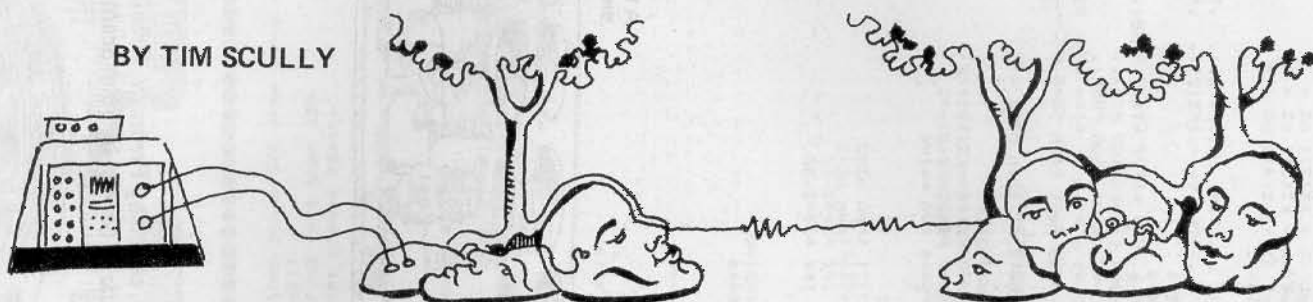


BIOFEEDBACK &

BY TIM SCULLY



PART I

Tim Scully has been designing biofeedback equipment and doing biofeedback research for many years. He is now working on a doctorate in psychology; his dissertation project involves researching and developing biofeedback systems and techniques for use in drug rehabilitation.

Tim is also teaching a computer class to fellow inmates at a Federal penitentiary. Although prison resources are scarce and he is not allowed to solicit donations, he is hopeful of somehow eventually acquiring a computer system for the prison.

Tim has received permission from prison officials to work on a project to modify a computer system which will allow a cerebral palsy patient to communicate. He plans to make his work available to the public to allow others to duplicate his efforts.

What does your computer have to do with your feelings? Will your computer ever be able to understand what you are thinking? Research in biofeedback and physiological monitoring with microcomputers may soon provide answers to such questions.

Biofeedback. That's learning to control biological processes by feeding information about the process, from a measuring instrument, back to the student. Physiological monitoring is simply measuring

biological processes and perhaps recording and analyzing them.

Biofeedback has become a rewarding area for research, an accepted part of medical practice and a popular educational/entertainment process. There are some good reasons for this: it turns out to be possible to learn at least some voluntary control of any body process that can be measured. The learning process can be as brief as a dozen hours for many body processes, and most interesting of all, control of your body's process brings with it some control over your own consciousness (mood and cognitive mode).



The biological processes most commonly measured in biofeedback training are skin temperature, muscle tension, skin resistance and brainwaves. Each is measured by a specialized instrument and each varies with changes in consciousness. Skin temperature at the fingertips, for example, is for many people a sensitive indicator of mood and stress. If you are feeling safe, relaxed and happy, your fingertips are probably warm. But if you are feeling uncomfortable and stressed, your body may respond as though in a life or death situation: with the fight or flight response. Part of this response is the withdrawal of blood from the hands and feet so that the vital muscles and organs are prepared for running or fighting. The re-

sult of reduced blood circulation in your hands is that they get cold. This process can be triggered by worry over giving a speech or by being caught in rush hour traffic. Biofeedback training in hand-warming is done to teach relaxation and stress management skills.

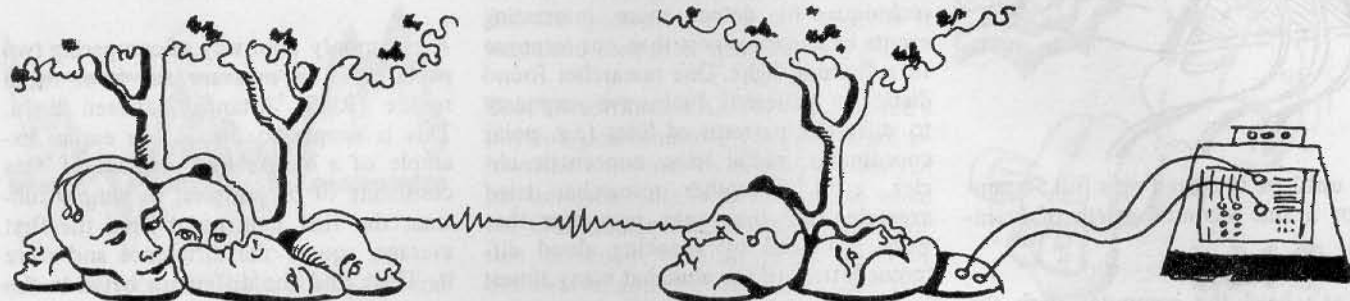
We are all aware of using our muscles to move ourselves around and to move objects. We are less aware of the complex patterns of muscle tension which shift with our changing moods. These patterns are superimposed on the gross muscle action necessary for movements. When we are under stress, for example, we use bands of tense 'muscle armor' to protect ourselves from real or imagined threats. A sensitive instrument, the electromyograph (EMG), can pick up the electrical signals of muscle action. The EMG is used in biofeedback training in muscular control. Such training may be simple deep relaxation training, or it may be more complex retraining of muscles damaged by trauma, stroke or cerebral palsy.



The electrical resistance of our skin also changes with mood. You've probably noticed that sweaty hands can be an indication of stress or arousal. Sweat contains salt and conducts electricity well. We are less conscious of more subtle changes that take place in the permeability of cell membranes in our skin which produce smaller but rapid changes in skin resis-



MICROCOMPUTERS



tance with variations in mood and arousal. Such a change in skin resistance is sometimes called a galvanic skin response (GSR) and GSR is one of the principal measures in the traditional lie detector.

The electrical activity of the brain leaks out onto the scalp and the signals which can be measured there are sometimes called brainwaves (more properly EEG or electroencephalograph signals). You've probably heard of alpha waves. Alpha is the brainwave frequency range from 8 to 13 Hz and may appear during eyes-closed relaxation or meditation. Brainwave signals are complex, constantly changing and varying depending on which part of the scalp they are picked up from.

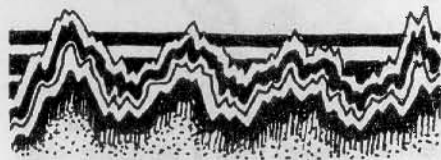
Trying to measure events in consciousness by looking at the electrical signals leaking through the scalp is a little like trying to find out what is happening inside your computer by analyzing the signals that leak out through its cabinet. It is possible, but involves sorting out signals of interest from many unrelated signals which can be considered to be 'noise'.

This same problem of 'signal to noise ratio' exists for any effort to relate any other physiological measure such as muscle tension or skin resistance to events in consciousness. Although the events in consciousness in which we may be interested do influence each physiological measure, other influences also modify each physiological measure. This means that we are faced not only with the prob-

lem of decoding the body's language, but also with the problem of sorting out the language from the background noise. This is a little like trying to learn a new language at a cocktail party.

COMPUTER ANALYSIS

Modern information theory and computers can come to our rescue. A computer can be used to look for the signals of interest buried in background noise and can be used to look for physiological response patterns typical of different thoughts or



feelings. If we want to use a computer to analyze a signal, the first step is to get information about the signal into the computer. Brainwaves are wave-like; they are tiny voltages that vary from moment to moment. Just as water waves on the ocean average out to sea level, brainwave voltages (as they are usually measured) average out to zero volts in the long run. It is the tiny variations, first positive and then negative, in voltage that we want to analyze.

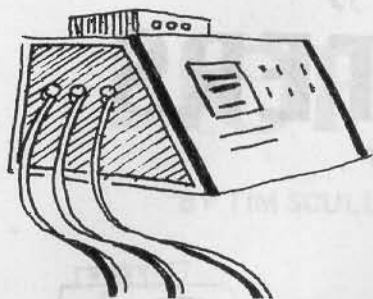
An A/D converter, or analog to digital converter, is used to sample the brainwave signal at regular intervals. Each time it samples the brainwave signal it measures its voltage and converts that measurement into digital form — a form which

the computer can accept. The A/D converter might sample 50 times each second, thus providing the computer with 50 numbers each second. Each number is an instantaneous voltage level of the brainwave signal. If we've chosen a fast enough sampling rate, we could ask the computer to use these numbers to draw a graph of the brainwave signal, and the graph would look very much like the original brainwave signal. That's a good test to see if we are giving the computer enough information about the brainwave signal.

Let's consider a classical example of computer analysis of brainwaves. One of the major contributing factors in our brainwave production is the electrical activity of the brain resulting from the processing of sensory data. A computer can be used to pick out the part of the brainwave signal that is contributed by our response to a particular sensory stimulus, such as a flashing light. This response will be buried in the total brainwave signal made up of many contributions.

Suppose we flash a light in a person's eyes once each second and at the same time measure and digitize brainwave data from her and send this data to our computer. The experiment is easiest to run if we let the computer control when the light flashes and when the A/D converter samples. The light is flashed and at the same instant the first sample of brainwave data is digitized and stored in the computer's memory, at the beginning of a block of memory set aside for this experiment.

One 50th of a second later the computer gets another sample of brainwave data and stores it in the next memory location in the block we'd set aside. One 50th of a second later a third sample is collected and stored, and we continue sampling and storing samples in the order they are re-



ceived until we've stored up a full 50 samples, or a full second's worth of brainwaves.

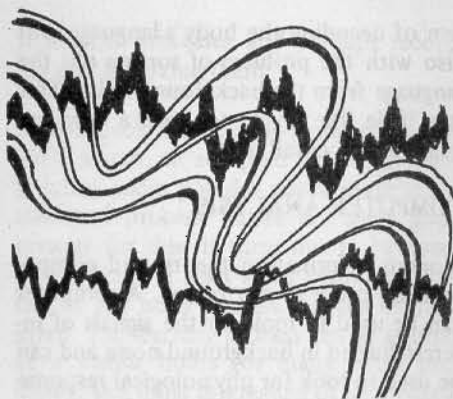
Now let's have the computer flash the light again and begin collecting a new batch of samples of the brainwave signal. The first sample from the new batch should be added to the first number stored in our block of memory. The second sample gets added to the second number stored in memory and so on. At the end of two seconds we will have collected two complete sets of 50 brainwave samples and we'll have added them together. If we were to have the computer stop collecting new data at this point and go through those 50 memory locations and divide all the numbers found there by two and then print out the result as a graph, we'd get a picture of the average of the two one-second segments of brainwave data.

In the usual experiment of this type we wouldn't stop with only two flashes of the light. We'd go on to average together as many as 40 or 50 flashes and their brainwave responses. The result of this averaging process is that the brainwaves that are unrelated to the flashing light tend to average out toward zero, while any brainwave response which is caused by the flashing light will tend to be reinforced by each additional flash that we add to the average. We've found a way to extract the signal from the background noise.

The technique we've just described is called visual evoked response averaging. A special purpose computer called a 'computer of averaged transients' (CAT) is often used for this type of work. A CAT is

useful in situations where a response of interest is buried in background noise unrelated to the stimulus which produces the response. For a CAT to be useful, the response must be time locked to the stimulus. The CAT has been used to study brainwave responses to lights, sounds and to touch. Your general purpose micro-computer could be programmed to operate as a CAT.

Researchers have tried to apply the CAT technique to detect more interesting events in consciousness than our response to a flashing light. One researcher found distinctly different brainwave responses to different patterns of lines (e.g. polar coordinates, radial lines, concentric circles, etc.).¹ Another researcher tried averaging the brainwave responses that were produced by speaking aloud different letters of the alphabet many times;



he did find different patterns typical of different letters.² The traditional CAT technique usually involves looking at a single physiological event, such as the brainwave signal from a particular scalp location. But when this technique is expanded to include the recording and separate averaging of many different physiological signals, some very interesting possibilities develop.

RESPONSE PATTERNS

As we've seen, the power of the CAT lies in its ability to pick a weak response out of strong background noise by averaging many responses. Suppose we do this for many physiological measures; the result is a set of response patterns, one for each measure. Now we can ask our computer to compare a single response, in real time, for each physiological measure with its corresponding set of stored average response patterns.

If an event we are interested in isn't happening, we'd expect most of the current physiological data to be unlike our pre-recorded patterns, although one or two measures may appear similar to the pattern we are looking for just by coincidence. But if an event we are looking for is happening, each of the measures we are looking at will be at least a little more similar to its recorded pattern (which we know is typical of the event) than we could expect from chance.

A commonly used way of comparing two patterns is to measure the 'root mean square (RMS) distance' between them. This is simple to do. In our earlier example of a one second segment of data consisting of 50 samples, we simply subtract the first data point from the first average, square the difference and store it. Then find the difference between the second data point and the second average point, square that and add it to the last square. If we keep this up for all 50 points, we'll end up with the sum of the squared differences between the individual points. Then we divide by the number of points (in this case 50) and take the square root of the result. That's the RMS distance; it'll be small if the patterns are similar.

If we measure a large number of different physiological events at once (let's say that we measure brainwaves from many different scalp locations) then we can sum



the RMS distances from each scalp location's pre-recorded average and get the same kind of improvement in signal to noise ratio that we got from averaging many repetitions of the event. We can use a kind of 'spatial averaging' in place of averaging over time.

SPATIAL AVERAGING

This idea of spatial averaging has been tried out. In a series of experiments at

Stanford Research Institute,² a computer was taught to identify the word an experimental subject was thinking. Before you get excited about 'mind reading' by your computer though, you should know the limitations of this experiment.

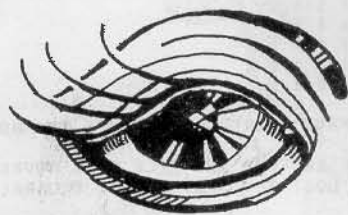
The first, and perhaps most important, limitation was that the word had to be thought on command from the computer. This is because of the precise timing re-



quired for comparing the stored patterns with the sample brainwaves; small timing errors reduce accuracy considerably. The next limitation is the size of the computer's vocabulary; in the first series of experiments it was the words put, school-boy, coughdrop, tip and had. These words were recognized correctly by the computer about 2/3 of the time by the comparison of EEG signals from 4 scalp locations with stored patterns for each word.

Another big limitation is the speed of identification of words. In the early SRI experiments the major part of the computing was done off-line and the words were not identified in real time. In later experiments real time identification was achieved for a vocabulary consisting of the words right, left, up, down, near, far and stop, but the accuracy of identification dropped to 55%, even though 5 channels of EEG were analyzed.

Meanwhile, the idea of spatial averaging is being tried out in other applications. One very interesting project involves computer-aided instruction (CAI).



EOG

Pierre St Jean is an instructor in the Social Sciences Department at Algonquin College in Ottawa, Ontario. He is also researching methods for making CAI more effective through computerized physiological monitoring. He's using a Nova minicomputer to present CAI material on a CRT terminal in printed form. From time to time the program asks the student a question. If the answer the student types back on the terminal is correct, more new material is presented. If the answer is wrong, an alternative and more detailed presentation of the material is made and then more questions are asked.

That's traditional CAI. Pierre has added a physiological monitoring system which allows the computer to receive and analyze physiological data from its student while the CAI process is happening. Pierre's system presently monitors 4 channels of brainwaves, and one channel each of skin temperature, EMG (muscle tension), GSR/BSR (skin resistance) and EOG (electrooculograph, for measuring eye movements).

Pierre is in the process of finishing up software which will enable the NOVA to handle all this physiological data while it



GSR

is supervising CAI. The idea behind this is to look for patterns of physiological response (which may be different for different students) typical of good or poor performance at the CAI task. Some day it may be possible for the computer to distinguish between wrong answers given because of lack of understanding and those resulting from poor attention. Eventually we may be able to recognize the physiological signals that correlate with times when a student can learn well from reading, other signals may indicate that a film would be the best way to learn, others might lead the computer to suggest to the

student that it is time for a 10 minute exercise break or a brief meditation period.

We don't know yet if patterns like these can be reliably detected, but the existing research data are promising. The strategy for studying these patterns of physiological response will involve extensive use of computers.



The hardware which Pierre St Jean is using was built for him by Aquarius Electronics in 1974, with some recent additions. Experience from the design of this, and other, computerized physiological monitoring and biofeedback systems has led to the design of an S-100 compatible set of plug-in printed circuit modules for interfacing physiological data to microcomputers.

Part II of this series will describe more recent research using microcomputers to look for physiological correlates of emotional states. We'll also talk about other approaches to relating physiological and psychological events, primarily biofeedback. The essential idea behind biofeedback training is the use of a sophisticated system of instruments to improve the sensitivity and range of our internal perception abilities temporarily so that we can learn more about ourselves and about how to 'shift gears' mentally and physiologically from one state of consciousness (mood and mode of cognition) to another.

FOOTNOTES

1. Clynes, Manfred 'Sentic: Biocybernetics of Emotion Communication,' *Annals of the New York Academy of Sciences* 220:57-131 (1973).
2. Pinneo, L.R. and Hall, D.J. 'Feasibility Study for Design of a Biocybernetic Communication System,' Stanford Research Institute final report (1975).