TAPPING THE BICAMERAL MIND:
A NEW APPROACH FOR PETROLEUM ENGINEERING MANAGEMENT

Elizabeth A. Underwood
Chevron U.S.A. Inc.

INTRODUCTION

The petroleum industry has had to curtail incoming manpower in the last few years due to a changing economic landscape. This change has made optimal use of engineering resources imperative. The optimization need not cause major upheavals within the industry. A shift in managerial thinking and a strategic integration of engineers and engineering managers into functional syndicates will aid in tapping the engineering energy and expertise present in an organization.

The human brain processes information in several ways. Individually, these brain processing patterns determine how a person perceives and processes information. If the various processing mechanisms are drawn together, a powerful decision-making/problem-solving entity is formed.

The discipline of petroleum engineering possesses within it areas of expertise that require different information processing mechanisms. All of these areas require, to a degree, the linear, exacting method of problem-solving common to all forms of engineering. Further differences exist, however, between the various functions of petroleum engineering. A reservoir engineer must have the ability to see a geologic structure thousands of feet below the earth's surface and envision the ebb and flow of fluids within the porous rock. A production engineer is required to monitor the operation of pumping units, tank batteries, and similar equipment in order to optimize well productivity. In many engineers, these functions overlap, but both functions require separate information processing systems. The reservoir engineer must access his spatial, or analog, system, and the production engineer must access his mechanical, or digital, system.

The purpose of this study was to evaluate a sample of petroleum engineers to determine the presence or absence of definitive information processing patterns within assigned functional classifications. The results of this study could provide petroleum engineering managers a means of tailoring engineering teams to work with optimal effectiveness both together and separately. The concept may further be extended to the management of a company by choosing managers to operate in particular capacities according to their information processing and managerial styles. The identification of brain dominance patterns may become invaluable in the strategic development of companies over the long term by providing a method to optimize the resource of engineering expertise available.

REVIEW OF LITERATURE

Anatomy of the Brain

During the time of the ancient Greeks, the human brain was studied as a composite of myriad parts, each with a specific function making up the whole of man's motivation and behavior. During the Middle Ages, the Dark Ages for science, the study of medicine was reduced to little more than folklore and superstition, and the wealth of knowledge handed down from the Greeks was regarded as heresy. In the ninth century, the School of Salerno reestablished the learned tradition in Western medicine on which modern science is based.

By the nineteenth century, the brain was once again studied as many parts comprising a whole. Although many of the conclusions of the researchers during this time have been proved incorrect, the resurrection of the study of brain mechanics has led to enormous strides in brain theory during this century. Neuroanatomists now have a clearer understanding of the brain's functions and the integrative roles of these physical locations within the brain in shaping these functions. Although current theory supports a "whole brain" concept, that is, brain functions are distributed within the entire brain, some functions can be localized in specific portions of the cerebrum.

Before mapping the various functions of the brain, a basic understanding of brain anatomy is necessary (Figure 1). The human brain is an electrochemical organ weighing less than three and one half pounds. Comprising only two percent of human body weight, this organ is the most active energy consumer. During normal activity, the brain accounts for twenty percent of the body's oxygen usage. The basic component of the brain is the neuron. The brain contains 100 billion neurons, no two of which are alike. These neurons communicate by means of 1000 to 10,000 links. The two cerebral hemispheres are joined by the corpus callosum consisting of 300 million nerve fiber connectors.

From an evolutionary standpoint, man possesses a triune brain, a brain made up of three distinct parts. Paul MacLean, of the National Institute of Mental Health, Laboratory of Brain Evolution, has described a triune brain. The first, and oldest, is the R-complex brain system, or the archipallium. The R-complex dates from the Mesozoic Era and is commonly referred to as the reptilian portion of the whole brain. This lumpy mass of tissue is about the size of a lemon and grows out of the upper end of the spinal cord. The second brain system is the limbic system, or the paleopallium, and is wrapped around the old R-complex. This brain system developed shortly after the decline of the dinosaurs. The third brain is the neocortex, or neopallium and comprises the outer layer of the whole brain. These three brains did evolve one from the other. Each brain evolved independently in response to man's changing survival needs. The triune brain is best regarded as a superimposition of one brain into another.

Each portion of the brain just mentioned has definitive characteristics. In many determinations of brain function, researchers must look at a damaged brain. From outward symptoms and tests identifying a disturbance of the brain's functions or behavior, it is possible to deduce the location of the lesion causing the disturbance. From many such cases, neuroanatomists have managed to describe the character of specific brain parts. Starting with the primitive R-complex, this brain is characterized by motives activating aggression, territoriality, and xenophobia. Functionally, the R-complex can further generate two types of behavioral flows. The first is characterized by slavish, ritualistic, magical and territorial senses. The other side evoked the devious, cunning, savage, and stalking senses of early man. The limbic system as a whole is the brain's primary source of emotionality. The limbic system houses two emotional frames of reference. One frame embodies dedicated, organized, and crusading behavior. The impulsive, sociable, spontaneous, and risking senses arise from the other mind frame of the limbic system. The programming of the limbic system and the R-complex is extremely powerful and must be controlled and monitored by the neocortex. Otherwise, the brain would act only on impulse. The neocortex may be described overall as the logical, methodical, and most highly organized part of the mind. The cerebral cortex is divided into two cerebral hemispheres. Each hemisphere is divided into four portions called the frontal, parietal, temporal, and occipital lobes (Figure 2). As in the previous discussion, each lobe has definitive characteristics of function and behavior. Alexander Luria, the great Russian neurophycisist, studied the frontal lobes extensively. He found that the frontal lobes perform no sensory or motor functions. Injury to these lobes will result in no loss of sensation, movement, perception, or speech. The frontal lobes are connected to the brain stem and serve primarily to activate the brain and to regulate attention and concentration. Luria found that these lobes participate to a great degree in every complex behavioral process. Luria also determined that portions of the parietal and occipital lobes are the site of spatial analysis. These lobes and the concept of hemispheric asymmetry will be discussed in greater detail in later sections.

The single most significant ability differentiating humans from animals is the ability differentiating humans from animals is the ability of speech. Anatomically, the speech areas of the brain are located in the supplemental motor cortex, Broca's Area and Wernicke's Area (Figure 3). The development of speech resulted in the profound changes in the human brain during the Pleistocene Age. The nature of speech ability and its role in the determination of brain dominance patterns will be discussed in the next section.

Lateralization of Speech

A marked characteristic of the human brain is the enlarged forebrain not present in lower animals. This enlargement was forced by the development of speech and language. Research at the University of Tokyo has concluded that the brain is programmed by the vocabulary and sentence structure of the language that is spoken. This programming is the lateralization of speech function. In 1861, a young French surgeon, Paul Broca, began his study of the localization of speech function in the human brain. By 1864, Broca had convincing evidence that the speech centers were localized in the frontal lobes, and further were lateralized in the left hemisphere. Contemporary neuroanatomists accept that most human speech capabilities are located in various places in the left hemisphere. Speech is not, however, localized in the frontal lobes alone.

In addition to speech ability in the frontal lobes, specifically Broca's area, researchers have also identified function in the supplementary motor area and in Wernicke's area. The supplementary motor area, on the top of the left frontal lobe, is involved in the articulation of speech. Broca's area, lower down at the back of the left frontal lobe, is involved in articulation, vocabulary, inflection, and the complexities of grammar. Wernicke's area, comprising the posterior part of the left temporal lobe and parts of the parietal area, is responsible for vocabulary, syntax, interpreting meaning, and understanding speech. Damage to these areas produces a variety of disfunction. Damage to the supplementary motor area produces a loss of speech that is cleared up in several weeks. Damage to Broca's area results in a loss of speech that is permanent in some patients and not so in others. Damage to Wernicke's area is most severe, and results in a permanent loss of meaningful speech.

The lateralization of speech ability has led to the study of hemispheric asymmetry in the brain. Not only is speech localized in specific portions of the cerebrum, but other abilities area as well. The following section will explore this division of labor between the left and right hemispheres.

Hemispheric Asymmetry

Neurophysical research has shown that each hemisphere of the brain is capable of perceiving, learning, remembering, and feeling independently of the other, but that some differences exist in the way in which each hemisphere deals with incoming information. This asymmetry is not a product of modern civilization. Marjorie LeMay has found that right-left differences emerged approximately 30,000 years ago. In The Right Brain, Roger Sperry is quoted:

> ...we deal with two separate spheres of conscious awareness, i.e., two separate conscious entities or minds running in parallel in the same cranium, each with its own sensations, perceptions, cognitive processes, learning experiences, memories and so on.

Sperry conducted research at the California Institute of Technology on split brain patients. These patients had undergone a commissurotomy, surgically separating the corpus collosum and selected commissures connecting the hemispheres. Sperry's research provided an excellent opportunity to observe the behavior of two separate processing mechanisms within the same brain.

The most obvious example of the concept of asymmetry is the differing abilities of the two hands. Most people possess a dominant hand. The brain controls the body in a contralateral manner. The left side of the brain controls the right half of the body, and the right side of the brain controls the left side of the body. Handedness may be used as a predictor to determine the organization of higher functions in the brain. The hemisphere controlling the dominant hand almost always controls speech also. One would expect, therefore, that right-handed people would possess speech function in left hemisphere and left-handed people would possess speech function in the right hemisphere. Handedness is not, however, always reliable in determining the location of speech centers. Eighty-five percent of the world's population is right-handed. Ninety-eight percent of those process speech in the left hemisphere. Fifteen percent of the world's population is left-handed or ambidextrous. Only thirty percent of this sample process speech in the right hemisphere. It is obvious that a significant portion of the population does not fit the simple hypothesis of contralateral hand and speech dominance.

A more descriptive terminology would be to consider the two cerebral hemispheres in terms of their function and not their geography. The hemisphere housing the speech centers of the brain can be considered the "digital" hemisphere, and the other may be considered the "analog" hemisphere. Extensive laboratory research has led to this terminology. The electroencephalograph (EEG) has been used to identify areas of brain activity during the performance of certain tasks.

The EEG is a pattern of changes in electrical activity in the brain at a particular moment. Alpha waves and beta waves are used to determine hemispheric activity. Alpha waves are low-voltage slow waves present over the entire brain in a resting state. When the brain is active, low-voltage fast waves, or beta waves, suppress the alpha waves in the area of activity. When subjects respond to verbal stimuli, such as spoken or written words and syllables, brain activity is higher in the digital hemisphere. When the stimulus is a dot pattern or the task is a spatial one, greater brain activity is in the analog hemisphere. Moreover, there is a differentiation in the perception of verbal stimuli. When subjects are asked to read technical literature, greater activity is in the digital hemisphere. When the subjects read stories with metaphor, imagery, and elements of emotion, surprise, and humor, greater brain activity is in the analog hemisphere.

An equally significant implication for establishing hemispheric dominance relies on a chemical reaction in the brain. This dominance ensures the continuance of the electrical activity monitored by the EEG. Chemical nutrients are found in the body's blood supply, and, with the addition of low-level radioactive tracers, the blood flow through the body can be monitored. The tracer is introduced into the blood stream by way of an inert gas inhaled by the subject. When similar tasks as those in the EEG research are administered, the active portions of the brain "light up" on the monitoring screen. Although activity is present throughout the brain, a greater concentration of activity is present in the expected hemisphere.

The research just cited emphasizes two information processing mechanisms located in two distinct parts of the brain. The fact that the radioactive tracers in the previous example show activity in other areas of the brain, not just the analog or digital hemispheres, implies that the two distinct information processing mechanisms exist over the entire brain. The mechanisms themselves are separate entities. The emphasis in this study will be on the analog and digital processing mechanisms and not on the analog and digital processing hemispheres.

Investigators of this subject have postulated that a "basic incompatibility between the mechanisms generating the processing styles" accounts for the evolution of these two styles into two distinct entities. In the course of evolution, the functions of the analog and digital processes began to diverge. Areas inclined toward digital processing become more adept at generating rapidly changing motor patterns such as those involved in the fine control of the hands and vocal tract. These areas also became increasingly skilled at dealing with the rapidly changing auditory patterns produced by the vocal tract during speech.

Individually, the digital process is more skilled at sequential processing in general, and is, therefore, the more analytic of the two processes. It is important to note that this mode of processing applies to all incoming data, not just speech. Visual information accessed by the digital process is treated in an analytic manner by being broken up and reorganized in terms of features. Brenda Milner of McGill University in Canada believes that verbal memory is a digital processing characteristic. Alexander Luria and Roger Sperry have presented evidence that the digital process is dominant in mathematics and mathematic manipulation. Perhaps the predisposition of the digital processing mechanism toward memory and speech accounts for the fact that over long periods of time the brain exhibits slightly more digital activity. The activity in the brain has been found to switch between the digital and analog processing modes about once every minute. As the digital process became specialized in analytic processing, the analog mode became "more adept at simultaneously processing the type of information required to perceive spatial patterns and relationships." This specialization may be the outgrowth and elaboration of the processes considered basic to vision and visual memory, or imagery. The analog process is more holistic and synthetic in handling all kinds of incoming information. The analog processing mode is superior in the perception of part-whole relationships. This process is also responsible for certain spatial skills and musical abilities. Geometry and spatial math, such as subsurface geologic structure is handled by the analog process. The specific processes involved in the analog mechanism are distributed over a larger area in the brain than those involved in the digital process. This is perhaps because of the holistic and simultaneous posture of the analog mind. A characteristic of the analog process is what is regarded as intuition. A problem is presented to the whole brain. The analog mechanism quickly produces an "intuitive" response while the digital process more laboriously analyzes the problem and delivers its solution sometime later. Oftentimes, the "intuition" and the true solution agree. Researchers believe that the reason the analog solution takes the form of intuition is that the analog mode has no speech, that is, no language or code, to explain why or how the conclusion is reached.

The analog processing mechanism is, therefore, elaborated on and refined by the digital processing mechanism. The true differences in the processes is in their perceptual ability. For example, both perceive a spatial relationship equally well, but the digital mode translates the information into a sequence of features representing lines and spaces. The analog mode perceives the relationship as a three-dimensional grouping of surfaces in space. Both perceptions are necessary for a full understanding of the spatial relationship presented.

David Loye, co-director of the Institute of Future Forecasting, describes this processing duality as "our linear, mathematical intelligence" and our "visual, mechanical, intelligence." Further, Loye describes the digital information processing network as the analysis of the flow of information one bit at a time. He describes the analog processing network as an analysis of information as a whole in a parallel and simultaneous sense. Jerre Levy of the University of Chicago describes the processes as two strategies: the digital analytic strategy and the analog holistic strategy. As early as 1829, England's first psychologist, James Mill, described two kinds of thinking. Mill wrote about a thinking process utilizing successive order, or order of antecedent and consequent existence (the digital network , and a thinking process utilizing synchronous order, or order of simultaneous existence (the analog network). Mill's early identification of two thinking processes leads to the idea of the analog space-bound visualizer and the digital time-bound calculator operating together in one mind. The splitting of information processing operations provides the basis for the concept of our analog mind providing our spatial world wherein our digital mind marks off time within it.

The Metaphor of Space and Time

The earliest and most basic orientation of the human mind, and of all other life forms, is to space. The analog processing network depends greatly on an internal sense of space to assimilate incoming information.

Time, however, is a fabrication of the stereotypical digital sense. The sense of time developed within the temporal lobes of the limbic system at the time when the functions of the analog and digital processes began to diverge. Janos Holubar has found that the brain's alpha waves, at a frequency of ten per second, may be man's referent when estimating time in terms of minutes. The human brain has internalized the sense of time in the course of evolution. Neurosurgeon Joseph Bogen has explained that, because of the digital mode's specialization for serial processing, this network is the site for our sense of "clock time." Bogen further explains that possibly the most important distinction between the processing systems is "the extent to which a linear concept of time participates in the ordering of a thought."

Although time is accepted as a digital sense, the analog network also has a sense of time within a spatial framework. David Loye describes this time as "spatial time" and believes that this sense orients us within the "serial time" of which we are aware. Spatial time is internal and offers no external perception, but is responsible for the concepts of past and future. Serial time is only aware of a sequence of events as they occur. Spatial time is aware of the passing of time. Luria has pointed to these two senses of time as neural mechanisms evolved for the job of world construction. Spatial time allows the orientation of the body in space or the "synthesis of stimuli into simultaneous groups, essential for the creation of an adequate image of the outside world." Serial time is responsible for "the integration of individual stimuli arriving consecutively in the brain into temporally organized, successive series." A good example of the concept of time within a spatial framework is the new conception of time within the context of physics. The analog based visual space-time diagrams have been added to the digital power of mathematics. This conception of time has been sited as a reason for the tremendous jump in physics research since World War II.

This concept of time is also involved in the functional sequence of the brain. The brain's functional sequence is the basis for the complex mechanics of planning and will be discussed in the next section.

Planning - A Functional Sequence in the Brain

Thus far, this review has examined the brain in an evolutionary sense, from bottom to top, and in a processing sense, from side to side. The brain also has specific functional abilities from back to front. Alexander Luria did extensive research on the functional abilities of the brain. Luria found that the frontal brain has a crucial involvement in planning, programming, and intentions. He stated that the frontal lobes play "an essential role in the synthesis of goal directed movement."

The planning process is a complicated, iterative function. The brain first reacts with attention to a potential problem requiring solution. The brain's problem solving system is then activated, simultaneously screening out all irrelevant matter. The problem solving processes involved refer to past experience by means of active recall maintained in the frontal lobes. The problem solving systems then identify the problem and it is separated, classified, and analyzed by components. A formative question is projected in the form of a hypothesis. Next, the frontal lobes project a goal for action. This is the portion of the planning process that sometimes causes anxiety due to its complexity. The brain signals the necessary motor and speech functions to activate the plan. Finally, the brain monitors the result by means of feedback loops and compares this feedback with the original goal. Described sequentially in this manner, the planning process appears impossibly cumbersome, but the brain goes through a similar series of steps whether the "problem" requires a fraction of a second to make a decision or weeks of data collection and mathematic manipulation to complete a project.

The frontal lobes may be considered a manager of the analog and digital information processing networks in the way in which it calls upon both to work in the planning process. The ability to plan and carry out courses of action is extremely important. Patients with damage to the frontal lobes have difficulty in creating plans, choosing action corresponding to these plans, and carrying out any course of action decided upon. Luria studied patients with frontal lobe damage and found that they were unable to

> analyze the component elements of the conditions, formulate a definite strategy for the solution, carry out the operations required by this strategy, and then compare the results with the original conditions.

Data gathered by Luria and later researchers has further defined planning and execution in terms of the location of brain activity. The planning/execution process is begun in the region of the temporal and occipital lobes. The amygdala, located in the temporal lobe, controls arousal and is necessary for sensory detection. The temporal/occipital area regulates the energy level and tone of the cortex and provides it with a stable basis for the organization of its various processes. This area contains components of parts of the brainstem and those areas controlling wakefulness. Disturbance of this area inhibits the discrimination of stimuli. This region is the mechanism by which the brain identifies a situation requiring resolution.

The next area involved in the planning/execution process is the parietal lobe. This lobe plays a decisive role in the analysis, coding, and storage of information. Disability in this area seriously impairs the ability to handle complex problems that entail an organization of input in simultaneous matrixes. Anatomically, this function involves the basal ganglia necessary for activation of the information processing mechanisms.

Once a situation requiring attention is identified and the information processing modes are activated and receiving input, the hippocampus connected to the frontal lobes coordinates the arousal and activation of the temporal/occipital area and the parietal lobe. The frontal lobes are responsible for the formation of intentions and programs for behavior. It is this area that is involved in the execution of the plan constructed by the activation of the parietal area.

The functional sequence in the brain is therefore: (1) sensory detection, (2) plan construction, and (3) plan execution. All portions of the sequence are operating in a simultaneous manner when a problem is presented, but one or two of the three are usually dominant.

The Whole Brain Concept

All the previous discussion has dealt with the brain as parts comprising a whole. A significant new concept is that of the whole brain. The brain acts as many brains all at once - high, middle, low, right, left, front, and holographic. It is the holographic descriptor that has led to the whole brain concept. Each part of the brain contains the sum of all the parts as in a hologram.

Many brain parts are involved in all activities, but one or two areas play a more important role than others at a particular time. The brain has no "command center," but is a network of interacting brain structures. The cerebral hemispheres are connected by the millions of fibers in the corpus callosum. This connection links the reasoning and speech capacities of the digital processing network with the mapping and imagery of the analog processing network. Brain processes do not involve one information processing network to the exclusion of the other. Rather, the relationship between the two is usually the dominance of one or the other depending on the nature of the activity. Researchers have found that when one processing mechanism is engaged, the other will suppress itself as if to reduce interference with the more active mechanism. The interaction between processes is necessary. The analog process by itself has very poor logic and language ability, and the digital process by itself lacks the creativity found in the analog mind. The most creative problem solving requires the integration of both processes' unique abilities. Most people do seem to favor one mode of information processing over another, but others are double dominant managing to counterbalance the chaos of the analog with the order of the digital. Creativity may be enhanced in those people whose brain structure permits a greater interplay between the verbal and non-verbal abilities.

PROCEDURE

This study was designed to identify the brain processing patterns preferred by groups of petroleum engineers. The instrument selected for examination was developed by Don Edward Beck, director of the National Values Center in Denton, Texas. The procedure followed in conducting this study was divided into the following three areas: (1) selection of sample; (2) collection of data; and (3) statistical analysis of the data.

Selection of Sample

The sample used in this study consisted of two nested samples: Sample 1 and Sample 2. Data from an expected source was not available, making it necessary to combine the data collected by the researcher with similar data from the National Values Center. For the sake of clarity, Sample 2 will be discussed first. Sample 2 consisted of 89 respondents to an expanded version of the BrainScan Assessment System. This expanded version was designed to evaluate a total of 18 descriptive measurements of information processing and functional sequence. The respondents in this sample included petroleum engineers from various departments and at various levels of management from several major and independent oil companies. This sample also included a group of petroleum engineering educators.

Sample 1 consisted of 86 petroleum engineers responding to an earlier version of BAS administered by the National Values Center. This earlier version evaluated only the information processing measurements of BAS. The scores on these nine measurements from the 89 member sample and the 86 member sample were normalized and combined to provide a total sample of 175. The scoring mechanisms used on each version of BrainScan were identical in design. When the scores on the information processing measurements of the two samples were normalized, no discrepancy in scoring was involved. Therefore, Sample 1 was used to evaluate 175 petroleum engineers on the nine earlier measurements. Sample 2 was used to evaluate 89 petroleum engineers on the nine newer measurements.

Collection of Data

Data for Sample 2 were collected through the administration of BAS to petroleum engineering faculty, to participants in professional industry courses representing a variety of oil companies, and to employees of one independent and one major oil company. Data for Sample 1 included the pertinent data from Sample 2 and data from petroleum engineers employed by a major oil company evaluated by the National Values Center.

In addition, the engineers in Sample 2 were requested to complete a Professional Information survey. These data were used to determine the engineers' professional classifications and job satisfaction. This survey was, of course, not available to the respondents in Sample 1.

Research Instruments

The key research instrument used in this study was the BrainScan Assessment System (BAS). BAS is designed to determine the information processing network preferences of individuals, or the combination of preferences accessed by a group of individuals. The instrument evaluates responses to a variety of questions to quantify the respondents' brain processing patterns (digital or analog), as well as a multiplicity of other aspects of brain processing.

The BrainScan Assessment System was validated on a sample of 1275 respondents in 1984 at a university in the Southwestern United States. This sample represented a cross-section of professionals in the United States and other countries. Among the respondents in this sample were engineers from disciplines other than petroleum engineering, educators, communicators, and corporate executives. Validity of BAS was established by reviewing the literature from which items in the instrument were derived (content validity), by utilizing additional instrumentation (criterion validity), and through factor analyses (construct validity).

BAS reports on a total of 18 measurements of the brain's processing mechanisms. Information processing mechanisms are quantified by means of the Analog Dominance and Digital Dominance scores. The extent to which the cerebral cortex and the limbic/R-complex system affect information processing is reflected in Cerebral Cortex

Processing and Limbic/R-Complex Processing, respectively.

The roles of the cerebral cortex and the R-complex and limbic system are also included in four quadrant scores. These four scores represent a partial breakdown of the Analog and Digital Dominance scores. The Analog Information Processing network describes a process whereby analog perception is combined with neutral cerebral cortex processing to generate an unemotional flow which results in an imaginative, synthesizing, and metaphoric outcome. The Analog Internal Processing network is a flow of information where analog perception is more heavily influenced by the emotional R-complex and limbic systems to generate an outcome marked by impulsiveness and seeming irrationality. Digital Information Processing is a network combining neutral processing and linear, exacting perception. The result is an unemotional data processing system located primarily in the cerebral cortex. Digital Internal Processing is a network of neutral processing within the context of the emotional limbic/R-complex system. The outcome is a detailed and categorical approach dependent, however, on environmental stimuli. Individuals possessing this processing network appear almost territorial in their perception of duties and responsibilities.

Another measurement of BAS is the Entrepreneurial Factor. This factor represents the accumulation of responses to a series of items designed to reflect the risk-taking, highly energetic, goal oriented mind set that is often associated with entrepreneurial behaviors. Pragmatic individuals who foresee possibility in the ordinary and are better able to cope with complexity than regimentation, are to be found within the entrepreneurial community.

A similar measurement to the Entrepreneurial Factor is an assessment of the particular managerial style of a respondent. Translation Management represents a system in which the participants follow set rules and maintain the status quo. Transition Management is a system in which the participants are better able to see opportunity and implement change.

The preferential functional sequence of an individual is assessed by three scores: World Sensing, Plan Construction, and Complex Plan Execution. BAS also evaluates an individual's creativity. This score depends on responses to questions designed to access the creative abilities of an individual, whether leisurely or professional in nature. The final assessment of BAS is the sensory accessing preferred by the respondent when receiving information. Visual Accessing reflects a preference for written materials, illustrations, and demonstrations. Auditory Accessing is the degree to which the respondent prefers spoken instruction and information. Kinesthetic Accessing describes a preference for the "feel" of what is presented beyond the usual visual and auditory presentation of information.

Statistical Treatment of the Data

For the purposes of this study, the petroleum engineers responding to BAS were divided into seven classifications: (1) Reservoir Engineers; (2) Production Engineers; (3) Drilling Engineers; (4) Upper-Level Managers; (5) Geological Engineers; (6) Petroleum Engineering Educators; and (7) Technical Managers. Technical Managers were those managers directly supervising engineers and projects on a day-to-day basis. Upper-Level Managers were those managers more involved in the corporate decision making of a company. Geological Engineers were practicing petroleum engineers with a background in geological engineering.

Two types of statistical tests were used to analyze the data. The One-Sample-t-test is the most common statistical test used in research of this type. The t-test is used to test for group mean differences when there are two groups. A value of "t" has an accompanying "p," or probability level. The larger the value of "t," the more significant the difference in the means of the two groups. Conversely, a small value of "p" is desireable. Values of "p" less than 0.05 are evidence of a significant difference between the two group means. This test was used to test for differences in petroleum engineers and the control population associated with the sample.

The second statistical test used was a One-Factor Analysis of Variance, or ANOVA. This test is the most traditionally and widely accepted form of statistical analysis. ANOVA tests for group mean differences between two or more groups using a single statistical operation. This operation is a comparison of the variance between the groups with the variance within the groups. The result is an "F value" and an associated probability. The "F value" is the variance between means divided by the variance within means. As in the One-Sample-t-test, a large "F value" and a small "p" value indicate significant differences between the group means. This test was used to test for significant differences within the sample of petroleum engineers.

Means and standard deviations were obtained for both samples and for two control populations relating to each sample. One-Sample-t-tests were performed on Sample 1 comparing processing mechanisms of petroleum engineers to a control population of 1527. This control population included respondents to the earlier version of BAS. The validation population of 1275 plus participants responding after the validation were included in this group. These processing mechanisms included Digital Information Processing, Digital Internal Processing, Digital Dominance, Analog Information Processing, Analog Internal Processing, Analog Dominance, Entrepreneurial Factor, Cerebral Cortex Processing, and Limbic/R-Complex Processing. One-Sample-t-tests were employed to compare the functional sequence and managerial styles of petroleum engineers in Sample 2 to a control population of 189. This control group included the respondents to date to the newer version of BAS. Both control populations represented a cross-section of individuals in a variety of professional capacities.

One-Factor Analyses of Variance were performed on both samples to determine differences between pairs of petroleum engineering classifications. Additional One-Factor Analyses of Variance were employed to compare individual classifications with the remainder of the sample.

For all statistical measurements, the results were interpreted with the 0.01 and 0.001 probability levels considered representative of highly significant results. The 0.05 level of probability was considered representative of significant results. A significance of 0.05 indicated that 95 out of 100 respondents would be expected to be significantly different from the group to which they were compared. Similarly, a significance of 0.01 indicated that 99 out of 100 respondents would be significantly different, and a significance of 0.001 meant that 99.9 out of 100 respondents would be significantly different. These levels of significance are noted as follows: ***, significant at the 0.001 level of probability; **, significant at the 0.01 level of probability; and *, significant at the 0.05 level of probability. The results of the statistical analysis are presented in Tables 1-4.

CONCLUSIONS

As a group, petroleum engineers were significantly different from a control sample of professionals in the way in which they processed information, implemented projects and plans and in the way in which they preferred to manage and be managed. In terms of information processing mechanisms, petroleum engineers markedly preferred digital accessing to analog. Reservoir engineers, production engineers and technical managers exhibited this preference particularly. Petroleum engineers holding positions as upper-level managers, however, preferred analog accessing or a combination of digital and analog accessing.

This combination of processing mechanisms is called double dominance. The engineer who is double dominant processes information in a digital manner as much as he does in an analog manner. The engineers studied were classified as having digital, analog, or double dominance according to their profiled BAS scores. Technical managers and production engineers were overwhelmingly digitally dominant. More reservoir engineers were also digitally dominant, but almost a quarter of these engineers exhibited a preference for analog processing or a combination of analog and digital processing. This result is to be expected due to the spatial sense and intuition necessary in reservoir engineering. Reservoir engineers posted unusually high scores in Analog Internal Processing. This processing network is the seat of hunches and similar unexplainable decision-making abilities. Three quarters of the upper-level managers sampled indicated double or analog processing. Upper-level managers scored unusually high in Analog Information Processing. This network is marked by the conceptual, holistic, and synthesizing abilities necessary in managers at this level within a company. Too few drilling engineers and geological engineers were sampled to draw firm conclusions, but it is of interest to note that geological engineers were, by far, more analog or double dominant. Although these engineers were practicing as production or reservoir engineers, their background in geologic structure and related spatial topics was evidenced in their information processing.

Petroleum engineers scored higher than the control population in their accessing of Cerebral Cortex Processing. The precision required of engineers implements the linear, detailed thought processes of the cerebral cortex. Limbic/R-complex Processing was rejected by the sample as a whole, as would be expected, but reservoir engineers showed a preference for this process. A high score in Analog Internal Processing is closely associated with a high score in Limbic/R-complex processing. The assessment of preferred information presentation indicated that petroleum engineers prefer Visual presentation over Auditory or Kinesthetic presentation.

When studying the Entrepreneurial Factor posted by petroleum engineers as a group, these scores were lower than those of the population. Upper-level managers, however, indicated a high entrepreneurial sense. It is this ability that is important to the innovative and imaginative management of an oil company. In terms of management styles, upper-level managers overwhelmingly chose a transition style. Technical managers rejected transition management in favor of a translation style of management.

The functional flow of activity within an organization was seen in the functional capabilities of the engineers studied. In the area of Sensory Detection, or the ability to identify a problem requiring resolution, reservoir engineers, production engineers and technical managers scored low within the group. Upper-level managers scored high in this area. In the area of Plan Construction, reservoir engineers, production engineers, and technical managers scored higher than the group and upper-level managers scored lower. Finally, in the area of Plan Execution, upper-level managers showed a greater ability than the other engineers in the group.

IMPLICATIONS

In the last several years, oil companies have had to rely on fewer technical personnel. If an effort is made to tap the energy and expertise of engineers, a reduction in personnel need not mean a reduction in productivity. The effort recently has been to streamline an organization in order to adjust to a smaller cash flow. One can assume that the better engineers have been retained and that every effort is made to recruit the finest candidates for entry level positions. The industry is now in a position to make a subtle shift in the use of engineering brain power.

Heretofore, the nature of engineering work has dictated, to some degree, the management attitude of the engineering organization. Although engineering is principally a digital function, there are a multitude of approaches to a given problem to generate the correct solution. Similarly, the engineers possessing these many approaches respond best to a variety of management styles. It is not possible to accommodate each engineer's conception of management, but an effort can be made to maximize the expertise within the engineering sector of a company by using the analogy of the whole brain.

The life cycle of a project can be seen to evolve from an analog inception through a digital realization. If engineers are grouped in such a way so as to draw on the analog expertise of some and the digital expertise of others, a whole brain syndicate is formed. The present structure of most engineering departments would not change. Each engineer would work separately in his area, but the opportunity the syndicate affords would be present at all times. By being aware of the variety of brain dominance patterns present in an engineering group, managers can form a functional integration of these neurological processing patterns. Evidence suggests that, in some cases, a disparity exists between the preferred processing pattern of an individual and the task to which he is assigned. One aspect of this research determined the job satisfaction of respondents. In several instances, an engineer possessed a particular processing pattern not congruent with his job classification. In approximately 70 percent of these cases, the engineers expressed less than adequate job satisfaction. A focus on the information processing patterns of engineers may result in greater job satisfaction, hence, lower attrition, and in higher productivity and innovation.

The same techniques may be applied to the management sector to aid in the strategic development of organizations. This research has identified two types of engineering managers: technical and upper-level. The striking differences in these two types may inadvertently lead to the idea that all first-line technical managers should be digitally dominant and manage in a translation style, and that all upper-level corporate managers should be analog dominant and manage in a transition style. In reality, both types of managers exist at all levels within the organization. The emphasis is to place these managers where they will be the most effective. To implement this change, it is necessary to shift away from the present technical, hierarchical management toward a systemic, holistic management. Such a shift will allow the integration of the multitude of brain processing patterns among engineers and engineering managers. This synergy of management attitudes will address the variety of people, projects, and ideas in the oil industry. A good example of a brain syndicate is the sample of petroleum engineering educators examined in this study. This group showed very little significant difference within the sample. Of the ten educators evaluated, six indicated digital dominance and four indicated analog or double dominance. This group approaches a whole brain syndicate. This syndicate of function is as important in industry as it is in the academic sector.

RECOMMENDATIONS FOR FURTHER RESEARCH

This research should be replicated on a larger sample of petroleum engineers to verify the results determined in this study. The factors of age, experience, and sex differences should especially be explored. An important area of study is the shift in dominance patterns over time. To explore this aspect, a group of entry level engineers should be assessed through BAS, and the process repeated on the same group at three to five year intervals. The same process could be used with college freshmen entering Petroleum Engineering.

Further research of this kind may improve the manner in which petroleum engineers are placed in particular capacities, and in the overall development of technical and management teams.

TABLE OF NOMENCLATURE

df = degrees of freedom; number of independent observations in a sample minus the number of population parameters which must be observed from sample observations

F value = The variance between a sample divided by the variance within a sample

md = the difference in the means of a sample

Mean = arithmetic average of sample observations

mean sq. = an ANOVA term for the variance; a sum of squares divided by its degrees of freedom

N = number of independent observations

p = probability of the occurrence of an event

P-value = same as p

S.D. = the standard deviation of a sample of independent observations; describes the dispersion among a set of observations in a distribution

Standard Error = the standard deviation of a sampling distribution

t = theoretical distribution used to determine significance of experimental results based on small samples

t value = same as t

t probability = same as p

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Table 1
Means and Standard Deviations for Sample 1

		Population	Petroleum Engineers	Reservoir Engineers	Production Engineers	Drilling Engineers
	N =	1527	175	51	27	8
Digital Information Processing	Mean:	52.527	65.566	66.510	68.296	68.500
	S.D.:	22.033	18.910	15.894	13.997	20.277
Digital Internal Processing	Mean:	72.631	78.674	83.569	83.370	78.500
	S.D.:	22.834	21.839	20.021	14.812	21.640
Digital Dominance	Mean:	165.942	189.097	196.255	202.074	192.500
	S.D.:	50.348	45.042	39.474	23.077	53.753
Analog Information Processing	Mean:	58.965	55.223	49.686	51.259	46.250
	S.D.:	23.542	22.725	21.344	19.080	16.748
Analog Internal Processing	Mean:	56.667	44.583	46.902	40.593	46.250
	S.D.:	25.673	20.087	18.967	13.965	33.200
Analog Dominance	Mean:	151.912	127.869	122.549	116.407	119.500
	S.D.:	50.992	44.888	39.648	21.745	61.832
Entrepreneurial Factor	Mean:	6.328	5.790	5.459	5.711	5.763
	S.D.:	1.182	1.402	1.374	1.630	1.483
Cerebral Cortex Processing	Mean:	112.546	121.457	117.529	120.963	116.000
	S.D.:	23.652	20.047	17.531	22.833	7.597
Limbic/R-Complex Processing	Mean:	128.930	124.263	131.157	126.593	125.750
	S.D.:	21.695	21.695	18.417	16.888	18.483

		Population	Geological Engineers	Engineering Educators	Technical Managers	Upper-Level Managers
	N =	1527	6	10	44	33
Digital Information Processing	Mean:	52.527	58.333	69.200	74.909	46.909
	S.D.:	22.033	20.057	29.921	13.540	17.700
Digital Internal Processing	Mean:	72.631	65.667	73.200	87.136	54.424
	S.D.:	22.834	17.178	32.169	14.800	21.312
Digital Dominance	Mean:	165.942	162.333	183.900	212.455	134.848
	S.D.:	50.348	38.825	61.307	27.466	45.495
Analog Information Processing	Mean:	58.965	63.333	59.600	46.136	80.485
	S.D.:	23.542	15.883	21.598	15.210	22.305
Analog Internal Processing	Mean:	56.667	57.333	51.800	34.227	57.758
	S.D.:	25.673	15.933	34.467	15.481	23.371
Analog Dominance	Mean:	151.912	157.500	139.100	103.250	179.727
	S.D.:	50.992	34.576	66.050	31.899	43.660
Entrepreneurial Factor	Mean:	6.328	6.717	6.010	5.445	6.682
	S.D.:	1.182	1.309	1.604	1.259	1.088
Cerebral Cortex Processing	Mean:	112.546	122.667	129.800	122.318	125.364
	S.D.:	23.652	18.533	25.879	16.016	24.902
Limbic/R-Complex Processing	Mean:	128.930	124.000	126.000	122.955	114.030
	S.D.:	21.695	22.760	24.111	13.186	21.208

Table 2
Results of One-Sample-t-tests Comparing Processing Mechanisms of Petroleum Engineers to Control Population

		Petroleum Engineers	Reservoir Engineers	Production Engineers	Drilling Engineers
	N =	175	51	27	8
Digital Information Processing	t:	9.122	6.283	5.854	2.228
	p:	0.001***	0.001***	0.001***	0.061
Digital Internal Processing	t:	3.660	3.902	4.820	0.767
	p:	0.001***	0.001***	0.001***	0.468
Digital Dominance	t:	6.801	5.484	8.136	1.397
	p:	0.001***	0.001***	0.001***	0.205
Analog Information Processing	t:	-2.178	-3.105	-2.099	-2.147
	p:	0.031*	0.003**	0.046*	0.069
Analog Internal Processing	t:	-7.958	-3.677	-5.981	-0.887
	p:	0.001***	0.001***	0.001***	0.404
Analog Dominance	t:	-7.086	-5.289	-8.484	-1.483
	p:	0.001***	0.001***	0.001***	0.182
Entrepreneurial Factor	t:	-5.076	-4.517	-1.967	-1.078
	p:	0.001***	0.001***	0.060	0.317
Cerebral Cortex Processing	t:	5.880	2.030	1.915	1.286
	p:	0.001***	0.048*	0.066	0.239
Limbic/R-Complex Processing	t:	-3.352	0.942	-0.657	-0.587
	p:	0.001***	0.351	0.517	0.576

		Geological Engineers	Engineering Educators	Technical Managers	Upper-Level Managers
	N =	6	10	44	33
Digital Information Processing	t:	0.709	1.762	10.965	-1.823
	p:	0.510	0.112	0.001***	0.078
Digital Internal Processing	t:	-0.993	0.056	6.501	-4.908
	p:	0.366	0.957	0.001***	0.001***
Digital Dominance	t:	-0.196	0.926	11.233	-3.926
	p:	0.852	0.378	0.001***	0.001***
Analog Information Processing	t:	0.674	0.093	-5.595	5.542
	p:	0.530	0.928	0.001***	0.001***
Analog Internal Processing	t:	0.102	-0.447	-9.615	0.268
	p:	0.922	0.666	0.001***	0.790
Analog Dominance	t:	0.396	-0.613	-10.119	3.660
	p:	0.709	0.555	0.001***	0.001***
Entrepreneurial Factor	t:	0.728	-0.627	-4.652	1.869
	p:	0.499	0.546	0.001***	0.071
Cerebral Cortex Processing	t:	1.338	2.108	4.047	2.957
	p:	0.239	0.064	0.001***	0.006**
Limbic/R-Complex Processing	t:	-0.531	-0.384	-3.006	-4.036
	p:	0.618	0.710	0.004**	0.001***

Table 3
Means and Standard Deviations for Sample 2

		Population	Petroleum Engineers	Reservoir Engineers	Production Engineers	Drilling Engineers
	N =	189	2	10	22	7
Translation Management	Mean:	4.344	4.499	4.418	4.773	3.150
	S.D.:	1.656	1.446	1.467	1.368	1.380
Transition Management	Mean:	4.628	4.351	4.236	4.147	6.000
	S.D.:	1.418	1.462	1.462	1.409	1.189
Sensory Detection	Mean:	59.693	53.551	51.091	48.933	76.500
	S.D.:	20.250	18.906	18.941	15.040	35.716
Plan Construction	Mean:	65.164	67.944	68.242	71.600	49.000
	S.D.:	17.360	15.012	15.546	13.715	14.376
Complex Plan Execution	Mean:	61.905	60.562	58.000	58.667	67.500
	S.D.:	11.815	12.638	14.098	14.495	9.983
Creativity/Innovation Index	Mean:	2.543	2.378	2.315	2.320	2.550
	S.D.:	0.844	0.859	0.985	0.834	0.719
Visual Accessing	Mean:	5.714	8.742	7.515	10.267	6.000
	S.D.:	4.988	4.279	4.529	4.061	4.320
Auditory Accessing	Mean:	6.794	6.831	8.061	6.533	9.000
	S.D.:	4.945	4.187	5.160	3.815	3.830
Kinesthetic Accessing	Mean:	5.429	2.449	2.424	1.333	3.000
	S.D.:	4.999	3.026	3.455	2.225	2.582

		Population	Geological Engineers	Engineering Educators	Technical Managers	Upper-level Managers
	N =	189	2	10	22	7
Translation Management	Mean:	4.344	4.400	4.200	5.064	2.800
	S.D.:	1.656	0.283	1.964	1.197	1.347
Transition Management	Mean:	4.628	3.400	4.580	3.955	6.343
	S.D.:	1.418	0.000	1.510	1.206	1.459
Sensory Detection	Mean:	59.693	75.000	55.600	51.364	77.429
	S.D.:	20.250	32.527	28.826	15.022	22.263
Plan Construction	Mean:	65.164	80.000	66.900	70.727	47.714
	S.D.:	17.360	5.657	17.489	9.711	15.724
Complex Plan Execution	Mean:	61.905	48.000	67.200	60.727	73.714
	S.D.:	11.815	2.828	9.390	9.731	3.729
Creativity/Innovation Index	Mean:	2.543	2.100	2.900	2.200	2.943
	S.D.:	0.844	0.141	0.796	0.685	0.814
Visual Accessing	Mean:	5.714	14.000	10.400	8.909	6.286
	S.D.:	4.988	5.657	4.881	3.689	3.147
Auditory Accessing	Mean:	6.794	1.000	6.400	5.909	8.000
	S.D.:	4.945	1.414	3.864	2.793	3.830
Kinesthetic Accessing	Mean:	5.429	3.000	1.200	3.182	3.714
	S.D.:	4.999	4.243	1.687	3.126	2.690

Table 4
Results of One-Sample-t-tests Comparing Functional Sequence and Managerial Styles of Petroleum Engineers to Control Population

		Petroleum Engineers	Reservoir Engineers	Production Engineers	Drilling Engineers
	N =	89	33	15	4
Translation Management	t:	1.011	0.290	1.201	-1.730
	p:	0.315	0.774	0.250	0.182
Transition Management	t:	-1.787	-1.540	-1.322	2.308
	p:	0.077	0.133	0.207	0.104
Sensory Detection	t:	-3.065	-2.609	-2.771	0.941
	p:	0.003**	0.014*	0.015*	0.416
Plan Construction	t:	1.747	1.137	1.817	-2.249
	p:	0.084	0.264	0.091	0.110
Complex Plan Execution	t:	-1.003	-1.591	-0.865	1.121
	p:	0.319	0.121	0.402	0.344
Creativity/Innovation Index	t:	-1.812	-1.330	-1.036	0.019
	p:	0.073	0.193	0.318	0.986
Visual Accessing	t:	6.676	2.284	_4.342	0.132
	p:	0.001***	0.029*	0.001***	0.903
Auditory Accessing	t:	0.083	1.438	-0.265	1.152
	p:	0.934	0.160	0.795	0.333
Kinesthetic Accessing	t:	-9.291	-4.996	-7.130	-1.881
	p:	0.001***	0.001***	0.001***	0.156

		Geological Engineers	Engineering Educators	Technical Managers	Upper-Level Managers
	N =	6	10	44	33
Translation Management	t:	0.280	-0.232	2.821	-3.033
	p:	0.826	0.822	0.010**	0.023*
Transition Management	t:	-----	-0.101	-2.617	3.110
	p:	0.001***	0.922	0.016*	0.021*
Sensory Detection	t:	0.666	-0.449	-2.601	2.108
	p:	0.626	0.664	0.017*	0.080
Plan Construction	t:	3.709	0.314	2.687	-2.936
	p:	0.168	0.761	0.014*	0.026*
Complex Plan Execution	t:	-6.954	1.783	-0.568	8.379
	p:	0.091	0.108	0.576	0.001***
Creativity/Innovation Index	t:	-4.443	1.418	-2.349	1.300
	p:	0.141	0.190	0.029*	0.241
Visual Accessing	t:	2.071	3.036	4.062	0.481
	p:	0.286	0.014*	0.001***	0.648
Auditory Accessing	t:	-5.795	-0.322	-1.486	0.833
	p:	0.109	0.754	0.152	0.437
Kinesthetic Accessing	t:	-0.810	-7.927	-3.372	-1.687
	p:	0.567	0.001***	0.003**	0.143

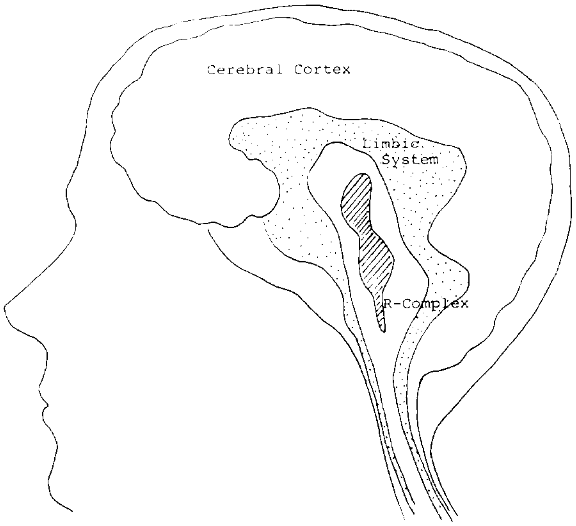

Figure 1 - The triune brain

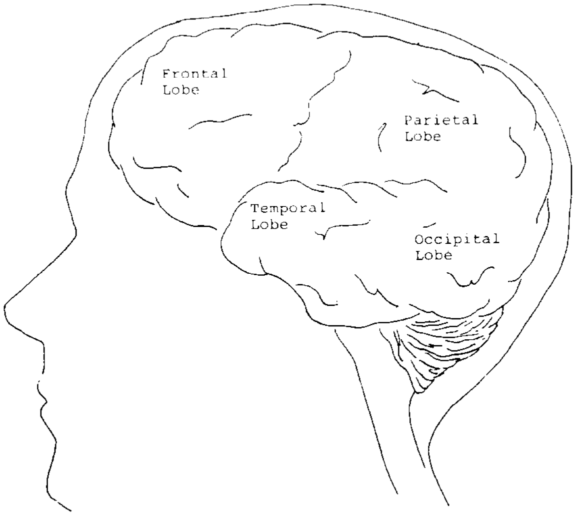

Figure 2 - Major lobes of the brain

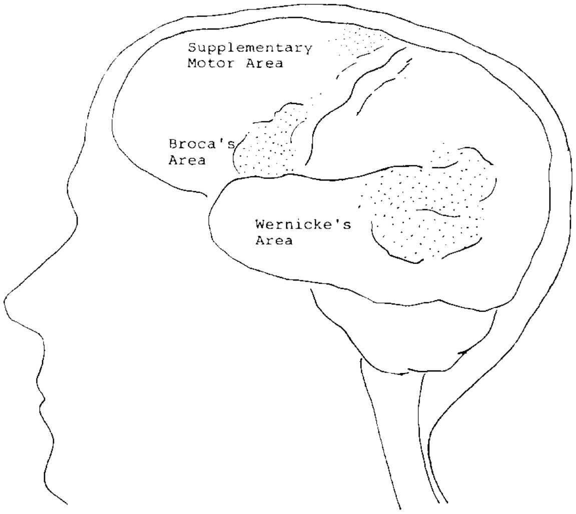

Figure 3 - Speech areas of the brain