# Sorting

# Out

## Some

In the history of man, few diseases or disabilities have evoked emotions as strongly as have dysfunctions of the brain. The brain's complexity still defies the most strenuous and rigorous attempts to comprehend it; the relationships of the brain to most of its functions remain quite obscure, though with some notable exceptions.

That the brain produces electrical potentials has been known for some 150 years. Knowledge about their precise origin, or their use in research or in some medical applications, is considerably more recent.

The electrical sensitivity of the nervous system was known to Galvani and

## Problems

Applications of scientific knowledge need never wait until all the answers are in. They often provide a few themselves. Volta in 1780 and 1800, but electrical activity in the brain itself was not detected or measured until 1875 when the British physiologist Richard Caton applied electrodes directly to the brain of a living dog.

In 1924, Professor Hans Berger of the University of Jena, Austria, placed electrodes over a human skull and, with a delicate galvanometer, measured waves of electric potentials in the living brain. He called his technique "electroencephalography," or EEG. Today it is believed this electrical activity reflects the total of excitatory and inhibitory influences in the nerve cells at any given time, as well as the actual electrical discharges occurring in huge numbers of the nerve cells. The EEG is a complex mixture of electrical rhythms, ranging between 0.5 and 40 cycles a second in frequency, and fluctuating in voltage between zero and about 100 millionths of a volt.

Overall, the brain generates about ten watts of power. But the electrochemical transfer along nerve cells does not square with efficient electrical engineering. The electrical resistance of the interior of a nerve fiber, a few micromillimeters in diameter, is 100 million times greater than that of ordinary copper wire. It has been noted that the resistance of one meter of a neuronal fiber would equate to 10<sup>10</sup> miles of 22 gauge copper wire, enough to cover the distance between Earth and Saturn ten times.

"This, of course," observes British biophysicist C. U. M. Smith, "is the price the animal organism has to pay for being held together by covalent bonds. Only very rarely in materials of this type are electrons free to drift through the atomic lattice."

Fifty years ago Berger detected the EEG pattern known today as "alpha waves," which have a frequency of eight to 12 per second and potentials around 20 to 50 microvolts. They're found in normal humans, especially in the parietooccipital region-concerned with vision and perception-when the person is relaxed with his eyes closed. Later discoveries were "beta waves," 13 to 30 per second, often associated with arousal and anxiety; the slower "theta waves," of four to seven per second, often excessive in adolescents with behavior disorders, and "delta waves," of 0.5 to three per second, which become abundant in normal subjects when asleep. The normal EEG contains a mixture of different amounts of these various rhythms.

EEG readings are taken by placing a series of eight to 19 electrodes at standardized positions on the scalp and recording the voltage patterns on paper or electronic readout mechanisms. The waves are complex, with intermixed frequencies and waveshapes. As clinical experience with them has accumulated, it has become possible to establish correlations between various more or less distinctive features of the abnormal EEG and a number of neurological diseases. These relationships are achieved on the basis of inspection of the complex voltage patterns observed in the EEG, and have made the EEG a useful clinical instrument. EEG's have long been routinely used, for example, to detect epilepsy and to locate brain tumors. The tumors are revealed by characteristic EEG patterns around the site of the growth. Epilepsy, which in mild forms is estimated to afflict one of every 100 to 200 persons, produces characteristically shaped waves when seizures are not present, and massive EEG discharges when they are.

"The EEG presents physiologists with reams of fascinating data," Isaac Asimov observed in 1962, "most of which they are as yet helpless to interpret." The outlook is no longer quite so bleak, though all the implications of the brain's electrical output are still far from understood. Current research targets range from the very specific to those that seek to provide basic general insights into brain function and malfunction.

A common feature of many of the most interesting new lines of research on the electrical activity of the brain is reliance on advances in technology. A major innovation, with far reaching implications, is the application of computer pattern recognition techniques in place of visual inspection of the EEG and for the extraction of weak signals. These can separate brain processing of specific information from the bewildering background of electrical activity concerned with other brain functions. This article discusses but a few of the many promising recent developments in this fieldthe tip of a scientific iceberg.

In the early 1960's, for example, Grey Walter and colleagues at the Burden Neurological Institute observed a variation from the familiar types of waves during the EEG response to some intellectual stimulation, or when some part of the body was moved by muscles. This new type of wave, which he termed a "contingent negative variation, or CNV," was found when a subject was presented with a stimulus (in this case an audible "click") leading him to anticipate or expect information (a second "click"). These waves are referred to as "expectancy waves," in that they seem to represent preparation, in anticipation of the performance of some intellectual task. These meaningful variations in brain waves, buried in the "noise" of a substantial amount of neural activity related to other functions, could be detected only through computer analysis of the wave forms. Many studies have confirmed that the electrical activity of the brain reflects cognitive processes related to the evaluation of the significance of environmental events. Neuropsychologists and neurophysiologists have described a variety of new electrical phenomena, like the CNV, which have important practical applications in addition to providing insights to the physiology of mental processes. Many of these phenomena involve the electrical response of the brain to a stimulus, called an evoked potential.

### The electrical activity of the brain reflects cognitive processes.

In the early 1970's, psychiatrist Maurice Doniger of McGill University found a new application for Grey Walter's discovery. He applied the Walter technique to psychotics and found discrepancies in their CNV potentials as compared to normal subjects. The results, he reported, were statistically significant and at least as good as traditional clinical diagnostic procedures.

#### Waves and point swarms

Beginning more than a decade ago with animals, and then with humans, neurophysiologist E. Roy John and his colleagues at New York Medical College have studied the electrical activity of the brain that relates to learning and memory. They are now in the process of applying the techniques that they have developed to an even more pervasive social problem than psychosis—basic learning disabilities.

Some of the electrical responses to neural test stimuli after learning, he says, reflect familiar but absent events. "They have a form as if the previous experience were really there, recorded in the brain. Some evoked potential waves," John explains, "are a reproduction by the brain of a previous event."

When John and his colleagues analyzed these patterns, they report, they found that they could be divided into two separate but interrelated processes, one constituting the brain's reflection of the stimulus at hand, and the other reflecting an interpretation of its meaning.

"When we obtained those results," John says, "it became clear that they offer an insight into mechanisms mediating memory and decisionmaking." Moreover, these phenomena were both pervasive and robust; they were not difficult to find.

John and his team worked extensively on developing the mathematical tools with which to extract such data from the complex wave forms. They employed methods of pattern recognition which describe the morphology of waves in numerical terms. These led to their development of a technique of factor analysis, which can be considered as a type of mathematical taxonomy of evoked potential waves—the sorting, sequencing, and classifying of these phenomena on the basis of their inherent mathematical characteristics.

Basically, John and his colleagues treated evoked potentials as mathematical elements—vectors—in a multidimensional space, where each dimension represented the voltage at a different time along the wave. The wave thus became a point in mathematical multidimensional space. A series of waves, then, became a point swarm, which, when sorted with techniques called factor analysis or cluster analysis, enable the researchers to determine whether subgroups of points within the swarm correlate to the behavior of the animals used.

"About four years ago," John explains, "we reached the conclusion that the mathematical and physiological techniques we and others had devised were so powerful, and the phenomena which had been observed so consistent and so steady, that we ought to be able to apply analogous techniques to people with cognitive disorders—of whom there are a great number."

According to prevalent estimates, some seven to ten percent of schoolchildren have learning disabilities caused by brain dysfuction; at the other end of the developmental spectrum, John notes, some 50 percent of the aged suffer some form of cognitive impairment. By using numerical taxonomy to evaluate electrophysiological measures, John feels that persons suffering from physically based impairment could be distinguished from those whose disabilities arise from emotional problems.

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This is potentially far more important than using these techniques to distinguish neurological accidents, such as strokes (about 300,000 of which occur in Americans each year) or epileptic seizures, he feels. "The bulk of those you can do very little for," he says. "On the other hand, if you find a kid having trouble in school, or who is going to, you can often intervene. So the prognosis is far more optimistic; you can get enthusiastic about the payoff."

To be able to adapt these methods to a mass screening technique, John and his colleagues faced four tasks:

(1) To scan the literature to select electrophysiological phenomena that would reflect sensory or cognitive functions.

(2) To develop an essentially automatic technology to gather such data rapidly and accurately.

(3) To devise computer techniques to extract functionally significant numerical measures from these phenomena.

(4) To relate these measures to the brain's anatomical structure in the effort to identify specific processes in the brain that correlate with specific cognitive or learning disorders.

It would be impossible to do this in any other way, especially on a mass screening basis, he points out. First of all, John notes, the conventional EEG is not sufficiently sensitive to reflect these processes, especially when evaluated by visual inspection rather than quantitative methods. Moreover, there are only some 4,000 qualified neurologists in the country, of whom about 250 specialize in childhood disorders—far short of the number required to even begin to screen the Nation's population of learningdisabled, even if they had the tools and scientifically sound knowledge to do so.

His screening technique consists of placing 19 EEG electrodes on the subject's skull according to an internationally standardized system. Through a computer, each subject is then presented with a wide variety of visual, auditory, and tactile stimuli. This set of stimuli, and the different contexts in which they are embedded, constitute a set of items in an electrophysiological test of brain functions related to sensation, perception, and cognition. The complete test takes about an hour, but shorter portions can be given separately. The full test results in an output of 50,000 numbers, stored on tape by the testing computer. This is where John's numerical analytics come into play. The pattern of functional values reflected by these numbers is classified in an associated computer. "This is a formidable task in data compression, which we're still struggling with," he notes.

Before it can be used routinely, the procedure will require validation and calibration. So far, John has applied "a feeble version" of his diagnostic procedure to a population of 175 normal and learning-impaired children and to a group of 175 hospitalized aged persons, which included a cognitively unimpaired and a senile group. The ability of the numerical taxonomic procedure to distinguish between normal subjects and their peers with cognitive difficulties, John reports, was 88 percent for the children and 91 percent for the older group. The testing and data analysis methods are being further refined and a data base is being gathered; an interdisciplinary team has been organized by John to work with a special school for the cognitively impaired to develop remedial programs specific to the different patterns of brain dysfunction revealed by the test in the 1,000 pupils of the school.

"We're in the first stage of something

very promising," he feels. Mass screening when perfected, he notes, could cost as little as \$10 per test, and should permit the early identification of youngsters with such brain dysfunction before serious side effects arise. The costs of developing and applying these new methods are slight, compared with present costs to society of about \$10,000 per year to keep a child in special training school, and upwards of \$3,000 per year to maintain an impaired adult, John declares.

#### Substituting senses

The determination, via EEG and other techniques, that the brain is not committed to a neural pathway once established—that it can bypass damaged areas and restore impaired functions such as speech via alternative pathways—has led researchers down other promising therapeutic channels.

Surgery to relieve the trauma of severe epilepsy has not only affected those symptoms, but has also led to significant knowledge about the brain and its ability to adapt. In more than 1,000 such surgical operations, Wilder Penfield and his colleagues at Montreal University have mapped, with the use of electrode probes as stimuli, large functional areas of the brain. In the human being, in contrast to lower animals, only a very small proportion of the brain is committed to motor or sensory functions. The remainder of the brain's cerebrum, the parietal lobe and temporal lobes, is apparently used for speech, perception of the body image, and spatial relationships.

### Finding no effect of brain damage was even more important.

In working with Penfield, Donald Hebb was interested in determining the effects of frontal lobe injury. He found nothing at all and, in his words: "It took me six months to realize that finding no effect of brain damage was even more important than if I had found one. The lack of behavioral impairment in some of these large brain injuries was highly significant." Damage away from the specialized areas for speech, vision, motor, and sensory functions seemed to result in little impairment of intellectual functions. Thus, such functions would appear to be distributed within a large volume of the tissue of the brain.

The potential adaptability of the nervous system suggested by such findings has been exploited in a practical sense in a series of experiments by Paul Bachy-Rita and his colleagues at the Smith Kettlewell Institute in San Francisco. Pursuing the question of whether and how some senses might be substituted for others (as the blind use braille to read, for example), this team developed a television system which, linked to a series of vibratory or electrode stimulators, imposed "visual" images tactilely on subjects' skins. In general, the system shows that sight-deprived persons can perceive some gross images with this system. Bach-y-Rita and his colleagues still do not know precisely why: "The mechanism is clearly not in the peripheral receptor organs and probably not in the spinal cord nor in the brainstem; it probably lies in the brain, and its elucidation will add to our general knowledge of human brain function," they report.

Their work so far, however, has "demonstrated the practicality of the system in the field of learning. For example, blind students are able to read graphical material (such as bar graphs) and to identify geometric projections. The spatial concepts learned by blind students are not available to them by any other known means."

One offshoot of this work is being applied to teaching situations by a former colleague of Bach-y-Rita's, Helen Schevill, who developed a system of tactile aids to assist reading-disabled children.

It is estimated that more than ten percent of U.S. schoolchildren suffer from various reading disabilities. Moreover, sociologists find that some 75 percent of juvenile delinquents are impaired by reading disorders, leading to the speculation that perpetually frustrating experiences in school work impel these youngsters toward their delinquent behaviors.

In her work at Smith Kettlewell Institute, Schevill noticed that learningdisabled children did not seem to perceive in space or time in the same way that normal readers do. She modified the tactile end of the television system so that it would project the forms and shapes of letters onto the chests of reading-impaired children. Basically, the devices are boxes about 3<sup>1</sup>/<sub>2</sub> inches square with rows of seven rods each. The rods can protrude instantaneously to project patterns onto the skin. The timing can be varied so that each letter thus traced can be presented in as little as one-fifth of a second or, for beginners or students with severe impairments, considerably longer periods. As each letter is presented tactilely, a luminous screen presents the same form to the subject's eyes. (See *Mosaic*, Vol. 6, No. 1, Jan/Feb 1975.)

After trials with the device in San Francisco, Schevill moved her research to Philadelphia, which has some 30 schools specialized to train children with reading problems. While she still regards her work as experimental, the results of attempts involving dozens of students so far have been encouraging. Not only have learning-disabled children shown a substantial improvement in reading ability, they have enjoyed doing so. The tactilely instructed students consistently make 20 to 25 percent greater progress in reading than those trained by other methods.

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For the majority of the children, tactile practice on the chest, which integrates both brain hemispheres, Shevill says, facilitated tactile discrimination skill not only on the chest, but on the palms of the hands as well. This, she notes, reflects the sensory flexibility of the brain. The children who have a strong, nondominant spatial function, she has found, are able to reinforce the weaker auditory and visual processing from the dominant function. On the other hand, she says, there is a small proportion of children who have a very weak, nondominant, spatial function and a stronger visual processing ability. These children have no success in chest discrimination. After training on the chest, however, they show superior tactile sensitivity on their preferred hand. This, she says, "reflects an aspect of sensory inflexibility of the brain, since these children are unable to integrate information from both hemispheres and are processing a nondominant function with their dominant hemisphere."

#### Magnetism and modification

Recently, an adjunct to the EEG has been devised, and is still in the experimental stage. Physicist David Cohen and his colleagues at the National Magnet Laboratory at Massachusetts Institute of Technology have developed shielded rooms and highly sensitive magnetic field detectors able to reveal patterns of magnetic fluxes in the human body. Their equipment permits them to detect fields as weak as one billionth that of the Earth's magnetic field, as low as about  $1 \times 10^{-9}$  gauss. They have detected alpha waves in the brain with fields typically ten times this strength-10<sup>-8</sup> gauss.

In their work so far, they have measured magnetic waves from both normal brains and those of epileptics, and compared their MEG's (Magneto-Encephalograms) with EEG tracings taken at the same time. They have found that alpha wave MEG's and EEG's do not differ, but that MEG's of sleeping subjects and of epileptics differ substantially from their EEG's.

Cohen's approach makes available to researchers, for the first time in a practical way the brain's output of directcurrent electricity, in addition to the AC output measured by the normal EEG. Skin and other effects mask DC output which, when detected magnetically, can reveal information about brain function otherwise unavailable.

#### Cohen's approach makes available...the brain's output of direct-current electricity.

The EEG and other techniques, along with advances in instrument sensitivity derived from research in physics and electronics, have vastly extended man's ability to make observations about his most basic nature. The most intriguing aspect of these new developments and applications of the EEG is that they let man perceive, and to a small extent, modify, his intellectual functions.

Two such applications (being examined by U.S. Naval Academy researchers among others) are whether learning to control alpha waves can help a student with his grades, and whether knowledge of EEG patterns can be used to measure one's concentration on critical tasks: a pilot landing an aircraft after a long flight, or radar and sonar operators maintaining intense attention over prolonged periods.

The Naval Academy researchers first selected a sample of volunteers in two different academic grade ranges: between 3.5 and 4.0 and between 2.0 and 2.5, on a scale of four. Two groups of 25 each from among the high-scoring and low-scoring midshipmen were given a variety of the same tests to measure their brain-wave activity while solving problems, while resting, and while under stress. Academy researchers found that the high-scoring group produced greater amounts of alpha waves when they were resting, and that their brain-wave production differed significantly from the low-scoring group under all three conditions.

The Navy scientists did not find that alpha control itself helped significantly in improving one's grades. They did learn, however, that those who learned alpha control and who formerly had difficulty falling asleep at night could, after learning to modify their alpha waves, readily go to sleep.

After the initial testing, ten men with lower grades were taught to control their alpha waves, by using the EEG and monitoring equipment. The objective was to see whether learning alpha control could lead to academic improvement. One man was able to achieve control of his alpha rhythms to the extent that he could send Morse Code with it, while another could control the amplitude of the waves.

The next phase of the study centered on the identification of differing alpha patterns when the subject was concentrating and when he let his attention wander. Having identified the differences, Academy doctors then developed an "attention level analyzer," into which the desired level of alpha activity could be set (allowing for a slight daydreaming factor) and deviations from this level electronically monitored. If the subject exceeds the allowable daydreaming factor, the monitor trips an audible tone which signals the subject that his mind has strayed too far from the task at hand. Here is where the Navy researchers see utility for pilots, radar operators, and even long-distance bus and truck drivers.

"The device will work with about 75" percent of the population," reported USNA's Karel Montor, "and in fact might be a guide to selecting personnel whose attention levels can be monitored. It may also be useful," he adds cautiously, "in teaching persons how to concentrate."

In each case-Schevill's effort to help the learning-disabled exploit the flexibility of the neural network, John's effort to correlate brain malfunction to learning disability, and the efforts at the Naval Academy and elsewhere in the research community to take advantage of the brain's ability to monitor and regulate its own activities-the research described here is representative of the accelerating pace of applied as well as basic research into brain function and malfunction. There are parallel efforts in many areas to apply new insights and technologies to the problem of more severe malfunction and the acute mental disease and severe behavioral aberrations that can accompany them. But uniformly, it seems, applications are proceeding on the same careful, laborious, tentative basis as does the best research. Small insights raise the possibility of small—though significant—therapies.

As one neurophysiologist puts it: "Gradually, brain scientists will accumulate hard information on what hooks to what, what goes where. In ten or 15 years, we're going to know the human nervous system. We now have a realistic expectation that we have the techniques, we have the tools to really pin down the gross structure of the brain. And we have to know that in order to know the physiology of the brain.

"But it will come a piece at a time. We're several years from a quantum jump (in knowledge of brain physiology) that will present really broad and useful applications to the clinician."

To John, however, "that 'quantum jump' is a mythical beast, whose existence is implied by analogy with other fields. Broad useful [research] applications are steadily forthcoming and will continue to be made by hard work, not by sudden insights for which we must wait dutifully."