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Final Report *November 1975*

ORGANIC BIOFIELD SENSOR

By: H. E. PUTHOFF AND R. FONTES
ELECTRONICS AND BIOENGINEERING LABORATORY

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SRI Project 3194 (Task 3)

Approved by:

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Information Science and Engineering Division

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ABSTRACT

The purpose of the investigation reported here was to assess the feasibility of the use of a special class of device (organic sensor) for real-time contactless measurement of psychological stress or other psychological or physiological state in a human subject being monitored. To this end special detectors were developed so that the electrical activity and micromovements of plants (Philodendron oxycardium, Mimosa pudica) and algae (Nitella) could be monitored. The activity of these sensors while in close proximity to a human subject viewing slides of varying emotional content was then examined. The sensors were located inside Faraday cage electrical shielding to eliminate trivial electrical artifacts. To provide an objective indicator of emotional response during viewing, the subject's GSR (galvanic skin response) was recorded to provide a signal to cross-correlate with the organic sensor output.

Pilot experiments with the algae Nitella indicated that they were not responsive to the activity of human subjects in close proximity, and therefore experimentation with Nitella was terminated early in the program. With regard to plant sensors, however, experimental findings with twelve subjects indicate that the electrical activity of plants in close proximity to a human subject viewing slides of putative emotional content, although not in one-to-one correspondence with subject GSR, nevertheless shows in some cases (20%) strong evidence of correlation with GSR.* Furthermore, such electrical activity is found not to be an

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* Subject S-3: $p < 4.2 \times 10^{-4}$; $p < 0.024$, replication experiment.

Subject S-4: $p < 0.038$.

artifact of plant micromotion, the latter being uncorrelated with either subject GSR or plant potential. Furthermore, it is not a system artifact due to slide tray activity or signals in the GSR channel (determined by automated control runs). Thus, although we must reject the hypothesis that subject GSR and plant potential fluctuations of a nearby electrically shielded plant are in general correlated, there is evidence for a degree of correlation beyond that expected by chance.

CONTENTS

ILLUSTRATIONS

TABLES

Final Progress Report November 30, 1975

SRI Project 3194

Task 3

ORGANIC BIOFIELD SENSOR

I Objective

The objective of this program was to assemble and test organic sensors of the plant and algae varieties to determine their usefulness as real-time contactless indicators of psychological stress or other psychological or physiological changes in a human subject being monitored.

II Background

Of current interest with regard to monitoring physiological variables is the possibility of contact less systems in which the pickup probe is a convenient component such as a plant or other common biological organism. A sensor system of this type, if successfully developed, would constitute a convenient device for monitoring the physiological or psychological state of an individual, especially during moments of heightened emotional activity.

There has been some indication in the quasi-scientific literature that real-time indicators of the emotional state of an individual could be registered by plants whose electrical activity was being measured by standard polygraph equipment.1-3* Such claims are in dispute, however, due to failures in replication attempts in some laboratories.[4,5]

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*References are listed at the end of the report.

To determine the validity of claims made for such biological sensors, especially with regard to the usefulness of such devices as real-time indicators of the psychological or physiological state of an individual, the Electronics and Bioengineering Laboratory of SRI agreed to build and test a few simple organic probes.

The program effort therefore consisted of the following efforts:

- The selection of appropriate plant and algae organisms to act as detectors.

- The design and fabrication of appropriate coupling devices to mate organic sensors to electronic circuitry.

- The design and execution of an appropriate experiment to determine whether signatures of sensor signals correlate with changes in stress of a subject being monitored.

III Sensor Design

A. Development of Algae Sensor

To begin, sensitive electroding and electronics were developed for use in monitoring the electrical activity of an algae (Nitella). Such development was the necessary precursor to experiments designed to determine the usefulness of such an organism as a biofield sensor.

Nitella is an algae which is known for its unusually large cells. A single Nitella cell may grow to be 10 inches long and 2 millimeters in diameter (see Figure 1). A second unusual property of Nitella lies in its capacity to be triggered into producing electrical signals, called action potentials, which propagate along the length of the cell wall. The action potential (Figure 2) corresponds to ion displacement across the cell wall and can be measured externally. It is because of these clear, distinctive, and easily recorded action potentials that the Nitella was first chosen as a possible biosensor. A glass-insulated electrode stage was developed to permit measurement of Nitella action potentials over prolonged periods without damage to the cell wall

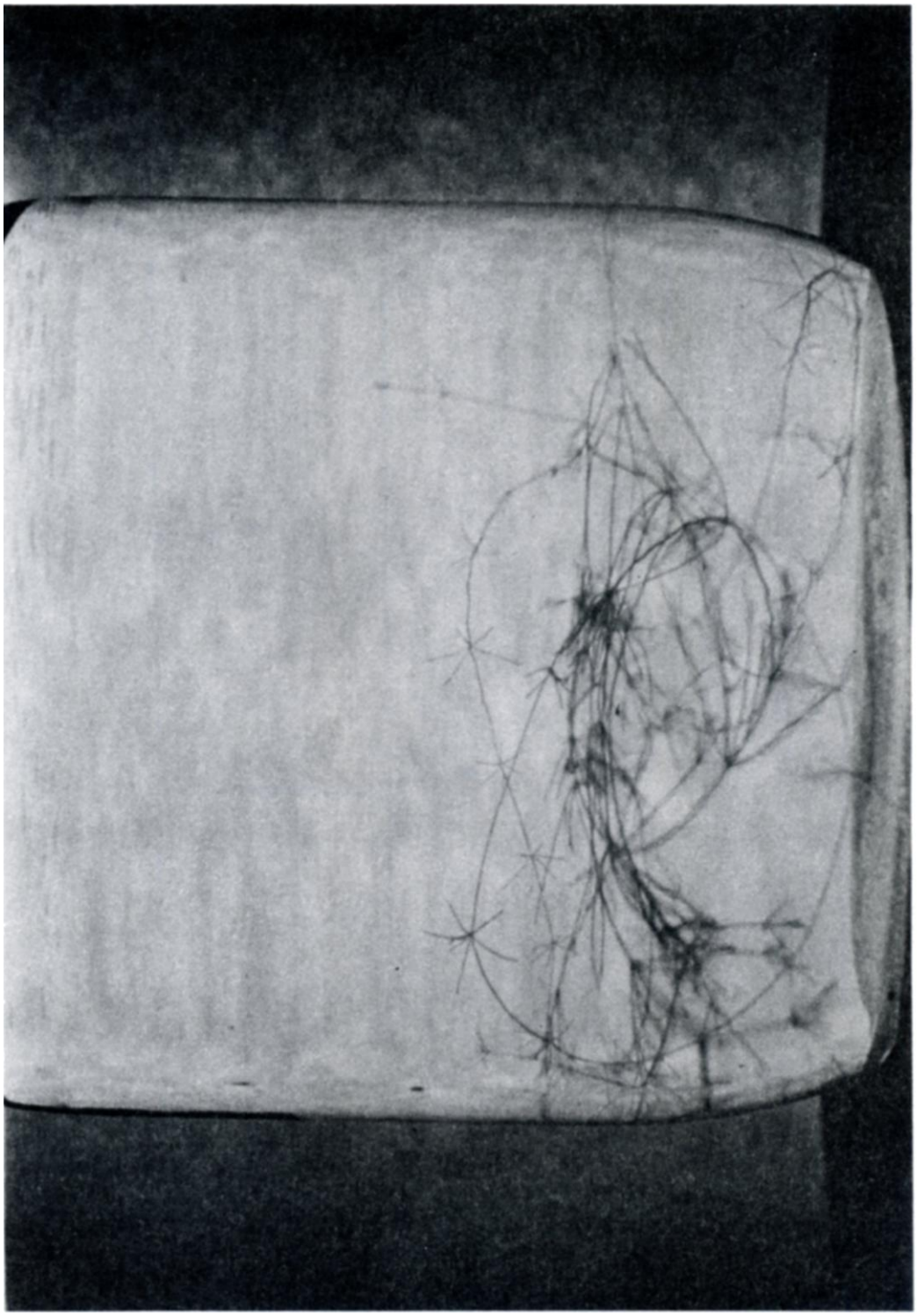

FIGURE 1 ONE-GALLON NITELLA AQUARIUM
Strands between nodes are single cells.

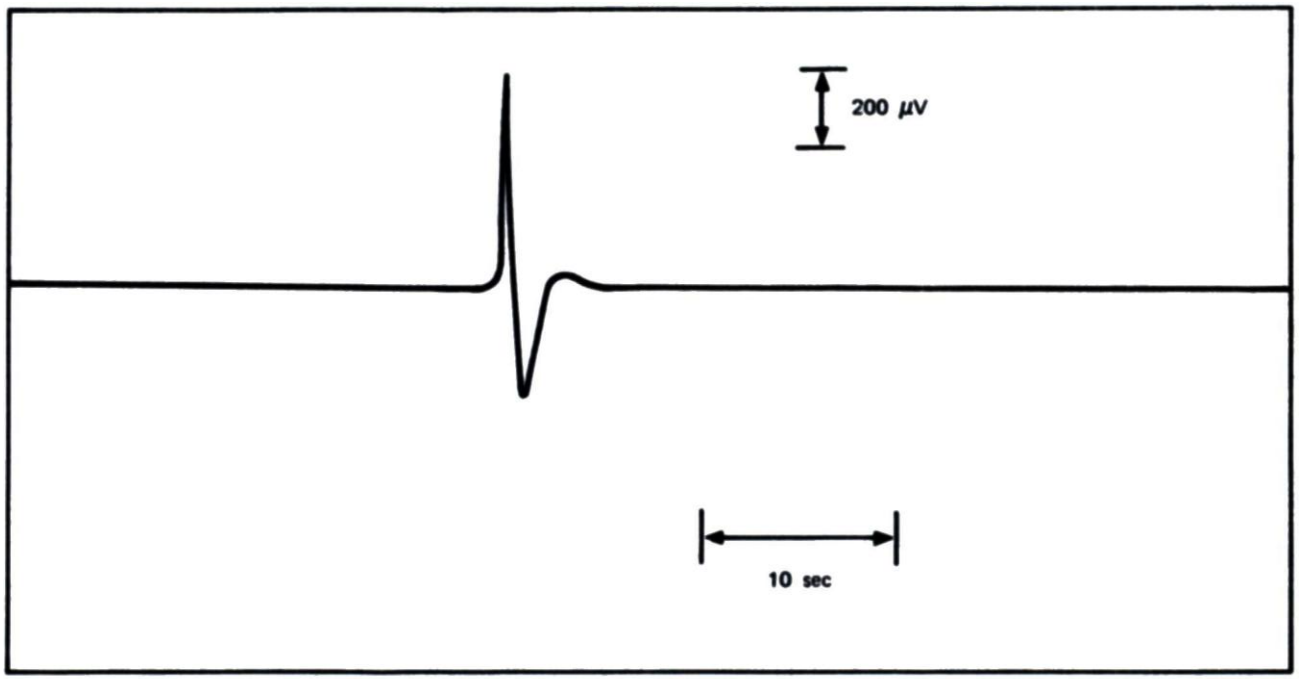

FIGURE 2 ELECTRICAL SIGNAL (ACTION POTENTIAL) FROM A SINGLE NITELLA CELL IN SOLUTION AS MEASURED BY GLASS-INSULATED ELECTRODE STAGE SHOWN IN FIGURE 3

from silver chloride electrode surfaces (see Figure 3). In this unit the Nitella cell is held by glass rods in the center of two silver-chloride-coated silver electrode rings in such a way that at no point does the cell touch the electrodes. (This technique was developed to replace an earlier contact electrode system when it was discovered that action potentials could be measured in solution at a distance of centimeters from the cell.) In the contactless electrode system, a Nitella cell may be monitored for days at a time without discernible damage to the cell.

In addition to the measurement of the electrical activity of single cells, it is also possible to measure the activity of an entire aquarium, as shown in Figure 4. The Nitella biosensor system has therefore been developed to a stage where it is possible to measure both the electrical activity of a single cell and the summed activity of a large number of cells.

As a pilot study, numerous experiments were conducted with several different subjects in an effort to observe the generation of action potentials in Nitella in response to nearby human activity. In spite of extensive efforts in this direction no substantial results were obtained. Therefore, work with Nitella was terminated.

B. Development of a Plant Sensor

A common household plant (Philodendron oxycardium) was first chosen for the potential role of plant biofield sensor. Such plants have been found previously to exhibit a high degree of electrical activity, allegedly sensitive to environmental influence.

1. Micromotion Detector

In order to discern whether the observed electrical activity is simply a result of plant micromotion, and whether plant

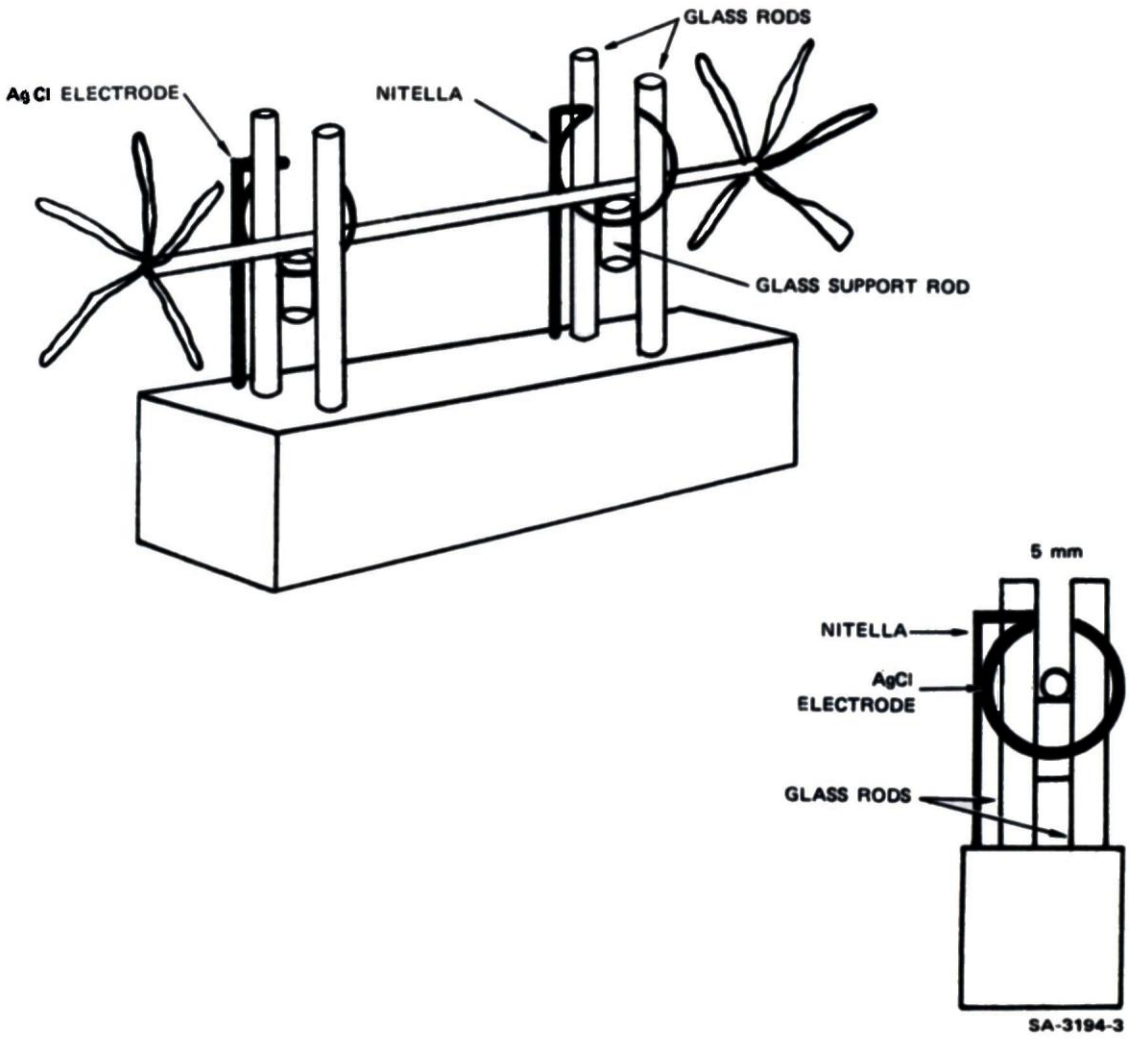

FIGURE 3 GLASS-INSULATED ELECTRODE STAGE FOR NONDESTRUCTIVE MEASUREMENT OF NITELLA ACTION POTENTIALS

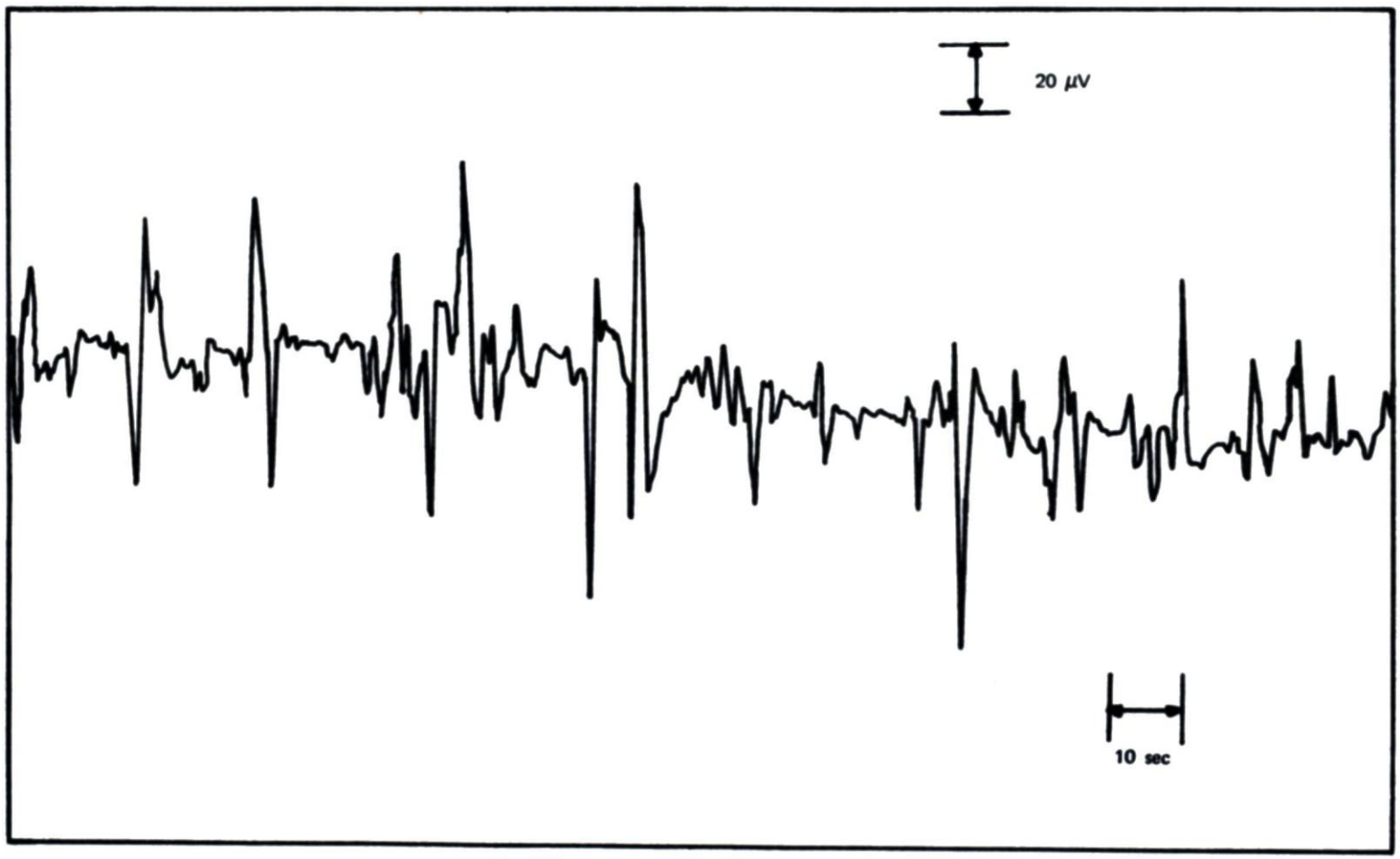

FIGURE 4 ELECTRICAL SIGNAL FROM ONE-GALLON NITELLA AQUARIUM CONTAINING ≈ 300 CELLS AS MEASURED BY 1" X 1.5" SILVER – AgCl ELECTRODES PLACED 4" APART

micromotion itself might constitute a useful signal in a biofield sensor application, special micromotion detectors were developed as an auxiliary to an electrical activity monitoring system. The initial plant movement experiments were done with members of the philodendron family. However, it quickly became apparent that plants with much greater capacities for movement would be better suited for the task. As it turned out, the plant which had the most suitable movement characteristics also had large electrical signals (not unlike the action potentials of Nitella) which travel along the plant's stems and are associated with its move¬ments. This plant is the Mimosa pudica, or "sensitive plant."

The movement of the Mimosa pudica is most often" stimulated by the influence of light and dark. However, a variety of other stimuli can also affect it, such as mechanical stimulation (touching), heat, cold, and gaseous phenomena. If, for example, the secondary petioles (the leaves) of the Mimosa are touched, the leaflets fold upward until they touch, the secondary petioles in turn also fold upward until they meet, while the main petiole (which supports the 2 to 4 secondary petioles) falls downward, bending at the pulvinus (the swollen base of the leafstalk) which attaches to the main stem of the plant. All this occurs in as little as a second. Not all Mimosa pudica movements occur this fast, however. In fact, most Mimosa movements occur at speeds just below the observable level (like that of a minute hand of a clock). This speed is still many times faster than that of most plants however. It is within this range of movement that the experiments with Mimosa pudica have been conducted. To monitor such movements, two micromotion detectors were developed to measure in real time extremely small move-ments having very little associated force.

The first detector is shown in Figure 5. The heart of the mechanism is a light-emitting diode set opposed to a phototransistor (photon-coupled interrupter module General Electric H13A1-H13A2) which

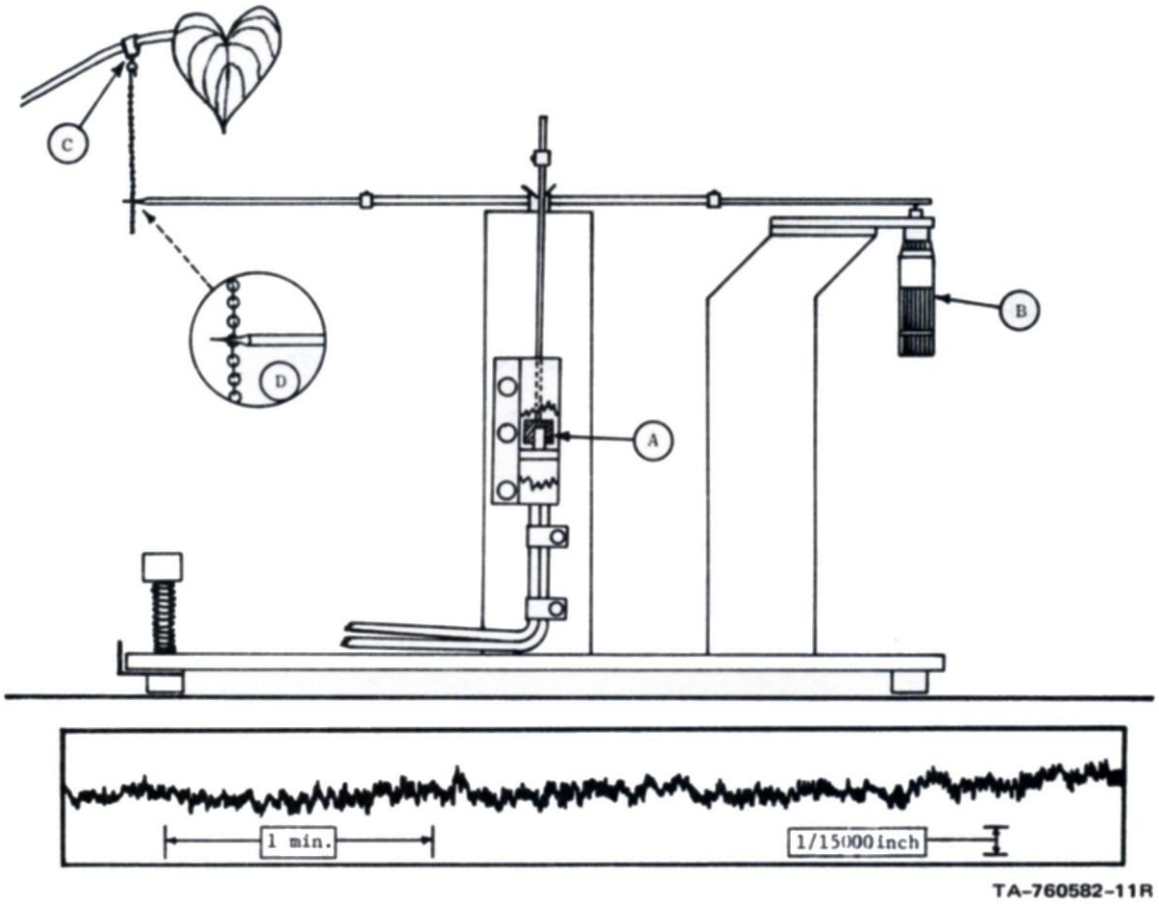

FIGURE 5 SHOWN IN THIS DIAGRAM IS THE FIRST MICROMOTION DETECTOR DEVELOPED

In order to measure a plant's movement with this device, a fine wire loop is fixed to the plant by running a narrow section of tape around the plant stem and then around the wire loop. A fine gold chain is then hooked to the loop (C) and the instrument then attached to the gold chain (D). At point (A) the mechanical motion is transduced into an electrical signal by the movement of a grey scale negative between a light emitting diode and a photo transistor. The output of the instrument being tested for noise and drift is shown in the graph at the bottom of the diagram. As can be seen in the graph the instrument's maximum sensitivity is approximately 1/15000 inch. A micrometer (B) is used to calibrate the instrument.

is interrupted by a photographic negative of a continuous gray scale. The gray scale is attached to the bottom of a pendulum arm which, in turn, is attached to a level arm activated by plant movement via a fine gold chain. Thus, plant movement is translated into variations in light intensity which are transduced into an electrical signal by the photo-transistor. At the bottom of Figure 5 is a section of a test graph showing the instrument's stability under optimum conditions. As can be seen in the graph, approximately 1/10,000 inch resolution is the maximum that could be expected while 1/1000 inch would be a good working figure.

It was found in preliminary tests with plants that an instrument of greater resolution and linear output was needed. The instrument shown in Figure 6 was built to meet these requirements. The sensitivity of the instrument is one microinch.

In Figure 7 the micromotion detector is shown attached by way of a gold chain and hook (A,B) to a Philodendron leaf. The use of the detector in the context of the final experimental setup is shown in Figure 8. The apparatus at the left monitors the plant (Mimosa pudica) for electrical activity (described later) while on the right the micromotion detector shown in Figures 6 and 7 monitors the plant for movement by means of the lever arm labeled A. In Figure 9 the plant and monitoring apparatus are shown inside a cage of copper screen and Plexiglas which shields the plant from simple electrostatic effects, radiofrequency interference (RFI), and also movement due to air currents.

In experiments involving the measurement of plant movements smaller than 1/1000 inch a special platform shown in Figure 10 was used. This platform was isolated from building vibrations and floor movements and allowed for measurements of plant movement down to 20 microinches.

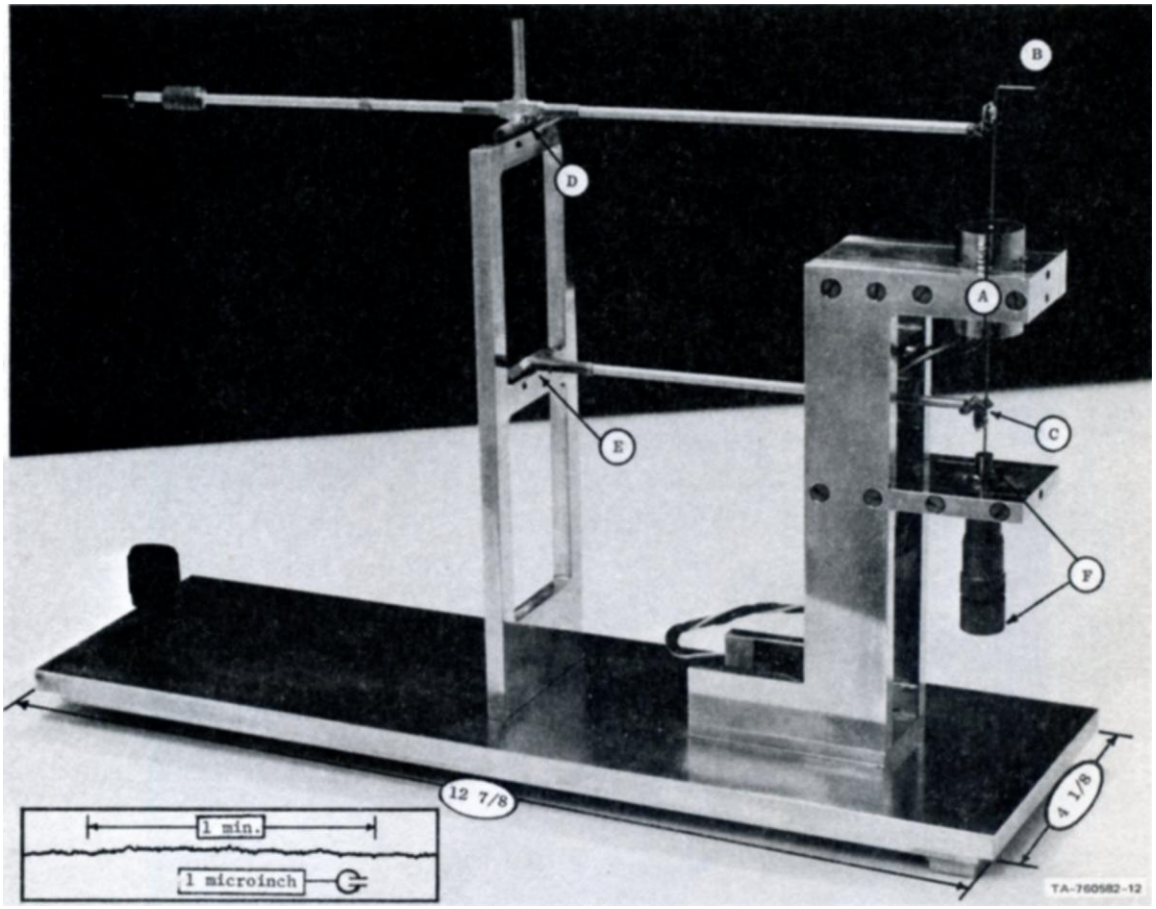

FIGURE 6 THE PLANT MOVEMENT DETECTOR ABOVE IS CAPABLE OF MEASUREMENTS AS SMALL AS 1/1,000,000 OF AN INCH

However, its normal operating range is from 1/1000 to 1/10,000 of an inch. The component which actually measures the movement is a differential transformer (A). Its movable core is hinged between points (B) and (C). Two lever arms hinged at points (D), (B) and (E), (C), form a parallelogram that holds the core centered within the opening of the differential transformer as it moves up and down. A micrometer (F) is used to adjust and calibrate the system.

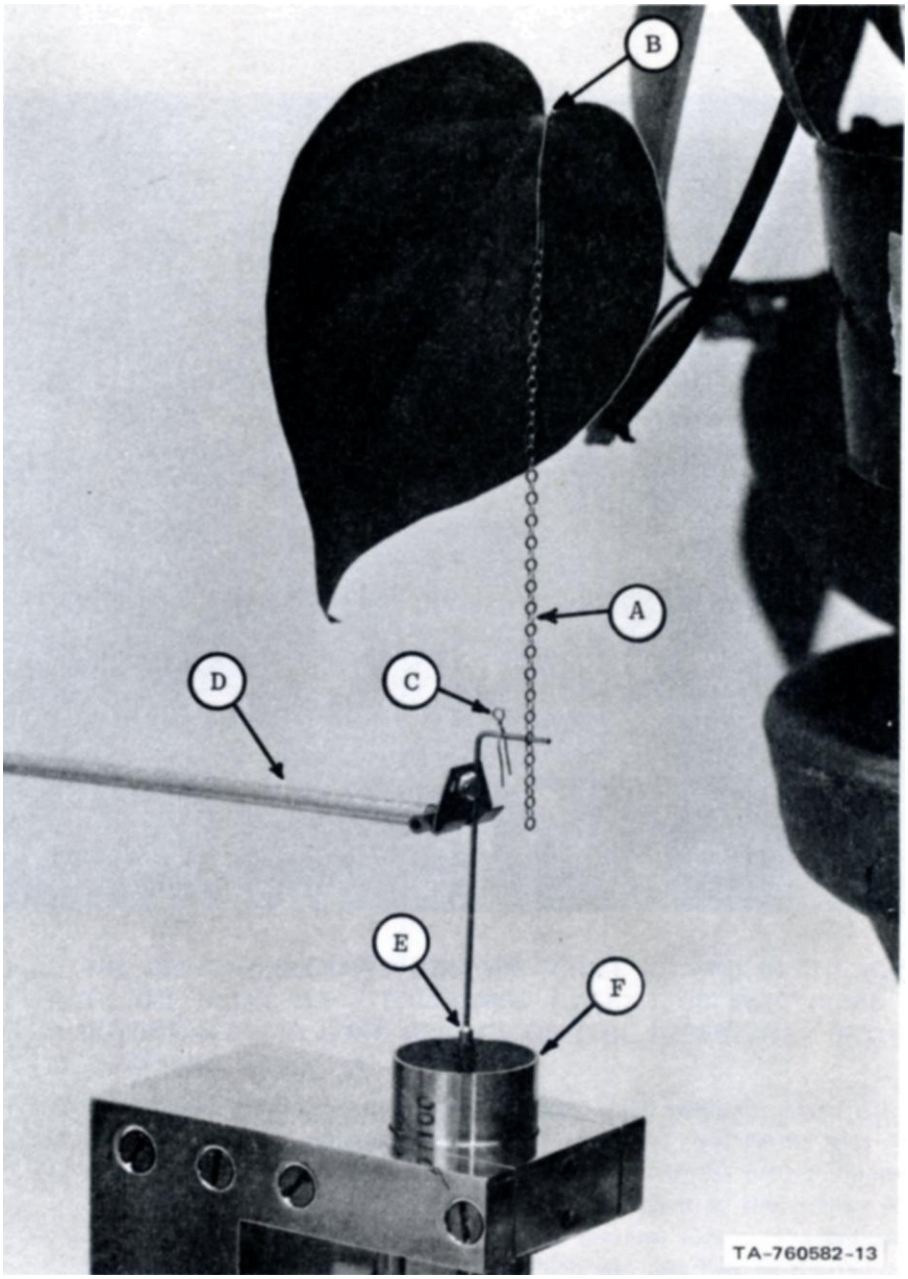

FIGURE 7 HERE A PHILODENDRON OXYCARDIUM LEAF IS ATTACHED BY A HOOK (B) AND GOLD CHAIN (A) TO THE PLANT MOVEMENT DETECTOR

The lever arm (D) and transformer core (E) are held taut against the chain (A) by a 5 mg weight (C). A movement of the core (E) within the opening of the differential transformer (F) produces a change in the output voltage of the transformer which is proportional to the movement.

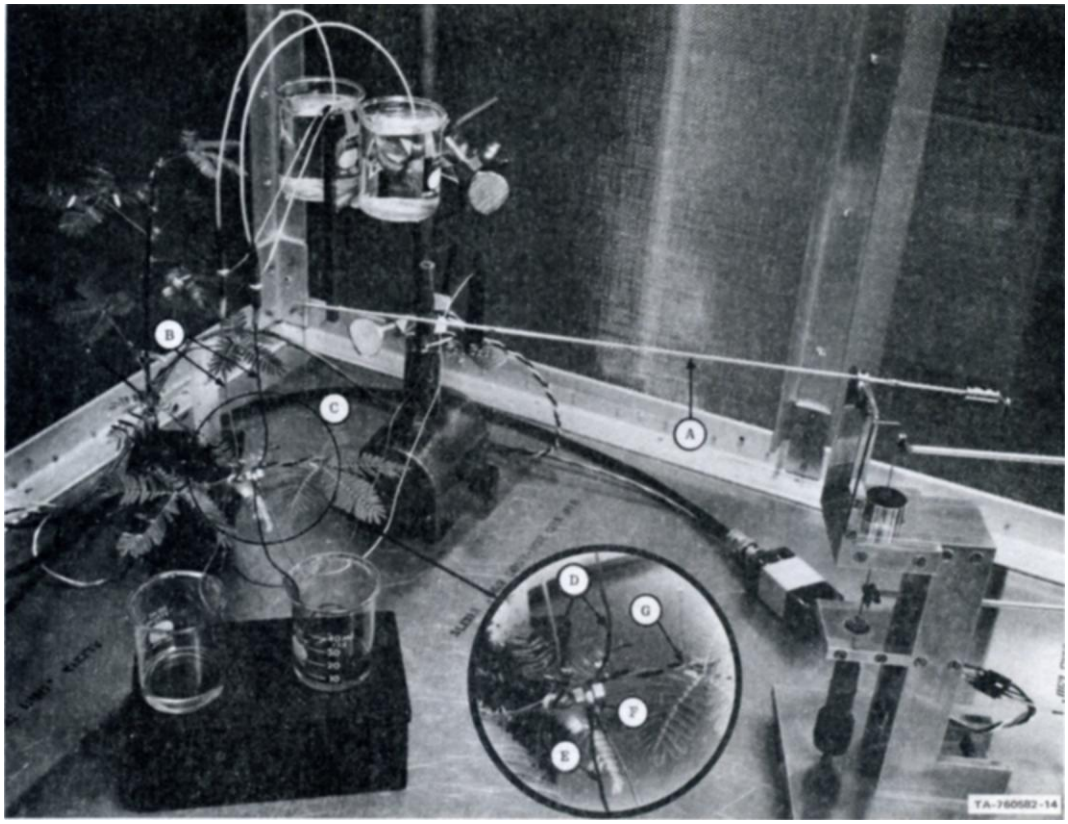

FIGURE 8 THE ELECTRODES SHOWN WITHIN CIRCLE (C) AND IN THE BLOW-UP TO THE RIGHT, WERE DEVELOPED TO MONITOR ELECTRICAL POTENTIALS FOR LONG PERIODS OF TIME DEPENDABLY WITHOUT DAMAGING THE PLANT

Water flows down from the upper beakers along polyester wicks (D), over the electrodes (F), onto a second set of wicks (E), and finally into the lower set of beakers. This process keeps the electrodes constantly wet and in electrical contact with the plant stem. The plant in this picture is a Mimosa pudica or sensitive plant. In the previous picture, the philodendron leaf was shown supporting the chain which was attached to the movement detector directly, while in this figure the chain is supported by the lever arm (A). This has been done, in order to keep the weight of the chain from pulling down on the delicate leaf. The Mimosa pudica moves such relatively large distances (1 or more inches) in such short periods of time that a 20 to 1 reduction lever arm (A) must be used just to keep its movements within the range of the movement detector.

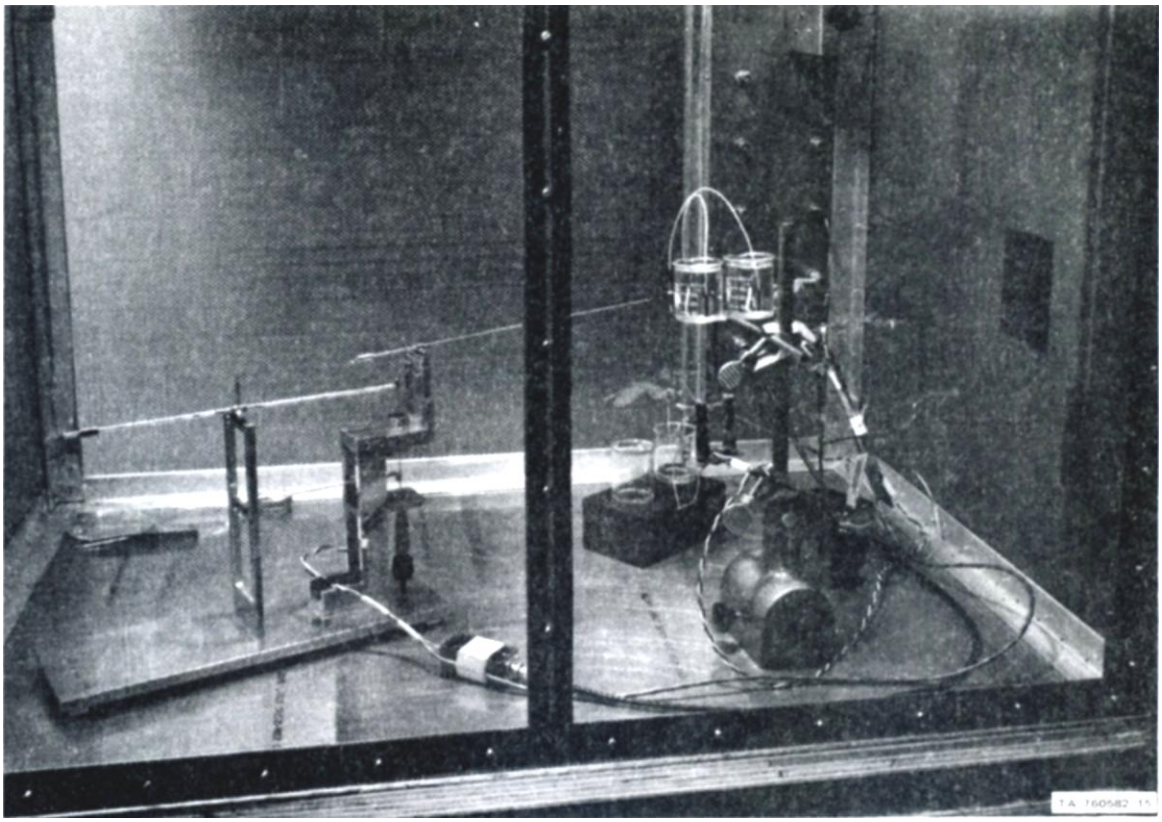

FIGURE 9 THE INSTRUMENTS SHOWN WITHIN THE COPPER SCREEN AND PLEXIGLAS CAGE ARE SHIELDED FROM ELECTROMAGNETIC RADIATIONS, ELECTROSTATIC EFFECTS, AND AIR CURRENTS

The cage itself is mounted on two 1-inch thick plywood boards with rubberized horse hair between them, as can be seen in the extreme lower right-hand corner. The boards are in turn resting on four special shock-absorbing rubber feet, which rest on a Plexiglas stand sitting on a concrete floor.

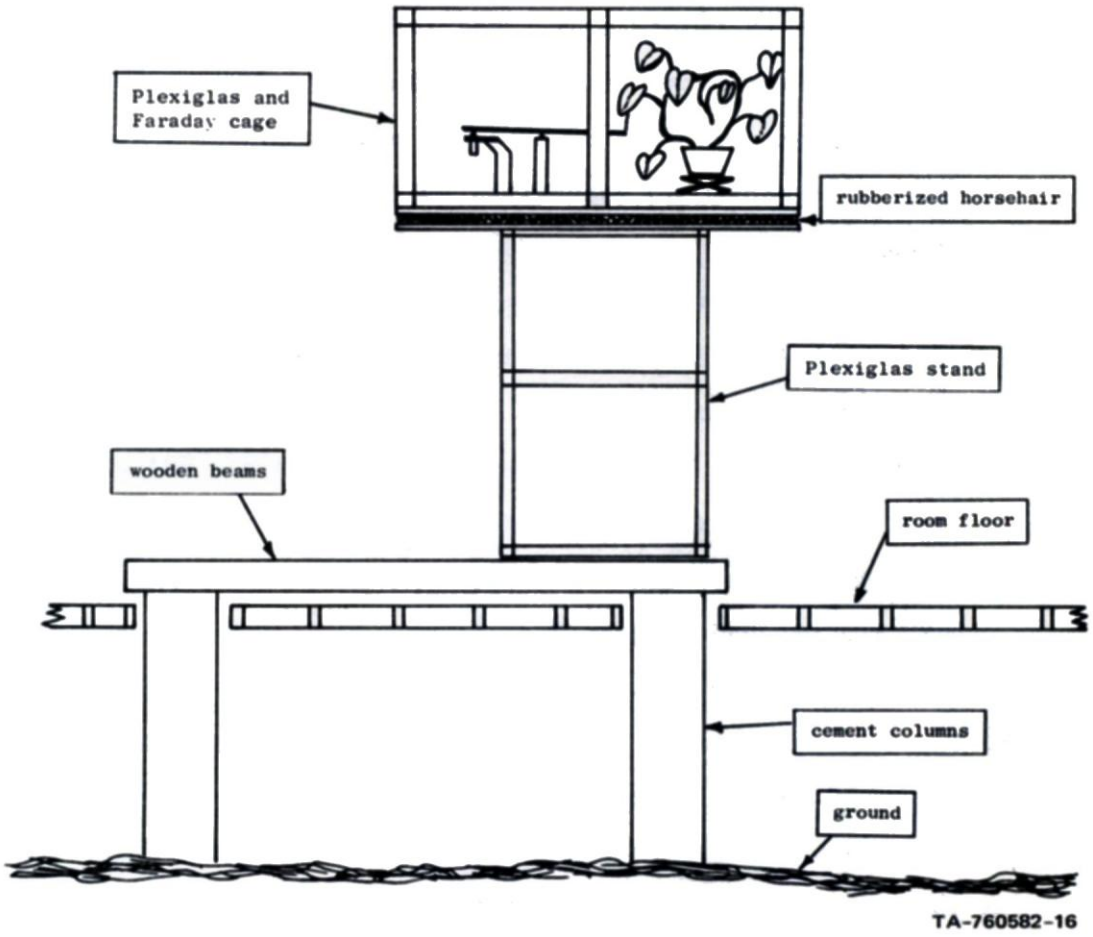

FIGURE 10 IN THIS DIAGRAM THE FARADAY CAGE AND PLEXIGLAS STAND ARE RESTING ON WOODEN BEAMS SET ON CEMENT COLUMNS WHICH ARE SUNK INTO THE GROUND

The floor and building vibrations are in this way isolated from the cage. With this method movements as small as 20 microinches have been measured.

2. Electrical Activity Detector

In order to monitor the electrical activity in the plant leaf, a number of electrode systems were developed before a final version was settled on. The first consisted of four microplate surfaces of AgCl, each with a circular cross section one millimeter in diameter. Two microplates four millimeters apart were placed on each side of the leaf, each pair opposing the other. A small drop of saline solution was used on each of the four electrodes to form low-impedance contacts between leaf and electrodes. The difficulty of maintaining stability in the face of drying out of the electrode-plant interface led to a second version, shown in Figure 8, in which continuous solution flow along polyester wicks kept the interface damp. Finally, the electroding of the plant was changed from saline wicks to microelectrode needles of tungsten. In the new electrode arrangement, two locations on one of the plant's stems were independently monitored by two sets of differential electrodes. Thus, four electrodes were inserted into the stem of the plant, all within 45 millimeters of each other. Because the Mimosa pudica is a very delicate plant, the tungsten needles used were only 5 millimeters long and 0.004 inch in diameter. These were inserted into and through the stem and were left there, supported only by the stem. The wire leads from the needles were of extremely fine single-strand enameled copper wire (#40). This wire conducted no vibrations or movements from the Faraday cage to the needles, thus eliminating the false signals often generated by the vibration of microelectrodes. The resistance across the electrodes when inserted into the Mimosa pudica was approximately 5 megohms. Two differential 100-megohm remote probes were placed inside the Faraday cage to pick up the signals from the electrodes, while outside the cage two Grass preamplifiers amplified the signals.

With regard to the comparison of results obtained with the electrical and micromotion detectors, experiments conducted using the apparatus shown in Figures 6 through 10 indicate that the electrical signals monitored in plants appear to be independent of micromotion created by forces external to the plant; however, micromotion (or macromotion in the case of Mimosa pudica) which is generated from within the plant itself frequently has associated electrical signals.

IV Experimental Procedure

A. Apparatus

The goal of the experimental series described in this section was to determine whether the measurement of plant micromotion and plant potentials might serve as indicators of changes in psychological state of a human subject in close proximity to a plant. The subject's GSR (galvanic skin response) was recorded to provide an objective indicator of the subject's internal processes.

In pilot observations, apparent correlations between subject GSR and plant recordings were sometimes observed under varying conditions with several subjects. Therefore, a formal experiment was designed and carried out to determine the significance of such observations.

In the pilot observations the observed correlation between subject GSR and plant response appeared most pronounced when the subject, in close proximity to the plant, subjectively experienced a sudden strong psychological change. For the purpose of the experiment, we therefore chose as a stimulus condition the sequential viewing of a series of 30 slides, 12 of which were designated target stimuli, *18 control stimuli.

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*Slides 2, 5, 6, 10, 13, 14, 19, 20, 24, 28, 29, 30.

The 12 target stimuli, so designated on the basis of pre-experiment observation of GSR response in volunteer male subjects, consisted of nine slides of female nudes, two slides of death scenes (firing squad, gangster slaying) and one a surrealistic painting by Goya of human dismemberment. The 18 control slides consisted of nature scenes of apparent neutral content.

The physical arrangement of the experiment is shown in Figure 11. As is shown, the subject (C) was seated in front of a rear projection screen (D) at a distance of about 20 inches. The screen was 9 inches by 9 inches, thus occupying the entire central portion of the subject's visual field. The slides were projected onto the screen by an automatic carousel projector (E) located directly in front of the subject. A partition (L) separated the subject from the plant but more importantly it isolated the changing light of the projector from the plant (an important precaution, since plants are known to be phototropic). The plant had its own light source located directly above it while the rest of the experimental room was dimly lit. The experimenter (A) conducted the experiment from within the room and had his own station where he could control (H) the slide projector (E), event market (I), and resetting of the GSR (G). The arrangement of the plant (N), placement of the electrodes (P), of the micromotion detector (0), and of the Faraday cage (M) within the experimental room are also shown. The arrangement of the plant and apparatus within the Faraday cage were also shown in Figures 8 and 9 (with the exception of the electroding of the plant which was changed from saline wicks to microelectrode needles of tungsten, as discussed earlier). The signals from the electrodes are amplified by two differential 100-megohm probes (P) inside the Faraday cage, and further amplified by two Grass preamps (Q) outside the cage.

The preamp high and low band-pass filters were set at 0.1 Hz and 100 Hz, respectively. The sensitivity of the micromotion detector (0)

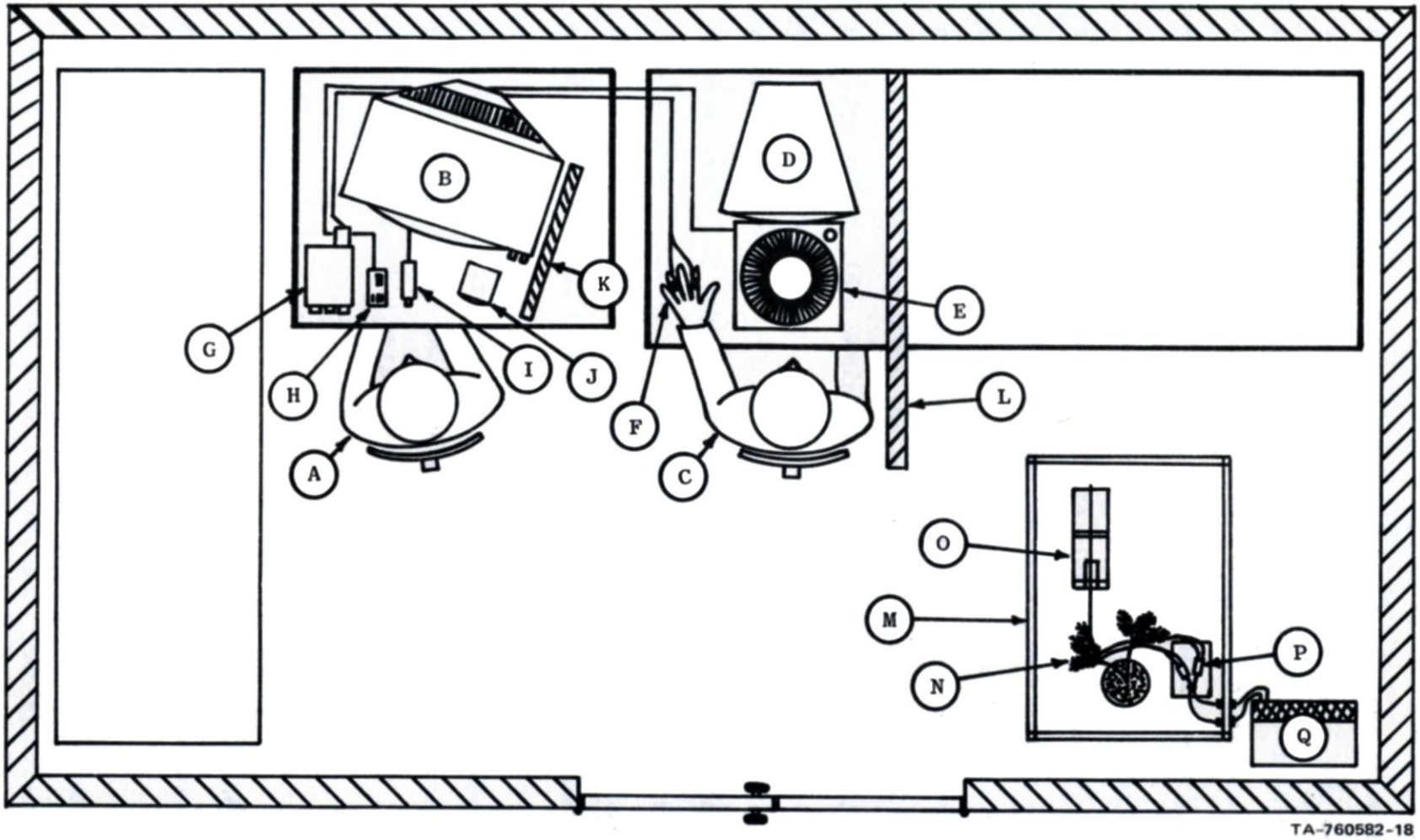

FIGURE 11 IN THIS DIAGRAM AN OVERHEAD VIEW OF THE SETUP OF THE LAB FOR THE HUMAN GALVANIC SKIN RESPONSE (GSR) AND MIMOSA POTENTIAL EXPERIMENT IS SHOWN

(A) Experimenter; (B) Video monitor; (C) Subject; (D) Rear projection screen; (E) Slide projector carousel; (F) Galvanic skin response (GSR) electrodes on subject's fingers; (G) GSR controls; (H) Slide projector remote control; (I) Event marker for strip chart recorder; (J) Clock, timer; (K) Partition; (L) Partition; (M) Plexiglas and Faraday cage; (N) Mimosa pudica plant; (O) Micromotion detector; (P) 100-megohm high-impedance probes; (Q) Grass DC preamp D5 series.

was set to ±1/6000 inch, having a high-pass filter with a time constant of 15 seconds. The GSR was not dc filtered, and therefore required periodic nulling or "centering" by the experimenter. The sensitivity of the GSR was set to ±lOO ohms. The two potential signals from the plant, the micromotion signal, the GSR signal, and the event marker were all recorded on a Mark 200 four-channel Brush recorder.

The Brush recorder was located in a room across the hall from the experimental room because of its vibration and noise. A video camera monitored the remote recorder and displayed the image on a video monitor (B) in the experimental room. In order to avoid distracting the subject, a partition (K) was put up between the video monitor and the subject. The experimenter could see the subject's GSR activity and the plant activity on the video monitor. This served three purposes: (1) it allowed the experimenter to recenter the GSR needle; (2) it allowed the experimenter to label artifactual GSR signals due to the subject's physical movement, deep breathing, or movement of electrodes on the subject's fingers; (3) it allowed the experimenter to ask for further in formation when unusual GSR-plant potential correlations occurred. (For example, in one case there was a strong correlation between the large GSR spike and a large shift potential in the plant. When the experimenter saw this he immediately asked the subject what he was experiencing. The subject answered that the slide (a night snow scene, presumably neutral) reminded him of a bad skiing accident he had experienced in the past.)

B. Experimental Protocol

Ten male volunteers were used as subjects in the experiment. Twelve data runs in all were carried out, two subjects participating twice.

The subjects were briefed on the experimental design, and therefore were not naive as to the purpose. Each experiment ran 15

minutes (30 slides, 30 seconds viewing time each). The subject was instructed to look at each slide for the full 30 seconds and that his only task was to experience the content of the slides.

To begin the experiment, the subject was seated facing the Screen, and electrodes (F) were taped onto his second and fourth fingers in order to monitor his GSR. The various pieces of equipment were then adjusted and the subject's GSR was allowed to stabilize before the experiment began. Consideration was given as to whether or not the subject should be allowed to speak during the experiment. After weighing the advantages and disadvantages of this it was decided to allow the subject to speak, but not to encourage it. It was desirable that the subject responses be as natural as possible under the circumstances; further, it was felt that valuable feedback might be lost by arbitrarily prohibiting speech. Finally, concentration on the slides for the full period of time was stressed. The order of the slides was the same in all experiments. At the completion of the experiment the subject was asked to remain still for approximately 10 seconds following the last slide. The GSR electrodes were then removed and a brief discussion followed to inquire whether any of the slides had any special significance to the subject.

C. Control Protocol

As a control for the series of experiments involving subjects, a second series of experiments was conducted having no human involvement whatever (neither subject nor experimenter). To do this it was necessary to develop electronic equipment that would run the entire experiment automatically. Extensive care was taken in the development of this equipment in order to duplicate as nearly as possible the exact circumstances of the original experiments.

First, the protocol of the control series was designed in such a way that no one involved in the operation of the experiment would be in the area during the time that the machine was operating the experiment.

Second, the protocol was designed such that no one involved in the experiment knew which slide was being shown at any given time in order to prevent biasing of data in the unlikely event of long-range experimenter effects. Two experimenters were necessary to make the experiment a blind one. The task of the first experimenter, E1, at the onset of the series of experiments was to shake a die in a metal box in order to obtain a number from 1 to 6. This number indicated the number of projector advances which would occur before the first slide appeared on the screen. (This was done only once as the same number was to be used throughout the series of experiments for the purpose of cross correlation of all the control runs.) Once the offset number was obtained by shaking the die, the slide tray on the projector was then rotated backward from slide number one the proper number of positions. E1 then advised the second experimenter, E2, that the tray had been properly offset. E1 then left the experimental area. E2 waited for a random period of time between 1 and 10 minutes in order to prevent E1 from having any knowledge of when the experiment would start. E2 then started the equipment which ran the experiment. At this point E2 left the experimental area. Neither experimenter would return to the area for at least 35 minutes until the completion of the experiment. With this protocol neither experimenter knew which slide was appearing at any given time during the experimental session, thus preventing any long-range interaction which might arise from the experimenter having knowledge of which slide was showing at any given moment.

To ensure that the monitoring apparatus of the subject and the plant were completely noninteractive, GSR activity similar to that of

an actual subject was automatically generated during the control experiments. This was done by hard wiring a base resistance of 56.4K ohms to the GSR bridge, and then periodically applying a 20K ohm increase to the 56.4K ohms as a GSR fluctuation. Thus, a 56.4K ohm base resistance would increase to a 76.4K ohm reading. This GSR fluctuation was set to occur at the onset of every fourth slide, hold for 4 seconds, and then return to the base resistance of 56.K ohms and remain there throughout the next three slides. This cycle was repeated on every fourth slide throughout the 30 slides.

The electrical equipment which automated the control experiments performed the following functions:

(a) It advanced the slide projector one frame every 15 seconds.

(b) It supplied the 56.4K ohm base resistance for the GSR bridge.

(c) It created a 20K ohm increase in resistance at the onset of every fourth slide, held this resistance for 4 seconds, and then returned to normal.

(d) It triggered the event marker on the Brush recorder at the onset of each slide.

(e) It terminated the equipment after advancing 36 frames.

Nine control experiments were carried out altogether. These experiments were conducted consecutively. Other than the changes which have just been mentioned, all aspects of the control experiments remained identical to those of the experiments involving subjects.

V Experimental Results

A. Subject Runs

A section of raw experimental data as recorded on strip chart is shown in Figure 12*. Top to bottom are subject GSR, two channels of plant potentials from different locations on the plant, and plant micromotion. Time runs from right to left. One observes that the micromotion channel (set on a very sensitive scale) shows little activity and therefore it is not considered further. Correlations, to the degree that they exist, are between GSR and plant potential activity. Furthermore, potential is observed not to be an artifact of plant micromotion.

The analysis of the data was carried out as follows. Each channel contained thirty 3D-second data blocks per run. For each run the thirty 30-second data blocks were examined, channel by channel, on the three channels and a number obtained for each block (magnitude of maximum excursion). Thus, a run yielded three lists of thirty numbers each. The sample mean $\bar{x}$ and sample standard deviation s_x were then computed for each of the three lists.† Of the two lists corresponding to plant potential measurements, the list containing the larger sample mean (indicating greater average plant electrical activity) was chosen as the list to be analyzed and compared with the GSR list. The sample means and sample standard deviations are listed in Table 1.

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* Subject S-3, slides 9-18.

† $$\bar{x} = \frac{\sum_i x_i}{N} \quad , \quad s_x = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N}}$$

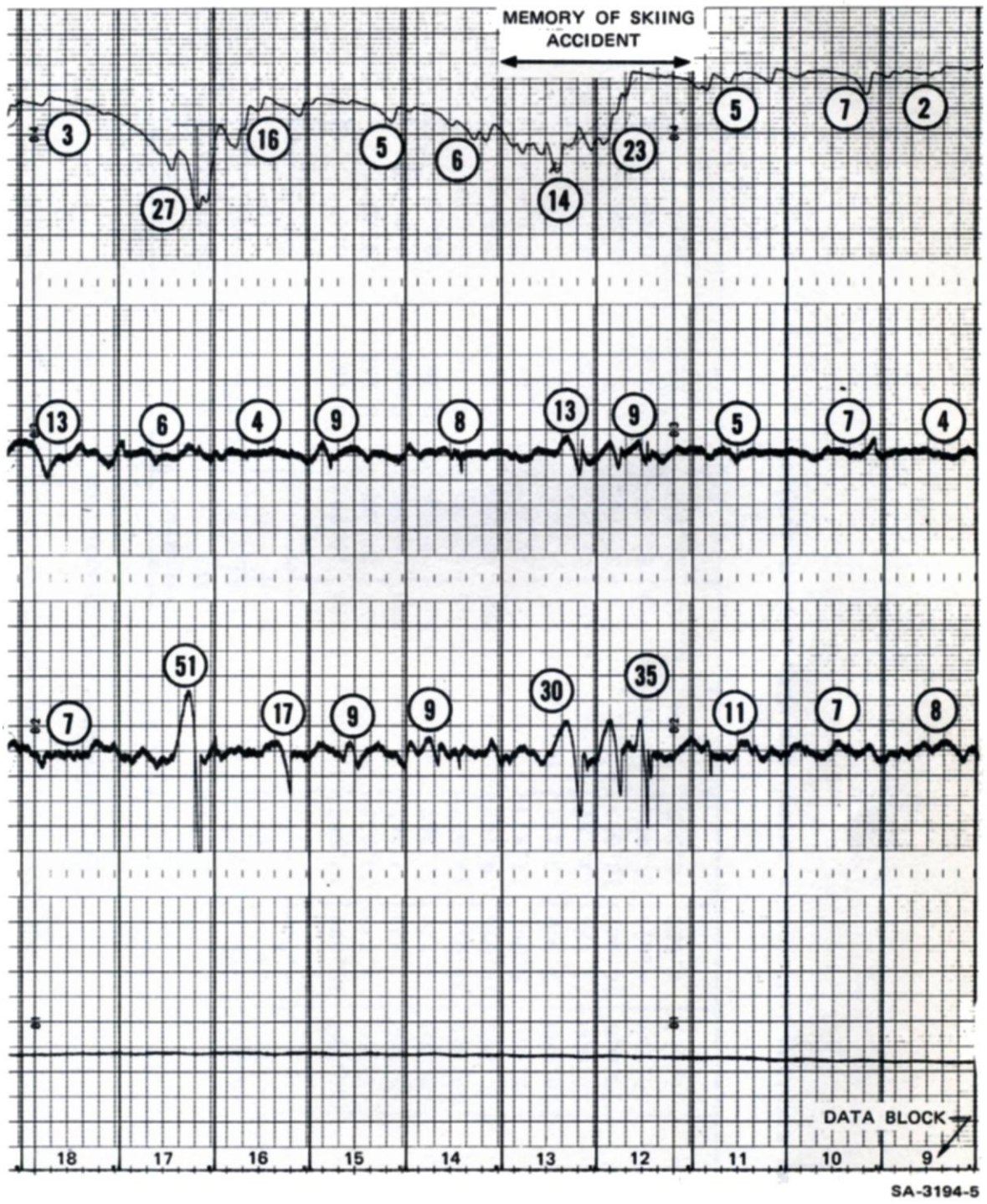

FIGURE 12 EXPERIMENTAL DATA

Subject S-3, data blocks 9-18. Top to bottom are subject GSR, two channels of plant potential (from different locations on plant). and plant micromotion. Time runs from right to left. Note correlations, especially in blocks 12-13,17.

Table 1

PLANT POTENTIAL-GSR CORRELATION

Subject	Subject GSR		Plant Potential		Least-squares fit $y = mx + b$		Correlation Coefficient	Probability (1-tailed)
	$\bar{x}$	s_x	$\bar{y}$	s_y	m	b	r	p
S-1	11.167	10.699	17.967	11.586	-0.200	20.203	-0.185	0.17
S-2	9.367	4.778	20.933	19.206	-0.653	27.049	-0.162	0.20
S-3	9.800	7.273	13.967	9.904	0.772	6.396	0.567	0.00042
S-3'[a]	6.100	4.770	10.367	6.626	0.504	7.294	0.363	0.024
S-4	22.222	26.052	14.667	12.317	0.166	11.032	0.346	0.038
S-5	18.724	14.536	9.103	3.133	-0.046	9.960	-0.212	0.13
S-6	6.400	5.891	11.833	3.707	0.112	11.114	0.179	0.17
S-7	10.400	7.306	10.133	6.349	-0.111	11.287	-0.128	0.25
S-8	13.800	11.574	13.267	10.602	-0.165	15.548	-0.180	0.17
S-8'	13.000	14.541	19.857	15.317	-0.107	21.251	-0.102	0.30
S-9	13.167	8.653	11.667	8.491	0.019	11.417	0.019	0.46
S-10	5.667	4.628	14.500	7.464	0.045	14.244	0.028	0.44

[a]Prime notation indicates a second run with a given subject.

In order to determine whether plant potential signals provide contactless measurement of physiological change as recorded by subject GSR, an analysis to determine the correlation between the two was carried out. For each thirty-block run a least-squares-fit linear regression line $y = mx + b$ was plotted,[6] with plant potential as the ordinate (y), and GSR as the abscissa (x). (The values for m and b are given in Table 1.) This then permits one to calculate the correlation coefficient r between plant potential and GSR as $r = m(s_X / s_Y)$.[6] The resultant correlation coefficients for each of the runs are also given in Table 1.

To determine whether the values of the correlation coefficients indicate significant correlation, we examine the variable $z = (1/2) \ln[(1 + r)/(1 - r)]$ which is approximately normally distributed with standard deviation $\sigma_z = 1/(n-3)^{1/2}$ if the variables x and y can be considered to have normal distribution functions, a reasonable assumption for the null case of expected random magnitudes of plant potential and GSR noise.[6] The data in the last column of Table 1 indicate that in three cases out of twelve (Subjects S-3 and S-4) there were statistically significant correlations between the magnitudes of plant potential and GSR excursions. For Subject S-3 the correlation was quite significant ($p = 0.00042$) and on a repeat run with him the result replicated, although at a lower level of significance ($p = 0.024$). The conclusion to be drawn from this part of the study, therefore, is that although we must reject the hypothesis that subject GSR and plant potential fluctuations of a nearby electrically shielded plant are in general correlated (with regard to large changes during 15-second intervals), there is evidence, statistically too strong to ignore, that such correlation can be substantial for a given subject. Further research would be required to determine why such a correlation might exist for some individuals (in our case 20%) but not for others.

Independent of whether plant potential correlates with GSR, a second hypothesis to be investigated with regard to plant monitoring as a contact1ess stress indicator is whether plant signals are significantly higher during the presentation of target stimuli than during control stimuli. Therefore, a second analysis was carried out in which the maximum excursions of the plant's electrical potential during each 1S-second trial were examined as before, this time with regard to a comparison of the means during the 12 target stimuli and the 18 control stimuli, respectively.

Since the sample numbers 12 and 18 are small, the Student's t distribution for small samples is used.[7] In the absence of an effect (null case) we would assume that the plant potentials would be normally distributed. We then look for a significant value of the variables[8]

$$t = \frac{\bar{x} - \bar{y}}{\left(n_x s_x^2 + n_y s_y^2\right)^{1/2}} \left(\frac{n_x n_y (n_x + n_y - 2)}{n_x + n_y}\right)^{1/2}$$

which has a Student's t distribution with $n_x + n_y - 2$ degrees of freedom, where $\bar{x}, \bar{y}$ are the sample means of the target and control data groups of size $n_x = 12, n_y = 18$. The results of this analysis are shown in Table 2.

What we observe is that in only two cases (S-7, S-8) is there a statistically significant difference between the means of plant potential perturbations during the target and control stimuli. Such a result suggests two possibilities: (a) the two types of stimuli do produce differences in subjects, but such differences are not tracked by perturbations in the plant potential; (b) subject responses to the two types of stimuli are not differentiated, and therefore no statistically significant difference should be expected, even under the hypothesis that the plant potential perturbations do correlate with subject response.

Table 2

PLANT POTENTIAL

Subject	Target Stimuli (n_x=12)		Control Stimuli (n_y=18)		Student's t Variable (d.f.=28)	Probability (1-tailed) p
	$\bar{x}$	s_x	$\bar{y}$	s_y		
S-1	21.25	11.50	15.78	11.12	1.258	< 0.15
S-2	23.92	20.73	18.94	17.83	0.678	< 0.30
S-3	13.50	6.65	14.28	11.56	-0.204	< 0.60
S-3'[a]	8.58	3.48	11.56	7.84	-1.195	< 0.90
S-4	10.33	4.07	16.72	14.42	-1.445	< 0.95
S-5	9.67	3.32	8.72	2.85	0.808	< 0.50
S-6	12.83	4.81	11.17	2.53	1.190	< 0.15
S-7	13.33	8.23	8.00	3.27	2.387	< 0.025
S-8	18.50	14.17	9.78	4.79	2.330	< 0.025
S-8'	21.83	18.72	17.88	11.75	0.673[b]	< 0.30
S-9	12.75	11.16	10.94	5.99	0.555	< 0.30
S-10	11.75	2.24	16.33	9.01	-1.667	< 0.95

[a] Prime notation indicates a second run with a given subject.

[b] Degrees of freedom (d.f.)=27 (recorder malfunction for 1 data point).

To check whether (b) or (a) is the case, a differential analysis of the type performed with regard to plant potential is carried out for the GSR data. The results are tabulated in Table 3. With the GSR data taken as an objective indicator of differential subject response to target and control stimuli, we find evidence for a difference in only two cases, S-2 and S-5 (where, however, it is quite strong).

Therefore, it appears that neither in the case of plant potential measurement alone nor by direct subject GSR measurement alone are the responses to target and control stimuli clearly differentiated from each other as two separate categories. Thus, the evidence for contact less plant potential measurement of subject stress must rest not

Table 3

GSR

Subject	Target Stimuli (n_x=12)		Control Stimuli (n_y=18)		Student's t Variable (d.f.=28)	Probability (1-tailed p
	$\bar{x}$	s_x	$\bar{y}$	s_y		
S-1	10.25	9.58	11.78	11.35	-0.372	< 0.65
S-2	13.08	5.39	6.89	1.82	4.347	< 0.0005
S-3	10.25	6.40	9.50	7.78	0.268	< 0.40
S-3'[a]	5.83	3.44	6.28	5.48	-0.245	< 0.60
S-4	23.27	17.05	21.50	30.73	0.167[b]	< 0.45
S-5	28.08	16.68	12.12	7.65	3.341[c]	< 0.0025
S-6	8.25	5.78	5.17	5.64	1.402	< 0.10
S-7	7.58	3.38	12.28	8.52	-1.757	< 0.975
S-8	16.75	10.34	11.83	11.93	1.127	< 0.15
S-8'	9.00	11.80	15.59	15.53	-1.157[d]	< 0.90
S-9	12.33	8.26	13.72	8.86	-0.418	< 0.70
S-10	5.42	5.04	5.83	4.32	-0.230	< 0.60

[a]Prime notation indicates a second run with a given subject.

[b]Degrees of freedom (d.f.)=25 (recorder malfunction for 3 data points)

[c]d.f.=27

[d]2 d.f.=26

on a differential analysis of signals generated during "target stimuli" and "control stimuli" periods, but rather on the plant potential-GSR correlation of Table 1 directly, independent of the division of the data blocks with regard to the nature of slide content.

B. Control Runs

As in the subject runs, for each of the nine control runs the 30 sec data blocks were examined, channel by channel, on the three channels

(two plant potential, one artificial GSR) and a number obtained for each block (magnitude of maximum excursion). Thus, a run yielded three lists of 30 numbers each. The sample mean $\bar{x}$ and sample standard deviation s_x were then computed for each of the three lists. Of the two lists corresponding to plant potential measurements, the list containing the larger sample mean (indicating greater average plant activity) was chosen as the list to be analyzed.

The analysis proceeded on a differential basis as carried out for the data of Tables 2 and 3. That is, of interest was a measurement of the plant potentials during the trials (n_x =8) in which the artificial GSR signal was injected into the system as compared with those trials (n_y =22) in which no artificial GSR was generated. The appropriate data is tabulated in Table 4, where the Student's t variable for small samples is examined for the difference between the means of GSR and non-GSR cases for each of the nine control runs. As can be seen in the last column, there are no significant differences between plant potentials associated with GSR trials as compared with non-GSR trials. From this we conclude that plant potential perturbations are not an artifact correlated with activity in the GSR channel of the experiment.

VI Summary and Conclusions

The purpose of the investigation reported here was to assess the feasibility of the use of a special class of device (organic sensor) for real-time contactless measurement of psychological stress or other psychological or physiological state in a human subject being monitored. To this end special detectors were developed so that the electrical activity and micromovements of plants (Philodendron oxycarduum, Mimosa pudica) and algae (Nitella) could be monitored. The activity of these sensors while in close proximity to a human subject viewing slides of varying emotional content was then examined. The sensors were located

Table 4

CONTROL RUN DATA

Control Run	Artificial GSR (n_x=8) $\bar{x}$	s_x	No GSR (n_y=22) $\bar{y}$	s_y	Student's t Variable (d.f.=28)	Probability (1-tailed) p
1	19.000	18.378	23.091	15.408	-0.598	< 0.75
2	19.250	7.031	20.455	20.473	-0.157	< 0.60
3	18.750	19.357	10.591	10.710	1.407	< 0.10
4	18.375	10.136	12.773	10.409	1.268	< 0.15
5	12.875	7.524	10.227	13.531	0.507	< 0.35
6	8.750	7.496	13.545	10.547	-1.142	< 0.90
7	8.375	6.836	3.545	7.620	1.523	< 0.10
8	7.375	7.729	14.545	14.776	-1.265	< 0.90
9	6.625	7.381	7.455	11.102	-0.190	< 0.60

inside Faraday cage electrical shielding to eliminate trivial electrical artifacts. To provide an objective indicator of emotional response during viewing, the subject's GSR (galvanic skin response) was recorded to provide a signal to cross-correlate with the organic sensor output.

Pilot experiments with the algae Nitella indicated that they were nonresponsive to the activity of human subjects in close proximity, and therefore experimentation with Nitella was terminated early in the program. With regard to plant sensors, however, experimental findings with twelve subjects indicated that the electrical activity of plants in close proximity to a human subject viewing slides of putative emotional content, although not in one-to-one correspondence with subject GSR, nevertheless did show in some cases (20%) statistically significant evidence of correlation with subject GSR.* Furthermore, such electrical

*Subject S-3: $p < 4.2 \times 10^{-4}$; $p < 0.024$, replication experiment.
Subject S-4: $p < 0.038$.

activity is found not to be an artifact of plant micromotion, the latter being uncorrelated with either subject GSR or plant potential, nor is it a system artifact due to slide tray activity signals in the GSR channel. Thus, although we must reject the hypothesis that subject GSR and plant potential fluctuations of a nearby electrically shielded plant are in general correlated, there is evidence for a degree of correlation beyond that expected by chance.

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