain research with regard to higher psychological functions. Firstly the two hemispheres are specialized for different functions — the left is responsible for logical, verbal abilities and the right for visuospatial, creative abilities. Secondly, the two hemispheres utilize two different mechanisms of processing stimuli. Each makes its own contribution to understanding the mechanisms of higher intellectual abilities. However, in the author's opinion, the right hemisphere's mode of processing stimuli needs more immediate consideration in the field of education. As Bogen (1975) rightly points out, the two hemipheres employ two different "sets of information-processing rules" to process information.

The dual nature of higher intellectual abilities had in fact been recognized long before research in the split-brain was even undertaken.

Historically, some philosophers and students of the mind have shown a tendency to divide intellectual functions into two classes. As Sri Aurobindo had rightly emphasized in 1910, the education of both classes of intellectual functions in the child is important. In the words of Sri Aurobindo, a yogic philosopher (1977):

> The intellect is an organ composed of several groups of functions, divisible into two important classes, the functions and faculties of the right hand, the functions and faculties of the left. The faculties of the right [sic] hand are comprehensive, creative and synthetic; the faculties of the left [sic] hand critical and analytic ... the left limits itself to ascertained truth, the right grasps that which is still elusive or unascertained. Both are essential to the completeness of the human reason. These important functions of the machine have all to be raised to their highest and finest working-power, if the education of the child is not to be imperfect and one-sided (in Bogen, 1977, p. 134 and 136).

On an analysis of the above, it becomes apparent that the two classes of functions mentioned by Aurobindo are associated with the two hemispheres of the brain in modern terms. Thus, even though knowledge of the two hemispheres of the brain was not available, duality of mental faculties was recognized. Some western thinkers have also talked of two parts of mental organization, for example: rational versus intuitive, explicit versus implicit, analytic versus synthetic. Although these terms are varied, they have a common thread running through them. They all refer to different processes of the two cerebral hemispheres. Further, dichotomies of mental organization have been listed by Springer and Deutsch (1981):

Dichotomies

Intellect	Intuition
Convergent	Divergent
Intellectual	Sensuous
Deductive	Imaginative
Rational	Metaphoric
Vertical	Horizontal
Discrete	Continuous
Abstract	Concrete
Realistic	Impulsive
Directed	Free
Differential	Existential
Sequential	Multiple
Historical	Timeless
Analytic	Holistic
Explicit	Tacit
Objective	Subjective
Successive	Simultaneous

Evidence indicates that only the left hemisphere of the brain is capable of communicating its thoughts in words. There is, however, a difference between thoughts expressed in a natural language and thoughts not thus expressed which nevertheless are propositional in form. A thought is propositional in form just in case the structure of the thought is analogous to that of a sentence, e.g., Tony is tall. Because of this we can say that such thoughts are linguistic in form but the language in which it occurs is the "language of thought". This is the Cognitivist point of view (Fodor, 1980).

Some theorists (Blakeslee, 1980) could be interpreted as holding that the right hemisphere has its own separate chain of thoughts neither expressed in the words of a natural language nor propositional in form. Though these non-propositional thoughts are an important part of our personality and abilities, they continue to be ignored and misunderstood because they are so difficult to translate into words. The left hemisphere receives all the attention because of its linguistic domination. However, when we look closely at the physical appearance of the human brain, a clear-cut double brain consisting of two mirror-image hemispheres joined by several bundles of nerve fibers becomes visible. Hence, it becomes extremely difficult to ignore one half of the brain just because it lacks in verbal ability. There is no justified reason to believe that concrete, analogic, synthetic and spatial functions of the right hemisphere are inferior to the abstract, analytic and temporal functions of the left.

Of course, split-brain research has strongly suggested that the functions of the right side of the brain involve non-propositional 'image processing'. [A dissenter to this view is Pylyshyn (1981).] These images explain the fact that the right hemisphere can put together the pieces of a jigsaw puzzle while the left remains puzzled. The right hemisphere gains a tremendous advantage over the left in dealing with complex visual pattern tasks. The same holds true for the left hemisphere with regard to verbally oriented tasks. In a normal person, there is constant shift from one mode of thinking to the other. There is no single mode of thinking present in an individual. The demands of the problem switch on one mode of thinking which becomes dominant and the other relatively less active. There is no such thing as a complete "on" and "off" switch in the brain for a particular mode of thinking in the normal person. The two hemispheres work in a coordinated manner, the difference is of dominance. Due to the verbal dominance of the left, it gains much more popularity than it really deserves. The right brain outperforms on tasks that require "a feel for it". For example, it becomes almost impossible to describe verbally the configuration of lines used to draw a cube on a piece of paper. The impossibility of verbalizing such concepts is clearly seen in the split-brain patient's futile attempts at drawing with his right hand (controlled by the left hemisphere). The effectiveness of the right hemisphere at drawing is noted in a comparative set of drawings given in Fig. 5.1 (Blakeslee, 1980). The right hemisphere is also very efficient at recognizing the whole from disguised or fragmented parts. The split-brain patient using his left hand has no difficulty in associating the parts with the complete whole. The right hand, however, can only make the most obvious associations (Blakeslee, 1980).

Stated simply, there are strikingly different styles and strategies for information processing in the two hemispheres (Bogen, 1977). This is clear for musical and dancing abilities: no matter how much verbal instructions are given, these cannot be mastered without the right hemisphere's help. Amateur musicians show a right hemisphere dominance for musical stimuli, whereas professional musicians indicate either a left hemisphere dominance or no dominance at all (Gordon, 1983). What of 'intuitive' abilities? On the Cognitivist hypothesis, these may be essentially no different in form of processing than other explicitly cognitive activities: they are simply faster and unconscious. On the dual process hypothesis, intuitive abilities require a different mode of processing residing characteristically in the right hemisphere. Which of the two hypothesis is right is far from being resolved at the present time. For the present thesis however, the author is in support of the dual process paradigm.

Often we have read about well noted scientists who have experienced a sudden flash of the solution to a problem while not

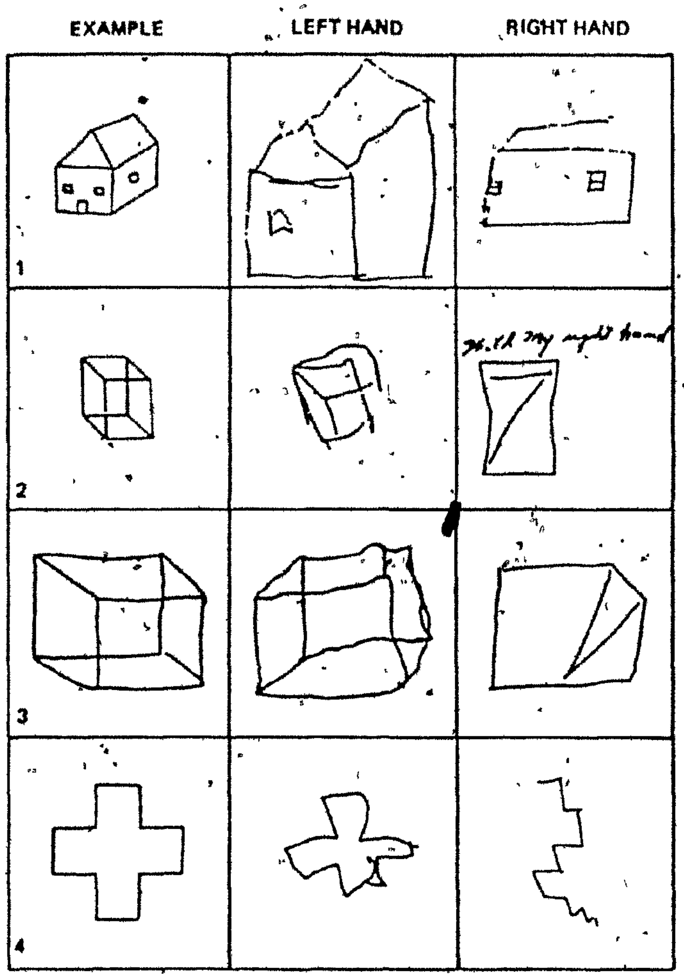


Fig. 5.1

(From Blakeslee, 1980)

even working at it. Most creative breakthroughs, even in mathematics, are a result of this intuitive leap that are later carefully analyzed in logical terms by looking at the result. Max Planck, the father of quantum theory, wrote in his autobiography that the creative scientist must possess: "... a vivid intuitive imagination for new ideas not generated by deduction, but by artistically creative imagination" (in Koestler, 1964, p. 147). Similarly, Einstein himself noted (in Rosen, 1972):

> **... I rarely think in words at all. A thought comes and I may try to express it in words afterward ... . the words or the language as they are written or spoken do not seem to play any role in my mechanism of thought ... The elements are, in my case, of visual and some of muscular type ... Conventional words or other signs have to be sought for laboriously only in the secondary stage when the mentioned associative play is sufficiently established and can be reproduced at will (p. 684).**

The above two quotes clearly indicate an interplay between the two modes of processing in scientific inventions too. Though western intellectual pursuits appear to be "verbal, abstract, rational" left hemispheric functions, "preverbal, concrete" right hemispheric functions do play a crucial part in scientific creativity. Even most of our ordinary activities employ both modes of cognitive processing (Galin and Ornstein, 1972). The two complement each other but do not readily substitute for each other. For example, complex spatial relationships can be processed in words but these can be processed more effectively using visual-kinesthetic images. The interplay of the two cognitive modes can be seen in our daily lives. Let us take an example of a tourist in Halifax. He wants to go to a particular place and asks for directions. What happens initially is that we begin with words like "take a right turn, go two blocks, then turn left" and then unknowingly fall back on gesturing with our hands. This situation might be familiar to most of us. Galin and Ornstein (1972) further point out that processing stimuli through inappropriate cognitive modes may not only be less efficient but may actually interfere with processing through the other mode. Paredes and Hepburn (1976) too have emphasized intercommunication between the two cognitive modes while working at the solution to a problem. According to these two investigators, a solution to a problem does not depend upon 'either'/'or' one type of cognitive mode over the other. There can be several back and forth switches before a final solution is worked out.

Sometimes the split-brain patient finds himself in a problematic situation when both hemispheres try to take control. In one case, a split-brain patient was asked to do a block arrangement test with his right hand. The patient's left hand was constantly trying to help his right hand. After the experimenter stopped him twice, he finally sat on his left hand. After repeated frustration, he was allowed to use both his hands. Again, the battle started in which the two hands continued to fight to gain control over one another (Blakeslee, 1980). However, the two cognitive modes develop a working relationship in the normal person and conflicts do not arise. In any case, the left hemisphere can assert its dominance over the entire body if it so desires. Further, in tasks requiring immediate response, control passes to the hemisphere that is first to provide a solution. When both hemispheres function in equal partnership, learning ecology is characterized by: (i) higher feelings of self-confidence, self-esteem, and compassion; (ii) wider exploration of traditional content subjects and skills; (iii) higher levels of creative invention in content and skills (Samples, 1977). He labels left hemispheric functions as 'rational' and right hemispheric functions as 'metaphoric'. A distinction between the two is beautifully made by Samples (1977):

> Progress in rational (left-hemisphere) functions leads to the reduction of variables and higher tendencies to separate thought qualities. Progress in metaphoric (right-hemisphere) functions leads to the proliferation of variables and higher tendencies to synthesize thought qualities. The rational processes are linear, the metaphoric processes cyclical. Rational processes are exclusive while metaphoric processes are inclusive (p. 690).

Other studies by Levy (1968, 1974) suggest that the style of processing used by the right hemisphere is rapid, complete, whole-pattern, spatial and perceptual. She also noted that the two different ways of processing (left-hemispheric and right-hemispheric) tended to interfere with one another, inhibiting maximal performance. Thus, it appears that both hemispheres of the brain employ high-level cognitive modes, each different, but both involving thinking, reasoning, and complex mental functioning. The two hemispheres might support, complement, and even inhibit each other sometimes. Experiments by Kinsbourne (in Saks, 1979) indicate that we are capable of doing several different tasks at once sometimes, but not always. In one experiment, subjects were taught to balance a small metal rod on their index finger. After they had gained mastery over the task, they were asked to repeat a series of test phrases while balancing the rod on the left index finger first, and then while balancing on the right index finger. He found that the performance of the subject's left hand was not affected by repetition of the phrases. However, balancing performance on the right hand deteriorated drastically while repeating the test phrases. The poor performance was due to the same (left) hemisphere being involved both in speaking as well as balancing the rod on the right index finger. Attempts to solve a geometrical problem as well as watch a football game on the television is another example in which performance would be drastically reduced.

The specialization of the two hemispheres in two different tasks (verbal and nonverbal) has been well established both from split-brain studies as well as studies of normal people. Kumar (1973) studied the nature of the conceptual process in the right hemisphere of commissurotomy patients. A concept formation test consisting of 16 wooden blocks varying in shape, height, width and weight was developed for lateralized tactual presentation to the patient's right or left hand. The patient was asked to sort these blocks into four categories of height-width only: tall-wide; tall-narrow, short-wide and short-narrow. The right hemisphere (left hand) successfully completed the task whereas the left hemisphere (right hand) could not conceptualize the required categories and categorized the blocks according to their shapes. The performance of the two hemispheres is clearly seen in Fig. 5.2. In another study of normals, the specialized functions of the two hemispheres was noted. The brain's electrical activity from both cerebral hemispheres was recorded while subjects were engaged in verbal and spatial tasks Ornstein, 1977). An electrode helmet was placed over the subject's head, as given in Fig. 5.3. Findings indicated that when a subject is writing, more alpha rhythm appears in the right hemisphere than in the left, and while arranging blocks, more alpha is noted in the left hemisphere than in the right (Fig. 5.4). Thus the hemisphere not involved

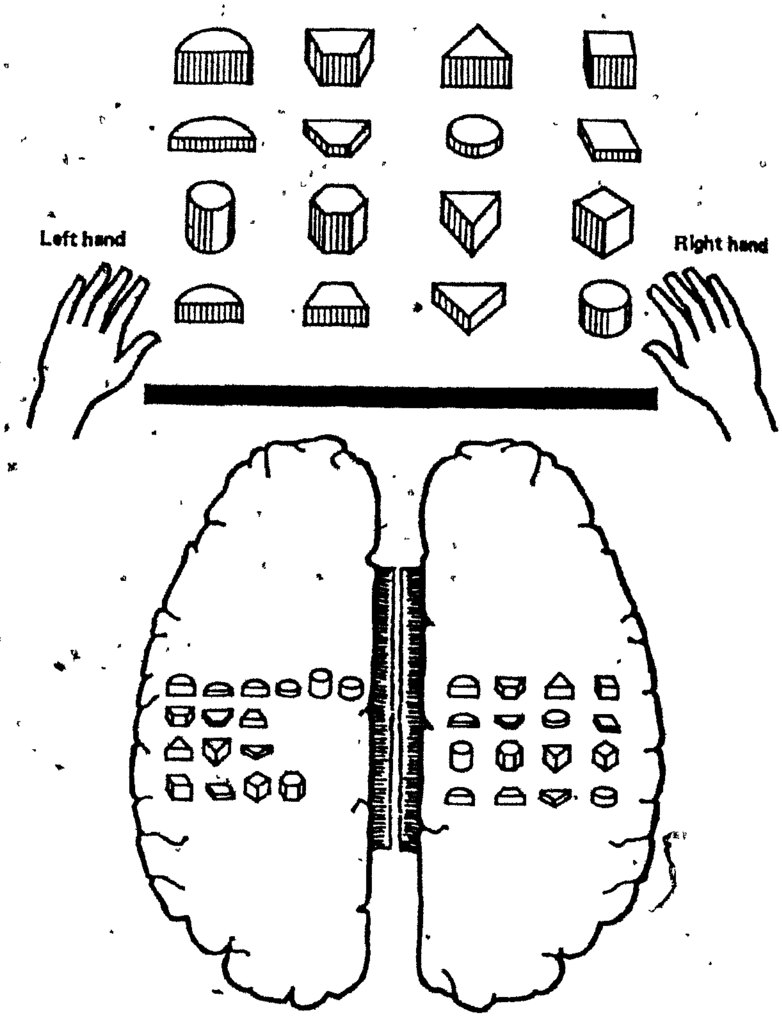


Fig. 5.2

(From Kumar, 1973)

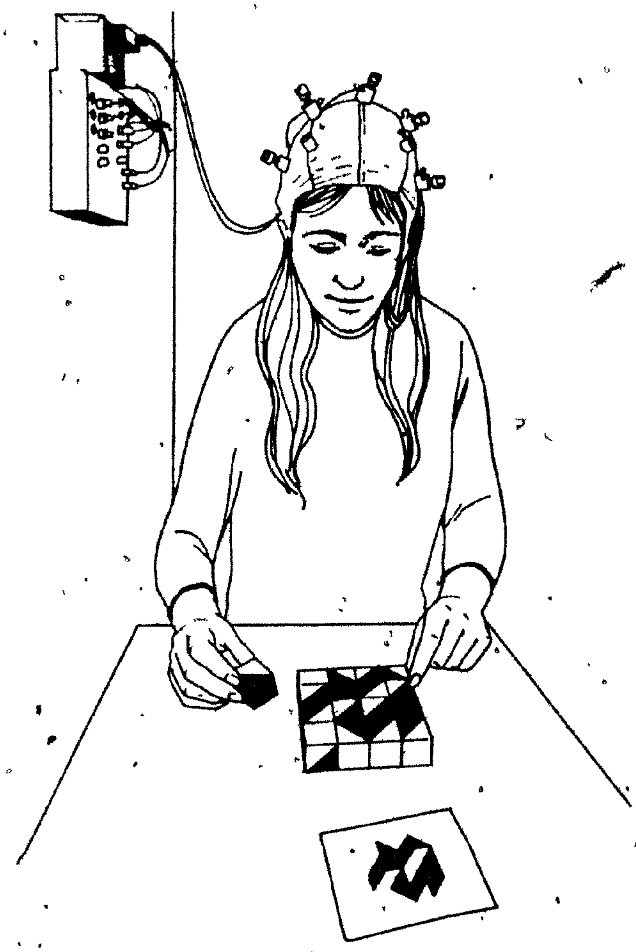
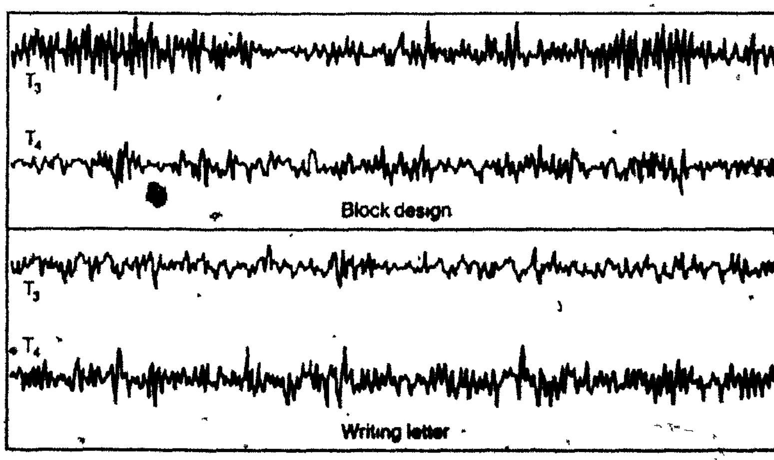


Fig. 5.3

(From Ornstein, 1977)

T_3 (left hemisphere)



T_4 (right hemisphere)

Fig. 5.4

(From Ornstein, 1977)

in the task was "turned off". Alpha rhythm is taken conventionally as a sign of this "turn off". Lateralized functions of the two hemispheres are further supported by results from another investigation of the two cognitive modes (Kocel et al., 1972). They attempted to relate lateral eye movements to cognitive processing. The direction of lateral eye movement was strongly modified by the demands of the cognitive task. Verbal and mathematical (left hemisphere) questions elicited more movements to the right as compared to spatial and musical (right hemisphere) questions. Hence, despite the feeling of being "one person", our brain has two distinct hemispheres, each with its own way of processing information, each with its own way of interpreting external reality. The two hemispheres are mediated and integrated by the connecting thick bundle of nerve fibers, the corpus callosum. As Edwards (1979) summarizes:

> We have learned that the two hemispheres can work together in a number of ways. Sometimes they cooperate with each half contributing its special abilities and taking on the particular part of the task that is suited to its mode of information prcessing. At other times, the hemisphere can work singly; with one half "on", the other half more or less "off" ... may also conflict, one half attempting to do what the other half "knows" it can do better. Furthermore, it may be that each hemisphere has a way of keeping knowledge from the other hemisphere. It may be, as the saying goes, that the right hand truly does not know what the left hand is doing (p. 31-32).

By now there is sufficient evidence that there are two ways of processing information and that each of the hemispheres is specialized to a certain degree in certain functions. As, for example, reading, writing and arithmetic belong to the left hemisphere largely and imaging, creativity and music mainly belong to the right hemisphere. The reason I am including the words "largely" or "mainly" is that most of these activities require some degree of cooperation from its partner. The classification into a left hemispheric or right hemispheric activity reflects a domination of one or the other hemisphere. In other words, it becomes a matter of who gets the lion's share. The different characteristics of processing by the two hemispheres are clearly outlined by Edwards (1979). What distinguishes hemispheric specialization is not so much certain types of stimuli (example, words for the left and faces for the right), but the mode (verbal or nonverbal) through which the stimulus is processed (Bogen, 1975; Levy et al., 1972; Wittrock, 1978). It is the way of processing the stimulus that is the distinguishing feature between the two hemispheres.

The use of the left hemisphere for analytical and sequential thinking is continuously emphasized by the intellectual community in dealing with reality. No doubt our rational analysis has led mankind to survive and grow, but in the process also created problems for contemporary civilization. Problems related to population, pollution and medicine are the result of linear thought processes. Solutions to these are constantly advocated but are mostly linear incomplete answers. Often more problems are created by the solutions. For example, technological methods of food production have eliminated starvation as a major problem for most of the world but have made obesity a common problem in many western countries. Hence, the linear mode alone has not been very successful in solving complex problems of our highly technological society. A shift from the linear processes (which are more individualized) to holistically and 'other' oriented relationships can provide solutions to complex, collective problems (Ornstein, 1976). This obviously involves a development of the right hemispheric mode of processing information. Until recently, the mainstream in western culture has largely remained dissociated from holistic approaches (right hemispheric mode of processing). This is clearly reflected in our educational systems that provide a lopsided education with emphasis on 'basics'. To encourage right hemispheric mode of processing in the school setting, we do need a more comprehensive knowledge and understanding of its capacities.

There is considerable evidence indicating the right hemisphere's superiority in visuospatial abilities from studies of normal and clinical subject populations (e.g. cases of unilateral damage and split-brain patients). However, the nature of its superiority is still controversial due to procedural differences between different studies (Young and Ratcliff, 1983). Young and Ratcliff (1983) suggest an approach for researchers to demonstrate, within a single experiment, tasks or stimuli differing on only one factor which leads to the presence or absence of right hemisphere superiorities. This technique utilizing hemisphere X task or hemisphere X stimulus design has not been much used. Umilta et al. (1978) investigated laterality effects using simple and complex geometrical designs and nonsense patterns on normal right-handed subjects. The right hemisphere superiority was noted only for complex geometrical patterns. The left was superior for simple geometrical patterns and nonsense figures. These investigators concluded that the left hemisphere utilized single feature discrimination of stimuli whereas the right hemisphere used a spatial strategy. Another study by Young and Ellis (1979) reflected the superiority of the right hemisphere for the processing of complex spatial information.

A large number of studies investigating the ability of right hemisphere in perception have used 'face' as the stimulus. Ellis (1983) after a review of the literature in this area provides a simple flow-diagram model of the processes underlying face perception (Fig. 5.5). Ellis (1983) comments: "It indicates a right hemisphere superiority for classifying incoming patterns as faces establishing internal representations for novel faces; and perceiving emotional expression in faces." There is no difference between the two hemispheres for face structure analysis. The left utilizes a serial process involving special analysis of the features of the face. The right, on the other hand, uses a more holistic analysis in which spatial relationships between features are emphasized. Familiarity or unfamiliarity of the face can be equally identified by either hemisphere. Both hemispheres of the two split-brain patients were found to be equipotential in selecting pictures of patients' self, relatives, public figures and historical characters (Sperry et al., 1979). Despite some degree of controversy in the field, it can be safely concluded that the right hemisphere does have the slight advantage in certain aspects of face processing. To assign a complete dominance of the right hemisphere in face processing would go against the integrated functioning of the two cerebral hemispheres in the normal person. As Gazzaniga and Le Doux (1978) assert, the mind is integrated rather than divided into two entities. According to them, the two hemispheres differ in degrees of expertise in a particular process. Neither is exclusively specialized in a particular function. The two hemispheres perform different parts of an integrated performance (Broadbent, 1974). Therefore, it can be said that the right hemisphere plays the major part and the left hemisphere the minor part in face processing.

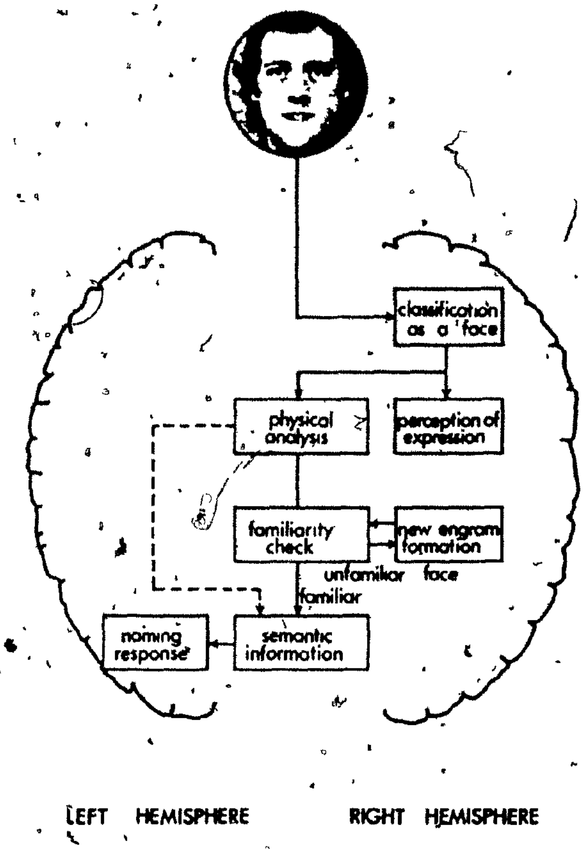


Fig. 5.5

(From Ellis, 1983)

Music is another area of specialty of the right hemisphere. The acceptance of a left hemisphere specialization for language and right hemisphere dominance for music has gained popularity (Gordon, 1983). This is best illustrated in an advertisement by a major stereo headphone manufacturer:

> Give your right hemisphere a break! While your left hemisphere goes out every day and discusses, analyzes, or manipulates reality for the sake of earning a living, the right hemisphere nags and complains about being dragged along on mundane errands. Stop that right brain ennui!! Give the right side of your brain its favourite treat - music (in Gordon, 1983, p. 65).

On an examination of the literature in the field, it is evident that such a clearcut lateralization does not exist. It becomes again a matter of major and minor input of the two hemispheres in music. Most of the experimental work on lateralization of music has utilized the dichotic listening technique in which two auditory stimuli are presented simultaneously, one to each ear. This leads to a binaural competition that has been maintained to functionally block the homolateral neural pathways to the hemisphere in favour of the contralateral neural pathways. Hence, a dominance of left ear would imply a right hemisphere superiority; right ear dominance, left hemisphere superiority; and no ear dominance, no hemispheric superiority. The dominance of contralateral pathways was originally noted by Kimura (1961a). She noted greater right ear deficits (right auditory perception) as a result of left temporal lobe damage. Subjects without brain damage also showed consistent right ear dominances for dichotically-presented digits (Kimura, 1961b). Soon this technique was used for presenting musical stimuli. A left-ear superiority on a test of dichotic melody recognition was interpreted as a left hemisphere predominance in verbal stimuli processing and the right hemisphere predominance in nonverbal stimuli processing (Kimura, 1964). To gain further clarity of the terms "verbal" and "nonverbal", Kimura (1967) emphasized the need for further research to find out stimulus characteristics that are associated with either right- or left-ear superiority. Though the majority of musical tasks used in dichotic-listening studies demonstrated a right hemisphere superiority (dominance), some musical stimuli have led to either a left hemisphere dominance or no dominance at all (Gordon, 1983).

In one study, two different letter sequences were sung to two different melodies by two different singers and the subject was asked to recall the letter sequence or the melody or the singer (Bartholomeus, 1974). Findings indicated no significant difference between ears in singer recognition, but significant right-ear (left hemisphere) superiority for letter sequence recall and significant left-ear (right hemisphere) superiority for melody recognition. Since the same auditory stimuli were presented to the same subjects on all three tasks, findings indicated that laterality effects in audition are not entirely determined by stimulus characteristics but are also dependent on task requirements. In other words, the same stimulus could produce either a left or a right hemisphere dominance depending upon its task requirements. The two hemispheres were able to process information simultaneously and each was capable of control, depending on the one most needed to complete the task. This principle of dynamic hemispheric participation was also observed in patients with complete cerebral commissurotomy for a series of visual stimuli split down the middle and then rejoined in the middle to make composite right-left chimeras. When these recombined (chimeric) figures were flashed to the patient while his gaze was centered, each disconnected hemisphere completed its pattern-half into a complete figure. The left hemisphere dominated when a verbal response was required while the right took the lead when a simple recognition by pointing was required. Hence, we come down to the same conclusion that the task requirements do have a major input in processing the same stimulus.

There have also been controversies surrounding hemispheric dominance in musicians and non-musicians. Earlier the major role of the right hemisphere in non-musicians had been emphasized. But this has not been found to be true for the musicians group. It is pointed out that since musicians are trained to use step-by-step analytic procedures in learning music, their left hemisphere seems to dominate in processing musical stimuli. However, sufficient evidence to support the above is still lacking (Gordon, 1983). Further, the question of individual hemispheric dominance has been taken into account. Those who are more inclined to use their left hemisphere would show a left hemisphere dominance for a majority of tasks as compared to those more inclined to use their right hemisphere. But here again the statement lacks empirical evidence. It becomes a matter of either an individual's own hemispheric dominance that is important or the differential specialization of the two hemispheres that is more important in processing any information. To me, evidence so far gives more weight to the specialization of the two hemispheres in different functions (with a major and minor role, of course, in order to maintain integrity of the mind). In a review of various findings, Gordon (1983) comes to the conclusion:

> ... it is inappropriate to lateralise music to any one hemisphere. Dominance for music is dependent both on the task to be performed and the mix of specialised skills needed from the right and left hemispheres ... it is relevant to ask whether the hemispheric bias of musicians is left dominant as suggested by their training; right dominant as suggested by the apparent (developmental) location of music assessed by most passive listening tasks; or either right or left ... Considerable work is still needed to address the problem of how hemisphere-biased individuals interact with hemispheric-biased stimuli and whether these biases can be changed (p. 81-82).

Until recently, language capabilities had been largely assigned to the left hemisphere. The consensus that emerged from clinical as well as split-brain patient studies was that the left hemisphere was responsible for linguistic abilities in right handed people. Now, researchers are accepting the fact that the right hemisphere also has some linguistic capabilities. Searleman (1977, 1983) attempts to update the evidence for right hemisphere language skills from brain damaged as well as normal subjects. The functional plasticity of the brain in the first few years of life has been noted (Basser, 1962; Zangwill, 1960). Basser maintains that functional plasticity continues to occur until puberty. Other researchers like Krashen (1973) believe that language lateralization is completed by the age of 5 years. To avoid such controversies, more valuable information about the right hemisphere's linguistic capabilities can be obtained from cases of left hemispherectomy in adults as well as from split-brain patients. After observations of patients with left hemispherectomy, Smith (1966) noted that immediately after the operation, patients were able to respond nonverbally to spoken command, but any form of expressive language was impossible to perform. Going through the literature on language skills of the right hemisphere, it becomes evident that the ability to produce speech is usually much more lateralized than the ability to comprehend speech. The right hemisphere is capable of matching objects with their verbal description (Nebes and Sperry, 1971). A commissurotomy patient, when asked to blindly pick out an object with his left hand that 'makes things look bigger', picked out a magnifying glass. To check whether cross-cuing (Gazzaniga, 1970) had occurred, the patient was then asked to guess what his left hand had picked out and he replied a "telescope'.

Thus far, there is no convincing evidence that the right hemisphere can produce speech. Some split-brain patients, however, can spell very simple words by tactually manipulating letters with their left hands (Gazzaniga, 1970; Gazzaniga et al., 1977; Gazzaniga and Le Doux, 1978; Levy et al., 1971; Nebes and Sperry, 1971). Some can even write the word just finished with the left hand (Nebes, 1974). Left hemisphere interference has also been noted when the right is engaged in performing a task. In one case, a commissurotomy patient, L.B., was given a pipe to feel with his left hand first and then asked to write the name of the object with the same hand. The patient started to write 'PI' but then his left hemisphere took the control and he wrote the word 'PENCIL'. Soon after, he scratched out the last four letters and verbally reported that he did not know what the object was (Levy et al., 1971). When asked to draw the object with the left hand, L.B. was successful in drawing a pipe. It is seen that the right hemispheres of hemispherectomy and split-brain patients possess some ability for comprehension of written and particularly spoken language. Searleman (1983), however, cautions not to generalize these findings to the normal population because many of the patients studied had suffered early damage to the left hemisphere. Due to functional plasticity, these patients might have developed linguistic abilities in both hemispheres to a greater extent than a normal person.

A number of studies have been conducted on normals to determine the degree and direction of language lateralization using the technique of dichotic listening and tachistoscopic presentation of verbal stimuli to visual fields. Here also findings are not consistent, though a few of them do provide clear evidence for language comprehension abilities in the normal right hemisphere. The right hemisphere was found to be superior to the left for the initial stages of letter processing. When perceptually degraded letters were presented, subjects were more efficient at extracting the relevant features of the letters with their right hemisphere-LVF (Hellige and Webster, 1979). Another study by Bryden and Allard (1976), indicated an increased proficiency of the right hemisphere in 'preprocessing' verbal stimuli as compared to the left. In their experiment, subjects were asked to name laterally presented letters printed in 10 kinds of typefaces. Results indicated that perceptually difficult typefaces led to right hemisphere (LVF) superiorities. Based on their findings, it was postulated that the right hemisphere supercedes the left at holistic processing operations even when a verbal response is expected.

The right hemisphere has been considered as a global processor as opposed to an analytic processor (left hemisphere) by many researchers

(Levy, 1974; Martin, 1979; Nebes, 1974; Semmes, 1968). As Levy (1974) comments: "The right hemisphere perceives form, the left hemisphere detail ... The right hemisphere lacks a phonological analyser; the left hemisphere lacks a gestalt synthesiser." The global or gestalten approach to stimuli processing has been found useful in the early stages of learning to read. As Pirozzolo (1978), while summing up the role of the two hemispheres in reading, remarked: "... the right hemisphere may be indispensable in beginning reading when children are learning to recognize letters and words as gestalts." To sum up, the available evidence both from split-brain and normal studies points toward a clear development of language comprehension abilities in the right hemisphere. Language production capabilities of the right hemisphere in normals are still in their early stages of investigation due to lack of appropriate non-clinical techniques for investigation. In cases of left hemispherectomy patients are sometimes able to produce over-learned, automatic phrases (Smith, 1966). For the present, it can safely be concluded that the right hemisphere is not devoid of linguistic capabilities and does possess to some extent ability for language comprehension. Evaluation of the full extent of right hemispheric language skills is still in its infancy. As Searleman (1983) has rightly said:

> A major limiting factor in trying to evaluate the full extent of right hemisphere linguistic abilities, in both clinical and normal populations, may be the left hemisphere's tendency to suppress or interfere with right hemisphere linguistic activities. Perhaps the reason why the right hemisphere is generally more successful at language perception as opposed to production is because the left hemisphere is more successful at inhibiting the latter activities. If the left hemisphere is free to function and exert control, then it may well be impossible to ever accurately assess the full extent of the right hemisphere's linguistic capabilities (p. 105).

A number of studies in brain research point out that boys and girls think differently. The first clue to brain differences between the sexes came from observations of male and female infants. From birth, females tend to be more sensitive to sounds, more proficient at fine motor tasks and learn to speak at an earlier age than boys. Girls are also more attentive to social contexts than boys. Girls surpass boys in language skills at an early age and this advantage remains throughout life (Harris, 1978; Restak, 1981; Saks, 1979). Boys generally exhibit early visual superiority and are clumsier at fine motor performance. However, they are better than girls at tasks involving total body coordination. Boys respond to nonsocial stimuli as quickly as they do to social stimuli (Restak, 1981). Women have been found to be inferior to men in spatial ability and appear to be more confused about left and right than men are (Harris, 1978). Women show a lesser degree of cerebral lateralization (Bryden, 1982; McGlone, 1977, 1978). McGlone (1978) administered a battery of psychological tests, including the WAIS and an aphasia test, to 85 right-handed adults with damage to the left or right side of the brain. She found that left-hemisphere damage in men impaired verbal I.Q. more than nonverbal I.Q., whereas right-hemisphere damage lowered nonverbal performance relative to verbal. Women, on the other hand showed no effect of side of lesion. Their verbal and nonverbal I.Q. scores were not significantly different for damage to the left or the right side of the brain. Thus, lateralization was observed in the males and not in females. Levy (1974), too, has noted that bilateral representation of language-related processes is more common in women than in men. In general, there is a greater lateralization trend in adult males for verbal tasks in auditory and visual studies. With regard to nonverbal tasks, there is some evidence for greater lateralization in females on auditory tasks and a weak to greater lateralization in males on visual tasks (Bryden, 1982).

Significant sex-related differences have been noted in children with regard to spatial functions by Witelson (1974, 1976). She devised a test of tactual perception known as "dichaptic" stimulation test for using with children. In this testing situation (Fig. 5.6), subjects were first asked to palpate two hidden nonsense shapes simultaneously for 10 seconds using the index and middle fingers and then select the correct two shapes from a group of six visually presented alternatives. The test was administered to 200 right-handed boys and girls ranging in age from 6 to 13 years. Her results indicated that the right hemisphere was more specialized than the left for the processing of spatial information in boys. In girls, a bilateral representation was found at least until adolescence. The clearer lateralization for spatial information in boys was also observed in most of the adult studies (Bryden, 1982). Thus, the consensus for a greater degree of lateralization in males seems to emerge with regard to verbal as well as nonverbal stimuli.

Additional evidence for sex-related differences comes from brain anatomy studies (Geschwind and Levitsky, 1968; Wada et al., 1975; Witelson and Pallie, 1973). The left temporal planum tends to be larger than the right. Wada et al. (1975) observed that the left planum was larger in adult males than in adult females and more male infants than female infants showed the reverse pattern of asymmetry. In contrast, Witelson and Pallie (1973) observed slightly greater asymmetry

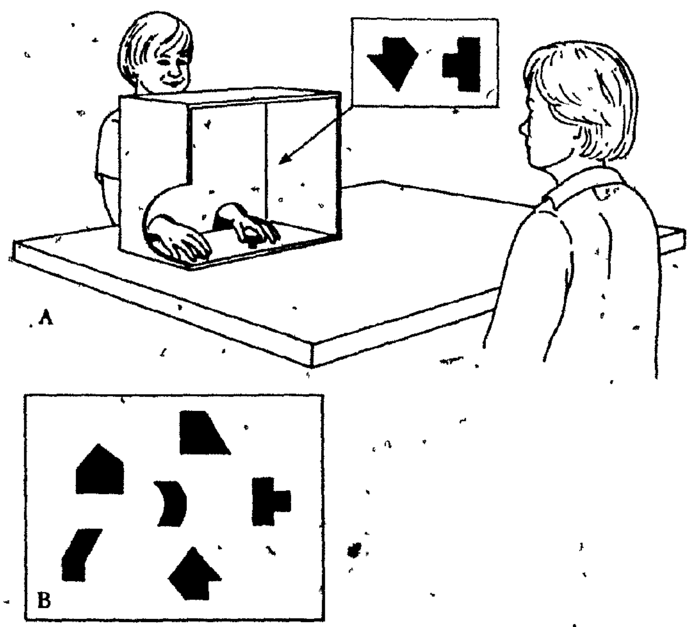


Fig. 5.6

(From Springer and Deutsch, 1981)

in famale infants. Thus, the link between anatomical asymmetries and functional asymmetries is, at present, not clearly established. Sex differences have also been observed in brain growth. Epstein (1978) points out that brain growth spurt for girls at age 11 years is about twice that of boys at that age, while almost the opposite is true at the age of 15 years. Another study by Purdue University researchers indicates that by the time boys and girls reach high school, boys' brains seem to be more functionally balanced than the girls' (in Saks, 1979). Performance of 38 high school students on two sets of spatial tests and two analytic/linguistic tests were compared. Researchers discovered that "girls tended to use their left hemisphere in processing all the tasks, and much more so than boys on spatial tasks" (in Saks, 1979). These sex-differences in brain growth and hemispheric asymmetry in dealing with verbal and nonverbal tasks can serve as guidelines in the schools for the benefit of both the sexes. It should not, however, be used as a measure of superiority and inferiority in verbal or nonverbal tasks. Superiority of females in verbal ability or superiority of males in spatial tasks does not in any way indicate the intellectual level of either males or females. The verbal and nonverbal characteristics of the two hemispheres are merely two ways of processing stimuli. When stimuli are perceived, they are not acted upon in their raw form, but are processed through the two modes of processing. The difference between the two lies in their major and minor roles in a particular task.

When considering the processes and functions of the brain, it is important to note that each process or function involves various areas of the brain working in harmony. Studies have shown involvement of many parts of the brain in learning tasks basic in schools, such as arithmetic and reading (Ingvar and Schwartz, 1974; Lassen et al., 1978; Livanov et al., 1964, 1973). In one study by Lassen et al., (1978), the images of blood flow clearly indicated the patterned involvement of multiple areas of the brain working in different patterns. These patterns were dependent upon the problem and its content. Thus, it seems it is the brain as a whole that is involved in the learning process. There is no doubt that the brain (two hemispheres) is equipped with two modes of processing stimuli - propositional and appositional strategies (Bogen, 1977), and simultaneous strategies and analytic and gestalt strategies. There has been more emphasis on process specificity than material specificity of the two hemispheres (Bogen, 1977; Levy et al., 1972; Wittrock, 1977, 1978, 1980). Hence, Wittrock (1980) rightly states: "If ... stimuli are processed by ... two different strategies and are learned in two different organizational systems, instruction should be designed accordingly to facilitate these systems." It is unfortunate that the present educational system is so dominated by the left-brain verbal concept that left-brain approaches are encouraged even when these are not really appropriate. "Any partnership in which one partner is both silent and invisible is bound to develop in a lopsided way" (Blakeslee, 1980). Our understanding of hemispheric functioning and processing can become very useful in balancing the curriculum of the schools that are presently educating only half of the brain. Learning situations and strategies could be developed to complement the two modes of processing stimuli, thus leading to the development of an approach to teaching the "whole child". Gardner (1983) argues that we are all born with a potential to develop a "multiplicity of intelligences" (MI), most of which are ignored by our testing society. According to him, the potential for musical accomplishment, bodily mastery, and spatial reasoning, and the capacities to know oneself as well as others constitute the multiple forms of intelligence. These must be added to the typically tested list of logical and language skills measured by a standard I.Q. test. Now, the question that arises is: How do we achieve our goal? According to Bogen (1977):

> One answer might be that we give equal time to each hemisphere. This is not simply a matter of enrichment, but of saving from neglect a cognitive potential as important for high-level problem solving as language skills (p. 148).

Similarly, Bower (1970) concludes that a strictly verbal-encoding model of learning and memory is incomplete. According to him, "dual processing systems" comprising nonverbal, imagery processes (right hemisphere) and verbal symbolic processes (left hemisphere) are needed for effective learning and memory. He found that the rate of recall of lists of words increased when subjects used the techniques of mental imagery as well as rote verbal memorization in learning. The generative model of learning presented by Wittrock (1977, 1978, 1980) indicates that teaching methods that present verbal information in a synthetic spatial or imagery strategy can facilitate memory in normal learners as well as in patients with left sided lesions. Educators need to emphasize the interdependence of the two hemispheres. The development of a whole brain which involves an appreciation of significant contributions of each hemisphere by including an understanding of the kinds of tasks it performs and the conditions under which it performs as well as the importance of the hemispheres working in harmony is the most essential criterion for curriculum development (MacKinnon, 1981).

Introducing right-brain learning in the curriculum might be useful in actually enhancing rather than inhibiting left-brain learning. A curriculum that allows students to process information through both modes (left and right) of processing can lead to greater frequencies of success than a one-sided curriculum permitting only one mode (left) of processing information (Grady and Luecke, 1978; Guckes and Elkins, 1981; Kettering, 1979). Brain research shows that all individuals have the potential (maybe in different degrees) of using their right-brain capacities. The same of course may be said for the left hemisphere functions too. Individuals may differ in degree of potential to use the left hemisphere. Thus, a child who appears to be a slow learner might be slow only in regard to left hemisphere functions. He may be a very capable right hemisphere learner. The potential is waiting to be channeled into the proper direction. It is true, education has its limits, and even the present highly refined rational teaching techniques cannot make everyone an "A student" in "basic" subjects. However, to the same degree that verbal or logical teaching can improve performance in basic subjects, the skills of the right hemisphere can also be developed by education (Blakeslee, 1980).

Though educators now are increasingly concerned with the importance of right-hemisphere functions (e.g. creativity and holistic thinking), the educational curriculum still incorporates left-hemisphere tasks. The core subjects are reading, writing and arithmetic. One might find a few "art" classes, "creative writing" classes and perhaps music courses too, but these are optional. If a student is not participating in these classes, hardly any teacher or parent is much concerned. On the other hand, if the same student is not doing well in reading or maths, it becomes a matter of great concern for both the teacher and the parent. Now that neuroscience has provided a much more detailed analysis of the capacities of the human brain, an attempt can be made to teach the "whole brain". First of all, an awareness of recent advances in brain research is needed among teachers, parents and policy-makers. Teacher training programs could include a brief course on "brain research". This does not imply that one has to learn neuroscience but a basic knowledge of the structure of the human brain, its course of development from birth to final maturity around the age of 16 or 17 years and its dual mode of processing stimuli would be sufficient to deal with children with varying degrees of orientation towards left- and right-hemispheric functions. The subject of "split brain" in itself is so fascinating that it would be an enjoyable experience of learning for most teachers. Parents often attempt to channel their children toward a particular profession because that vocation has a high status or a good income. The reasoning behind this is that it is best for their child's future. What they don't know, however, is that they are doing more harm than good to their child by pushing him toward a vocation that is not suitable to his mode of processing (left hemispheric or right hemispheric). By expecting the child to do well in maths and science when he is oriented towards creativity and music, parents are fulfilling their own needs rather than the child's needs. Such attempts sometimes result in a disaster when the child grows up. He might end up with frustrations and problems of adjustment in his career if he is too late in realizing his own potentials and interests. Hence, an elementary knowledge of the dualistic nature of the functioning of the brain would enable parents to understand their children better. Knowing the mental capacities of their children, parents might help in providing the proper environment for a full development.

MacKinnon (1981) recommends the establishment of programs that introduce and/or provide whole brain tasks and experiences to parents and educators. This can be accomplished in a variety of workshop activities. Drawing exercises designed by Edwards (1979) can be used to experience the right hemisphere's method of dealing with the task of drawing. Betty Edwards uses the terms "L-mode" and "R-mode" to simplify the terminology of left- and right-hemisphere functions. In order to get a firm grasp of these two modes, she recommends certain exercises for imaging based on two graphic images of L-mode and R-mode (Fig. 5.7). Thereafter, exercises designed to help the individual shift from his dominant L-mode to his subdominant R-mode are provided (Fig. 5.8). This cognitive shift is a subjective state that only the individual can experience through drawing exercises. A left hemisphere comparison of the right hemisphere's drawing with the analytically stiff copying (often confused with successful drawing) can be quite interesting. Another activity designed by Bergquist (in MacKinnon, 1981) is playing a game of Petals Around the Roses, a child's game which uses dice. The dice are thrown and, depending on the configuration of dots on the dice, a holistic image of a rose is experienced. The center dot on each die becomes the center of the rose and the dots surrounding

L — MODE

R — MODE

L-mode is the "right-handed," left-hemisphere mode. The L is foursquare, upright, sensible, direct, true, hard-edged, unfanciful, forceful.	R-mode is the "left-handed," right-hemisphere mode. The R is curvy, flexible, more playful in its unexpected twists and turns, more complex, diagonal, fanciful.

Fig. 5.7

(From Edwards, 1979)

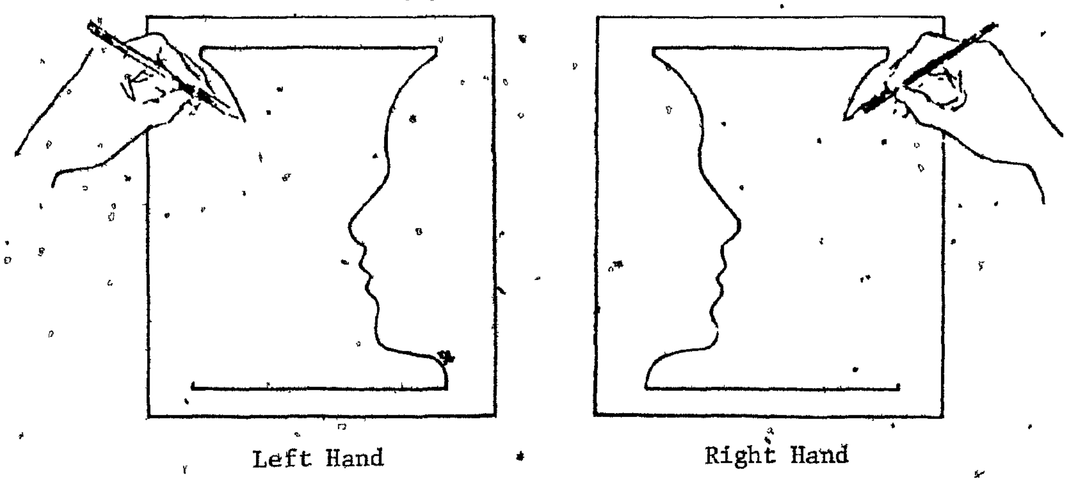


Fig. 5.8

(From Edwards, 1979)

it become its petals. Those not containing a center dot are not roses. Most young children pick it up very quickly, whereas many highly academic professors get frustrated and angry when they find themselves unable to understand and analyze the dice. As MacKinnon (1981) comments:

> This experience is very successful at simulating what it is like to be a child seeing things one way and having others (like their teachers) see them another ... these examples provide the participants with the opportunity to experience, first hand, the differences between the brain processes. Although the goal of the educational program is whole brain teaching and knowing, the experience of DIFFERENCES is extremely valuable for individuals who may be in what Robert Samples calls a "left-brained rut" (p. 125).

Next, the existing curriculum in the schools has to be thoroughly reformulated to provide holistic education to its pupils. It is not the curriculum in itself that needs to be changed, rather its rationale, process and ultimate value needs re-examination (MacKinnon, 1981). The basic subjects - reading, writing and maths - will remain in the curriculum. Other subjects - social studies, science, health, physical education, art and music - will still be a part of the curriculum. Only the method of handling these subjects will change both on the part of the teacher as well as the learner. The traditional method of presenting information requires students to absorb, learn and remember as much as they possibly can. The more they remember, the better the learning. In this method, the direction and flow of information is from 'subjects' to the individual (Buzan, 1983, Fig. 5.9). The student is bombarded with textbooks and examinations that right from the beginning create feelings of fear and anxiety. The net result in general

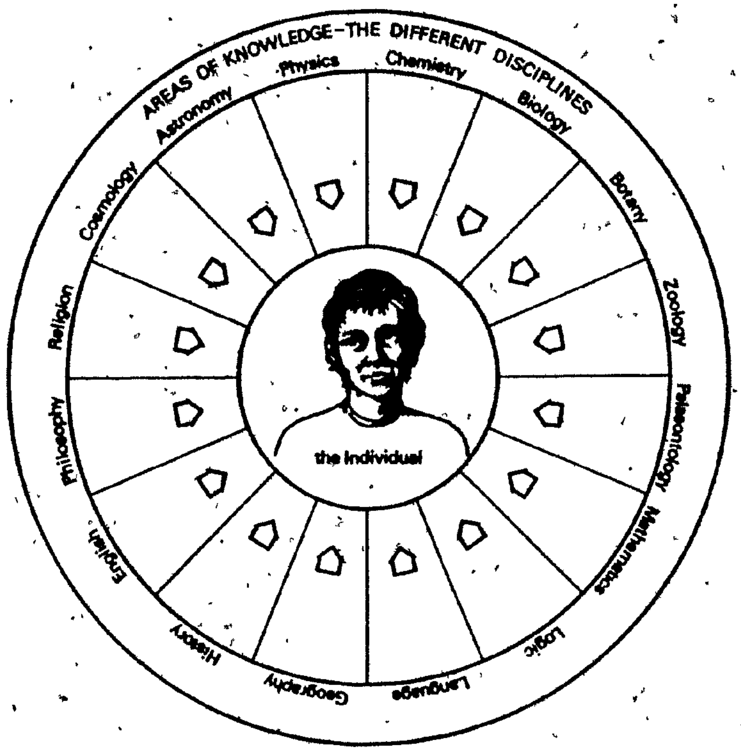


Fig. 5.9

(From Buzan, 1983)

is less effective learning. Education here becomes directed only at a small group of students who are capable of handling the threat and get through the examinations with good grades. However, the majority keeps struggling hard to keep up with the linearly oriented system. Hence, what the students at present need for a full mental development is first of all a better and clear understanding of themselves. Only then can they pursue learning about other things (subjects) most effectively. This is again clearly represented by Buzan (1983) in Fig. 5.10. This new system of education would concentrate on students' abilities first and then the subject matter. Each student thus will be able to proceed at his own pace with the appropriate mode of processing tasks. As a result, both teaching and learning would become more satisfying, enjoyable and productive.

Individual teachers' role in the educational system is of prime importance. It is true that they may be powerless to change the content of the curriculum. At best, they may be free to cover any number of topics within a given subject. In the worst situation, teachers may be provided with a complete list of facts to be taught in a specified order. In either situation, however, the teachers enjoy a certain degree of freedom to use their own instructional methods of teaching. Thus, if the teacher is aware of the two modes of learning and has a concern for integrated learning, he can utilize methods of instruction that stimulate both sides of the brain. In other words, the teacher's own interest in holistic learning and efforts toward using methods of instruction that stimulate and develop both hemispheres of the brain may be helpful in eliminating many of the learning problems of their

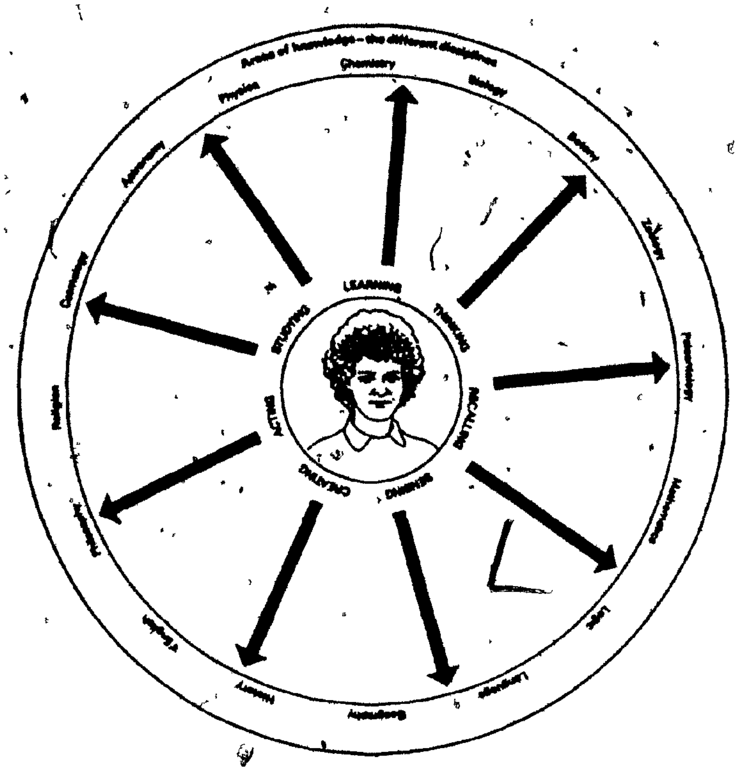


Fig. 5.10

(From Buzan, 1983)

students. The advantage of stimulating both sides of the brain would aid in strengthening each student's less developed hemisphere of the brain (left or right as the individual case may be). In effect, students in general would be learning much more about the world around them by going beyond the limits of verbal rationality.

With the development of both hemispheres of the brain, students can dramatically increase their abilities to deal with various tasks (Blakeslee, 1980). Many highly educated intellectuals habitually attempt to use their left brain for totally inappropriate tasks and get frustrated. Certain tasks, like sports, art and music, require an "intuitive feel" which is incomprehensible to the left hemisphere. Right-brain knowledge has been found to be crucial in a variety of purely mental tasks, such as maths and science. Most creative breakthroughs are a result of an "intuitive leap" that must then be carefully analyzed in logical steps by looking at the result. Thus, it is extremely important to encourage use of both modes of processing stimuli in our youngsters who are going to be adult contributors in society tomorrow in various capacities. Blakeslee (1980) rightly comments:

> A real reform of the educational system will not occur until the individual teachers learn to understand duality of their students' minds. With this awareness it becomes only natural to conduct the class in a way that keeps the attention of both the verbal and the non-verbal minds (p. 59).

It is interesting to see that young children are extremely comfortable and skillful in functioning both spatially as well as analytically. Most of them sit in front of the television for hours without complaint, and also adjust in traditional classrooms where reading and arithmetic are taught. By the time the child enters primary school, his spatial skill is sufficiently developed to accomplish even complex holistic tasks as well as perform an analysis of those tasks (Guckes and Elkins, 1981). A young child, when asked, can give all the details of a popular television series, plot, setting, and characters without any traditional instruction. It is the school system that essentially stops appreciating those skills and encourages them towards the basic subjects of reading and arithmetic. In fact, learning to read is of the utmost importance. A child having problems in reading becomes a major concern for parents and teachers. Reading becomes a foreign and threatening school activity for some children because of the pressure which they are not ready to handle. A patient delay until the child is ready to learn might become satisfying and meaningful to the child. Growth periods cannot be ignored if we are to provide an enjoyable learning experience for the child. The child as an individual is much more important than attempts to make him learn to read and in the process create emotional problems for the child that might be more harmful in the long run. According to Guckes and Elkins (1981): "One of the least recognized but greatest motivating factors for teaching young children is the activities they explore naturally and the skills they develop during this exploration." These young children could learn in their own way in a kind of setting where appropriate stimulation is provided but no pressure is exerted on them. This would allow each child to learn at his own pace. This seems to be very important, especially for young children who enter school for the very first time.

With the introduction of a hemispherically balanced method of teaching (utilizing the two modes of functioning) in the school, a change in the process of student evaluation is also needed. The current practice in general is based on the student's ability to deal with linear and sequential functions. Furthermore, most tests employed for assessing their abilities are language dominated. Nonlanguage-based tests are needed to give a greater opportunity to students who are right-hemisphere dominant (superior in nonlanguage abilities). It is just possible that many students are being misjudged because of inappropriate tests used for evaluation. Hence, Grady and Luecke (1978) emphasize that tests should be designed to evaluate abilities of children who are oriented visually and metaphorically but not verbally. As a result, many students may get a chance to increase their scores.

Tony Buzan (1983) has emphasized the importance of "mind maps" for recall and creative thinking. The mind map approach is not only more effective in learning as compared to memorizing a whole list of information in a logical sequence, it is also a far more effective measure of abilities of children who are visually oriented. Buzan (1983) has provided few examples of mind maps drawn by school children. The first one (Fig. 5.11) consists of normal writing of a 14 year old boy who was seen as reasonably bright, but messy, confused, and mentally disorganized. The sample of his writing is from his 'best notes'

7) SETTING Time + places in which the novel is situated

8) IMAGERY The kind of images the author uses to describe (usually by simile or metaphor)

9) SYMBOLISM One thing stands for another
The witches in Macbeth signifying evil

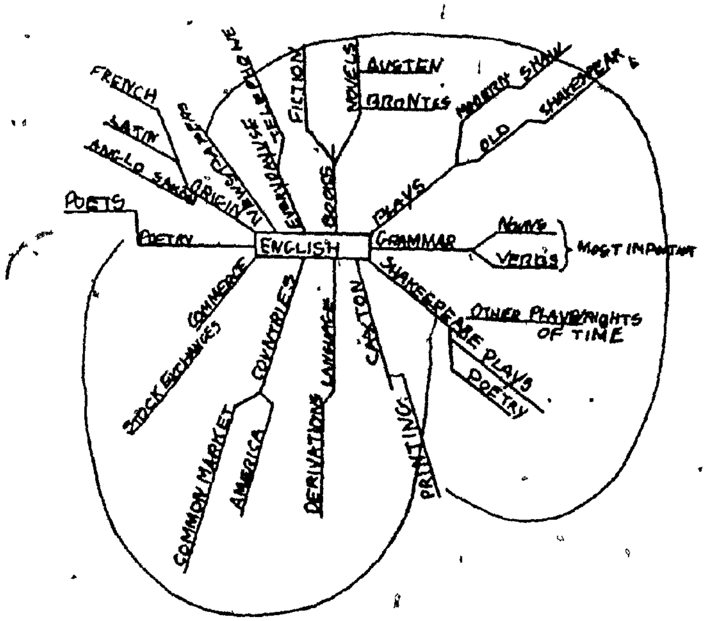


Fig. 5.11

(From Buzan, 1983)

and indicates clearly why he was described as he was. The mind map of English just below his writing was finished in five minutes which is just the opposite of his writing. This clearly shows how a child can often be misjudged due to an inappropriate method of examining him. The next map (Fig. 5.12) was drawn by a boy who failed O level economics twice and was described by his teacher as having a great deal of problems with thinking and learning together with no knowledge of his subject at all. The map completed in five minutes definitely indicates the opposite. These two are just a few examples of inappropriate evaluation of talented children. The third map (Fig. 5.13) is a display of an extraordinary creativity in maths which is usually considered to be a dull and dry subject. This map is by an A level grammar school girl on pure mathematics. She took only 20 minutes to complete it. A professor of mathematics estimated that it had been done by a university honours student probably in two days. This of course is a reflection of an outstanding talent of creativity not very common among children. However, it is a very good example of how even dull and boring subjects can be made exciting learning experiences.

Thus, methods of evaluation should provide opportunity for either a language or a non-language mode of expression. Also, equal credit should be given to a child who simply answers the question in a diagrammatic form. He should not be made to suffer just because he did not submit an answer of five solid pages in the form of language. The method of evaluation should focus on whether the child has understood the concept or not regardless of the mode of expression. It is true that some children are good at language but that does not mean that

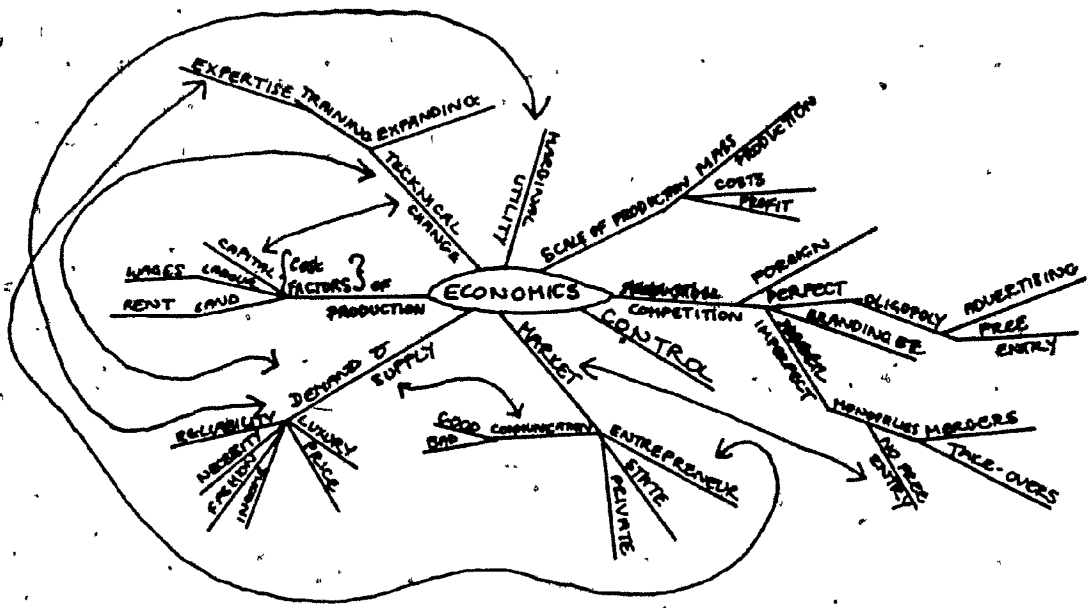


Fig. 5.12

(From Buzan, 1983)

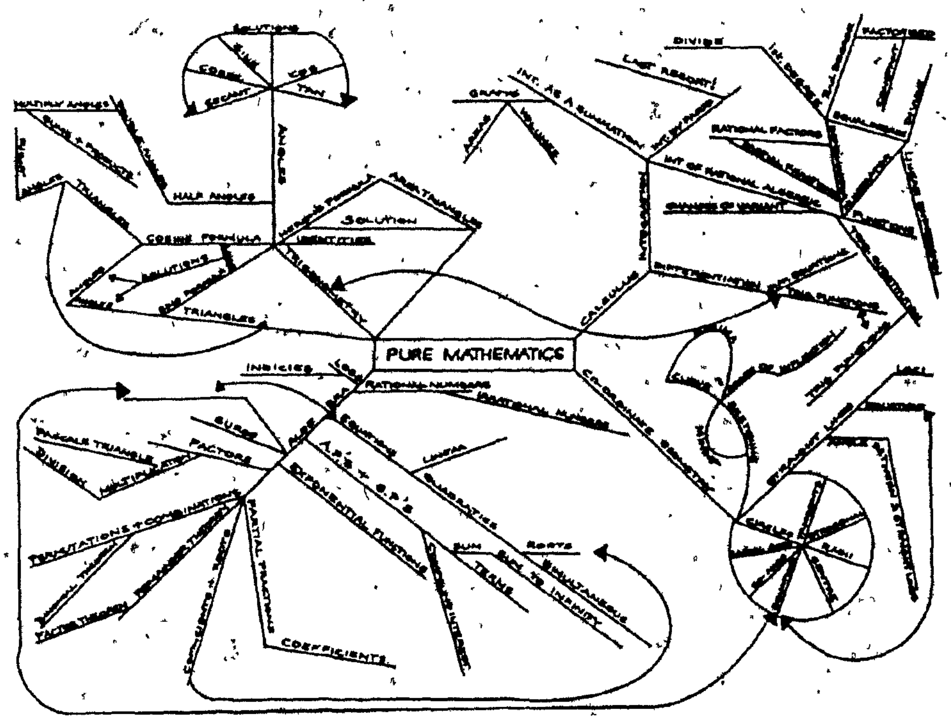


Fig. 5.13

(From Buzan, 1983)

others who are equally good at visual images and maps are in any way inferior to them as far as learning is concerned. Learning history, geography, science or mathematics does not impose a necessary condition that one has to be very good in language. As long as the child possesses the basic knowledge of the language he can certainly learn these subjects given the opportunity. The term 'opportunity' here implies the mode of presentation of material to be learned. This obviously depends on the teacher. It is the teacher who is presenting the material in the class and, hence, assumes the responsibility of 'getting through' to all learners.

It is well recognized now that one difference among learners involves preference for processing stimuli with one hemisphere or the other (left or right). Individuals differ in the way they process information. Just as a left-handed person uses that hand to write or draw, a left hemisphere dominant person shows a preference for verbal instructions as compared to visual instructions. However, as Grady and Luecke (1978) comment: "... as most tasks are done more skillfully and efficiently when both hands work together, so thinking is augmented by both hemispheres working together." Thus, a multimodal presentation of materials would lead to more effective learning (Buzan, 1983; Grady and Luecke, 1978; Guckes and Elkins, 1981; Hill, 1981; Kettering 1979; MacKinnon, 1981). At the same time it would do justice to all learners whether left hemisphere oriented or right hemisphere oriented in processing input. In addition, exposure through various modes would help students in developing their non-preferred skills too. The most basic method utilized for teaching must at least provide visual as well as verbal stimulation. This would allow the two hemispheres to work in harmony, hence promote full utilization of the brain in learning and thinking. Other modes of presentation could also be accomodated so that each learner could get opportunities to develop his scope of learning. The secondary (or non-preferred) hemisphere can acquire skills through experiences and encouragement in the classroom.

Hence, to incorporate both hemispheres of the brain in learning the teacher must introduce new materials in both a linear and a visual/spatial manner. This does not necessarily require two different lesson plans and two separate sets of materials. It demands that the teacher give visual/sptatial instruction as well as verbal. According to Grady and Luecke (1978), charts, maps, overhead transparencies, and manipulable objects can be used to help visualize verbal concepts. These materials do not have to be separated for those verbally inclined and for those visually inclined. With the choice on hand, most students are likely to use the more comfortable mode. However, it would be helpful for them to utilize their non-preferred mode. To facilitate the use of both modes, sometimes the teacher should deliberately present material in only one mode. This would enable the learners to develop their non-preferred mode too. As an example, the teacher may read a passage with no visual stimulation thereby restricting students from using their right hemisphere. On the other hand, a holistic hemispheric stimulus may utilize a slide-tape show with music to explain the concept. Further, individual students may also be given specific work to give them practice in stimulating their non-preferred mode. Hence, it can be seen that teachers can contribute a lot in helping all learners to use both sides of their brain in learning and thinking more holistically. At the same time, each student would get the benefit of using his own preferred mode too. Thus, individuality as well as some degree of diversity would be enhanced in each learner.

In order to develop both sides of the brain, the teacher should design learning experiences which provide a whole variety of opportunities to create a balance between the left hemisphere's verbal-analytical ability and the right hemisphere's spatial-synthetic capacity (Bogen, 1977; Grady and Luecke, 1978; Guckes and Elkins, 1981). This has been further supported by Wittrock's (1974, 1977, 1978) view of learning. Based on recent brain research, he has hypothesized learning as a 'generative cognitive process'. According to his model, verbal processes and imagery both can be used for active construction of meaning for events and subject matter. On an analysis of findings from a number of studies on recall among school children, Wittrock (1977) concludes that learning verbal materials by elaborating them in the form of images increases their level of recall probably because they are processed in two modes. This model interprets learning as a process which builds concrete specific verbal and imaginary associations through the process of transfer of prior experiences to new events and tasks. This view then has major implications for teachers. Teaching is viewed as more than simple reinforcement of correct responses to bits and pieces of information. It becomes a matter of organizing and relating new information to the student's previous experience and encouraging him to build his own representations for the present events.

Wittrock (1977, 1980) points out that it would be more fruitful to investigate how learners process the environmental material in various and multiple ways which may interact with one another. Instruction means different things to different learners based upon their information processing techniques as well as their experiences. Hence, the technique of teaching needs to develop sophisticated ways to stimulate the multiple processing systems of the brain. Further, Wittrock (1977) goes on to say that it is not a matter of determining a primary and secondary mode of instruction, rather instruction may be better when multiple modes are utilized. An important issue in teaching involves not finding out the dominant mode of each learner, but rather the selection of various modes of presentation that would facilitate an interaction between the two hemispheres. Also, it is essential to determine beforehand what types of processing of information is stimulated by the instruction material. This would help the teacher in assessing the instructional material (whether it is stimulating only verbal processing or only imagery processing or both verbal and imagery processing).

The instructional method influences processing of information. As, for example, pictures are generally processed in images but an instructional method using pictures might stimulate learners to describe these pictures with sentences. Therefore, what seems to be a pictorial method of instruction might be a verbal one or an interactive one, utilizing both verbal and imagery processes. In other words, instructional material should be understood in terms of the types of processing of information it stimulates not merely in terms of its apparent characteristics. This is extremely important if both hemispheres are to be stimulated among learners. Thus, Wittrock (1977) rightly concludes that: "we can facilitate learning with understanding and comprehension by stimulating the brain to process information generatively." This generative process of stimulating learners to construct meaning from the information available using their own experience would facilitate originality in learning and not just reproducing knowledge as presented by others.

Instructional design matched with the cognitive style (preferred mode) of an individual learner may facilitate his learning. The preferred mode or cognitive style can be assessed by observing which student is more interested in reading and writing but dislikes physical education class, or which one takes an object apart in five minutes but shows no interest in mathematics at all. Another aspect of assessment is the amount of success a child is presently experiencing in school. Children who are linearly oriented would obviously score better in reading, writing and arithmetic taught through a linearly oriented approach. On the other hand, children whose visual/spatial mode is the dominant one may be discriminated against as slow learners. Also, EEG and eye movement studies (Galin and Ornstein, 1972; Kocel et al., 1972) provide potential methods of determining the preferred cognitive mode of an individual. Determining the preferred cognitive mode of each student would help the teacher in recognizing his weak mode also. Thus, subject materials can be presented in a way that both of the student's hemispheres are stimulated but at the same time special attention can be directed at developing his nonpreferred mode. More specifically, this kind of approach would lead to an individualized instruction which, if implemented in the schools, would definitely enhance learning among all students. At present, however, the first step towards providing a more holistic approach to education for all learners would be to present learning materials in ways that promote stimulation of both hemispheres of the brain. This would give equal opportunity to all learners (linear or visual/spatial dominant) to process learning materials. The existing disadvantage of the visual/spatial oriented children would thus be eliminated. Individualized instruction at the present seems premature at this time.

As pointed out earlier, it is not necessary to change the curriculum itself, rather that methods of teaching need to be reorganized so as to provide a holistic approach to learning. It is interesting to see how even linearly oriented subjects of reading, science and arithmetic can be taught in a way in which both sides of the brain work in harmony and facilitate learning. Let us then first consider the teaching of reading and see how multiple processing systems can be stimulated. Reading is a much more complicated process than often considered. A complex set of cognitive processes is involved as the two hemispheres work in coordination in recognizing shapes and phonemes, in relating past experiences to the meanings of words, in comprehending sentence and story meaning by connecting prior learning to the present reading material. Further, transforming meaning into expression comprises: "a selection of relevant information and the synthesis of concepts, ideas, generalizations and each individual's affective response to his own interpretations." (Guckes and Elkins, 1981). Hence, it has been emphasized that both hemispheres must be stimulated. As Guckes and Elkins (1981) comment:

> From the first introduction to reading, instruction must build on the transfer of children's own experiences as new learning is based on previous learning. Involving the children's past learning [emphasized by Wittrock in the process of learning] by using discussions of their own immediate experiences as a basis for language use is the first step ... synthesizing these discussions and recording them in the form of Language Experience Stories to provide materials for the children's practice of word recognition skills keeps their learning activities connected to their own experiences. At the same time the children will be practicing right-brain visualization, creation and synthesis which is then transferred to the left brain for linear and analytical learning (p. 142).

These investigators further state that allowing each child to pick some "key words" (that have some importance for him) as vocabulary words to be learned and used in their verbal and written compositions could serve as a valuable task for connecting the affect and feelings of the right hemisphere to the left-hemisphere problem of composing word by word. Children need guidance in developing their ability to read critically and creatively. Techniques centered on the construction of specific images and verbal connections using children's past experiences develop attention and facilitate all levels of comprehension. Guckes and Elkins (1981) discuss the use of PSRT format

P Predict
S Support
R Read
T Test

which will stimulate both sides of the brain in building representations that will enhance both comprehension and recall. By offering his own supported prediction of a possible story outcome from information given at the beginning of the story, each child formulates his unique purpose and set for reading the particular story. The child synthesizes the clues available from the title and sometimes from a given introductory paragraph or picture in relation to his prior experiences. This is all carried out by the right hemisphere and later on the left hemisphere receives and analyzes. After reading the story, the child compares the details of the story with his initial prediction and in the process utilizes the holistic and synthetic approach of the right hemisphere.

Also, a dynamic interaction of small group discussion is of utmost importance for children in constructing relationships among the information gathered from their environment and their reading. Through group interaction, these children will learn to make inferences and judge their own perceptions and understandings (Guckes and Elkins, 1981). Generating these interactions becomes the responsibility of the teacher. The teacher, by putting questions (that do not necessarily require a right or wrong answer) in front of the children, will stimulate the children in developing their critical and creative aspect of reading. These students of reading must be allowed to use a combination of pictures and words to communicate their ideas. This would permit an integrated use of both hemispheres.

According to Grady and Luecke (1978), grammar can be effectively learned through drama. Students themselves figure out without being told that verbs are action words, because when they pantomime such words, they are moving physically. Similarly, prepositions can be understood as direction words because they find themselves giving directions when required to pantomime these words. Ability to write effectively again requires help from both sides of the brain. No matter how much grammar and punctuation a child knows, if he does not know how to organize and synthesize his ideas he would not be successful in communicating his ideas in a written form. Hence, right hemispheric integrative factors of language, such as metaphors, imagery, figurative language, which are helpful in relating facts to one another need to be developed from the very beginning (Guckes and Elkins, 1981).

An exciting writing activity developed by Rico (in Guckes and Elkins, 1981) to help inhibited children get through to the right-brain processes is "clustering". It uses a branching format to record and stimulate highly significant words so that the student is left to work in a non-threatening situation. The presentation of these significant words leads the student to pick out a topic and write a paragraph on it. Examples of a branching format and resulting compositions have been presented (Fig. 5.14) by Guckes and Elkins (1981). This kind of activity has been found to be very effective in enhancing students' expressive abilities as well as in developing interests in writing in learners from first grade to college. In other words, it is an activity for developing writing skills in all learners.

Guckes and Elkins (1981) mention another activity that gives direction to children on how to use inductive processes to identify patterns and to synthesize concepts and generalizations. This experience can be utilized in helping children formulate relationships between symbols and sounds (spelling and reading) in a way similar to extracting meaning from their real world. This activity consists of five steps as outlined by Guckes and Elkins (1981):

A. First the teacher identifies the patterns and the relationship to be synthesized by the children and selects words which follow the patterns.

B. Then the children experience the raw materials -- the words -- using varied modalities as they see, hear and say the words.

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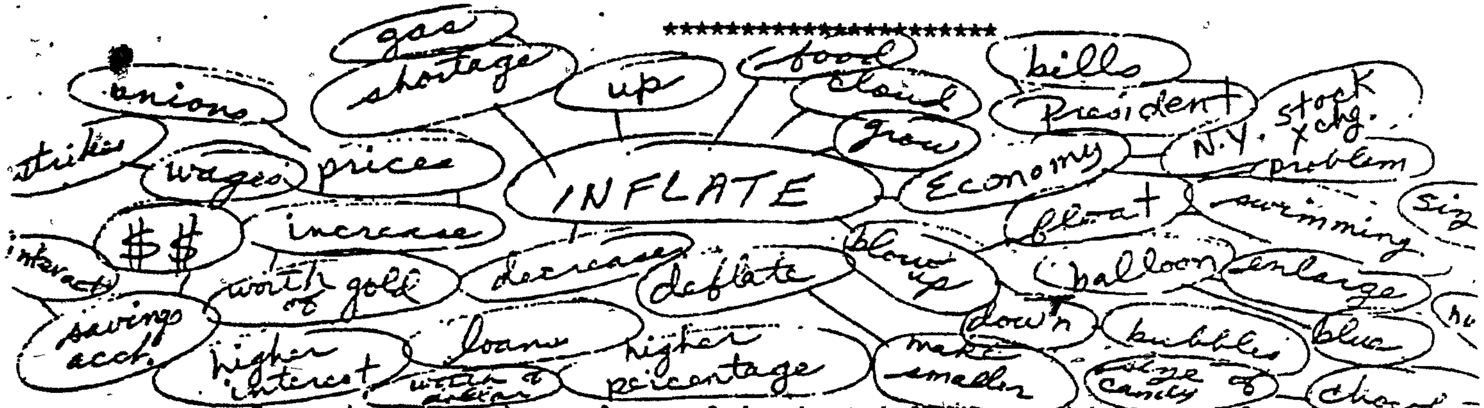
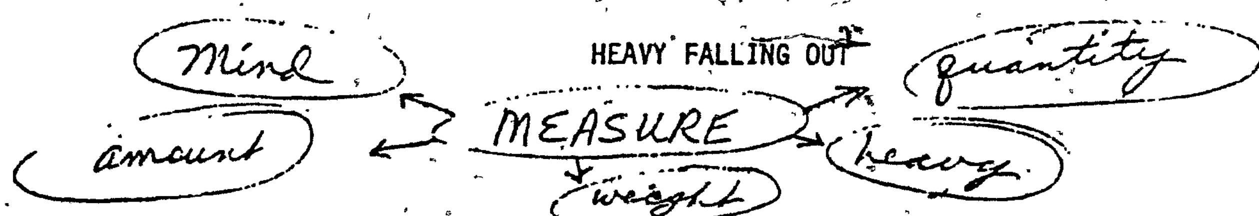


Every day you hear people complain about inflation and how terrible it is. The effect of inflation on candy bars upsets me the most. As inflation increases, the size of candy bars decreases. The packages are the same size, but the candy inside keeps shrinking. The companies claim that their prices do not go up, but you are getting less for your money. I fear that someday I will open up my candy package and there will only be a teeny, tiny, mini-chocolate chip-sized piece of tasteless chocolate. Inflation is terrible.

HEAVY FALLING OUT



The amount of love you give to someone cannot be measured. The type of love you share with someone cannot be determined. Only one person can weigh the quantity of the relationship. Love can't be measured, just treasured.

Fig. 5.14

(From Guckes and Elkins, 1981)

C. The third step is to lead the children in identifying the visual and aural patterns necessary to the relationship.

D. Next the children are guided to formulate a conditional statement -- If ..., then ... -- the generalized statement of the relationship.

E. This statement is then tested by using it with additional words both in isolation and in context, if appropriate (p. 145).

Though this activity follows a linear step-wise analysis (left hemispheric task), children develop their generalization ability through their synthetic ability (right hemispheric task). This helps in broadening their scope of learning. Also, it provides a training program for learning to use both sides of the brain in learning a task.

Science and maths, linear subjects, also involve visual thinking. The discovery method has been emphasized in learning both these subjects (Blakeslee, 1980; Guilford, 1981). Though it is true that in most parts of the world elementary arithmetic is taught largely through rote memorization, little attention is paid to the underlying concepts which often perplex not only the young children but also the teachers. There is not much room for questioning. The rules are given and students are required simply to memorize them so that they can solve problems by applying them. In other words, children who have a very good memory always score higher than the others. However, the situation in Japan is very different as pointed out by Gardner (1983):

> In Japan ... challenging problems are posed to entire classes, whose members then have the opportunity to work together over several days in an effort to solve these problems. The children are encouraged to talk to, and to help, one another and are allowed to make mistakes; at times, older children visit the classrooms, and aid the younger ones. Thus, what is potentially a tension-building and frustrating situation is alleviated through the involvement of children in a

> common effort to understand; ... plenty of support for ... collaborative effort, accompanied by a feeling that it is alright not to come up with an answer right away, so long as one keeps plugging away at the problems. Paradoxically, in our much more overly competitive society, this risk of not knowing the answer at the end of the class seems too great; neither teacher nor student can readily handle the tension, and so a potentially valuable learning opportunity is scuttled (p. 380).

Therefore, it is high time we learned our lesson. Let us impart the Japanese view and implement it in our schools. The subject of maths can be taught in a way that encourages this discovery process. A concept learned through the process of discovery requires less "memorizing" and promotes a deeper understanding and grasp of the concept. Simple computational problems are generally presented to students in graphic situations, but usually words are used. For example, subtraction may be presented to a second grade student with a problem like: "There were two bones. A dog took one of them. How many were left?" However, the same problem can be presented in a pictorial form as given by Grady and Luecke (1978) in Fig. 5.15 below.

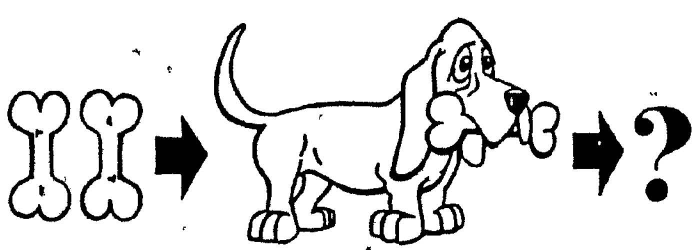


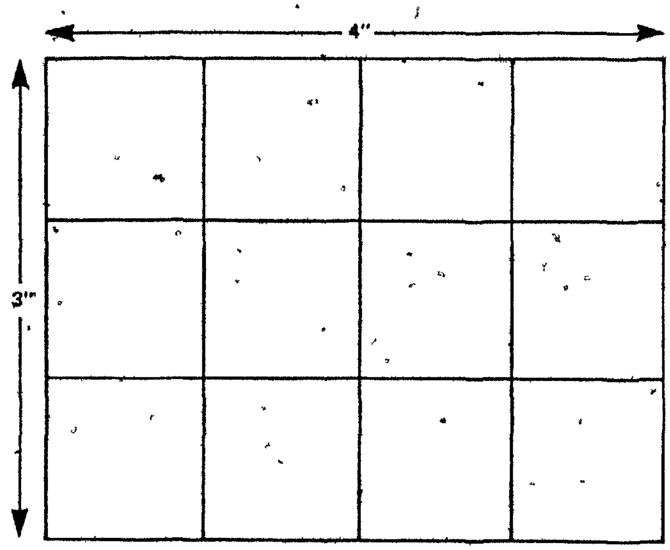
Fig. 5.15

(From Grady and Luecke, 1978)

The answer may be given as numeral "one" or in the form of a picture of a bone. These kinds of problems together with more traditional ones would stimulate both hemispheres. Students can be encouraged to make their own discovery in mathematical problems. Blakeslee (1980) gives an example of how the simple formula for finding out how the area of any rectangle can be learned (Fig. 5.16). After finding areas of several rectangles by counting squares, the student is instructed to generalize a formula for computing the area of any given rectangle. Several observations lead the student to discover that the area is the product of the length of the sides. Thus, he comes up with the symbolic form: Area = a x b.

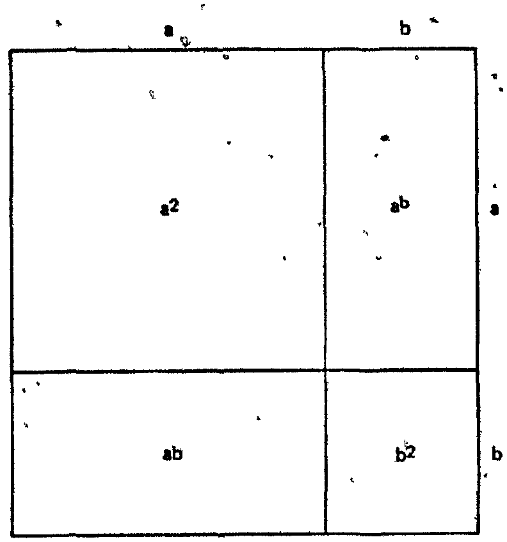
Albegraic concepts similarly can be more effectively learned through discovery. A graphical solution Fig. 5.17) to the problem of squaring a binominal: $(a + b)^2$ can be learned with greater understanding (Blakeslee, 1980). Once the student has drawn a square with the length of each side equal to a + b, the solution can be obtained by simple addition of the areas of the squares and rectangles within the larger square. Thus, the student discovers the equation $(a + b)^2 = a^2 + 2ab + b^2$.

In the field of geometry, manipulables and figures are traditional because it involves more visual/spatial ability. Theorems to be proven are generally intuitively clear when drawn. Proving the theorem becomes the task of transforming intuitive observation into verbal logic (Blakeslee, 1980). Perhaps as Grady and Luecke (1978) point out, students can also be encouraged to give their answers to geometrical problems in the form of drawing rather than verbal logic. The importance of interaction between the two hemispheres in the solution of



Area = a x b

Fig. 5.16



$(a + b)^2 = a^2 + 2ab + b^2$

Fig. 5.17

(From Blakeslee, 1980)

geometrical problems has been shown by Franco and Sperry (1977) in their experiment on split-brain patients. The task required the subjects to feel with one hand three geometrical shapes presented behind a screen and then decide which one best matched five similar figures that were presented visually. In one instance, the subject was presented with five different-sized equilateral triangles visually. While looking at these triangles, the subject had to feel three triangles behind the screen with one hand at a time. None of the three exactly matched the size of the visually presented triangles but there was only one that had all three sides equal in length. The left hand (right hemisphere) performance was slightly better than the right hand (left hemisphere) - 84 per cent versus 75 per cent. However, as the problems got more complex, the difference between the scores of the left hand and the right hand widened. Scores for four sided figures were 70 per cent (left hand-right hemisphere) versus 54 per cent (right hand-left hemisphere). Multisided figures resulted in still greater discrepancy between the scores - 82 per cent (left hand-right hemisphere) versus 45 per cent (right hand-left hemisphere). The increased efficiency of the right hemisphere indicates its effectiveness in dealing with visual/spatial problems. Since visual/spatial reasoning and verbal logic both are required for learning geometry, it is apparent why split-brain patients would face great problems because the communication channel between the two hemispheres is missing. The problems that normal students encounter in mastering geometry may be because of left brain-verbal logic emphasis in our present teaching system.

Learning of scientific concepts again is not wholly a left-brain function even though often it is classified as a left hemispheric function. The two hemispheres do interact in understanding these concepts (Blakeslee, 1980; Grady and Luecke, 1978). For example, learning about volcanoes would be far greater by setting up an experiment demonstrating volcano eruption than by merely reading books. Students would gain a clear concept through experimentation. It would also create interest and curiosity because they will be encouraged to make the discovery themselves. A little help and direction from the teacher would make learning of scientific concepts much more interesting and satisfying for the students.

To encourage intuitive reasoning in learning science, teachers can also attempt to present concepts through an experiment (nonverbally) first and then ask questions to obtain verbal responses from the students (Grady and Luekce, 1978). As an example, they indicate that a teacher could light two candles and place a jar over one without saying a word. Students could then start asking questions of the teacher as well as trying to think themselves about possible explanations, why one candle in the jar went out while the other outside remained burning. It would lead to various responses and tests to support their reasons. This kind of demonstration without answers leads to alternative modes of thinking and encourages dependence on intuition (Grady and Luecke, 1978). We all have heard about great scientific achievements that were first discovered intuitively and then explained in verbal logic. It is encouraging to note that experimental setup is generally used in the schools to teach scientific concepts. However, the setup could be modified in a way that learning becomes more of a discovery. The normal course of delivering factual information first and then experimenting needs to be reversed. The present author agrees with Grady and Luecke (1978) who emphasize experimental demonstration first, thus encouraging discovery or creative process. The ability to think creatively is not something to be learned suddenly. It is gradual and needs practice from childhood. As Blakeslee (1980) rightly remarks: "It is unreasonable to expect people suddenly to think creatively in graduate school if their formative years were spent just memorizing facts."

Even subjects like history, geography and social studies can be taught using both verbal and visual approaches. A balanced and visual presentation through pictures and films would provide a complete understanding of concepts. Maps and globes are traditional visual materials used in geography. Students can be encouraged to give their responses both verbally and nonverbally in the form of diagrams, maps and charts.

What we need then is to promote the development of holistic, simultaneous abilities in our youngsters. Since left hemispheric analytic skills are also important, they are not to be excluded from the curriculum. From the preceding pages, it can be seen that the two modes of processing stimuli working in harmony can lead to an increase in learning and understanding, no matter what the discipline is. At this point, it is not necessary to discuss the linear skills of the left hemisphere. The question arises: What are the major characteristics of the right hemisphere that need to be developed in children to provide a balanced approach to education? On examining the literature in the area, it appears that the major characteristics that need to be stimulated are: imagery, metaphoric thinking and creativity. Guiding children's imagery is very important in holistic learning (Beals, 1981; Blakeslee, 1980;

Kettering, 1979). In general, imagery is considered to be something on the order of hallucination because of our left-brain education that leads us to believe that reality is rational. It has been pointed out by Kent (1977) that the ability to experience images occurs very strongly in most children when they are young. With increasing age, these tend to disappear. Probably it is the educational system that gives very little support and encouragement that is responsible for the decrease in imagery. However, imagery has been found to be a powerful aid in learning verbal material (Blakeslee, 1980; Paivio, 1971). In an experiment by Paivio (1971), pictures, concrete nouns, or abstract nouns were presented on a screen for only 1/16 second at five-second intervals. The subjects were instructed to write down what they saw. Testing was done with two kinds of instructions given to subjects. In one case, the subjects were told that the experiment was conducted to note if they could identify the briefly flashed words and pictures. This was incidental memorization. Intentional memory was tested by asking the subjects to both write and memorize what they had seen on the screen. In both instances, half of the subjects were tested for recall after five minutes and the other half were tested a week after. Results indicated that recall of pictures was much better than recall of abstract words. Incidental recall score for pictures after one week was higher than the recall of intentionally learned abstract words after five minutes. Further, recall of concrete nouns was 75 per cent higher than abstract nouns. Concrete words can generate mental images of things they stand for and, hence, better recall; whereas abstract words cannot generate visual images and so visual images do not contribute to the memorization process.

Learning in the schools can be greatly enhanced if curriculum materials are presented both verbally and nonverbally using imagery. Reading or writing prose should be accompanied by a parallel flow of imagery in mind (Blakeslee, 1980). A lot more can be retained in the memory system via images. Imagery is a holistic process and therefore does not correspond to words on a one-to-one basis. Once a passage or a chapter is read, one gets the general idea and a general "feel" of the whole passage or chapter and forms images which help in retaining them for a longer period of time. Also, large chunks of verbal material can be stored in the form of images which is extremely difficult to store in words. In fact, using diagrams or maps for noting key concepts from the verbal materials presented in the classroom would definitely be more effective in understanding and learning the materials rather than extensive note taking (Blakeslee, 1980; Buzan, 1983). New vocabulary words learned with the use of images would provide a meaning beyond the limitations of verbal meanings. As Blakeslee (1980) puts it: "When words are imaged as they are learned, they evoke more than just a verbal translation when we hear them." The images are useful in encoding.

Buzan (1983) points out that in order to fully utilize the brain's capacity, one cannot ignore the importance of images or "mind maps". A good mind map may be very useful in making a speech, writing term papers, making notes and even preparing for an examination. Preparing for examinations is very tough, especially because one has to read vast amounts of material and then store this in the memory system until the examination is over. This memorization process, however, would become much easier if the student knows how to construct these mind maps. Through these mind maps, studying time would also be reduced to a great extent because extensive note making time would be eliminated. Hence, if children are trained from their early years of schooling in how to construct and use these mind maps, their learning would be greatly facilitated. Its benefit becomes apparent especially when the student enters university for higher studies where much more reading is involved. It is important to make a cautionary note here that this does not mean that mind maps are only good for academic work. It could equally well be utilized in any other area too, and so all the more necessary that children are encouraged to use them. Meetings can be specially productive if mind map structures are used by organizers of these meetings. As Buzan (1983) suggests:

> On a board at the front of the [meeting] room the central theme of the discussion, together with a couple of the sub themes, should be presented in basic map form. The members of the meeting will have pre-knowledge of what it is about, and will hopefully have come prepared. As each member finishes the point he is making, he can be asked to summarise it in key form, and to indicate where on the overall mind map he thinks his point should be entered (p. 115).

This kind of meeting would be more to the point and each member's contribution would be recorded. Each member would also have a mapped record of the minutes of the meeting that would serve as a reference point later on. Thus, its uses are numerous and the important point is that it does not exclude the left hemisphere entirely. Words, numbers, order and lines (left hemispheric processes) can and are used in constructing mind maps. These coupled with the organizational ability of the right hemisphere result in the so-called "mind maps".

Metaphoric thinking or right-hemisphere thought has been largely ignored by linearly oriented educational systems and cultures (Samples, 1976, 1977). Based on intensive research on children, Samples proposed four modes of metaphoric thinking that need to be developed in the schools. The four modes are: symbolic metaphoric mode; synergic comparative mode; integrative metaphoric mode; and inventive metaphoric mode. It was noted that use of the metaphoric modes lead children to develop more confidence and capability in investigating new "concepts, ideas and processes in rational ways". According to him, the child from age 4 onwards at any grade level is capable of performing effectively in each of these four modes. However, the use of these modes is de-emphasized throughout the years of schooling. A brief description of these modes seems appropriate here. In the first symbolic metaphoric mode, a symbol is ascribed to an object, process or condition. The symbols can either be abstract (letters, numbers, written words, etc.) or visual (a visual picture of an object, process or situation being represented). This mode is much used in the present society. Advertising and road signs are illustrated by these two forms of symbols. For some children and even adults, the abstract symbols may be easier to follow and for some the visual symbol may be relatively easier to comprehend. Therefore, both these symbols should be used in teaching. Use of only abstract symbols may sometimes lead to an unjustified labelling of a child as poor learner. Children having problems with symbolic abstract processes can be allowed to use symbolic-visual processes. To put it in another way, if a child is not able to write an idea, he can be asked to draw or paint it. Later, he can be asked to explain it in writing. This would make the task easier for such a child.

The synergic comparative mode refers to a comparison of two or more objects, processes or conditions in such a manner that they are integreated into a larger whole. The third integrative metaphoric mode involves a total immersion of oneself in the process of learning. Samples (1977) asked social scientists to use this mode of nonverbal exploration of highly technical concepts in their areas. After the integrative mode exploration was completed, the investigator asked children present to present their understanding of the concepts. The depth of their understanding was just unbelievable. In this integrative mode, the physical and psychic characteristics are extended into a direct experience with objects, processes, or conditions outside themselves. Lastly, the inventive metaphoric mode leads to the creation of a new level of understanding through self-initiated investigation of objects, processes or situations. The emphasis here is on 'creation' rather than 'discover' which is often encouraged in schools. Further, Samples (1977) adds that each child possesses the capacity for metaphoric thought at all levels of cognitive development. A comparison of natural capacity that exists at all stages of cognitive development and how in the process of schooling these modes are generally excluded (with the exception of symbolic metaphoric) has been shown in Fig. 5.18 (Samples, 1977). Thus, what is needed is to encourage metaphoric modes of thinking in children and to help them integrate with their so-called linear modes of thinking. The metaphoric modes of thinking, especially the inventive mode and visual imagery, leads to creativity. Research indicates that imagery is important in creativity both in arts and sciences (Gowan, 1981). Another investigator points out that guided cognitive imagery enhances creativity (Roberts, 1981). The process of such a guidance is presented in a report by an eighth-grade

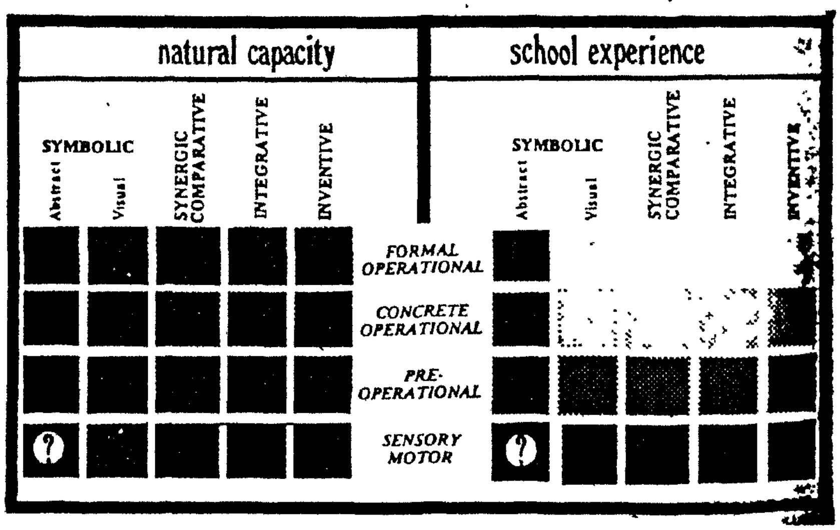


Fig. 5.18

(From Samples, 1977)

language arts teacher (in Roberts, 1981):

> ... After students have read the first part of a story or poem, I have them put their books aside and relax, making their bodies comfortable and loose all over. Then they reflect on in information covered thus far and pretend they are the author of the work. I tell them to put themselves completely into the given setting and temporarily become each character in the story. They try to experience the problems and joys presented in the reading up to the assigned point and go beyond that to create individual turning points, falling action, and conclusions. During the reflection period, I must act as a guide to ensure that students recognize the most important and moving sections of the assigned readings (p. 52).

The Wernicke area of the right hemisphere appears to be the control center for imagery (Jaynes, 1976). Imagery is at work all the time but during waking hours it remains largely suppressed due to dominance of left hemispheric functions. Art and music activities can be helpful in stimulating right hemisphere activity and thus give a break to the left hemisphere. Increase in right hemispheric activity would enhance creativity (Gowan, 1981). It is essential here to note that creativity is not entirely a right-hemispheric process. Both sides of the brain work in coordination to produce a new idea, art or achievement (Blakeslee, 1980; Garrett, 1976). The right brain is responsible for visual thinking and intuition and the left brain's ability is needed to grasp the value of the idea when it appears and explain it logically. This creative process is such that it can be encouraged in teaching science and maths. Creativity involves considering divergent possibilities and not necessarily work for a right answer. This approach has been applied to some experimental courses at the University of Illinois in which maths is taught from lower grades onwards by a "discovery" method rather than giving the principles (Guilford, 1981). Teaching science to children by the method of "discovery" is also being carried out at the University of Illinois. Thus, the movement towards introducing right hemispheric activity was begun to some extent. What is needed, however, is introducing such activities on a wider scale in the schools. The principal value of the findings of hemispheric specialization lies in providing scientific support for a more diversified curriculum that gives emphasis to various modes of presentation (verbal as well as visual/spatial) rather than a drastic change in the content of the curriculum.

The whole purpose of stimulating right brain activities is to provide a more holistic mental growth of children. Though theoretical understanding of the importance of activities such as art and play in learning is recognized in the field of education, not much attention is given to implementing it in practice. Art of drawing, music and physical education classes are usually arranged in the late afternoons and not much serious thought is given by the school authorities as to whether the children are progressing well in these activities. Also, these activities are considered to be causing interference in the more "academic" areas of learning. This very attitude needs to be changed. In fact, these activities may act as a relaxation activity and give the left hemisphere a rest period. In fact, school programs offering a balance between right and left hemispheric activities have produced high test scores in basic areas (Grady and Luecke, 1978). These two investigators point out that intermediate students in the "Learn To Read Through the Arts" program in New York have achieved significantly higher scores in reading. Fourth, fifth and sixth grade students participated in the program which relates art and reading activities.

Students who attend art classes six to eight times more often than the other students have been found to make significant progress in math as well as reading. In another program "Interdisciplinary Model Program in the Arts for Children and Teachers" (IMPACT) in Columbus, Ohio, students not only improved their scores in reading and maths but also exhibited superior problem-solving ability (Grady and Luecke, 1978).

Thus, the evidence is enough to indicate the advantages of right hemispheric activities not just for the sake of its own development but for the benefit of left hemispheric functions too. Singing (right hemisphere activity) can be combined with learning spelling (left hemisphere activity). The literature on the functions of the two hemispheres clearly indicates that there is a great deal of overlapping between them with regard to most of the functions. Even musical ability which is generally classified into the right hemisphere domain is handled by the left hemisphere too among trained musicians. Untrained musicians show a left ear (right hemisphere) dominance for musical stimuli, whereas trained musicians show a right ear (left hemisphere) dominance or no dominance at all (Gordon, 1983). These data then provide further support for an integrated functioning of the two hemispheres. Development of both are important in education to provide a more integrated holistic learning. A final note is that all learners are to be treated equally regardless of sex or handedness. There will always be a few more proficient than others at academic learning due to individual differences and, therefore, all need equal opportunity and encouragement for the pursuit of any subject taught in the schools.

Chapter VI

Summary and Conclusions

Attempts to keep up with the burgeoning literature in the field of brain research, especially related to split-brain, have not been easy but definitely exciting and enjoyable. The neurosciences have come a long way toward that point in sophistication about the human brain where its fascinating functional mechanisms are being discovered. The human brain probably is the most magnificent structure in the universe. The cerebral cortex, the most recently evolved part of the brain, is responsible for the more complex psychological functions, such as learning and memory. It consists of two hemispheres exactly alike in appearance with a duplicate of all the control centers found in one hemisphere. The two hemispheres are connected by a large bundle of millions of nerve fibers called the corpus callosum or the "great cerebral commissure" (Sperry, 1964). The corpus callosum, due to its physical prominence, has been a subject of much interest with regard to its functions in the brain. It is in fact the sectioning of the corpus callosum that gives rise to the phenomenon of "split-brain" (along with minor forebrain commissures).

An important characteristic of the split-brain is its bilateral predominance, each with its set of identical control centers over the brain stem and spinal cord which renders either one capable to a large degree of taking over and conducting the total behaviour of the body (Sperry, 1961). The split-brain approach provides the opportunity of comparison of the performance of the two hemispheres on the same task in the animal as well as in human beings. Moreover, the split-brain technique allows one to functionally compare a unilateral lesion with a symmetrical bilateral ablation (with regard to visual stimulation) when the eye ipsilateral to the lesion is kept open and the other eye sutured shut. When the eye contralateral to the lesion is open and the ipsilateral eye shut, the animal's behaviour (related to visual stimuli) is like the one in its preoperative state. Thus, Downer (1961) suggested that it can be possible in effect to remove brain tissue and replace it by opening and closing the appropriate eye.

Although the corpus callosum has a long history of investigations, results were largely inconclusive with regard to its functions prior to the discovery of the split-brain phenomenon (Joynt, 1974). A series of investigations by Akelaitis (1941a, b, 1943, 1944) and Smith and Akelaitis (1942) on patients with partial or complete callosal sections were unable to attribute a definite function to the corpus callosum. These patients did not show any significant change in their behaviour after the operation and, hence, the corpus callosum did not appear to be of importance. No wonder, once it had been said that the function of the corpus callosum was merely to keep the two hemispheres in place (Sperry, 1962). In other words, the corpus callosum was considered to be one of the largest and most useless among all the brain structures.

It was largely with the work of Sperry and his collaborators in the early 1950's that a surprising discovery was made. The two hemispheres of the brain were found to function independently after the sectioning of the corpus callosum. Initial experiments were carried out on cats who had their optic chiasm and corpus callosum both sectioned (Sperry et al., 1956; Stamm and Sperry, 1957). Results on the whole indicated that learning and memory occurred separately in the two disconnected hemispheres. Each disconnected hemisphere developed its own private learning and memory experiences that are in no way linked with the other hemisphere. Moreover, the two hemispheres could be trained simultaneously to learn diametrically opposed solutions to a particular task (Myers, 1962). No sign of interference was noted between the two processes of learning (Sperry, 1958, 1961). With the use of a specially designed apparatus, it became evident that concurrent learning of reverse tasks could proceed simultaneously (Trevarthen, 1960, 1962). This independence of the two hemispheres was only limited to the split-brain after the sectioning of the corpus callosum. Thus, it was concluded that the corpus callosum serves as a path through which interaction and cooperation occur in the normal brain resulting in unified behaviour.

Upon review of the studies on split-brain animals, it is apparent that the corpus callosum is important in the normal functioning of the brain. Two main viewpoints seem to emerge in the literature. According to one point of view, the corpus callosum is the link through which stored memory traces are available to each of the hemispheres. Cortical engrams are limited to one hemisphere only (Doty et al., 1973; Gazzaniga, 1963). When the need arises, stored memory traces are transferred to the other hemisphere via the corpus callosum. The corpus callosum is considered to be involved in integrating information from the two hemispheres. The other viewpoint considers it as responsible for laying down bilateral memory traces in the two hemispheres (Butler, 1968; Ebner and Myers, 1962; Hamilton, 1977). Upon analysis, it appears that neither is incorrect or contradictory. The integrative function of the corpus callosum is evident in the unified behaviour of the normal animal. Furthermore, due to bilateral sensory projections messages are received in both the cerebral hemispheres and integrated via the corpus callosum. It can be safely concluded that the corpus callosum makes a significant contribution to normal mental unity in animals as well as in humans.

The experiments on split-brain animals have to a large extent contributed to the investigations of mental functions in humans. Animal split-brain studies would continue to increase our understanding of the complexities of the human brain. Similarities in the structure between the mammalian brain permits variability in experimentation. The complexity of mental functions in humans places certain restrictions in terms of experimentation. Therefore, initial investigations are conducted on animals' brains. Results from these studies serve as guidelines for exploration of the human brain, when therapeutically justified.

The independent functioning of the two separated hemispheres in the split-brain animal generated questions concerning mental functions of the disconnected hemispheres in the human brain. Findings from split-brain laboratory animals indicated the possibility of discovering similar disconnection symptoms in humans. Geschwind and Kaplan (1962), while engaged in identifying disconnection symptoms in a patient with cerebral neoplasm and callosal infarction, noticed that although he could write clearly with his right hand, he could write "aphasically" with his left hand too. However, the patient was ignorant of what he had written with his left hand. Further examination led these two investigators to conclude that the patient's hemispheres had been disconnected due to a lesion in the corpus callosum. Later autopsy confirmed their conclusions. Lack of significant impairment of functions after sectioning of the corpus callosum in animals paved the way for the neurosurgeons to perform the split-brain operation on patients suffering from uncontrollable epileptic seizures. The purpose behind such an operation was to limit the seizure to one hemisphere. The first patient to undergo the operation was a 48-year old war veteran by Bogen and Vogel (1962). Since then, a number of patients have been operated on and thorough investigations have been conducted using various testing procedures.

Investigations at first did not show any noticeable change in the patients' behaviour. More careful observation led to the gradual discovery of changes in their daily behaviour. In general, spontaneous coordination of the whole body remained normal. However, some discoordinated involuntary movements of the limbs, compared with those observed in split-brain monkeys, were noted in varying degrees in different patients. Further specific tests revealed the main features of the split-brains. The right hemisphere's role in perception became evident (Gazzaniga, 1967). The left hemisphere dominated in verbal response and the right took over when nonverbal response was required. The right hemisphere, however, has some linguistic capacity in that it can identify a word by responding nonverbally. The upper limit of language capabilities in each hemisphere differs from individual to individual Gazzaniga, 1967). In the early years of life, the two hemispheres are equipotential. In case damage occurs to either, the other hemisphere is capable of taking over its functions. Speech is developed and maintained in the intact hemisphere (Basser, 1962; Searleman, 1977; Zangwill, 1960). The dominance of the left hemisphere is specifically related to its verbal function which is a unique characteristic of man.

One important point worth noting in the case of split-brains is that the major dominant hemisphere (usually the left) or the language hemisphere has no connection whatsoever with the minor (right) hemisphere (Sperry et al., 1969). Hence, when the major hemisphere does the talking, it is speaking for itself and can only guess about the other's activity. Evidence in support of simultaneous independent functioning of the two disconnected hemispheres has also been noted in the split-brain patient. The sectioning of the corpus callosum leaves the patient with so-called "two minds". Since there is no interaction between the two disconnected hemispheres, it provides the opportunity for separate exploration of functions of each hemisphere. In fact, much of the specialized functions of the two hemispheres has been discovered by testing each hemisphere independently without the other hemisphere's intrusion.

Linguistic ability has been largely associated with the left hemisphere in the case of normal right-handers and right hemisphere in the case of left-handers. However, Searelman (1977) points out that language is comprised of two aspects, namely production and comprehension of speech. There is a difference between the two which is often ignored. The left hemisphere dominates in the production of speech, but the right is also competent with regard to comprehension of language given the opportunity. It is probably this failure to distinguish between the two that one finds earlier remarks in the literature about the right hemisphere as being "mute" or "word-blind" or "word-deaf" (Geschwind, 1965a, b). A number of studies has been carried out to determine linguistic capacities of the right hemisphere (Gazzaniga, 1970; Gazzaniga and Hillyard, 1971; Sperry et al., 1969).

In general, the right hemisphere is able to comprehend nouns but verbs remain outside the domain of the right hemisphere. Investigations of a particular case, P.S., have demonstrated a wide range of linguistic capabilities in the right hemisphere (Gazzaniga et al., 1977, 1979). The 1977 study indicated that both hemispheres were capable of processing nouns, verbs, rhymes and antonyms. Further investigations provide evidence for verbal ability in the right hemisphere of P.S. (Gazzaniga et al., 1979). On the whole, the right hemisphere of P.S. has been found to be unique. Gazzaniga (1983) on the basis of his findings with split-brain patients concludes that various manifestations of linguistic capabilities in the right hemisphere are due to early damage to critical areas of the left hemisphere which prompted the other to take over its functions. This has been supported by the small sample of split-brain patients' medical history. At present, the consensus is that the right hemisphere does possess some linguistic ability in the split-brain patients. The extent of linguistic capacity varies from one patient to another. The dominance of one or the other hemisphere depends on the requirements of a particular task (Levy, 1983). The two hemispheres utilize two different modes of processing stimuli under the same conditions of sensory input and motor response. The linguistic capacities of the right hemisphere become apparent only under specialized testing conditions. Under normal conditions, the commissurotomized patient appears normal in his daily behaviour because of the dominance of the left hemisphere.

Mathematical ability is mainly controlled by the left hemisphere. Only very simple tasks, like matching numbers or adding 1 to numbers below 10, can be completed successfully by the right hemisphere of the split-brain patient. They are unable to perform tasks requiring addition or subtraction of two or higher numbers and multiplication and division (Sperry, Gazzaniga and Bogen, 1969). The right hemisphere has also been found to be capable of handling intermodal transfer tasks between vision, touch, hearing and other modalities. A solution learned through auditory stimulation, as an example, is easily transferred into vision or touch, and vice versa. The right hemisphere excels the left hemisphere in emotional sensitivity and spatial conceptions. Based on a series of investigations of spatial abilities in the two hemispheres (Nebes, 1971, 1972, 1973), it becomes apparent that the right hemisphere is superior in spatial tasks. A number of studies has shown that emotional reactions are initiated by the right hemisphere primarily (Gordon and Sperry, 1969; Ley and Bryden, 1979; Lishman, 1971). Thus, the right hemisphere is superior at handling emotional stimuli and spatial tasks.

The phenomenon of consciousness is one of the most fascinating as well as controversial concepts in the human psychological field. Split-brain literature has clearly demonstrated two separate minds after commissurotomy (Bogen, 1977; Gazzaniga, 1970; Sperry, 1966, 1967, 1968, 1974, 1976). A number of investigators believe in two modes of consciousness originating in the two hemispheres (Bogen, 1973; Ornstein, 1977). Bogen (1973) has provided a whole list of dichotomies suggested by various researchers. Sperry et al. (1979) have reported evidence of self-recognition and social awareness in the right hemisphere of the split-brain patient. This has further strengthened the right hemisphere's independent state of consciousness which is comparable to the left. Thus, it becomes obvious that both the left and the right hemisphere play significant roles in higher psychological functions - consciousness. To neglect either is unjustified. Under normal conditions, the two work in an integrated manner.

This duality of mind or consciousness in the split-brain leads to the question of the nature of consciousness in the normal individual. The question of mental duality has received considerable attention with respect to normal individuals with intact commissures. There are two points of view. According to one point of view, there is a single mind in the normal brain. The splitting occurs as a result of commissurotomy (Sperry, 1977). The other view maintains that there are two minds in the normal brain too (Bogen, 1969; Puccetti, 1973, 1976, 1977a, b, 1981). The researchers seem to agree on unity in functioning of the normal brain. The disagreement is related to the issue of 'one or two minds' in the normal individual with intact brain commissures. This controversy at present seems to be far from being resolved.

Split-brain studies on humans have contributed a great deal in understanding lateralization of mental functions as well as limitations of each with respect to linguistic abilities and visuospatial abilities. The characteristics of the right hemisphere have been revealed. All these findings have been helpful to researchers in making attempts to investigate the normal functioning of the human brain. Split-brain findings have been especially useful in discovering the dual modes of processing of stimuli by the two disconnected hemispheres. This discovery of the nonverbal mode of processing information by the right hemisphere provided the basis for exploration of the right hemisphere's functions and specific roles in various complex mental functions. Most importantly, it is realized that the right hemisphere is no less important than the left in complex psychological functioning of the individual.

By the end of the nineteenth century, it was widely accepted that the two hemispheres, despite their physical similarity, are very different in their functions. The left hemisphere came to be regarded as the dominant hemisphere due to its control over language. It was considered to be important in interpreting sensory input and planning and controlling behaviour. The right hemisphere, on the other hand, was considered to be a mere relay center. The right hemisphere was known to control only elementary sensory and motor functions of the left side of the body because these are represented in mirror-image fashion in both hemispheres.

While brain lesion cases and split-brain patients have provided significant experimental evidence for specialization of the two hemispheres with regard to mental functions, investigations of normal individuals regarding hemispheric functions are needed to obtain further clarity on the subject. Findings from normal population studies would certainly be more representative of the functioning of the normal undivided brain. Also, studies of the functioning of the two hemispheres in the normal population are more readily accessible compared with small numbers of patient populations with unilateral brain damage and split-brain surgery.

Though left hemisphere superiority in speech functions had been accepted, no attempt was made to investigate anatomical asymmetry of the brain until 1968 when Geschwind and Levitsky investigated the structural organization of the temporal speech region in both hemispheres. These investigators observed a larger planum temporale in the left hemisphere as compared to the corresponding area in the right in 65 per cent of the brains. Only 11 per cent of the brains had a larger planum temporale on the right. The rest of the 24 per cent indicated no difference. In fact, their study led to a number of investigations on anatomical asymmetry of the brains examined postmortem (Le May, 1976; Wada et al., 1975; Witelson, 1977; Witelson and Pallie, 1973). Other studies on living brains using the techniques of cerebral angiography and computerized tomography or CT scan have been found to be useful in investigating the asymmetry of the brain. Information about anatomical asymmetries and functional asymmetries obtained from studies on the same normal individuals allows the investigator to infer the relationship between the two.

The literature on cerebral asymmetry and handedness are in agreement that asymmetry is correlated with hand-preference. On the whole, right-handedness is related to anatomical asymmetry in one direction and left-handedness with either less anatomical asymmetry or asymmetry in the reverse direction (Witelson, 1980). The phenomenon of asymmetrical functions of the brain observed in split-brain patients has been investigated in the normal human population to obtain further clarity on the subject. The techniques used for such investigations are often called noninvasive because they do not inflict any harm on the individuals. The visual system and the auditory system have been very useful in investigating the degree of contribution of the two hemispheres in a given cognitive function. Kimura's (1961a, b) studies on perceptual asymmetries using the dichotic listening technique provided evidence of lateral differences in the brain. Results of her studies pointed out that crossed auditory pathways gain dominance over the uncrossed ones in auditory perception.

Findings of other studies using tachistoscopic presentation and dichotic listening task were similar to Kimura's findings. Verbal material was found to be more efficiently analyzed by the dominant or "speech hemisphere", usually the left in right-handers. In the case of right hemisphere dominance in speech, performance was better through left-ear presentation of stimuli in a small group of patients as determined by sodium amytal technique (Wada and Rasmussen, 1960). When it comes to non-verbal auditory stimuli, the right hemisphere dominates. A left-ear (right hemisphere) superiority was observed in a group of normal subjects on a musical task (Kimura, 1967). Thus, it is the nature of stimulus that determines the direction of auditory asymmetry, and the asymmetry in turn reflects the different functions of the two hemispheres.

A series of experiments was conducted by Kimura (1969) to determine differences, if any, between the performance of the two hemispheres in spatial perception. Findings clearly indicated a left-visual-field (right hemisphere) superiority in handling visuospatial tasks. On the basis of her findings she also concluded that distinction between right and left hemispheres with regard to visuospatial ability may be more striking in men than in women. Visual studies with normal subjects follow the same technique of central fixation with tachistoscopic stimulation used in split-brain patients. In these studies, the two basic measures are speed and accuracy, the former considered to be more sensitive to lateral asymmetries. Reaction time, a measure of speed, has been useful in understanding the nature and logic of the information-transmission mechanism in the normal integrated brain (Berlucchi et al., 1971, 1979; Buchtel et al., 1978; Geffen et al., 1971, 1972;

Rizzolatti, 1979). In simple visuomotor tasks, the homolateral hand-visual hemifield combination produced faster reaction time than contralateral combination (Berlucchi et al., 1971). These results are consistent with split-brain findings obtained by Gazzaniga et al. (1967). In complex visuomotor tasks, however, the role of the specialized hemisphere becomes more important and, hence, stimuli projected to the specialized hemisphere elicits a smaller reaction time. As an example, letters or alphabets recognized by the right visual field (left hemisphere) give shorter reaction time than the left visual field (right-hemisphere). Similarly, left visual field (right hemisphere) is superior to right visual field (left hemisphere) in recognition of faces (nonverbal material). Thus, the nature of the task becomes important in determining hemispheric asymmetry.

Further, the degree of involvement of each hemisphere varies with different aspects of visual perception. In general, the right hemisphere appears to be of prime importance for complex visuospatial functions as well as for more basic perceptual processes. There is sufficient evidence to show that visual field asymmetry does exist. Controversies surround the dominance of one or the other hemisphere in various tasks. Both hemispheres are involved in processing complex visuospatial discrimination tasks. The difference between the two lies in degree of involvement. This is supported by results related to perception of emotional stimuli (Buchtel et al., 1978). The left hemisphere is faster in identifying ambiguous emotional stimuli. On the other hand, the right hemisphere is faster in analyzing clear-cut emotional tone of stimuli. Hence, it can be safely concluded that for any given task, there is one hemisphere which takes the major role and one which assumes the minor role.

EEG recordings have also been useful in studying asymmetries of the two hemispheres. Electrodes are placed on the scalp of the head and brain activity is recorded while the subject is engaged in a particular task. Galin and Ornstein (1972) were two of the early investigators to study EEG asymmetry in relation to the nature of the task in normal subjects. Their findings in terms of alpha rhythms of the two hemispheres indicated a greater involvement of the left hemisphere in verbal tasks and a greater involvement of the right hemisphere in spatial tasks. A large number of studies have been conducted on lateral cognitive asymmetry using EEG technique. Visual- and auditory-evoked potentials have been recorded from different areas in the two hemispheres using verbal and nonverbal or spatial tasks. In general, they all support lateral asymmetry. In addition, Galin and Ellis (1975) noted that even simple stimuli are processed differently by the two hemispheres depending upon concurrent cognitive activities. Moreover, lateral asymmetry has been observed in infants as as old as 6 months by recording brain activity from both hemispheres during presentations of normal speech and music stimuli (Gardiner and Walter, 1977). In summing up, findings from EEG studies on normal subjects do support lateral asymmetry observed in split-brain patients.

Another technique used to investigate lateral asymmetry in normal subjects is the cerebral blood flow technique. Changes in the activity of various parts of the brain are reflected in the relative amount of blood flowing through those areas. Findings from a few studies conducted support the general asymmetry observed with regard to verbal and spatial tasks. A verbal task showed an increase in blood flow in the left hemisphere whereas a spatial task showed a nonsignificant increase in right hemisphere blood flow. Subjects indicating an increased blood flow in the right hemisphere scored higher on the spatial task in comparison with those indicating either no change in flow or an increased left hemisphere flow (Gur and Reivich, 1980). Again, evidence of lateral asymmetry is clearly seen. It may be noted, however, that cerebral flow techniques are at present not sufficient to obtain information from the deepest regions of the brain.

Sex differences in terms of brain asymmetry have also been pointed out by a number of researchers. Larger perceptual asymmetries have been observed in men than in females on both verbal and spatial cognitive processes (Kimura, 1969, 1973; McGlone and Davidson, 1973; Levy, 1980). Males seem to surpass females in certain visuospatial tasks, indicating more clear specialization of the right hemisphere. Females, on the other hand, seem to dominate males in verbal fluency. This difference is reflected in early hemisphere specialization for visuospatial tasks in boys and in early specialization for language in girls. Lateralization is more marked in men with regard to cognitive processes than in women. In females, there seems to be a lesser degree of asymmetry with regard to verbal and perceptual processes (Levy, 1980). In other words, there is somewhat bilateral representation of cognitive functions. However, at present definite conclusions with regard to sex asymmetry in cognitive functions cannot be drawn.

The literature on cerebral asymmetry in normal subjects provides us with abundant evidence for lateralization of cognitive functions.

A few controversies are to be found but that is only normal in scientific studies. With the gradual development of dichotic listening, lateralized tachistoscopic presentation and EEG techniques, considerable knowledge has been obtained about the functioning of the normal brain. These findings from the normal brain as a whole support the phenomenon of laterality observed in split-brain studies.

The major controversy in the laterality issue has often revolved around linguistic functions of the two hemispheres. Though there is no dispute regarding the left hemisphere's dominance in language among right-handers, a serious problem exists with regard to the functions of the right hemisphere. Due to the nonlinguistic nature of the right hemisphere, it often becomes the target of being labelled as "passive" and "nonresponsive" (Gazzaniga, 1983). However, this is not accepted by all. Levy (1983) emphasizes the fact that the right hemisphere is active as well as responsive. This latter view has received much attention and a revolution towards attributing equal importance to both hemispheres in the field of education is in the air. Each one (left and right hemisphere) has its own method of processing stimuli and makes its unique contribution in the integrated functioning of the brain. In addition to the major difference between the two hemispheres in terms of functions (left hemisphere-verbal and right hemisphere-nonverbal or visuospatial) there is a basic difference between the methods of processing stimuli. The left hemisphere's approach is analytic and logical, whereas the right hemisphere's approach is gestalten holistic. It is the recognition of this basic difference that is very important in the field of education if it intends to provide equal opportunity for learning to all learners.

It is clearly evident that the present educational system is successful in terms of its primary concern for teaching its people to learn how to read and write. However, one can easily notice the widening gap between the needs of students and the abilities of the educational system to meet these needs. The discovery of various technological aids places definite limits to the goals of education. Youngsters are prepared for functioning in a technological society and in the process being less prepared to rely on their own capabilities. Development of sophisticated linguistic and logical-mathematical abilities are given top priority while, in general, spatial, bodily-kinesthetic, and other holistic forms of knowing receive only an incidental or optional status. The domination of verbal and logical-mathematical abilities in the present society considers the acquisition of various basic skills (largely in analytical abilities) the most important in the education of learners. The point, however, is: Are we doing justice to our young learners in terms of recognizing their needs and capabilities? It is well accepted that individuals are not all alike in their cognitive potentials and, hence, an effective educational system would be one that is tailored to the capabilities and needs of the particular individuals involved. In fact, as Gardner (1983) rightly points out, the cost of trying to consider all individuals the same or attempting to teach them in ways not suited to their preferred modes of learning may be very high in the long run. Hence, it is high time educators take a break and redefine their priorities for education. In order to redefine educational objectives, a great deal of knowledge available from brain research literature, especially split-brain, can be extremely useful. There is a growing need for educational and medical professions to work in collaboration to achieve a common goal - "the development and maintenance of a healthy brain and body" (Sylwester et al., 1981).

Epstein's (1974a, b, 1978, 1979) discovery of brain growth spurts related to the child's chronological age has important implications for education. Since mental growth is related to brain growth which occurs in "spurts" with in-between plateau periods, it is necessary to give special attention to the five stages of brain growth in the field of education. According to Epstein's theory, the brain growth periods are to be utilized for presentation of new material (related to Piaget's (1969) cognitive stages of development which corresponds to Epstein's brain growth stages) in learning. In other words, the content of the curriculum should be matched to the cognitive level of the child. The plateau periods on the other hand should be utilized for consolidation of materials learned in the previous growth period. Introducing learning materials that the child's brain is not ready to handle might place undue pressure on him often leading to learning problems and even loss of interest. This untimely burden may further lead to failures to deal with complex problems later when the child is equipped in terms of brain growth (neural connections have developed). The essence of Epstein's theory is that during critical age periods, spurts of brain growth occur that, in turn, prepare the child for handling complex tasks related to his cognitive development. Each brain growth period then becomes extremely important for each child's learning process. Hence, children need to be exposed to new intellectual challenges only during critical brain growth periods.

The school plays the key role in helping the child to move from one cognitive stage to another. It also directs him towards expanding his scope of experiential knowledge. The main role of the teacher is to find out the best method to reach the child at a given age level. This is dependent upon the cognitive level of the child. Once the cognitive level is determined through analysis of results from a test that emphasizes a single mental behaviour (like the one developed by Michael Schayer), the task is simply to present materials that match the reasoning level of the child. Or simply, by observing student behaviour, the teacher can find out the reasoning level of the child and then tailor their presentation of learning material accordingly. To sum up, the teacher's efforts combined with appropriate learning materials are critical to an optimum level of learning in children.

Knowledge gained about our cognitive functions from split-brain research has a lot to offer in the field of education. The cerebral cortex which is the most important part of the human brain consists of two hemispheres (with identical control centers) normally connected via a large bundle of nerve fibers known as the corpus callosum. In the normal brain, the two hemispheres function in an integrated manner. However, with the disconnection of the corpus callosum, the individual is left with so-called "two brains". The split-brain operation has made a major contribution in investigating complex psychological functions in man. Findings from split-brain operations led to the discovery of the major characteristics of the two hemispheres. It is well established now that the left hemisphere in normal right-handers is responsible for language and logical-mathematical abilities. The right hemisphere deals with visuospatial abilities, music and creative arts. This is the general distinction, although there is no clear-cut demarcation line between the two. Higher psychological functions are carried out by a joint activity of the two hemispheres (Luria, 1966a, b). One basic difference between the two lies in their mode of processing stimuli - the left uses an analytic mode and the right uses a holistic mode for processing stimuli. In other words, each individual brain possesses two modes of processing information.

The present educational system is mainly a reflection of a left hemispheric mode of processing stimuli. The emphasis is on logical-mathematical abilities of the child. Words and symbols have special significance. Far too much emphasis is placed on information gathering and much less on the process of learning. More time is spent on memorizing the results of other individuals, thinking at the expense of the child's own process of learning. Concepts of 'measurement' and 'objectivity' are continuously emphasized in dealing with behaviour. Any data that cannot be accommodated into the S-R paradigm are unquestionably rejected. Measurement of intelligence or I.Q. test is very common in the schools. These I.Q. tests (usually consisting of a verbal and nonverbal section) are again biased in that more emphasis is given to the verbal test scores. The greatest disadvantage is that based on these I.Q. scores, a child is judged and a sort of general impression is formed which can be often misleading. Age/grade norms are emphasized. Teaching for right answers is the general rule which, in turn, promotes fear of ignorance and an unhealthy guilt complex about ignorance in the child. The whole approach to teaching is thus a lopsided one (dominated by our left-brain) in which the other partner (right-brain) remains silent and invisible. To put it in simple terms, only one half of the brain is being educated.

It is interesting to note that at least now we are able to sense that there is a lot of talk about the two modes of the brain. The importance of both modes of experiencing the world is gaining popularity all over the world. However, what has happened is that two viewpoints seem to have emerged. According to one viewpoint - the traditional one - only the left hemispheric mode of perception is important and, therefore, must be utilized in teaching. The other viewpoint (right hemispheric) as Kettering (1979) puts it:

> ... demands that we emphasize the development of our understanding of the "big picture" (using our holistic abilities), that we provide students with the opportunity to see how various elements of a topic relate to each other, and that we provide kids with experiential approaches to accomplish this - activities involving all of the senses, in other words, involving the total person or the "whole child" (p. 33).

The point, however, is that neither one is a comprehensive approach and falls on the extremes of the continum. A complete right hemispheric approach would be equally disastrous in terms of educating just half of the potentialities existing within any individual brain. What is needed, in general, is a balanced approach so that children can operate in both modes and function successfully in school and ultimately in the broader spectrum of the society. They need both analytical abilities as well as holistic abilities to develop their full potentialities. We now know that each individual possesses two modes of processing stimuli and that usually one is dominant. Individuals differ in their dominance of mode, hence instruction employing only one mode of presentation might be suited for only one group of individuals. In a school setting where some children may be left-mode dominant and some right-mode dominant, an entirely left-mode or right-mode oriented approach may very well educate only half of its learners. Moreover, the other half left out may be labelled as "slow learners" or "problem kids" when the reality may be that these learners are not being reached because of the method of instruction that is inappropriate to their needs.

Hence, keeping in perspective the duality of the brain not only in terms of its functions but also in its mode of functioning, there is a strong need for implementing a change in the educational system in the schools. Since a great deal already is known about the left hemispheric functions but not as much about the right hemisphere, it is just appropriate to point out some of the important features of the right hemisphere that are not encouraged in education. Intuitive imagination, metaphoric thinking, music and creative arts fall within the right hemisphere domain. Intuitive imagination has been found to contribute in scientific inventions too. Yet it is not encouraged in youngsters. Often, thinking in images is considered to be 'abnormal'. Similarly, music and creative arts are not given priority because these are not "academic stuff". In fact, music and art classes might be good for relaxation after "heavy stuff" like maths and science. Also, children who have a feel for music or art may very well benefit a lot from those classes. Now that we have achieved greater understanding of the capabilities of the human brain, attempts can be made to educate the whole brain.

First of all, an awareness of recent findings from brain research is to be created among teachers, policy-makers as well as parents. Teacher training programs could include a brief course on this subject. It is not to be implied here that they are expected to learn neuroscience, rather a basic knowledge about the structure of the brain (cerebral cortex), its course of development, its asymmetrical nature and its dual mode of processing information would be very helpful in dealing with children with varying degrees of orientation towards left and right hemisphere functions. An elementary knowledge of the dualistic feature of the brain is essential for parents too for they are the immediate influential figures for their children. Often, parents channel their children's education from early years towards a profession that they think might be good in the long run (both in terms of status in the society as well as in income). This, however, may be damaging to their children if their interest and capabilities are not in line with their parents' aspirations. Hence, knowing the mental capabilities of their children, parents might provide a conducive environment. Further, establishment of programs that introduce a holistic approach to tasks may be useful experiences for educators and parents. Drawing exercises designed by Edwards (1979), for example, can be interesting and useful in experiencing the shift from the usual analytical approach to a synthetic global approach. This experience may lead to a better understanding of a different approach to experiencing the world.

The next step would be to reexamine the existing curriculum in the schools. It is not the content of the curriculum that needs to be revised, rather its process or method of implementing the curruculum that needs to be reconsidered (MacKinnon, 1981). The basic subjects of reading, writing and maths as well as other subjects like social studies, science, physical education, art and music can still be part of the curriculum. Only methods of teaching as well as learning need to be revised. Priority has to be shifted from subject matter to "learners". It is important that each learner is being reached out to in the classroom situation. Since individuals vary in their abilities and in their method of comprehending and expressing, only one method of teaching (the left-brain approach) would never work. It is here that the teacher assumes an important responsibility in being free to some degree in using their own instructional methods in the classroom. With an awareness of the two modes of learning, the teacher can incorporate methods of instruction that stimulate both sides of the brain, thus leading children to develop their full mental potentialities. Not only that, using both modes would provide for equal participation of all children (left-hemisphere dominant or right-hemisphere dominant) in the classroom. In addition, each student would get a chance to strengthen their weak abilities to some extent. In general, students would increase their learning experiences by going beyond the limits of verbal-analytical rationality.

Being exposed to two different ways of thinking, students would increase their ways of dealings with various complex tasks. Some activities like sports, art and music require an "intuitive feel" which is beyond the limits of the left hemisphere. In academic subjects (left-brain tasks) such as maths and science too require right-hemispheric ability for achieving a better understanding. The majority of creative inventions are results of an "intuitive leap" that are later analyzed into logical steps for left-hemispheric understanding. Hence, right-hemispheric mode of processing has to be taken into account while presenting various subject materials.

Closely linked with this balanced approach to teaching is the method of student evaluation. The current method of evaluation in general is based upon the student's ability to deal with linear and sequential functions. Most of the tests given are language dominated, they may evaluate only a section of students who are linguistically oriented (left hemisphere). Therefore, nonlanguage-based tests are needed to give equal opportunity to students who are superior in their nonlinguistic abilities (right hemisphere mode dominant). It just might be true that many students are misjudged due to inappropriate tests administered for evaluation purposes. Buzan (1983) has emphasized the use of "mind maps" for recall and creative thinking. In simple terms, students may be allowed to express themselves in a diagrammatic form that uses less language but definitely includes all the facts. To sum up, the method of evaluation should concentrate on whether students have understood the concepts or not regardless of their mode of expression.

It appears well established now that learners or individuals differ in their preference for processing information - either a left mode or a right mode preference. Hence, a multimodal presentation of curriculum materials would satisfy the needs of all learners. The most simple method then would at least incorporate verbal (left hemisphere) as well as visual (right hemisphere) stimulation. Verbal concepts can be presented in the traditional manner (textbook materials) as well as supplemented by charts, maps, overhead transparencies and manipulable objects to help children visualize verbal concepts. With choice available, students could select their preferred mode in learning. Also, it has been noted that a combination of verbal processes and imagery enhances learning (Wittrock, 1977). However, to avoid the extreme categories of left mode learners or right mode learners, the teacher can present some materials using only one mode of presentation - verbal or visual. Thus, a balance can be maintained and at the same time students can get an opportunity to develop their non-preferred mode. Individuality as well as some degree of diversity needs to be encouraged in each learner for his total mental development.

An important issue in teaching does not involve finding out the dominant mode of each learner, but rather the selection of different modes of presentation that would increase interaction between the two hemispheres (two modes of processing). At the same time, it is necessary to determine beforehand what modes are stimulated by a particular instruction material. This would further aid the teacher in planning different lessons for various subjects.

Though it may be beneficial to match instructional design with the preferred mode of each learner for maximum learning, the initial step in the author's opinion would be towards utilizing a balanced approach to teaching using both verbal and nonverbal modes. Individualized instruction at present seems premature. The balanced approach can be utilized in teaching any subject, whether it is reading, science, maths, geography or history as given in detail in the preceding chapter. Subjects like science and maths are taken for granted as being left hemispheric tasks. We have to break this conception. Evidence from brain research has made it amply clear that there is a difference in the two hemispheres' functions; more complex tasks require coordinated efforts of both hemispheres. Hence, both hemispheres need stimulation and training in education for optimal learning.

While utilizing both modes in teaching, it is at present important to encourage right hemispheric characteristics of imagery, metaphoric thinking and creativity. Since the left hemispheric mode is already being stimulated, the right hemispheric mode needs extra attention to achieve a balance. Once a balance has been achieved, then equal attention can be given to both modes. In the meantime, let us hope that we do not create "right brained ruts" in the next decade or so.

Cerebral asymmetry research findings have made a valuable contribution in the field of education by providing scientific evidence for constructing a more diversified curriculum that incorporates at least two modes (verbal and visual-spatial) of presenting curriculum material. There is no need for a complete revision of the contents of the curriculum. Development of both hemispheres is important in the field of education to promote a more integrated holistic learning in all learners, both male and female. The time has come for giving serious thought to implementing a change in the rationale of the present curriculum and training holistic individuals for tomorrow. We have trained sufficient "analytical" persons. Finally the author would like to end with a concluding note by Gardner (1983):

> ... since some individuals [teachers and educators] will continue to assume responsibility for planning the lives of others, it seems preferable that their efforts be framed by our growing knowledge of human minds (p. 393).

In conclusion, the author would like to remind the reader that the present thesis deals with only the neurophysiological findings related to higher cognitive abilities and attempts to draw their implications for education. The findings indicate that only one 'left' half of the brain is being emphasized in the schools. Here I would like to point out that enough studies have not been done to assess the current practice of teaching in the schools. This is desperately needed to implement changes in the curriculum in light of the recent advances in split-brain research. In light of the neurophysiological basis of this thesis, the author's view should not be inferred to favour a strict categorization of children on a biological basis. My intention is to devise ways for enhancing cognitive capacities all children possess, by creating an awareness among educators of some of the long ignored capacities of the other 'right' half of the brain.

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