

Fig. 1. (Top) Electric responses of an astrocytic glia from the midbrain of a kitten, cultivated *in vitro* for approximately 1 month. The recording microelectrode was introduced into the glia cell under direct visual observation by means of a phase-contrast microscope, at a magnification of 600. When the microelectrode was pushing the surface membrane of the culture, there was an upward deflection of the oscillograph beam. Penetration of the cell membrane is indicated by the arrow. The voltages applied to the extracellular stimulating electrode of 3.5-megohms resistance were -60 v, $+60$ v, two shocks at -60 v and $+80$ v, respectively. Room temperature was 28°C ; voltage calibration, 25 mv; time calibration, 20 seconds. [This record was obtained by us in the laboratory of Dr. C. M. Pomeroy at the University of Texas, in collaboration with Dr. W. Hild.] (Bottom) Electric responses of a "glial element" in the striate cortex of a cat, recorded with a hyperfine microelectrode. The beginning and the end of the resting potential are indicated by the arrows. The ripples of the base line are due to the pulsatory movement of the cortex. The intensities of stimulating current pulses (applied through a glass tubing of 1.5-mm diameter) were -10 ma, $+10$ ma, two shocks at -10 ma and $+14$ ma, respectively. Voltage calibration was 50 mv; time calibration, 20 seconds.

the order of 1 msec (and of amplitude of from 40 to 70 mv). It was found in this connection that the astrocytes in the same culture media produced, on direct stimulation, "electric responses" which had a duration more than 1000 times as long as that of the action potential of the nerve cells. This response of the astrocyte was characterized by a sudden depolarization (up to 40 mv) followed by a slow, roughly exponential return of the recorded potential to the resting level (see Fig. 1, top). The time constant of the exponential potential variation was around 4 seconds at 30°C and was nearly independent, within a certain limit, of the strength of the brief (10 msec or less) stimulating pulse. When two or more stimulating pulses, spaced over a short interval, were applied to the impaled astrocytes, the responses were found to summate. These electrophysiological properties of the glia cell resemble those of a slime mold, *Physarum polycephalum*, investigated previously by Tasaki and Kamiya (2). Later on, Chang and Hild (3) found that such electric stimulation of the glia evokes a slow mechanical contraction which lasts as long as 7 to 16 minutes.

In the investigation described in this report, an attempt was made to record slow electric responses from the glia cells *in vivo*. Cats were anesthetized with Nembutal. The skull was opened on both

sides to expose the lateral, suprasylvian, and ectosylvian gyri. After removal of the dura, the 3- to 4-mm tip portion of a pair of sharp stainless-steel forceps was pushed diagonally into the cortex; these forceps served to reduce the movement of the cortex and were also used as one of the stimulating electrodes. The other stimulating electrode was a glass tube, approximately 1.5-mm in diameter, filled with Ringer agar gel; it was placed on the surface of the cortex in the region between the two legs of the forceps. The stimulating circuit was completely isolated from ground and was closed for a period of from 5 to 20 msec by means of a mechanical switch operated by an electromagnet. The intensity of stimulating pulses was between 10 and 30 ma. The recording microelectrode was pushed into the region of the cortex where the density of the stimulating current appeared to be maximal. The ground electrode was a large coil of silver wire imbedded in Ringer agar gel; it was placed on the surface of the contralateral cortex. The resistance of the microelectrode was measured, during the course of penetration of the electrode into the cortex, by means of short electric pulses repeated at a rate of 1 or 2 per second.

When a negative direct-current potential of from 40 to 70 mv was recorded with the microelectrode, a pulse of stim-

ulating current was delivered to the cortex. This resulted on many occasions in a sudden small reduction in the observed "resting potential," followed by a gradual repolarization. The time course of this variation in potential was very similar to that observed in the glia cells in tissue culture (see Fig. 1, bottom). The amplitude of the variation in potential was found to vary with the stimulus intensity, within a limit. A reversal of the polarity of the stimulating current reversed the shock artefact (not shown in the figure), but the time course of the slow variation in potential which followed the artefact remained essentially unaffected (the only variation was in amplitude). Two stimulating pulses delivered a short time apart gave rise to a summation of potentials. No slow variation in potential was observed when the recording microelectrode was slowly withdrawn and the resting potential had disappeared.

The experimental findings described above suggest very strongly that the elements in the cortex of the cat which gave rise to slow "electric responses" are actually glia cells, and that these glia cells respond to electric stimuli as the glia cells in tissue culture do. It is probable that this slow electric response of the glia cell is followed by a slow mechanical contraction of the cell. The present experimental findings raise many interesting new problems in the field of brain physiology.

I. TASAKI

J. J. CHANG

Laboratory of Neurophysiology,
National Institute of Neurological
Diseases and Blindness,
Bethesda, Maryland

References

1. W. Hild, J. J. Chang, I. Tasaki, *Experientia* 14, 220 (1958).
 2. I. Tasaki and N. Kamiya, *Protoplasma* 39, 333 (1950).
 3. J. J. Chang and W. Hild, *J. Cellular Comp. Physiol.*, in press.
- 2 June 1958

Extracranial Responses to Acoustic Clicks in Man

Abstract. Electronic averaging of potentials recorded from the human scalp reveals the presence of small average responses following the presentation of click stimuli. These responses are first detectable near the subject's psychophysical threshold and vary in amplitude with click intensity. It is suggested that the short-latency components of these responses are cortical in origin.

Averaging techniques have recently been used by several investigators to detect extracranial responses to sensory stimuli. These responses are imbedded in

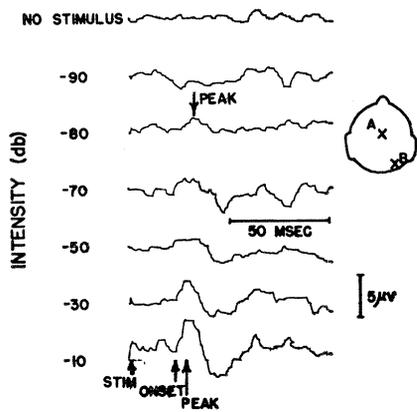


Fig. 1. Computed average responses to monaural, periodic clicks obtained from scalp electrodes for several stimulus intensities. Each trace represents the waveform of the average response to 400 individual presentations of identical click stimuli; the stimuli were presented at a rate of 1.5 per second. Upward deflection indicates that electrode A is positive with respect to electrode B. (Subject W.P., awake, eyes open, 10 Sept. 1957.)

the ongoing activity and are usually too small to be seen by direct inspection of the electroencephalogram (EEG). However, by use of different optical and electronic techniques, "average responses" to somatosensory (1), visual (2, 3), and auditory stimuli (4) have been obtained.

By the use of two different electronic averaging devices (5, 6) we have obtained responses to acoustic clicks from ordinary scalp electrodes in man. These average responses (see Fig. 1) are characterized by onset latencies of approximately 20 msec and peak latencies of approximately 30 msec and by response amplitudes and latencies that depend upon the intensity and the rate of presentation of the stimulus. The threshold for the appearance of a detectable average response agrees closely with the minimum intensity at which the subject reports that he hears clicks. Other response components with much longer latency [which may be identical with the so-called K-complex (7)] have been observed but are not described in this report (8).

Average responses with the latencies that we have given have been obtained from many of our experimental subjects. A given subject, under comparable conditions, yields similar average responses when he is tested repeatedly. The experiments were all performed in a sound-proof room, and the clicks were introduced to the subject through an earphone. Controls have been run that rule out eyeblinks as a source of artefactual responses. Responses are obtained from locations that are widely distributed over the scalp. The response to monaural

clicks is bilateral: electrodes placed symmetrically about the midline record virtually the same response. Our onset latencies are comparable to those measured by Dawson (1) for evoked responses to somatosensory stimuli and to those determined by Brazier (3, 5) for the visual system. These data, and the latency of the surface-negative component of evoked responses to clicks, in cats and monkeys, suggest that the responses which we obtain are cortical in origin. The fact that these responses can be obtained from many places on the scalp may reflect the deep location of the auditory cortex in man.

Figure 1 illustrates that, as the click intensity is increased, the peak amplitude of the response increases, while the peak latency tends to decrease. In other experiments we have varied the rate of presentation of the stimulus. Responses have been obtained for click rates as high as 10 per second, although the peak-to-peak amplitude of the most prominent component of the response tends to decrease with increasing rate.

It is interesting to compare, for a given subject, the psychophysical threshold with the stimulus intensity at which an extracranial response can first be detected with the aid of our averaging device. In subject W.P., the response is present, first, at -80 db (Fig. 1). Subject W.P.'s psychophysical threshold, as determined during the same experiment, is approximately -85 db. Other subjects have exhibited a similar correspondence between psychophysical thresholds and extracranially detectable responses.

C. D. GEISLER

L. S. FRISHKOPF*

W. A. ROSENBLITH

Research Laboratory of Electronics,
Massachusetts Institute of Technology,
Cambridge

References and Notes

1. G. D. Dawson, *J. Neurol. Neurosurg. Psychiat.* 10, 134 (1947).
2. W. Cobb and G. D. Dawson, "The form and latency in man of the occipital potentials evoked by bright flashes," *Intern. Physiol. Congr. 20th Congr. Abstr. Commun.* (1956), p. 182.
3. M. A. B. Brazier, "Studies of evoked responses by flash in man and cat," in *Reticular Formation of the Brain* (Little, Brown, Boston, Mass., 1958), pp. 151-168.
4. M. Abe, *Tôhoku J. Exptl. Med.* 60, 47 (1954).
5. J. S. Barlow, *Electroencephalog. and Clin. Neurophysiol.* 9, 340 (1957).
6. W. A. Clark, Jr., "Average response computer (ARC-1)," *Quart. Progr. Rept.*, Research Laboratory of Electronics, Massachusetts Institute of Technology (15 April 1958), pp. 114-117.
7. P. A. Davis, *J. Neurophysiol.* 2, 494 (1939).
8. This work was supported in part by the U.S. Army (Signal Corps), the U.S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U.S. Navy (Office of Naval Research).

* Present address: Rockefeller Institute for Medical Research, New York, N.Y.

6 October 1958

Ephemeral Natural Satellites of the Earth

Abstract. A discussion is presented of transient or short-lived natural satellites of the earth, which result from meteorites that only graze our atmosphere. Preliminary calculations show that only about 0.2 percent of the total number of the porous, stony meteorites which strike the earth will result in natural satellites. It is noted that such satellites also would be difficult to detect observationally.

In 1957 and 1958, the United States and the Soviet Union, in conjunction with the International Geophysical Year, have established several small artificial terrestrial satellites. The fascinating question arises as to whether these objects may be accompanied in their journey through space by certain "natural" satellites—that is, satellites that nature itself is continually contributing to the earth.

These natural satellites, if they do in fact exist, would originate from "near-miss" meteoritic trajectories that only graze the atmosphere of the earth, the meteorites being slowed sufficiently to enter onto a geocentric elliptical orbit. The natural satellite will not, of course, remain in its orbit indefinitely but, under the dissipative effects of drag, will spiral down to the surface of the earth or be consumed in flight. It is noted that there are other mechanisms for capture of natural satellites involving the attraction of the moon, the Poynting-Robertson effect, and so on; these processes are not analyzed in this report.

When first confronted by the suggestion of the existence of natural meteoritic satellites, one might hastily compute that the energy per gram that must be dissipated in order to slow a meteorite of any mass from escape speed to surface circular-satellite speed would be 31.2×10^{10} erg/g; moreover, reference to tables of heats of vaporization indicates that at most 10×10^{10} erg/g could be removed by vaporizing meteoritic material. How, then, could a meteorite become slowed sufficiently to assume a satellite orbit without becoming annihilated by aerodynamic heating?

In order to answer this question, one must recognize the fallacy of accounting for only the initial and the final energy of the meteorite. Actually, the whole meteoritic system, including the vaporized material, must be analyzed, and the conservation of energy must be applied in greater generality. In this connection the question can be clarified most directly by recourse to a simplified meteoritic model.

Let us assume that the meteorite loses no energy by radiation, conduction, sputtering, or any process other than direct vaporization, and that it moves in transitional flow. In order to account for the energy input to the meteorite, let us em-