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# UNUSUAL SEIZURE DISCHARGES ON STIMULATION IN THE LIMBIC SYSTEM OF THE MONKEY\*

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**INTRODUCTION:** During the course of an investigation concerning the effects of stimulation of the reticular formation and limbic system upon behavior in the monkey (*Macacca Mulatta*), we have observed some electrographic seizure activity in the amygdala which was, in our experience, unique.

After establishing the fact that we could consistently reproduce this activity in the temporal lobe of either hemisphere of our monkey, we consulted with Dr. Gloor<sup>1</sup> who conceded that the discharges were indeed somewhat unique; but he suggested further experience with other monkeys before such activity could be considered to have much significance.

We have at this time completed a similar set of experiments in another monkey and have been able to duplicate our results.

The method of procedure, both for stimulation and recording in the limbic system includes the implantation of a Jasper-Delgado type of electrode with four leads, having a distance of 2.5 mm. between adjacent pairs of contact tips.<sup>2,3</sup> These are placed stereotactically in the temporal lobe with the deepest contact in the amygdaloid nuclear complex. The leads are connected to the input of Techtronix 502 low level pre-amplifiers and the output of these is fed simultaneously to an Offner transistor electroencephalograph, an Ampex 1103 tape recorder and an Offner frequency analyzer.

Silver—Silver chloride scalp leads are attached with collodion and connected directly to the Offner Electroencephalograph.

At the conclusion of the experiments, the animals are sacrificed, their brains perfused and the electrode placement grossly verified. The specimen is then prepared for microscopic examination.

With previous experience we had established a stimulus pattern consisting of square wave pulses from a Grass SB-4 stimulator delivered at 400 cycles per second with a duty cycles of 0.8%. The voltage setting was often varied but always monitored as also was the current by an oscilloscope.

Such a stimulus pattern often produced motor responses and electrical after-discharges, but prolonged electrographic seizures were never observed. During a series of stimulation with different parameters in an attempt to bracket motor response thresholds, the duty cycle of the square wave was increased from 0.8% to 80%. When this was done prolonged electrographic seizure activity was invariably observed with the proper voltage setting.

**OBSERVATIONS:** The short duration electrical discharges (or after-discharges), which appeared immediately following cessation of stimulation (Fig. 1, 2) were

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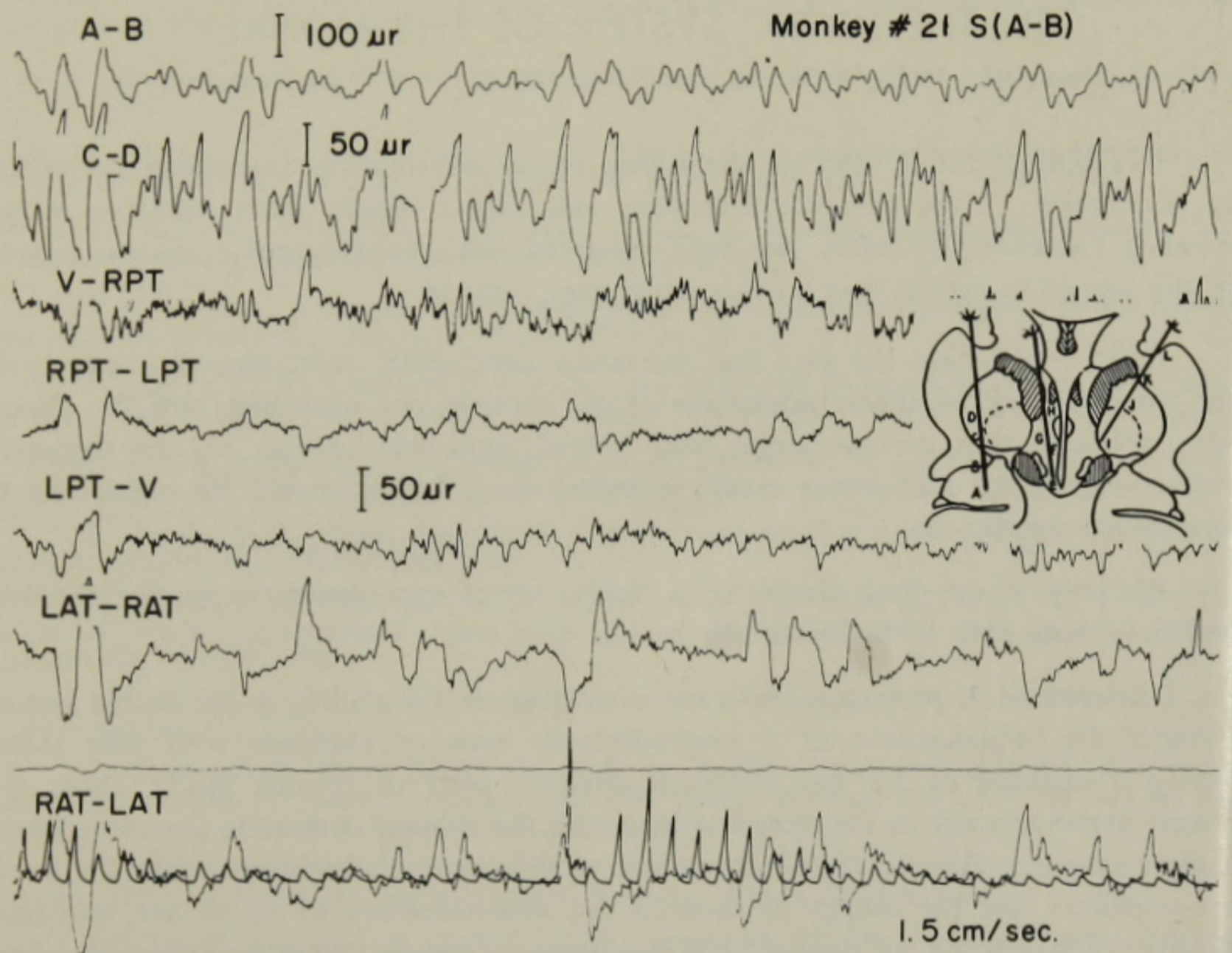


Figure 1

After-discharge immediately following stimulation of the amygdala. (A-B) and (C-D).

characteristic in form and frequency with previously reported amygdaloid seizures.<sup>4,5</sup> They lasted from a few seconds to a few minutes and neither their appearance nor duration appeared related to the magnitude of the duty cycle. As in other reports,<sup>6,7</sup> the cerebral cortex seemed remarkably free from this amygdaloid activity; however, other deep brain structures, forebrain nuclei, ganglia and hypothalamus frequently showed involvement. (Fig. 2).

The seizure discharges, which seemed to us unique, were always delayed in onset after cessation of the stimulus. This delay varied from one to more than ten minutes. If the stimulus produced an immediate after-discharge, then the onset of the prolonged discharge was delayed even further. The onset of this delayed seizure was usually heralded by a shift in the baseline (Fig. 3) equivalent to as much as 1200 microvolts in amplitude with a subsequent dip below the baseline and return to resting level. The entire biphasic process lasted about two to three seconds. The paroxysmal activity would immediately follow. The initial amplitude was usually low but built up slowly to as high as 200 microvolts. The dominant frequency was usually about 2½ to 3 cycles per second, although this (Fig. 4) frequency would shift to harmonics of 6, 12, and 24 cycles per second. The duration of these discharges was in some instances only four or five minutes; however, on two occasions the seizure lasted for over an hour and one seizure continued uninterrupted for an hour and fifty minutes.

*Limbic System of the Monkey*

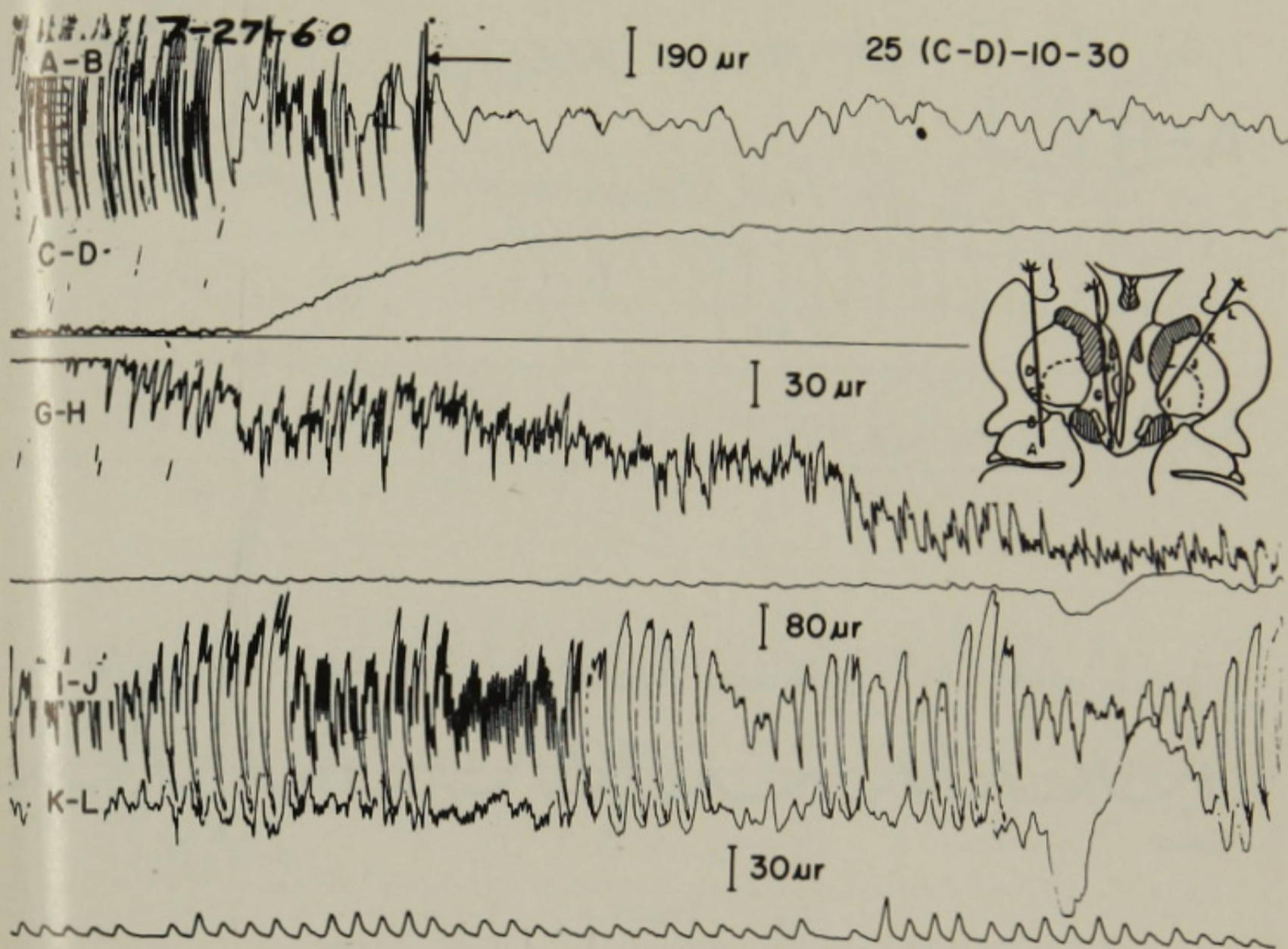


Figure 2

After-discharge spreading to hypothalamus (G-H) and contralateral basal ganglia (I-J) and (K-L).

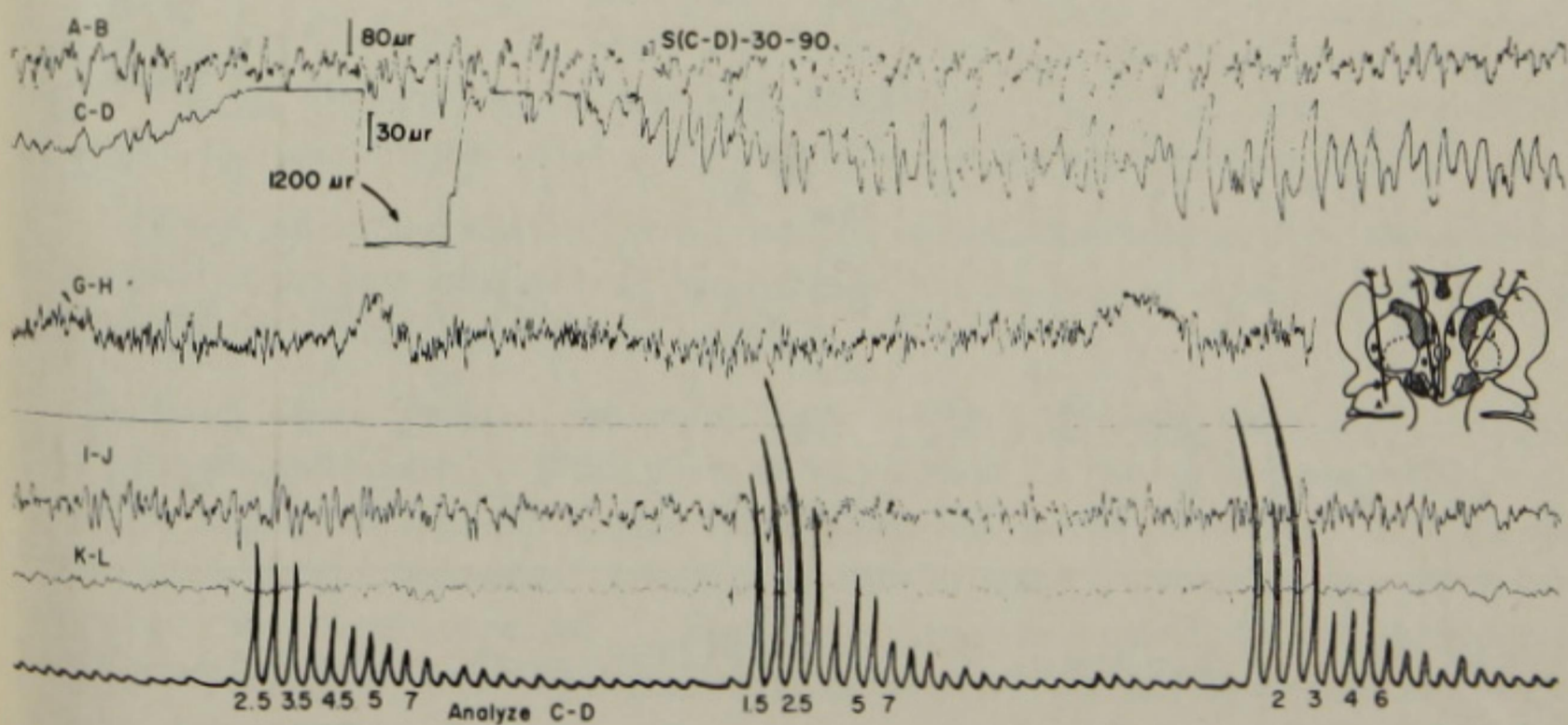


Figure 3

Delayed seizure discharge preceded by high amplitude "biphasic shift" of the baseline. (C-D).

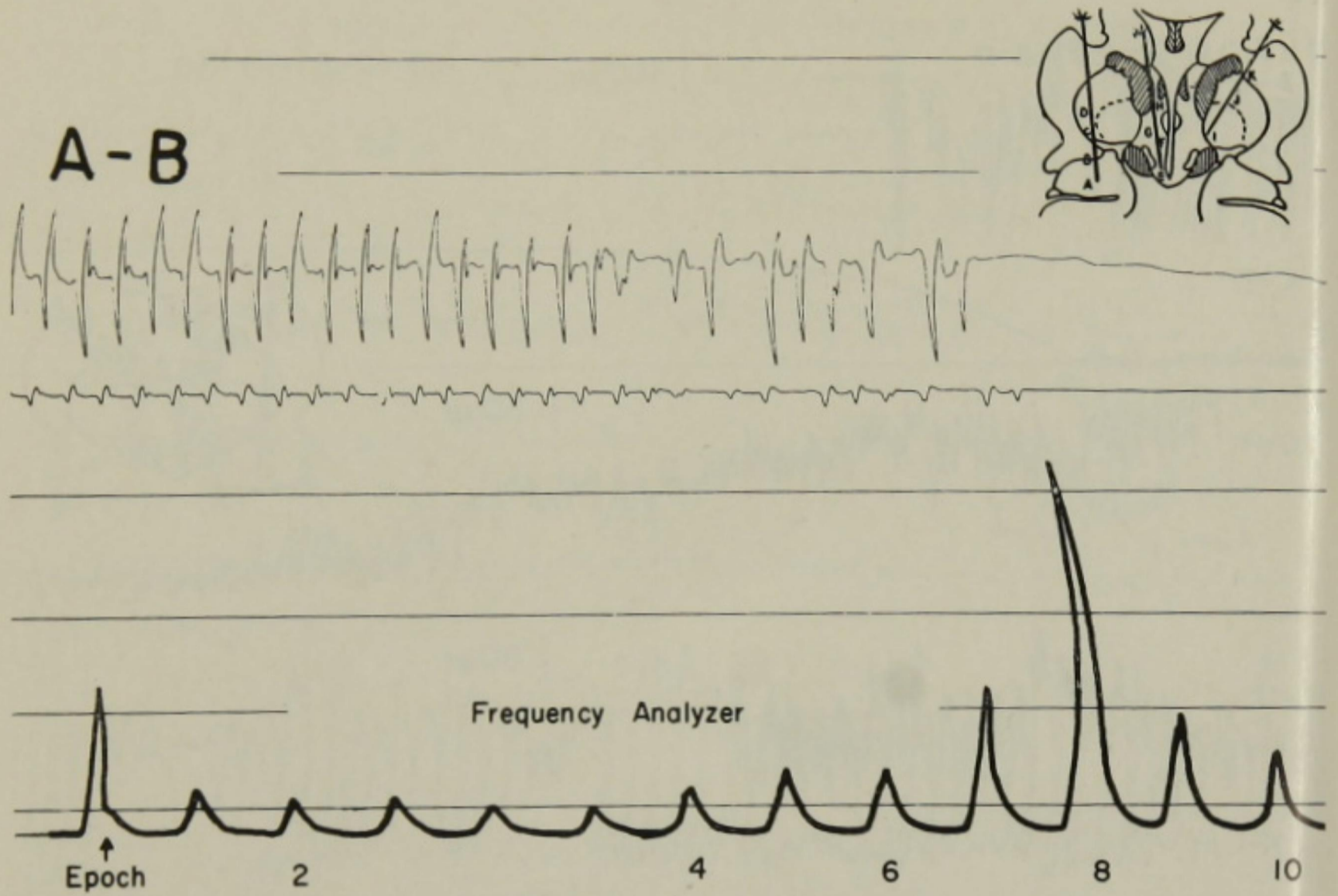


Figure 4  
Shifting of frequency spectrum and "harmonics".

S(C-D)-130-190

7-15-60

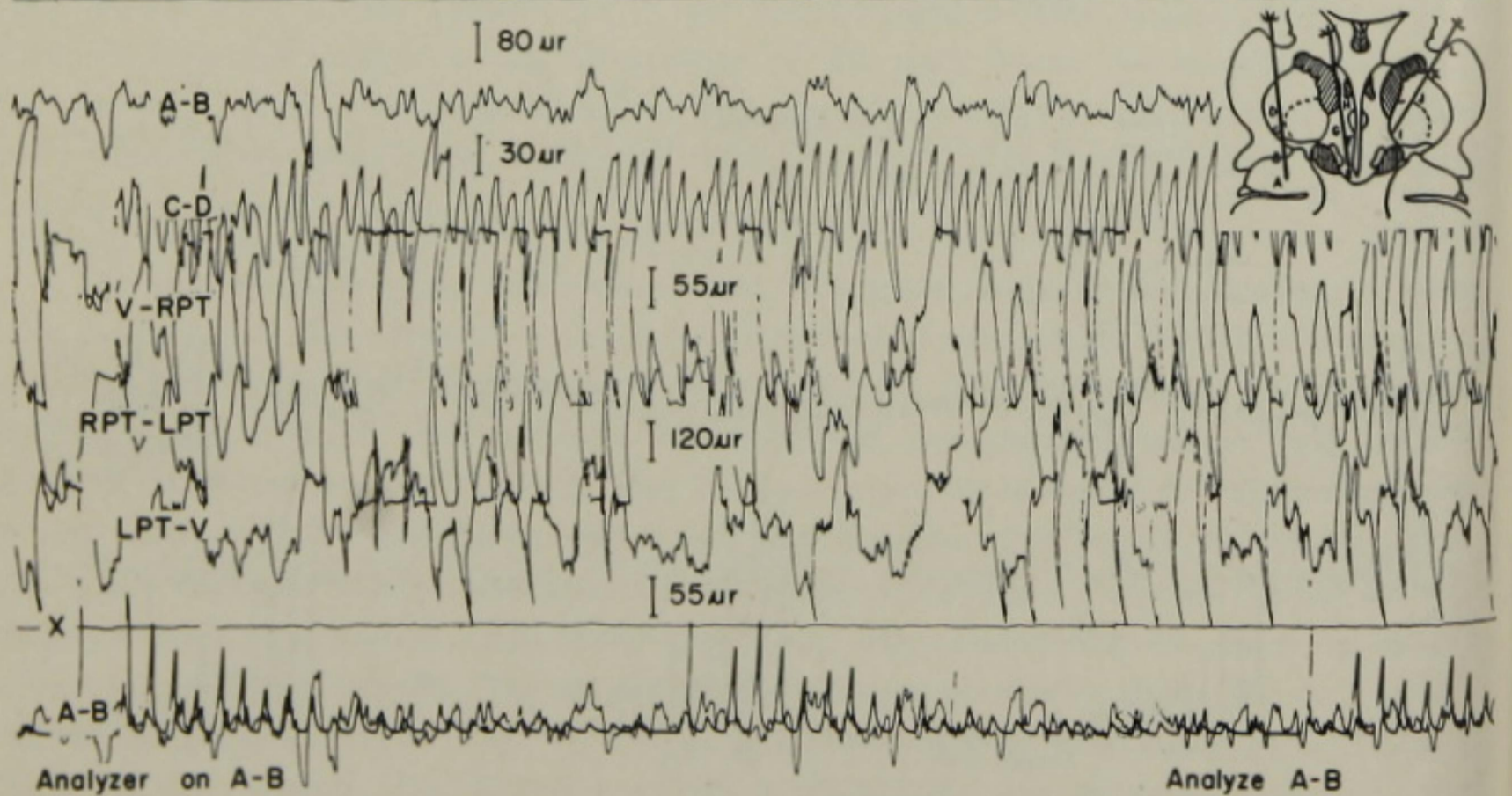


Figure 5  
A rare cortical response during a delayed seizure. (V-RPT) (RPT-LPT) and (LPT-V)

## Limbic System of the Monkey

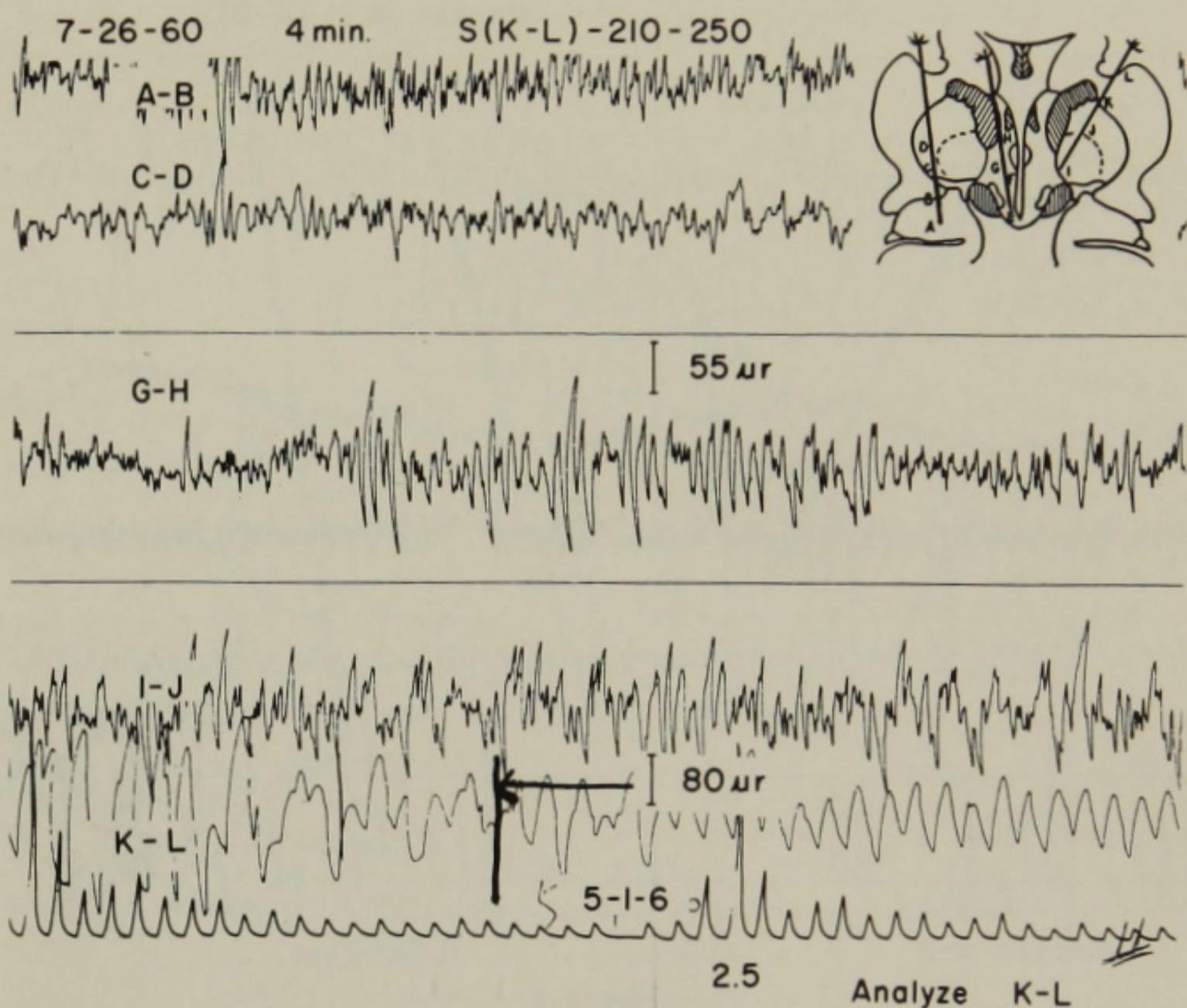


Figure 6

Hypothalamic response (G-H) during a delayed seizure.

These discharges were similar in their anatomical distribution to the after-discharges. On rare occasions they were seen in the cortex (Fig. 5) and hypothalamus (Fig. 6) and were frequently seen in the amygdala and in the basal ganglia of the opposite hemisphere (Fig. 7). Activity in these areas was delayed in appearance until the activity in the original site was well established, and it was seldom maintained for more than a few minutes.

Delayed, prolonged seizures were produced in both hemispheres with simultaneous stimulation of the amygdala of both hemispheres, but the time of onset of the discharge between the two sides was always different.

Behavior concomitants of unilateral limbic system stimulation have been described in a previous publication.<sup>8</sup> With bilateral stimulation of this system, in addition to the head turning, mouth and tongue movements, etc. noted previously,<sup>8</sup> a snake-like darting of the tongue was seen.\* Minimal changes in states of consciousness were suspected as the animal appeared to stare from time to time during the prolonged electrical discharges. Automatic repetitive movements of the hand also occurred. Reliable psychometric measurements were not possible on the two monkeys used in this investigation.

\*A movie film was shown of this behavior.

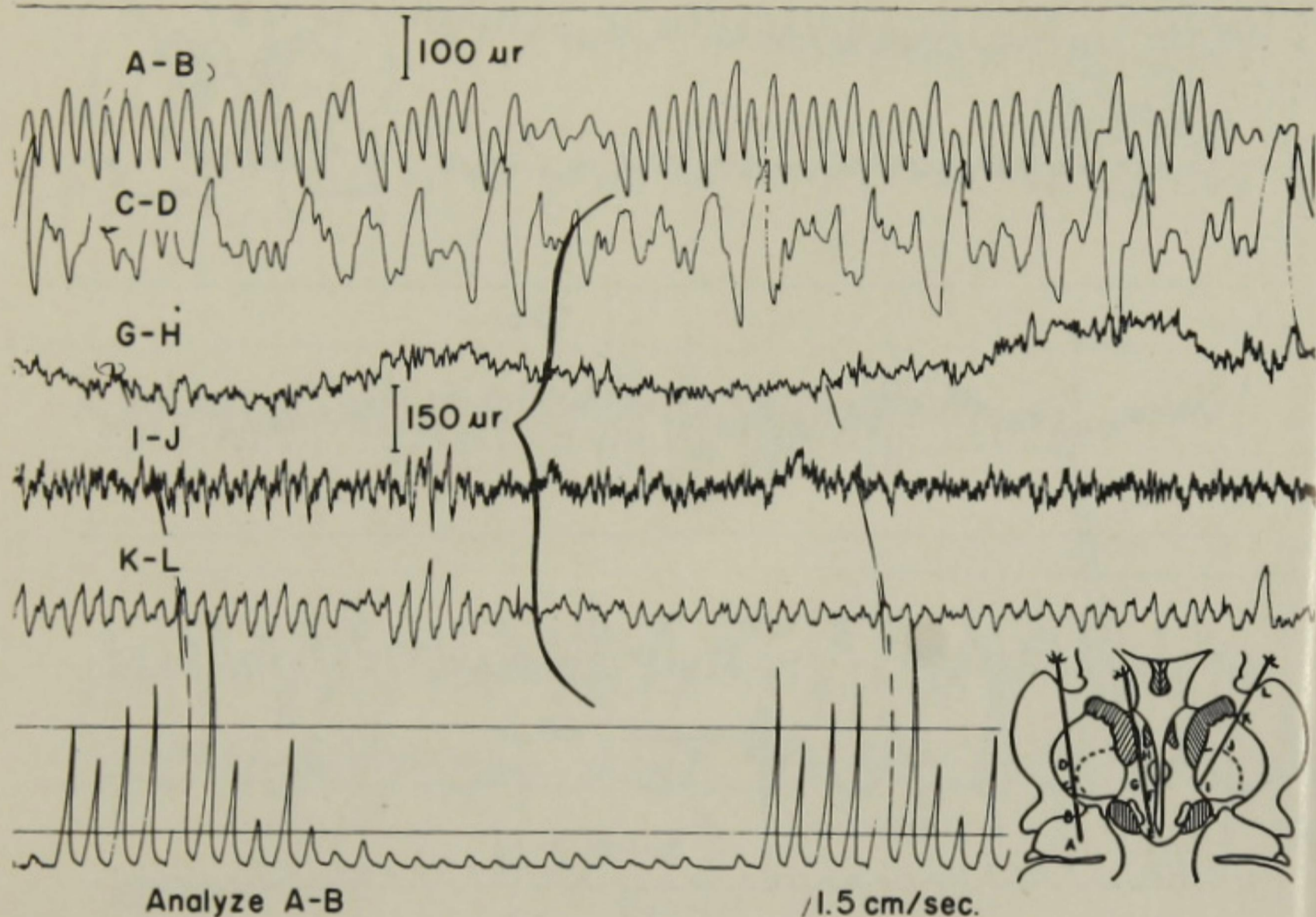


Figure 7

Spread of a delayed seizure (A-B) to the deep structures of the contralateral temporal lobe (I-J) and (K-L).

An anatomical examination both grossly and histologically showed that in one monkey the left electrode had its deepest contact in the core of the amygdaloid complex and its upper most contact near the anterior commissure. The right electrode had all four contacts within the globus pallidus and putamen (Fig. 8). In the other monkey both electrode tips were within the amygdaloid complex but the left one was a few millimeters deeper. One monkey had an electrode in the diencephalon with the deepest contact in the left ventromedial nucleus of the hypothalamus.

**DISCUSSION:** As can be seen from the evidence, we are dealing with a complex phenomenon which implies an interaction of several, at least, partly independent systems or circuits. The rhythmic discharge is localized in its appearance yet may be propagated to distant structures; however, the delay in appearance at the stimulus site and the delay in its propagation to other structures suggest an intrinsic genesis of the wave form rather than an extrinsic driving mechanism. Understanding of the nature of the mechanisms involved is certainly beyond the scope of the present findings. Further studies of micro-electric correlates and the vectors of stimulus parameters should be of help in this regard.

The above findings have shown a quality of temporal lobe electrical activity which is consistent both physiologically and anatomically with repeated experience. It is hoped that further study of this phenomenon will add to the concept of temporal lobe seizure activity.

## Limbic System of the Monkey

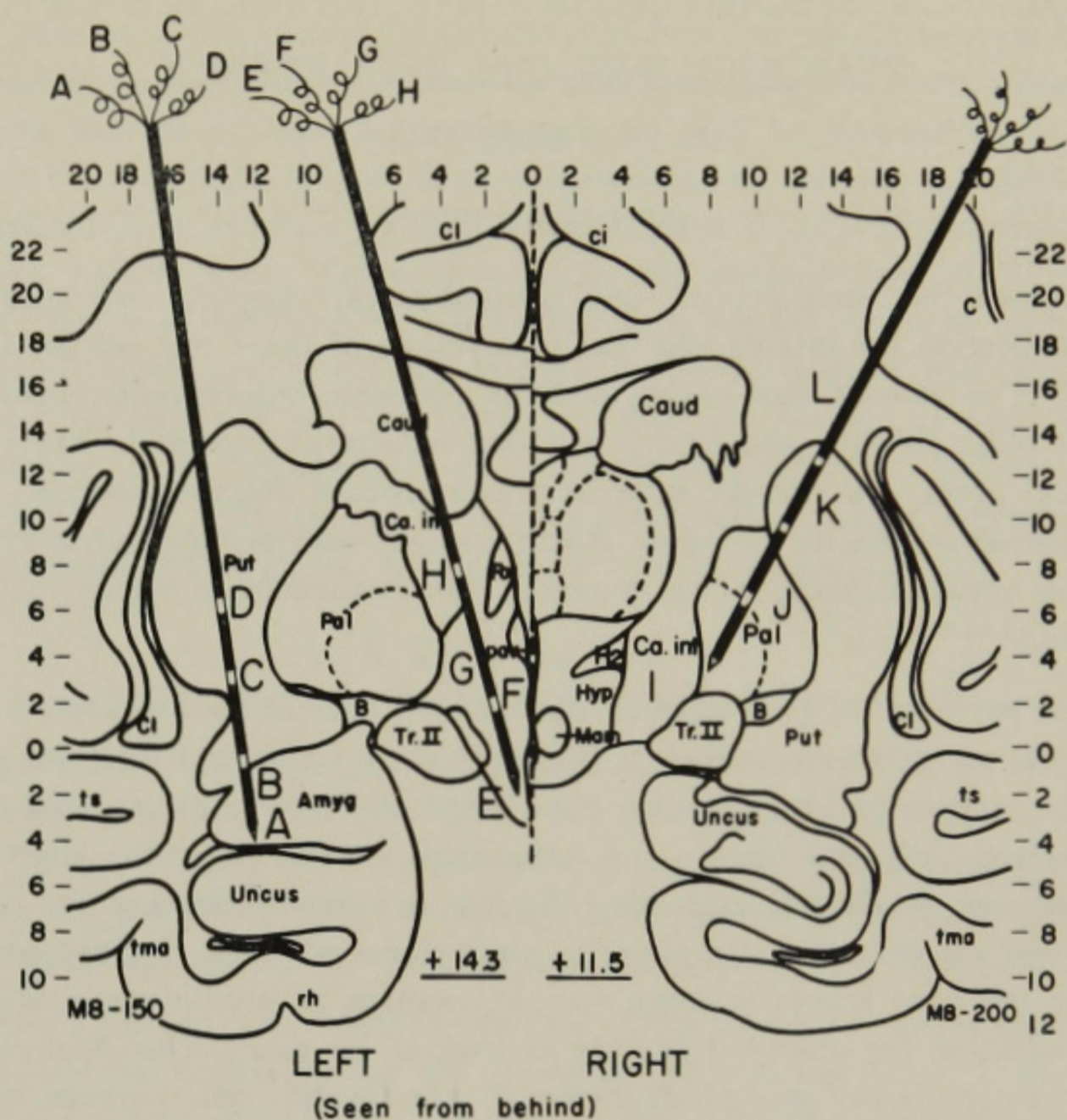


Figure 8

Placement of electrodes in monkey No. 21.

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