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A METHOD FOR STIMULATION AND SIMULTANEOUS ELECTROENCEPHALOGRAM RECORDING

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INTRODUCTION

This report presents aspects of techniques for the recording of electrical activity from one region of the brain, whilst stimulating another region. Recording of electrical activity as well as stimulation is by means of depth electrodes. The work was carried out to develop recording techniques to facilitate the investigation of the Etiology of States of Impaired Consciousness using Rhesus monkeys[1].

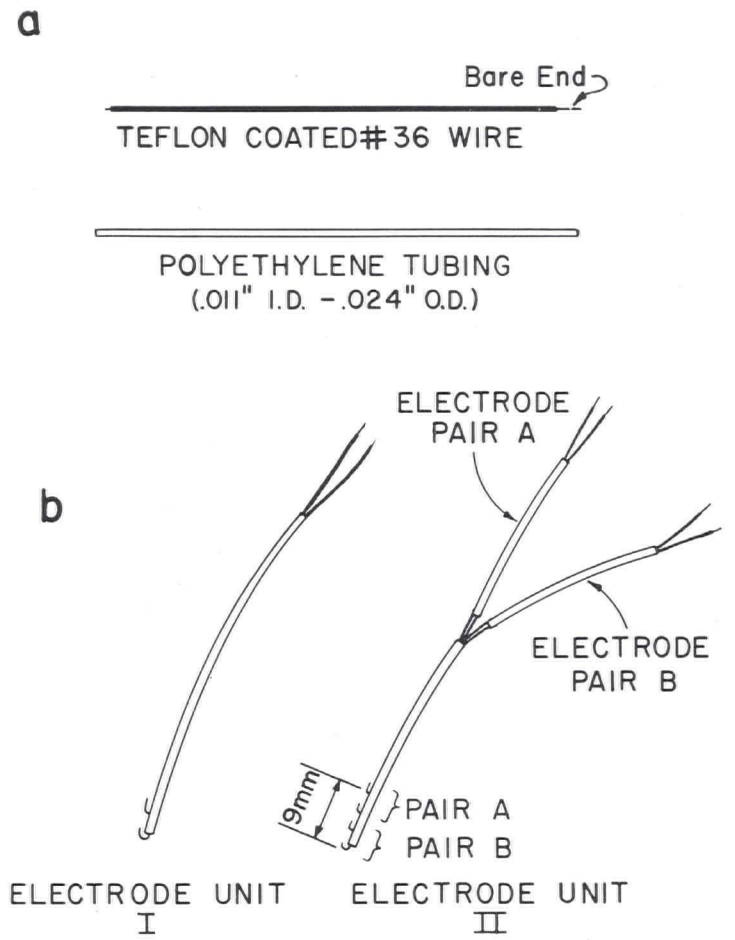

Figure 1
Electrode Units

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ELECTRODE UNITS

Two electrode units were made using teflon coated No. 36 wire, 92% platinum and 8% tungsten. The wire diameter was .005 inch and the teflon coating consisted of three layers each 0.0005 inch thick. Intramedic polyethylene tubing (inside diameter of 0.011 inch and outside diameter 0.024 inch) was used to cover the leads. Parts as sketched in Fig. 1-a being put together to form units as sketched in Fig. 1-b.

For electrode unit I, Fig. 1-b; one incision was made in the polyethylene tubing at 3 mm from the tip, and two wires were threaded through the tubing, one being brought out through the incision and one out at the tip. The teflon coating was then removed for approximately 3 mm by holding the wire ends in a gas flame. After bending the wire tips, the hooks were pulled in place.

For electrode unit II, a similar procedure was followed. Three incisions were now made at 3, 6, and 9 mm respectively from the tip, and four wires were threaded through. The four wires were split up in two pairs.

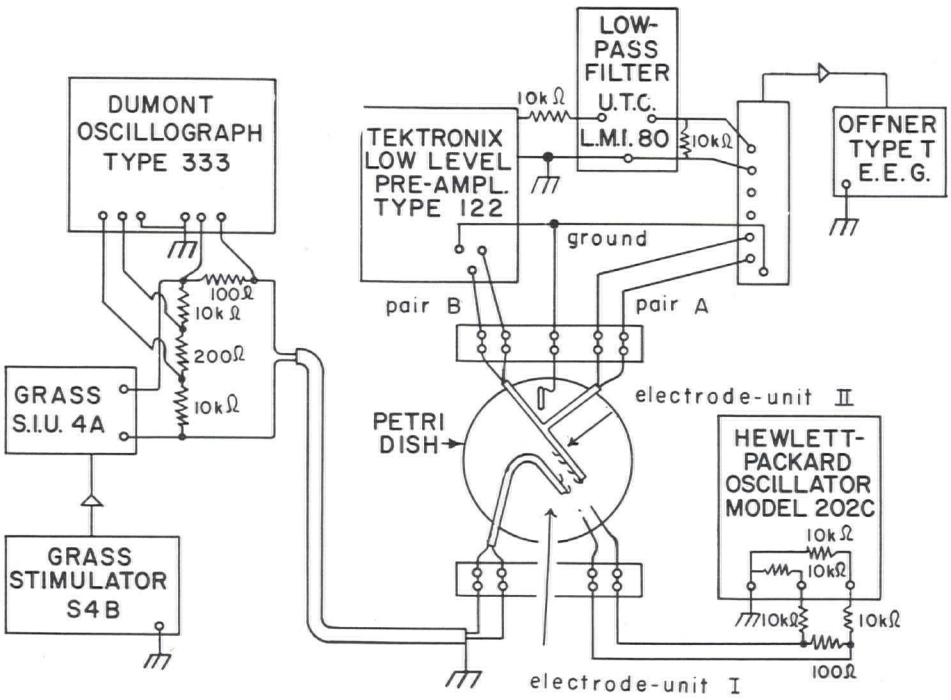

Figure 2

Schematic arrangement of apparatus for the demonstration of recording technique.

ELECTRIC CIRCUITRY

The electrode units I and II in Fig. 1-b were placed in a Petri dish filled with normal saline. They were positioned so that all the hooks (electrodes) were submerged in the saline. The exact location or precise distance of the electrode units was im-

material for this investigation. Two No. 20 wires at an approximate distance of 5 mm were submerged 1 cm and connected to a low frequency oscillator, (Hewlett-Packard, Model 202C). This oscillator simulated brain activity. A set of resistors was provided in order to reduce the voltage to a level suitable for this experiment. The frequency of the oscillator was set to 5 c/s, and the wave shape of the voltage supplied was sinusoidal. The activity set up in the saline was thus far from what would be expected from a monkey brain, but it served a purpose, as will become apparent later.

Electrode unit I is connected via a shielded cable to a combination of stimulator and isolation unit, (Grass Stimulator, Model S4B and Grass Stimulation Isolation Unit, Model 4A). The stimulator can be set to generate a train of rectangular pulses of desired height and width, while the number of pulses per second can be varied over a wide range. The duration of the train in this investigation was 10 seconds. The oscillograph (Dumont, Type 333) monitored the voltage and the current of electrode unit I.

Pair "A" of electrode unit II was directly connected to one channel of the E.E.G. (Offner, Type T) with balanced input. Pair "B" was connected to the balanced input of a battery powered low level preamplifier, (Tektronix low-level preamplifier, type 122). The frequency response of this low level preamplifier had a lower half power frequency which was adjustable to one of four values, 0.2, 0.8, 8 and 80 c/s respectively. The upper half power frequency could be set for one of five values, 50, 250, 1,000, 10,000 and 40,000 c/s respectively. The midband gain was either 100 or 1,000 as determined by a 2 position switch. We employed a lower half power frequency 0.2 c/s, an upper half power frequency of 1,000 c/s and a gain of 100, except for the recording of Fig. 7 where an upper half power frequency of 50 c/s was used.

A stainless steel rod submerged in the saline served as animal ground, and was connected to the appropriate terminals of the E.E.G. and the amplifier. The amplifier acted as a generator with an internal resistance of 1,000 Ω. The low pass filter (United Transformer Corporation L.M.I. 80) driven by this amplifier, however, is designed to be driven from a source with an internal resistance of 10 kΩ. For this reason, a 10 kΩ resistance was inserted between amplifier and filter. The filter is designed to be loaded by 10 kΩ and as the input impedance of the E.E.G. was well above this value, a 10 kΩ resistance was provided across the filter output. The frequency response curve of the low-level preamplifier low pass filter combination is shown in Fig. 3. The midband gain of this combination was 50. The filter had a cut off frequency of 80 c/s. The frequency response curve of the low level preamplifier with the upper half power frequency set to 50 c/s is partly shown in this figure. The E.E.G. recorder was chopper stabilized, the chopper frequency being 400 c/s.

OBSERVATIONS

The tracings (pen deflections as a function of time) of Fig. 4 were obtained with the set up of Fig. 2. The upper tracing corresponds to pair "A", the lower tracing to pair "B". To the left are calibration pulses, the calibration refers to the

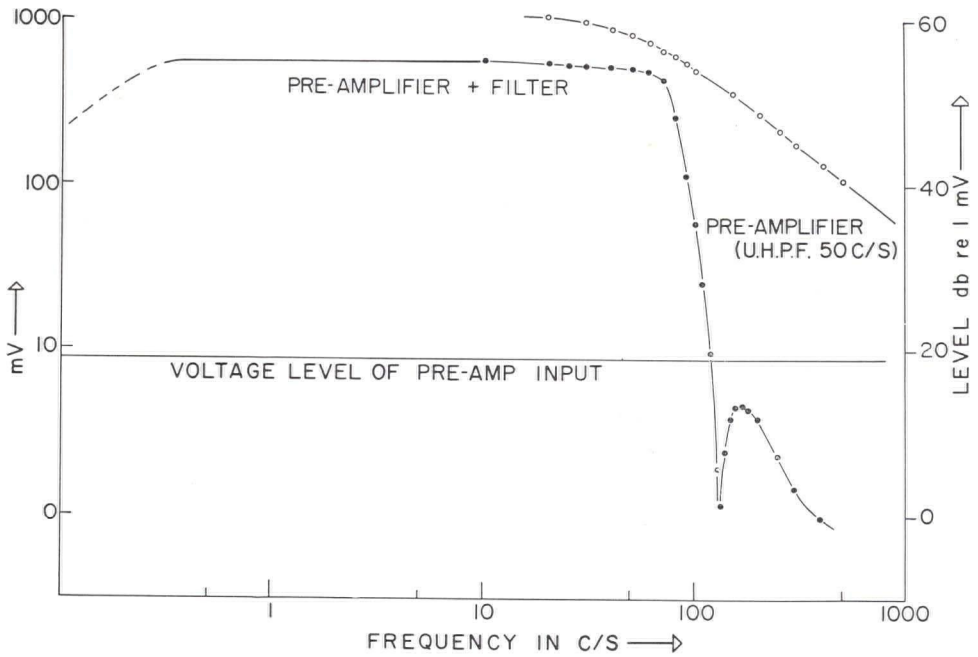

Figure 3

Frequency responses.
Solid circles: Frequency response of low-level preamplifier and filter.
Open circles: Frequency response of low-level preamplifier only, with upper half power frequency set to 50 c/s.

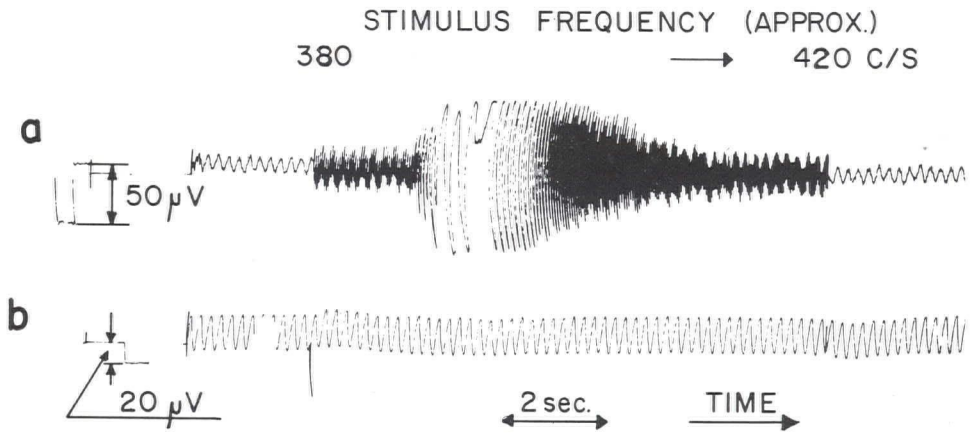

Figure 4

Recordings with arrangement as in Fig. 2. (Stimulating via electrode unit I).
A. From electrode pair A of electrode unit II directly to E.E.G.
B. From electrode pair B of electrode unit II through preamplifier and filter to E.E.G.

input of E.E.G. and low level preamplifier respectively. When switched to recording, the 5 c/s activity stands out clearly and measures peak to peak 14 μV across pair "A" and 40 μV across pair "B". When measuring the 5 c/s activity from one pair

of electrodes (as in Fig. 1) in various positions and locations (in the petri dish), firstly with the low-level preamplifier and secondly with the E.E.G. directly, the voltage as recorded by the former was usually 2 to 3 times the voltage as recorded by the latter. The voltage recorded thus depends on the input impedance of the measuring instrument. The low-level preamplifier input impedance is 20 MΩ paralleled by 50 $\mu\mu$F, while the E.E.G. input impedance is 200 kΩ at 15 c/s. Also noticeable is a noise component on the upper tracing (Fig. 4) which is due to the E.E.G. input stages. This noise component is roughly 2 μV as judged from the record.

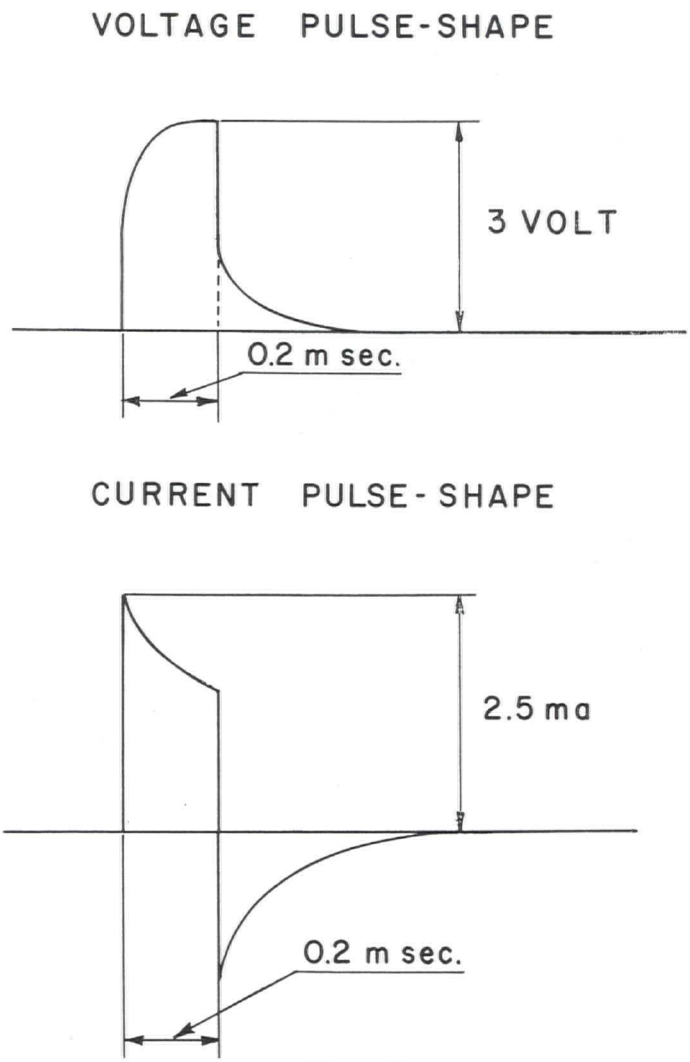

Figure 5
Stimulus voltage and current pulse forms.

A stimulus consisting of a train of pulses (for voltage and current shape and size, see Fig. 5), the repetition frequency of which was gradually varied from 380 to 420 c/s in a 10 second period, was turned on 2 seconds after commencement of

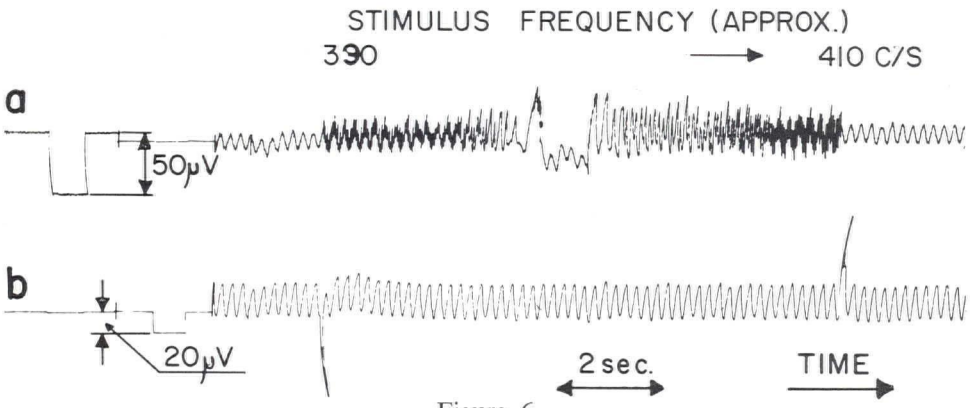

Figure 6

Recordings with similar arrangement as in Fig 2. (Stimulating via pair A of electrode unit II).
A. From electrode unit I., directly to E.E.G.
B. From electrode pair B of electrode unit II., through preamplifier and filter to E.E.G.

recording. This stimulus gives rise to large pen deflections in the upper tracing, the frequency of which seems to be related to the stimulus frequency. The pen frequency decreases from the onset of stimulus, goes through zero about five seconds later and increases subsequently. (The chopper frequency was 400 c/s.) The stimulus onset causes a spike in the lower tracing, but leaves otherwise the recording of slow 5 c/s activity unaffected. Ten seconds later stimulus was turned off causing a spike in the lower tracing. The tracings of Fig. 6 were obtained after the following changes in circuitry. Electrode unit I was connected to the E.E.G., and pair "A" of electrode unit II was connected to the stimulator. Pair "B" remained connected to the low level preamplifier and filter. The stimulus voltage and current pulse shape and size were as in Fig. 5. The upper tracing shows stimulus artefact somewhat smaller than in Fig. 4. The lower tracing has more pronounced spiking when turning the stimulus on and off. Slow activity of 30 μV peak to peak has no stimulus artefact (except for spikes) notwithstanding the fact that the stimulation voltage (see Fig. 5), is approximately 10^5 times larger than the signal recorded. Pair "A" and "B" were 6 mm apart whereas the distance between the two electrode units was approximately 1 cm.

DISCUSSION

The E.E.G. with chopper stabilization is not intended to be used for the recording of electrical activity of the brain whilst stimulating electrically some other area of the brain. For instance, when the stimulus frequency f_s is slightly less than the chopper frequency f_c, $\frac{1}{2} \cdot \frac{f_s}{f_c - f_s}$ pulses in a row will be presented to one contact of the chopper, the next $\frac{1}{2} \frac{f_s}{f_c - f_s}$ to the other contact. This cycle which takes $\frac{f_s}{f_c - f_s} \cdot \frac{1}{f_s} = \frac{1}{f_c - f_s}$ seconds to complete will thereafter repeat itself again and again.

A theoretical investigation by means of Fourier analysis, and assuming that the chopper circuit is followed by an A.C. amplifier with 400 c/s center frequency and with restricted band width, predicts a pen frequency $f_{pen} = 2|f_c - f_s|$, which relation

was verified. This demonstrates sufficiently, that when an E.E.G. with chopper stabilization is to be used in conjunction with stimulation, a means should be provided to turn the pen writers off whilst stimulating.

The low level preamplifier when used on upper half power frequency 50 c/s will amplify stimulus frequencies above 50 c/s to a lesser extent than the brain electrical patterns below 50 c/s. This filtering action is not sufficient to prevent stimulus interference as demonstrated in the lower tracing of Fig. 7 which was obtained whilst recording from pair "B" and stimulating on pair "A". The voltage and current pulse shapes were similar to those used before and the amplitudes were 0.35 volt and 0.35 mA respectively.

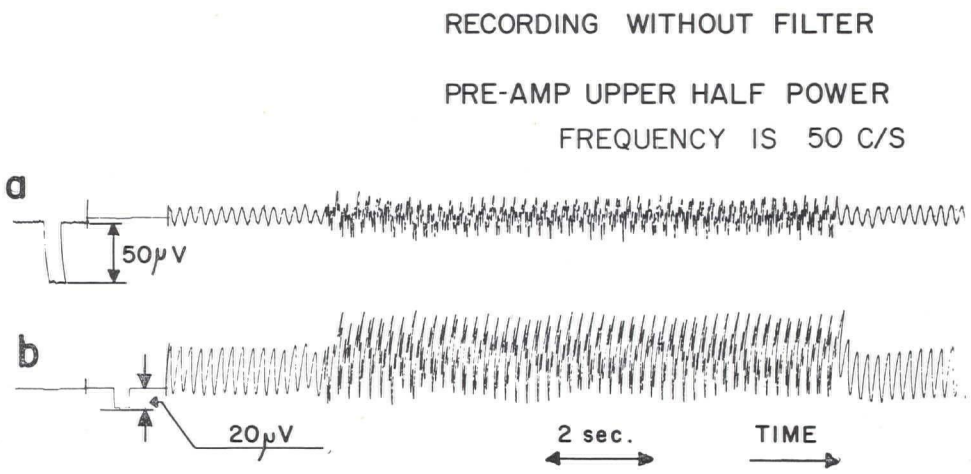

Figure 7

Recordings as in Fig. 6, but after removal of the filter and the adjustment of the upper half power frequency of the low-level preamplifier to 50 c/s. (Stimulating via pair A of electrode unit II).
A. From electrode unit I., directly to E.E.G.
B. From electrode pair B of electrode unit II., through *only* preamplifier to E.E.G.

Using the quadruple electrode unit, described above (as a depth electrode), E.E.G. recordings have been obtained during stimulation areas of the brain of the Macaca mulatta. Figs. 8 and 9 demonstrate the filtering efficiency of the system described above. The technique of placement of this type of depth electrode has been described in a previous publication[1]. The presence of stimulus was monitored by bleeding an appropriate proportion of the stimulating voltage through one E.E.G. channel.

CONCLUSION

A filtering system has been described which makes it possible to record brain activity during electrical stimulation of the brain with pulse repetition frequencies of 130 c/s or higher at a distance as close as 6 mm from the recording electrodes.

The author wishes to thank Dr. L. D. Proctor and J. Lukaszewski for their assistance during this investigation.

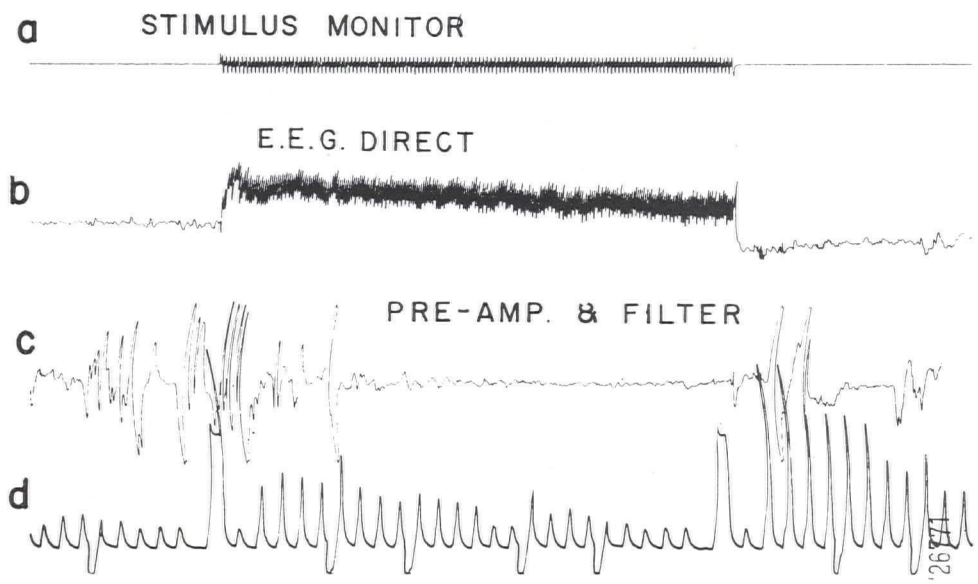

Figure 8

A. Monitor of presence of stimulation applied to a pair of electrodes in the mesencephalic reticular formation of a Macaca mulatta.

B. E.E.G. from a pair of electrodes in the hypothalamus with E.E.G. recorder connected to electrode terminals directly.

C. E.E.G. from a second pair of electrodes at a distance of 6 mm from those in B., using the low-level preamplifier and filter.

D. Record of frequency analysis of E.E.G. in C.

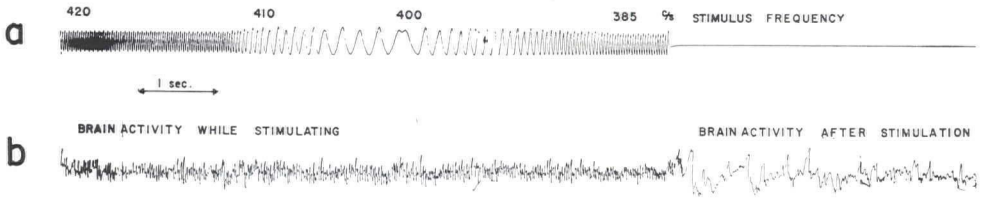

Figure 9

A. Monitor of presence of stimulation applied to a pair of electrodes (3 mm apart) in the hypothalamus of a Macaca mulatta. Note frequency change.

B. E.E.G. from pair of electrodes in the mesencephalic reticular formation, 15 mm from stimulating electrodes, using the low-level preamplifier and filter.

Note the change in brain activity upon cessation of stimulation.

REFERENCE

1. Proctor, L. D., Knighton, R. S., and Churchill, J. A.: Variations in consciousness produced by stimulating reticular formation of the monkey, Neurology 7:193, 1957.