$df = 1$, $p < .05$, with females producing more GSR's, but not to birthweight or base conductance level. The GSR magnitude, however, was significantly correlated with conductance baseline level, $r = +0.29$, $p < .05$.

Regardless of the exact neurophysiological mechanism directly responsible for the GSR (*7*), our data can be most parsimoniously interpreted as evidence that this mechanism is functional in the human infant as early as the first 24 hours after birth. In view of the dependence of the GSR on sweat gland activity, it should be noted that histologically the sweat glands appear to be capable of functioning as early as the 7th month of prenatal development, and further, that the sweat glands are functional at birth, with sensible perspiration demonstrable in response to the whole body's being heated on the day of birth (*8*).

Just as other neonatal autonomic responses to classes of stimuli have been observed (*9*), it appears that similar groups of stimuli will elicit the GSR. The response fluctuation within modalities and across days is not congruent with data for adults (*10*) in which the high probability of response evocation has made the GSR a frequent dependent variable in conditioning experiments (*11*). The question of the relatively low proportion of responses to stimuli cannot be answered by these data for infants, but it might be hypothesized that the threshold for GSR's is some function of position on the asleep-awake continuum (*12*). Although the positive correlation between the magnitude of the neonatal GSR response and conductance base level is in accord with results of Hord, Johnson, and Lubin (*13*), it does not follow the law of initial values (*14*) as it is usually interpreted.

DAVID H. CROWELL
CHRISTOPHER M. DAVIS
BARBARA J. CHUN, FRANK J. SPELLACY
Newborn Psychological Research Laboratory, Pacific Biomedical Research Center, University of Hawaii, Honolulu

References and Notes

1. A. Peiper, *Cerebral Function in Infancy and Childhood* (Consultants Bureau, New York, 1963), p. 25.
2. H. Jones, *Child Develop.* **25**, 106 (1930).
3. D. T. Lykken, *J. Comp. Physiol. Psychol.* **52**, 629 (1959).
4. C. Darrow, *Psychophysiology* **1**, 31 (1964).
5. D. H. Crowell, E. K. Yasaka, D. Crowell, *Child Develop.* **35**, 525 (1964).
6. S. Siegel, *Nonparametric Statistics* (McGraw-Hill, New York, 1965).
7. G. Wang, *Am. J. Phys. Med.* **36**, 295 (1957); **37**, 35 (1958).
8. L. B. Arey, *Developmental Anatomy* (Saunders, Philadelphia, 1954), p. 449; K. Bruck, *Biol. Neonatorum* **3**, 65 (1961).
9. H. J. Grossman and N. H. Greenberg, *Psychosomat. Med.* **19**, 293 (1957); E. L. Lipton, A. Steinschneider, J. B. Richmond, *ibid.* **23**, 472 (1961); *Pediatrics* **33**, 212 (1964).
10. R. C. Davis, A. M. Buchwald, R. W. Frankmann, *Psychol. Monogr.* **69**, 1 (1955).
11. R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1956); W. W. Grings, E. L. Lovell, R. R. Honnard, *Comp. Physiol. Psychol.* **54**, 143 (1961).
12. R. Q. Bell, *Biol. Neonatorium* **5**, 200 (1963); P. H. Wolff, *Psychosomat. Med.* **21**, 110 (1959); L. C. Johnson, *Psychol. Rept.* **15**, 549 (1964).
13. D. J. Hord, L. C. Johnson, A. Lubin, *Psychophysiology* **1**, 79 (1964); J. I. Lacey and B. C. Lacey, *Ann. N.Y. Acad. Sci.* **98**, 1257, 1322 (1962).
14. J. Wilder, *Psychosomat. Med.* **12**, 392 (1950); *Exptl. Med. Surg.* **20**, 126 (1962).

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Brain Telestimulator with Solar Cell Power Supply

Abstract. *A telestimulator has been constructed which is suitable for mounting on the heads of medium-sized* Macaca mulatta *or larger primates. It differs from previous units in that the battery supply is continuously recharged from ambient light by means of solar cells. The system features remote control of all stimulus parameters, constant current output, and remote selection of any of 11 electrodes. If additional transmitters are employed, simultaneous and independent stimulation of a number of primates in the same group is possible. A shielded room with a terminated antenna system is used to produce a homogeneous radio-frequency field for laboratory use.*

The ideal telestimulator for the primate brain should operate in the laboratory or in the field for long periods of time without requiring maintenance. Periodic changes of batteries subject both the animal and the experimenter to some risk and disturb the behavior under study. To circumvent this we have designed a unit which generates its own power. The unit, which measures 3 by 6 by 7 cm and weighs 200 g, is mounted directly on the animal's head (*1*). The upper surface of the unit contains an array of 40 solar cells which, when exposed to natural or artificial light, continuously recharge small nickel-cadmium batteries of 50 ma-hr capacity. These batteries provide uniform power during any dimming of the incident light caused by head movement or shadows. Figure 1 illustrates the power available from this 12-v supply under various light intensities. The power consumed by the stimulator consists almost entirely of a steady "keep-alive" current of 0.12 ma plus an additional 0.6 ma during periods of use. The figure also shows the time required to recharge the batteries under various light intensities after 1 hour of continuous use and includes a safety factor of 35 percent. Since the stimulator operates properly until the batteries are 25 percent exhausted, longer stimulation periods are possible if more time is allowed for recharging.

A frequency-modulated carrier (130 to 140 Mc/sec) from the transmitter is received by a solid-state, superheterodyne receiver (Fig. 2) stabilized by means of a crystal. The sensitivity of the receiver, −35 db, was purposely designed to be low so as to minimize interference from extraneous radio-frequency fields. The receiver is conventional with the exception that the RF, mixer, and oscillator stages are operated in cascade with respect to the power supply to conserve current. The limiter is regulated by voltage. Stimulation pulses, on the one hand, cause the carrier to deviate in a positive direction and send output pulses into the current-regulator circuits. Channel selection pulses, on the other hand, cause the carrier to deviate in a negative direction and send pulses into the channel selection circuits. In this manner, almost complete separation between channel selection pulses and stimulation pulses is effected.

Remote selection of any one of 11 stimulating electrodes in each animal is accomplished by a specially designed, miniature (28 g) stepping switch. There

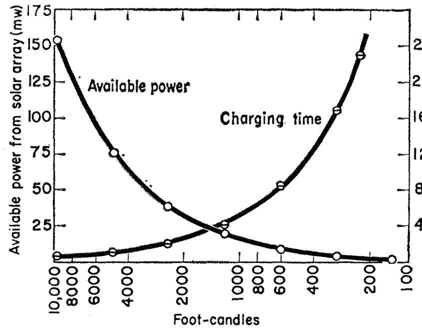

Fig. 1. Graph of power availability and of charging time after 1 hour of use under various light intensities. One foot-candle is equivalent to 11 lumens per square meter.

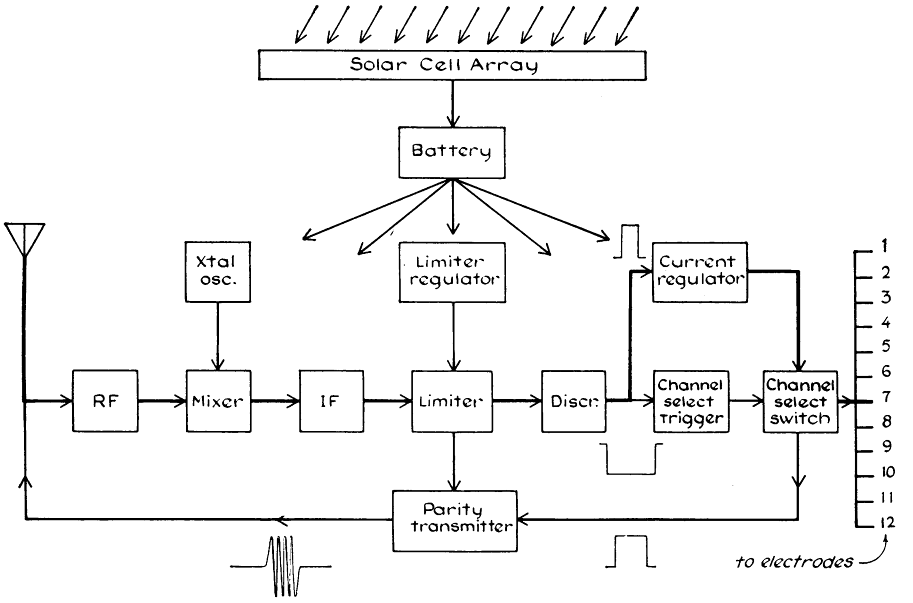

Fig. 2. Block diagram of the telestimulator. The heavy lines indicate the path of the stimulating pulses directed, in this case, to electrode 7 (antenna, RF stage, mixer, IF stage, limiter, discriminator, current regulator, channel-select switch, electrode).

is an additional 12th contact which is blank so that when the switch is left in this position between experiments no unwanted current can pass into the electrodes. Visual indication of the electrode channel selected is automatically provided on the experimenter's console, and parity between this indicator and the stepping switch can be maintained through two devices. First, when the solenoid of the stepping switch is pulsed, a momentary contact closes, effecting simultaneous pulsing of a small transmitter. Reception of this signal at the console produces an audible beep, confirming that the solenoid has operated. Second, one of the 11 electrodes is used to evoke an easily identifiable and stereotyped motor response which can be used to verify switch position. Should parity be lost, it can be reestablished by activating the stepping switch until the stereotyped response is evoked and then manually resetting the visual display.

The transmitter can be modulated by any standard laboratory stimulator. The stimulating waveform emitted by the telestimulator into the electrode is a cathodal, monophasic, rectangular pulse. Subject only to a duty cycle of 0.1 (ratio of pulse duration time to pulse repetition time) the pulse repetition rate is continuously and remotely variable between 0 and 200 pulses per second and pulse duration is continuously and remotely variable between 0.1 and 3.0 msec. The current intensity of the pulse is continuously and remotely variable between 0 and 1.0 ma, and is maintained constant to within ± 3 percent over an impedance range of 2,500 to 10,000 ohms.

Both the transmitter and the telestimulator are stabilized by means of a crystal. Independent, sequential stimulation of four animals in the same group is achieved by using a single transmitter with four switched carriers of slightly different frequencies and four telestimulators tuned appropriately. With additional transmitters, it would be possible to stimulate several animals simultaneously as well as sequentially.

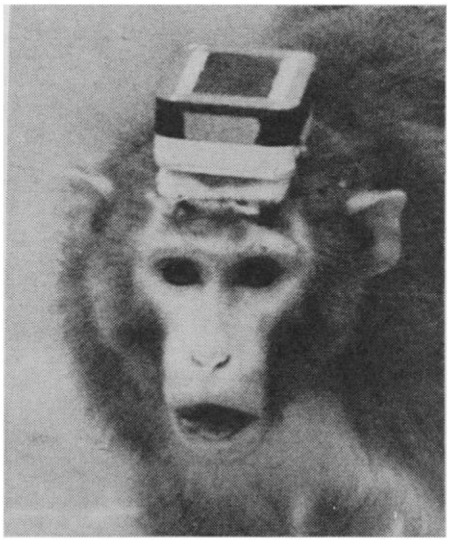

Fig. 3. An adolescent *M. mulatta* with a telestimulator in place. The solar cell array lies on the upper surface between the two white stripes.

Operation of the system outdoors at a distance from the transmitting antenna offers no problems. For use in the laboratory we employed a 100-db shielded room terminated to simulate a waveguide of infinite length. At a distance of ¼ λ (wavelength) from one end of the room a 377 ohm/m^2 absorbing film was mounted; at ¼ λ from the other end, the transmitting antenna consisted of a vertically polarized, half-wave dipole. Measurements indicated that the resulting RF field was sinusoidal and at no point varied more than ± 5 db from the mean power level. Power not absorbed by the animals is captured by the termination, preventing reflections.

For several months the system has been tested on two macaques (Fig. 3) with a total of 20 implanted electrodes. These animals were not disturbed by the presence of the unit on their heads. Operation within the shielded room was found to be very reliable and was not affected by movements of the test animal or of the other animals in the cage. The same behaviors as were evoked with conventional stimulation could be evoked daily for many weeks at the same threshold with the telestimulator. The tests confirmed the practicality of the power supply and of the general circuit design. Minor defects, such as a tendency of the unit to overheat and drift when exposed to light of 1.1 lu/cm^2 or more, occasional failure of the stepping switch to advance, and breakage when the unit is dropped or struck firmly against a hard surface, are being corrected.

From the standpoint of behavioral experiments, we think the major significance of this development is twofold. First, the solar-cell power supply establishes the practicality and desirability of generating power for telestimulation directly on the animal. By this means experiments on social interactions could be continued undisturbed for great lengths of time and, by eliminating the need to capture the animals periodically, it makes practical the use of larger primates, including the anthropoids. The current-generating capacity can be increased, in fact, by using animals with larger heads and will improve as solar cell technology develops. Second, the entire system is crystal-stabilized and the use of several transmitters will permit simultaneous and independent manipulation of sets of behaviors from all of the important members of a primate group. Together, these two features should permit many interesting experiments on primate behavior to be undertaken.

BRYAN W. ROBINSON*
Laboratory of Psychology,
National Institute of Mental Health,
Bethesda, Maryland 20014
HAROLD WARNER
Missile and Space Division, Space
Technology Center, General Electric
Company, Philadelphia, Pennsylvania
H. ENGER ROSVOLD
Laboratory of Psychology,
National Institute of Mental Health

References and Notes

1. B. W. Robinson, H. Warner, H. E. Rosvold, *Electroencephalog. Clin. Neurophysiol.* 17, 200 (1964).
2. A complete technical description of the system is in preparation. We acknowledge the valuable assistance of Mr. Morris Waxler and Mrs. Thelma Galkin.

* Present address: Division of Neurology, Stanford University School of Medicine, Palo Alto, California 94304.

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Neural Stage of Adaptation between the Receptors and Inner Nuclear Layer of Monkey Retina

Abstract. *The local electroretinogram of the monkey retina is recorded by intraretinal microelectrodes. Observations of the late receptor potential, isolated by selective clamping of the retinal circulation, show that when the retina is light-adapted by repetitive stimulation, the amplitude of the receptor potential is only slightly reduced over a slow time course. The reduction in amplitude of the* b-*wave is much greater and occurs much more rapidly. Thus there is a neural stage of adaptation between the late receptor potential and the generation of the* b-*wave by cells of the inner nuclear layer.*

The existence of neural mechanisms of adaptation within the retina has been reported in several notable papers (*1–3*). These neural mechanisms are little understood, but represent stages of adaptation in addition to photochemical adaptation, which results from the breakdown of photosensitive pigment by light and its regeneration in the dark. In the experiment described here, neural adaptation was demonstrated in the monkey retina by the direct recording of electrical responses from the receptors and from the inner nuclear layer. We show that one stage of neural adaptation occurs between these levels of the retina.

We obtained intraretinal recordings from the cynomolgus monkey (*Macaca irus*), using techniques already described in detail (*4*). The animals were anesthetized by thiopental sodium, relaxed by continuous intravenous infusion of succinylcholine, and given artificial respiration. A specially designed light stimulator was used for stimulation through the normal optics of the unopened eye (*4*). The retinal stimulus spots and the intraocular devices were all positioned under visual control, with the aid of a hand ophthalmoscope. Three needles were inserted into the temporal side of the eye, two of which were used as channels for electrodes. The microelectrode was of the tungsten type, with tip diameter less than 0.5 μ, and the reference electrode was a Ag-AgCl wire in the the vitreous humor. With this position of the reference electrode, it has been shown that an intraretinal microelectrode records almost exclusively a local electroretinogram (LERG) from a small area around the electrode (*5*). All components of this LERG, aside from the *c*-wave, are recorded at inverted polarity with respect to conventional ERG recordings (*5*). A steel rod with a rounded end was inserted into the third channel. This was used to apply pressure upon the optic disc, thus clamping the retinal circulation without affecting the choroidal circulation (*6*). This procedure abolishes ERG components which are generated by cells of the inner nuclear layer, but not the component which has been called PIII in the terminology of Granit (*6*). This component is maintained in a stable condition by the choroidal circulation, and studies of the isolated PIII have shown that it is generated by the receptors (*6, 7*). It is now called the late receptor potential, since an earlier receptor potential has been found which has no detectable latency (*8*). A variety of methods have shown that the *b*-wave of the ERG is generated by cells of the inner nuclear layer (*6, 9, 10*). Hence the comparative effects of light adaptation were observed for the late receptor potential and the *b*-wave, and the results are shown in Fig. 1.

Both series of responses in Fig. 1 were recorded from the same animal and the same area of the peripheral retina. Also, in both series the microelectrode was against the retinal side of the R-membrane, and this position has been shown by electrode marking to be against the retinal side of the pigment epithelium (*11*). Prior to the normal series of responses, the retina was first light-adapted by repetitive stimulation with the stimulus light until the responses were stable in both form and amplitude. Then the eye was adapted to darkness for 15 minutes, after which the time course of light adaptation by successive stimuli was traced. In the response series the stimuli served both to evoke the responses and to light-adapt the retina. After the normal series of responses the electrode was withdrawn from the retina, the retinal circulation was clamped to isolate the receptor potential, and the electrode was reinserted to the original level. The procedure was then repeated for the isolated receptor potential.

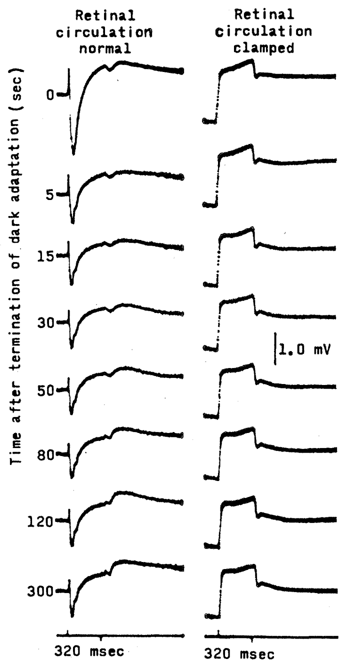

Fig. 1. The effect of light adaptation by successive stimuli upon the normal LERG (left column) and upon the late receptor potential after isolating it by clamping the retinal circulation (right column). Prior to each series of responses the retina was adapted to darkness for 15 minutes. Then the retina was light-adapted by a stimulus of 320-msec duration, repeated every 5 seconds, and each response was recorded. Representative records of this series are shown. The stimulus spot was centered upon the electrode; it had a retinal diameter of 2.72 mm and gave a retinal illumination of 3.28 log lumen/m^2. Direct-coupled amplification. Positive responses displayed as upward deflections, following the convention for ERG work.