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FINAL REPORT

Research Contract NAS 9-7237

Evaluation of the Neurophysiological Electrode-Amplifier-Harness System for Physiological Data Acquisition

CASE FILE
COPY

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1. Introduction

The experience in the Mercury, Gemini, and early Apollo series indicates that sleep and sleep/work cycles are important factors requiring critical attention in manned space flights. The increasing duration of the space missions has required that attention be focused on objective measures of the quantity and quality of sleep and other neurophysiological factors which may be modified in the weightless state.

The electroencephalogram, coupled with other physiologic parameters such as the electro-oculogram, provides a unique tool for the objective evaluation of the quality and quantity of sleep and may, with the use of computer methods of analysis, provide insight into other neurophysiologic alterations which may attend prolonged exposure to the weightless condition.

As early as 1963, NASA recognized that new techniques of data acquisition as well as data analysis would be required if reliable neurophysiologic data were to be obtained from human subjects in the special constraints imposed by the circumstances of space flight.

In 1966-67, a normative tape library of EEG and other data derived from 200 healthy male subjects in the 25-35 year age group was compiled and analyzed by a team of investigators from the University of California at Los Angeles and Baylor College of Medicine, working cooperatively under a contract from the National Aeronautics and Space Administration.

A pilot study of the feasibility of recording the EEG in space flight was conducted by the Baylor group and NASA using conventional electrodes in the Gemini VII flight.

The current project described in this report concerned the development of a special electrode and harness system for the acquisition of EEG and other neurophysiologic data in future space missions. This project was planned as a joint program, with the UCLA group taking the primary responsibility for the design and manufacture of the prototype system, and the Baylor group assuming responsibility for testing and evaluation. Design developments and modifications would be the joint responsibility of the teams.

The fundamental goal of the project was to develop a head cap, electrodes, preamplifiers, and harness which would facilitate:

a. Ease of application and removal
b. Repeated on-off use during extended periods

c. Comfort when worn for periods up to 24 hours, including 9 hours of continuous sleep
d. Detection of artifacts produced by such factors as sweating, eye movement, and muscle potentials

The system should yield high-quality EEG and other data under adverse conditions, including normal physical activity, eating, exercizing, etc., and should not produce adverse dermatologic reactions of scalp, face, or neck.

2. The Material Provided by UCLA for Testing and Evaluation

Three general types of material were provided by the UCLA group:

a. Caps of various materials and configurations
b. Electrodes
c. Electrolytes of various compositions
d. Preamplifiers incorporated into the electrode holders or elsewhere on the cap

3. Initial Design Period Concerned with Caps and Electrodes

Caps of various materials and configurations were tested on volunteer subjects and selected patients. Evaluation was made in terms of shape, size, fit, and conformation to the contours of the head.

The consistency and pressure characteristics of the cap in maintaining the electrode placements and skin contact were also determined, as were the comfort and ease of application.

The amount and character of residual gel after cap removal was determined in relation to the length of time the cap had been in place.

On the basis of these tests, information was relayed to the UCLA design group which resulted in:

a. Modification of the electrode holders in the cap
b. Adoption of Lycra® as the material for cap construction

(See Final Report, Research Contract NAS 9-7282, W. R. Adey.)

Seven types of electrode gel were evaluated in terms of consistency, irritative properties, and half-cell potential. These were also compared with commonly employed commercial electrolyte pastes and gels, including

Grass Paste® and EKG Gel®.* Of the gels provided by the UCLA group, the one whose composition was as follows provided the best compromise in terms of best half-cell potential and low irritative qualities.

NaCl	6000 mg/liter
KCl	400 mg/liter
$MgCl_2 \cdot 6H_2O$	200 mg/liter
$NaH_2PO_4 \cdot H_2O$	1500 mg/liter
KH_2PO_4	10 mg/liter

Natrosol was used as a gelling agent, and polyvinyl-pyrrolidone was used as a stabilizer and Zephiran Chloride (Winthrop Labs) as a preservative for the gel.

The various versions of the cap and electrolyte were tested in 32 subjects and 10 patients. In some subjects, several tests were carried out, and one of the investigators wore the final version of the preliminary series of caps all night on four different nights.

These initial studies have been summarized in previous interim reports.

Recording in routine clinical conditions produced clean recordings, indistinguishable in terms of the quality of the record and the amount of artifact present from recordings made under similar conditions using the silver-silver chloride clinical electrodes held in place with paraffin and gauze. However, the UCLA electrodes produced the same amount of artifact as the usual clinical electrodes when movement between the electrode and skin was produced. This type of artifact is generally believed to be related to the half-cell potential of the electrodes.

However, when such movements were sufficient to produce momentary displacement or disruption of the interface between skin and electrode, the UCLA electrode immediately thereafter yielded a good signal, free of artifact. In this respect, the UCLA electrode is a significant improvement over the types of electrodes and methods of attachment which are usually employed in routine clinical studies. In spite of vigorous body or head movements, either freely in space or against the mattress or pillow, the UCLA electrodes quickly stabilized, with little or no subsequent spontaneous "popping."

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*Burton Parsons and Co., Washington, D.C.

DC measurements of resistance were consistently 20, 000 ohms or more, but a drop in resistance of 2000-5000 ohms usually occurred after the electrodes had been in place for more than an hour.

The final version of the initial series of caps (tested without preamplifiers on the cap) proved to be reasonably comfortable and was tolerated by all test subjects in a single night's recording. One subject wore the cap on four different nights (two of them being consecutive) and experienced no difficulty in going to sleep and remaining asleep for a 6-8 hour period. All of the subjects sleeping in the caps showed slight pressure indentations and slight reddening of the skin after removal of the cap, but no marks or painful pressure points persisted more than a few hours.

Operational testing of the cap in the special environmental conditions of an underwater habitat proved to be the most rigorous test program for the electrode-cap system, and this is reported in detail in a subsequent section of this document.

4. The Final Version of the Cap with Preamplifiers, EEG, EOG, and EMG Electrodes

One cap with electrodes and preamplifiers attached was provided by the UCLA group for evaluation.

a. Evaluation of Input-Impedance Characteristics and Noise Level of the Amplifiers

1) Test Procedures

The test format illustrated in Fig. 1 was utilized to quantitatively evaluate the signal-processing capability of the individual recording-cap amplifiers. A 100 μV square-wave test signal from a signal generator with an output impedance of approximately 500Ω was first applied directly to the inputs, as shown in sections A of Fig. 1. (Suitable ground connections were maintained throughout the procedure.) The amplifier output signals were displayed on a graphic recorder (Grass, model 78). Samples were also obtained with the signal generator connected as shown, but switched off, to observe the inherent noise characteristics under no-signal conditions. This test sequence was then repeated, as indicated in sections B, Fig. 1, with 100 KΩ resistances inserted in series with each input lead in order to determine the input-impedance characteristics of the amplifiers.

2) Results

Under low impedance conditions (sections A, Fig. 1), inherent noise levels (referred to the inputs) ranged from a low of approximately 4 μV peak-to-peak (channel 6) to a high of approximately 12 μV peak-to-peak (channel 1).

Insertion of 100 KΩ resistances in the input leads consistently resulted in reduction of signal amplitude to values equivalent to less than 50% of the low impedance levels. Thus, the effective input resistances were in all cases somewhat less than 100 KΩ. Noise levels under high input-resistance conditions ranged from a low of approximately 20 μV peak-to-peak (channel 5) to a high of approximately 50 μV peak-to-peak (channels 2 and 3).

3) Comment

The results of these tests indicate that while acceptable recordings could be obtained from most channels with low-impedance electrodes (less than 10 KΩ), serious errors could result if interelectrode resistances in the 50-100 KΩ range were encountered. In such cases, amplitude discrepancies could occur, and the character of the recorded signal could be distorted by the inherent noise levels.

b. Recording Tests

The EEG, EOG, and EMG electrode placements and pulse sensor are indicated diagrammatically in Fig. 2. This figure also indicates the EEG montages used in the sample recordings which are illustrated hereunder.

Inherent noise, including sharp-wave transients, is particularly pronounced in the first two channels (see Figs. 3 through 7).

Eye movements are adequately registered in the lateral but not the vertical plane (Fig. 3).

EEG activity is adequately registered (note alpha in RC-RO channel in all figures), but inherent noise is excessive.

Head movements, side to side and forward to back, are accompanied by an obscuring degree of artifact only when quite strong (see Figs. 5 and 6).

The pulse-pressure recorder (Fig. 7) proved very difficult to position and maintain in operation unless it was held by hand against the scalp. This sensor is not considered to be usable in its present form for actual space flight.

5. Evaluation of an Automatic EEG Acquisition and Data-Analysis System — Results During Tektite 1

a. Introduction

In the three years, 1966-1969, a number of component assemblies have been developed under NASA contracts which are related to acquisition and analysis of EEG and other neurophysiologic data. Tektite 1 provided an opportunity to test operationally a prototype system specifically directed toward the task of monitoring and evaluating sleep during manned space flight. Because of potential future development as flight-qualified items, it was required that the prototype components be significantly reduced in size from those conventionally utilized in the clinical laboratory. It was decided to attempt to record, and analyze on-line, the sleep patterns of one member of the Tektite crew during the initial 10 days and again during the final 10 days of the 60-day mission.

Three basic subassemblies were to be evaluated: 1) the UCLA EEG-EOG-EMG electrode cap, 2) preamplifier and tape-recorder systems, and 3) an automatic EEG sleep analyzer.

The answers to a number of specific and practical questions were sought with respect to each subassembly, but with particular regard to the way in which the components performed as part of the complete system.

1) Electrode Cap

This assembly, as detailed in following sections, is designed to permit detection of EEG, EOG, and EMG activity from the head of the subject. Recording of such electrical activity in prolonged, extralaboratory situations, especially when the observer cannot have direct physical contact with the subject, requires several modifications of the usual methodology. The electrodes must be easily applied by the subject himself, and with little loss of time. They should be accurately but automatically positioned to ensure reliability of data. The electrodes must be durable and not easily dislodged by pulling, motion, or scraping. They should not be susceptible to movement artifact. Damage, irritation, or maceration of the skin cannot be tolerated because of the risk of infection. Finally, the array must be comfortable, even while the subject is sleeping or attempting to fall asleep. Evaluation of the electrode cap with respect to these requirements during the Tektite project would provide useful insight into the proper directions for further development.

2) Preamplifier and Tape-Recorder Assemblies

The Gemini series EEG preamplifiers had been extensively tested in laboratory situations and were known to perform well even with the relatively high interelectrode impedances presented by the electrode cap. The susceptibility to extraneous electrical interference was not so well known, however, and the conditions of the Tektite experiment, where recording was to be carried out in the subject's unshielded bunk in close proximity to other equipment, would provide a good test of this aspect.

A new series of EEG preamplifiers, developed for the Apollo program, were also included in the system to allow comparison and evaluation of improvements in noise rejection as well as any adverse effects of the environmental situation (increased atmospheric pressure) upon the electrical characteristics.

The reliability of the long-term magnetic-tape-recording system developed during the Gemini program would also be evaluated, as would the quality of the recorded data.

3) Automatic Sleep Analyzer

This device has been developed to permit continuous, automatic, on-line evaluation of a subject's state of consciousness. Its use during the Tektite project would permit an evaluation of its reliability under circumstances when the sleep periods might be expected to be altered because of unusual stresses and working conditions. The influence of unsuspected artifacts or environmental conditions would also be of importance in further development of the system.

b. Description of Equipment

1) Electrode Cap

The electrode cap developed by Dr. W. R. Adey (NASA contract NAS 9-7282) was used with only minor modifications during the initial 10-day recording period. Further changes which became necessary in the electrode system are detailed in the Results section below.

As illustrated in Figs. 8 and 9, the electrode cap contained six conventional EEG electrodes (F_1, F_2, C_3, C_4, O_1, O_2), two EOG electrodes (left outer canthus and central forehead), and two neck EMG electrodes, in addition to a ground located near the vertex. Also visible in Fig. 8 are the foam-rubber pads which were added in the posterior region of the head to increase comfort in the normal earth gravity condition prevailing in the Tektite module.

The scalp side of the electrode-cap assembly is demonstrated in Fig. 10, and the silicone-rubber sponge contacts are visible. These foam-rubber contacts were presaturated with an electrolyte gel, and, as indicated in Fig. 11, were easily replaced by the subject when necessary.

An exploded view of one of the cap electrodes is shown in Fig. 12 beside an assembled electrode. An Ag/AgCl pellet is contained in the clear plastic plug which also supports the amplifier lead cable. This component fits into the silicone-rubber housing which is molded into the fabric of the cap. The housing also accepts the foam-rubber sponge as illustrated previously Fig. 11. The complete electrode assembly is approximately 3 cm in length.

The material of the cap itself is elastic (Lycra®), and thus a constant light pressure is exerted upon the electrodes, maintaining contact between the foam-rubber sponges and the scalp.

To prepare the assembly for use before each sleep period, the subject removes and discards the old sponge contact, as in Fig. 11, injects 1 cc of electrolyte gel into the housing, and reinserts a new, presaturated sponge. This procedure requires approximately 10 minutes for the number of electrodes diagramed in Fig. 9. The cap is then positioned on the head and secured with a padded chin strap.

An isotonic electrolyte gel is utilized in order to minimize the possibility of skin irritation and infection. This gel also reduces the contact potential between body fluids and electrolyte and thus diminishes the magnitude of electrical artifacts associated with movements of the head. Interelectrode resistance is usually around 100, 000 ohms when the cap is first donned, but this drops to around 30, 000 ohms within a few minutes. However, even after 8 to 12 hours of continuous wear, the resistance usually continues to be about 20, 000 ohms, indicating preservation of the usual skin resistance.

2) Automatic Sleep Analyzer

This device was initially developed under NASA grant No. NGR-44-003-025, and a detailed description of the principles of operation is contained in the final report submitted to NASA. Further development is underway (NASA contract NAS 9-9418) to adapt this system for on-board EEG analysis and evaluation of sleep/waking cycles during manned space flight.

The general approach has been to determine the minimum amount of EEG and EOG information which is actually needed to make a proper decision and to determine the most direct way in which this information can be automatically extracted from the total EEG. The system tested in this operational situation is a laboratory prototype which uses conventional transistorized circuitry, occupies about $1\frac{1}{2}$ cubic feet of space, and provides an output in terms of the standardized clinical stages of sleep (awake, stages 1-4, REM). The system is essentially an amplitude-weighted, dominant-frequency meter for the 0.7 to 14 cps EEG bandwidth, with the output restricted to six distinct voltage levels. Since the device considers essentially the same criteria as those used in visual scoring, i.e., a combination of dominant frequency and amplitude, the results are in very close agreement with those of expert visual interpretation. An example of the output is provided in Fig. 13, which shows the sleep pattern for the aquanaut during project night #50.

3) General Scheme of Operational Situation

The physical locations and interconnections of the data acquisition, recording, and analysis equipment are indicated in Fig. 14. Within the Tektite undersea habitat, the EEG, EOG, and EMG activity was detected with the electrodes of the cap assembly and led to preamplifiers. Seven channels (5 EEG, 1 EMG, 1 EOG) were amplified by the Gemini series NASA preamplifiers (Beckman) and recorded on a miniature magnetic-tape recorder (Cook/NASA) which was located near the subject's bunk. Four channels (3 EEG, 1 EOG) were also led from the cap to Apollo series preamplifiers (Spacelabs) and transmitted to the surface monitoring van. Within the monitoring van, the data were displayed at selected paper speeds on a 4-channel Brush graphic recorder and simultaneously recorded on a conventional magnetic-tape recorder (Ampex SP300) at 1 7/8" per second (this served as a back-up system to the recorder in the undersea habitat). One channel of EEG and one of EOG entered the automatic sleep analyzer, and the results of the electronic analysis were displayed on the 2-channel graphic recorder (Brush) as illustrated in Fig. 13.

The performance of the automatic analyzer was constantly evaluated throughout the sleep period by an expert electroencephalographer who observed the EEG and EOG on the 4-channel graphic recorder and noted any areas of disagreement or any type of artifactual activity which might influence the results.

c. Results

1) General

In general, all components of the system performed well, and no problems were encountered which could be attributed to specific environmental conditions. In spite of the fact that recording was carried out in an unshielded bunk, in close proximity to other electrical apparatus, electrical interference was never a serious problem. Data were lost through equipment failure during only one recording period, recording night #51, when both the habitat recorder and surface equipment detected only random-appearing electrical noise. Although the reason could not be established with certainty, a transient fault in the preamplifier power supply is suspected. Approximately $1\frac{1}{2}$ hours of recording were lost during the initial portion of night #58 when the subject retired for the night (unobserved by surface monitors) and neglected to turn on his power switch. This was corrected later by another crew member when the situation was recognized. As discussed in the following section, no recording was attempted on days 3 and 7.

The quality of the recordings is illustrated in Figs. 15-23, which were made by playing the tape-recorded data from the habitat recorder back through a conventional Grass EEG machine. Fig. 15 shows the EEG pattern with the subject awake, reading in bed. The EOG channel demonstrates the typical scanning-type eye movements associated with reading. Occipital alpha activity is present intermittently in this eyes-open recording. Fig. 16 shows a high-amplitude burst of alpha which occurs when the subject closes his eyes, and Fig. 17 is from a long segment during which time the eyes were constantly closed. Fig. 18 illustrates the change with onset of sleep, showing the slower background activity and occasional vertex (C_3 and C_4) transient forms and lack of alpha activity. Stage 2 (Fig. 19) is characterized by the appearance of 14 cps spindle activity, and stage 3 (Figs. 20 and 21) by increasing amounts of intermittent delta activity. During stage 4 (Fig. 22), almost continuous delta is evident. Fig. 23 is from a period of REM sleep, showing the stage 1 EEG and occasional abrupt eye movements in the EOG channel.

Fig. 24, from the same recording night, demonstrates the way in which the data were displayed on-line in the monitoring van (from 4-channel Brush recorder) for interpretation by the electroencephalographer. The output of the automatic sleep analyzer (Fig. 13) has been discussed previously (Equipment section).

2) Problems Encountered

a) Recording Cap

During the first recording night the EMG electrodes, low in the occipital region, were found to be quite uncomfortable by the subject, in spite of the foam-rubber padding in this area. The discomfort was severe enough to require the subject to remove the cap before the end of the sleep periods of the 1st and 2nd nights. Consequently, recording was suspended for the 3rd night, and the caps were modified by removal of the EMG electrodes.

This only slightly improved the comfort, and the occipital electrodes were now the most bothersome, although the quality of the recordings continued to be good on nights 4-6. Because the subject began to notice discomfort persisting on throughout the day in the area where the occipital electrodes contacted the scalp at night, recording was not carried out on the 7th night. The cap was tried again on night 8, but since discomfort persisted, conventional chlorided silver-disc electrodes (Grass) were substituted for the cap on the last two nights (9 and 10) of the first 10-day recording period. These electrodes were applied by other crew members who had previously been trained in the technique of application.

Between the first and second 10-day recording periods, an extensive redesign of the electrode-cap assembly was made in an attempt to improve the comfort problem while still maintaining the prime requirements of durability, non-irritability, and satisfactory data acquisition. The major change was made in the electrode itself by reducing its size to 1/3 of the original length and removing all rigid plastic components. Fig. 25 compares the original electrode (model 1) with the redesigned (model 2) version. The large plastic assembly incorporating the Ag/AgCl pellet electrode was eliminated, and a flatter Ag/AgCl electrode disc was molded into a flexible silicone-rubber housing. The sponge was reduced in size and permanently attached to the housing. This electrode thus compromised the separation of body fluids and electrode — a feature of the original model — in favor of a flatter, more comfortable shape.

Fig. 26 shows the new cap on a subject in the laboratory. In preparing this system for use before a sleep period, the electrolyte gel is injected through a hypodermic needle inserted into the center of the foam rubber until the entire sponge is saturated.

Fig. 27 shows the modified montage used in the model 2 cap and for the final 10-day recording period. The frontal electrodes have been eliminated since they were unnecessary for the evaluation of sleep recordings.

The model 2 cap was worn by the subject during recording nights 50-58. A considerable improvement in comfort was reported by the subject ("80% better"), although he did continue to experience some discomfort in the scalp areas contacted by the electrodes. During the last day he also reported the presence of swellings or "bumps" in the occipital areas which he felt were related to the electrodes. The quality of the recordings continued to be good, and the increased comfort permitted uninterrupted records during this final period of the project.

(Note: Since completion of the Tektite project, further modification has been made in the electrode-cap system to increase the comfort, and the revised model was used successfully in the Ben Franklin Gulf Stream Drift Mission. A crew member wore this cap assembly during 15 preselected nights of the 30-day mission and did not experience either discomfort or scalp "bumps.")

b) Electrodermal Artifacts

Fig. 28 illustrates a phenomenon which was often seen during stages 3 and 4 of sleep, occasionally during stage 2, but never in stage 1 at the onset of sleep or during REM. These high-amplitude, slow transients often occurred in long runs, becoming almost continuous, and lasting up to an hour in some cases.

Although the GSR was not monitored in this subject, these events are probably related electrodermal responses similar to those described by Burch (1965) and studied in detail by Johnson and Lubin (1966). They were not seen in the two baseline studies of this subject; however, these two laboratory recordings were made using conventional EEG electrodes and routine skin preparation which results in low interelectrode resistance and destruction of the skin's ability to produce electrodermal responses. In contrast, the electrode cap preserves the integrity of the skin and presumably its ability to produce the responses.

3) Evaluation of Sleep Recordings

Although the significance of alterations in sleep patterns was not the primary goal of our participation in the Tektite project, several points are worthy of mention and further consideration. Figs. 29-33 compare selected aspects of the subject's sleep during the first and last recording sessions with the findings during the two baseline nights spent in the laboratory (B1 and B2). (Note: Split bars indicate that two sleep periods occurred during this day because of watch schedules during the first 10 days.)

a) Time to Fall Asleep

Fig. 29 shows the amount of time which the subject spent in bed before falling asleep for the first time. This time was measured from the point at which he was observed to get into the bunk until the first EEG signs of stage 2 sleep (vertex transients and spindles). Thus, for this measure, brief periods of drowsiness (stage 1) were included in the cumulative time.

The subject thus experienced no difficulty going to sleep during the first 10-day period, although the time does not appear to be significantly shorter than the baseline times. During the final days of recording, however (56, 57), there was a marked increase in the time before sleep onset — exceeding an hour in both cases. This same information is also shown in Fig. 30, which indicates the time required to reach stage 4.

It might be postulated that perhaps this increase in time before sleep onset was related to the anticipation of events associated with the end of the mission.

b) Total Sleep Time

Although the data are incomplete for the first 10 nights because of the situation explained in part 2) above, in general the subject's sleep time was considerably reduced below the baseline values during the first 10 nights, while the time during the final 10-day period was generally normal or more than normal (Fig. 31). This situation reflects the workload of the subject, which was heavy during the initial part of the project when a number of minor difficulties were present and night watches were required, and which was relatively light during the final phases when most systems were running smoothly.

c) REM Time

Although the total sleep time was generally reduced below normal during the first 10 days, as indicated in Fig. 32 there was a definite tendency for the total REM time to approach the baseline values (compare Figs. 31 and 32). This effect is seen more clearly in Fig. 33, which shows the percentage of total sleep time occupied by the REM stage. It is obvious in this figure that there was a marked increase above the baseline values in the percent REM time during many of the nights in the first 10-day session. During the final 10 days, the percent REM time was similar to or slightly below baseline values. The significance of this finding is unknown, but again it could be related to the increased workload, and perhaps stress, of the initial portion of the project.

d. Conclusions

The operational testing situation provided by the Tektite project led to three major conclusions or accomplishments:

1) The compatibility of all phases of the EEG acquisition and analysis system was assured, and no significant problems were encountered with respect to extraneous electrical interference.

2) The problems encountered with the electrode-cap assembly in the early phases of the mission led to extensive redesign and miniaturization of this unit.

3) The performance of the automatic analysis system demonstrated the ability to obtain reliable information concerning the subject's quantity and quality of sleep. Because of the immediate availability of the results, this information could theoretically be utilized to optimally regulate the subject's next work/rest period.

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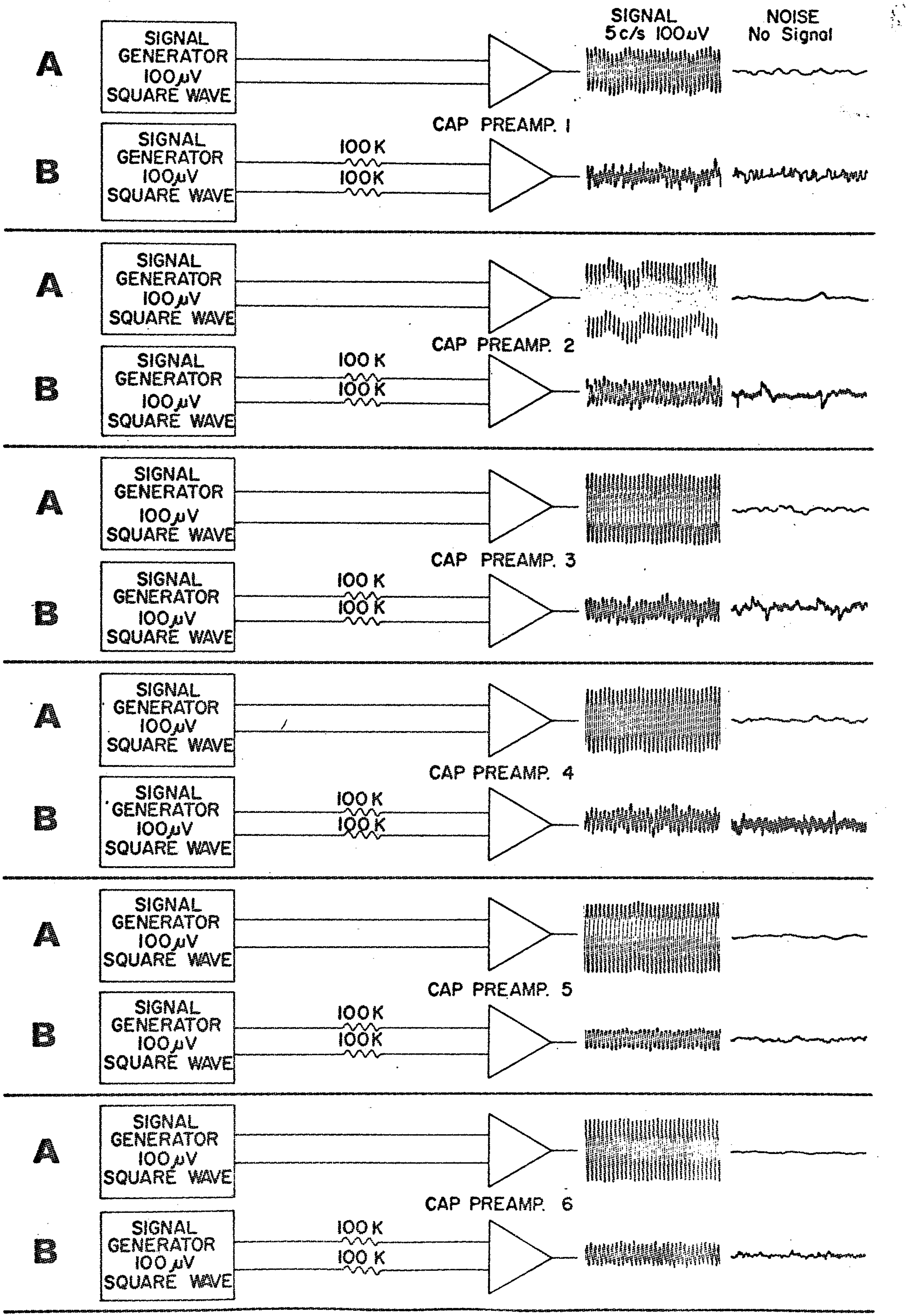
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NOISE
No Signal
A
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CAP PREAMP. 1
B
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100 K
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CAP PREAMP. 3
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CAP PREAMP. 5
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CAP PREAMP. 6
B
SIGNAL GENERATOR 100µV SQUARE WAVE
100 K
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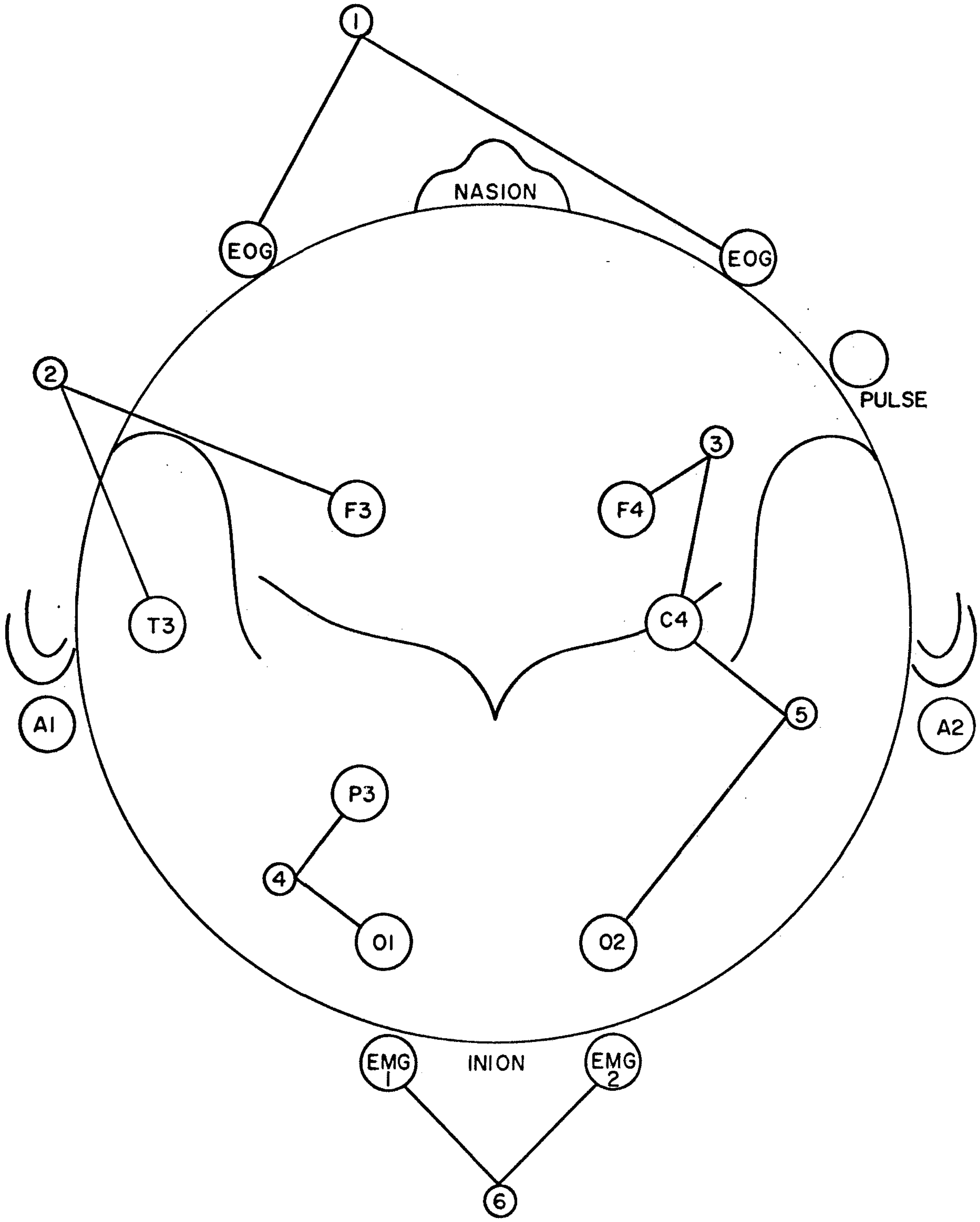
Fig. 1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NASION
EOG
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2
3
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P3
4
O1
O2
EMG 1
INION
EMG 2
6

Fig. 2

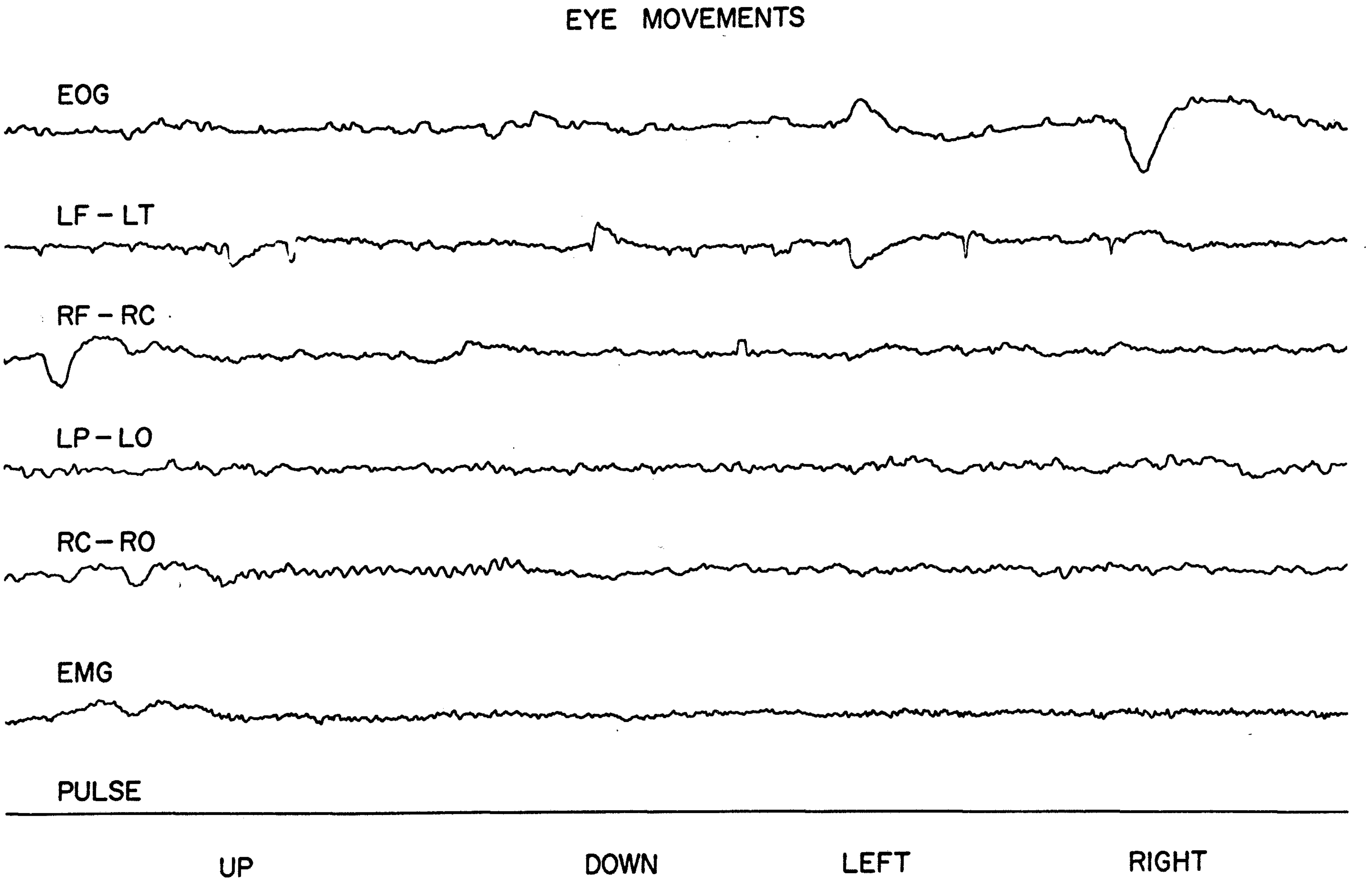

EYE MOVEMENTS
EOG
LF - LT
RF - RC
LP - LO
RC - RO
EMG
PULSE
UP
DOWN
LEFT
RIGHT

Fig 3

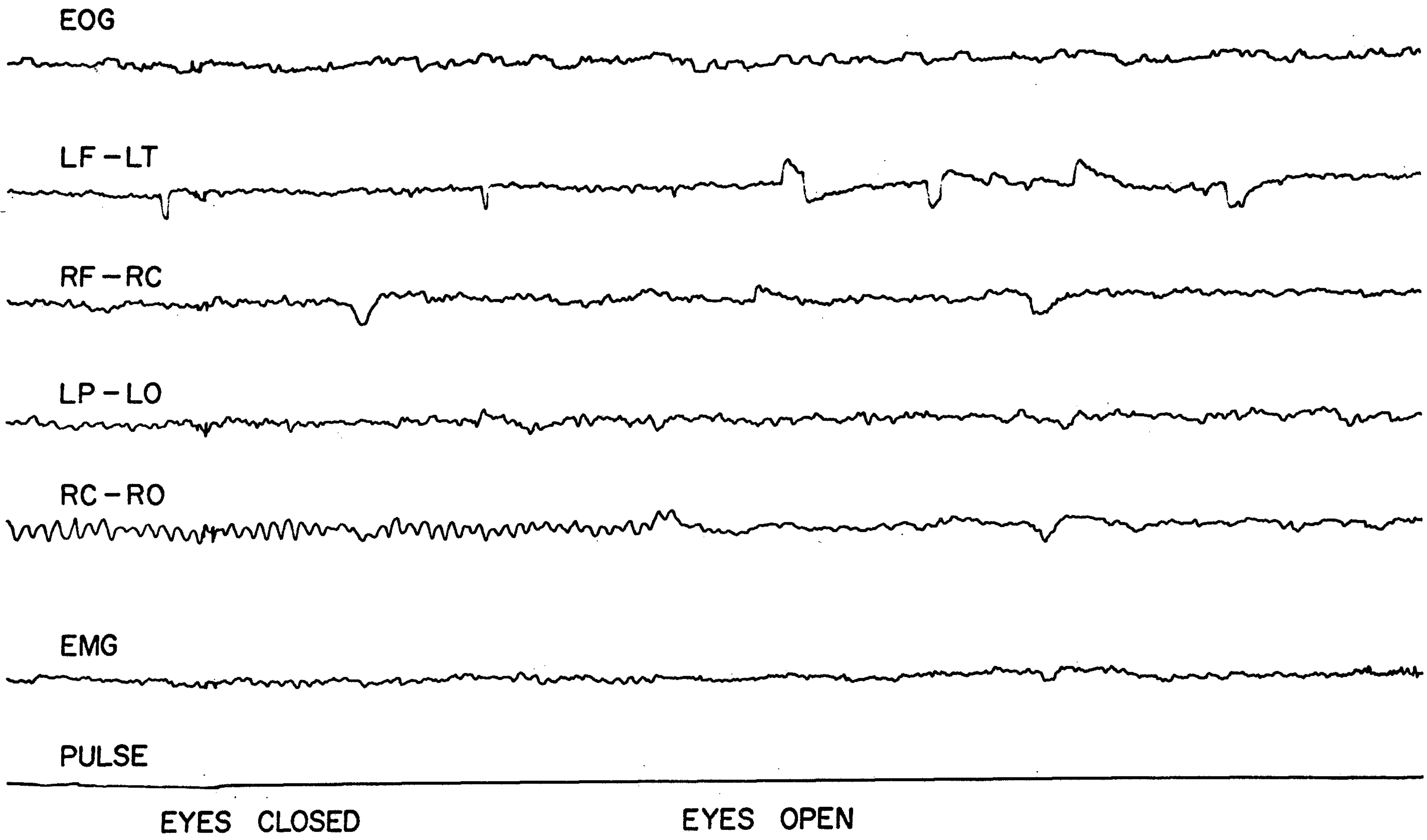


Fig. 4

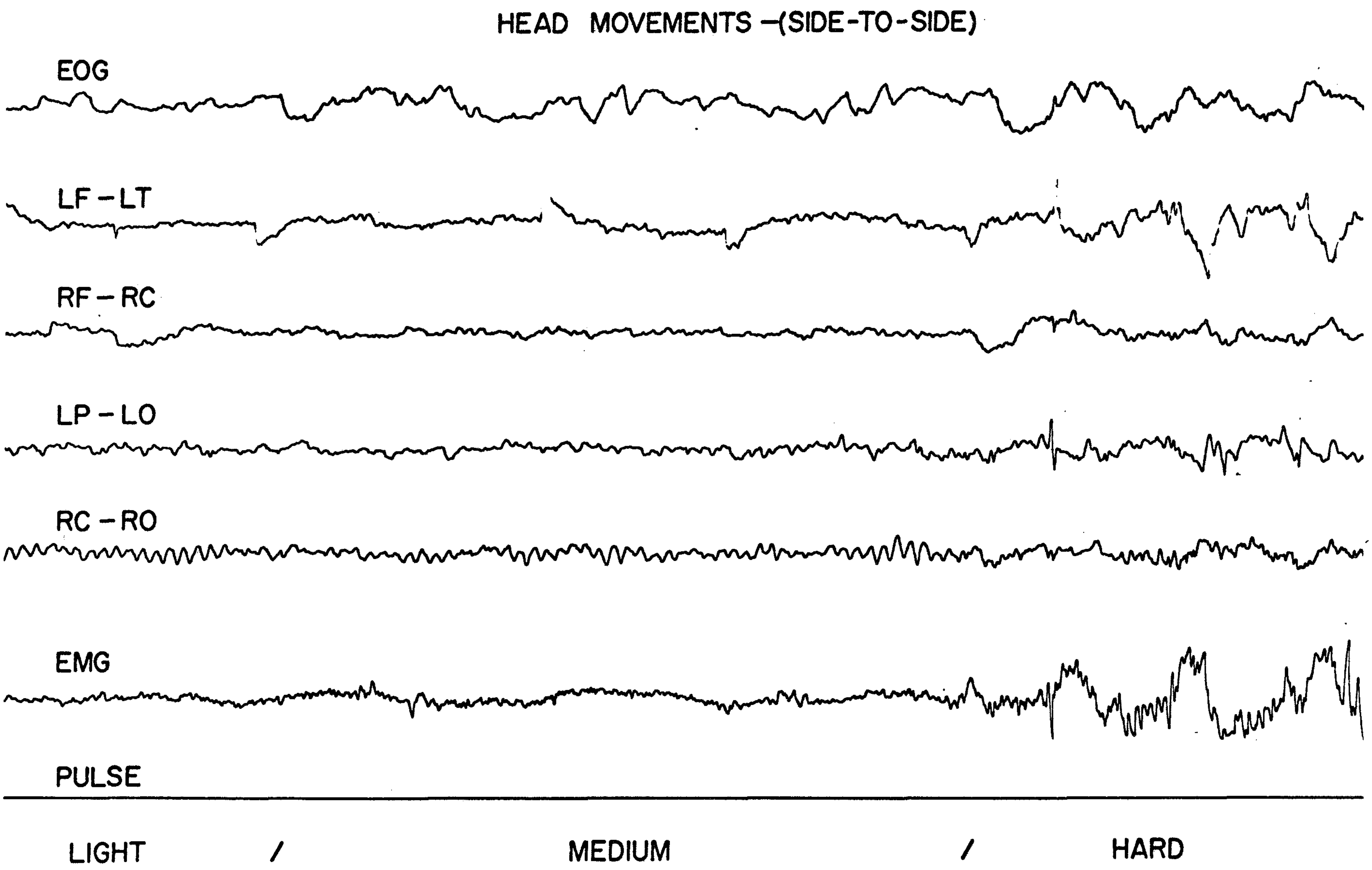

HEAD MOVEMENTS —(SIDE-TO-SIDE)
EOG
LF – LT
RF – RC
LP – LO
RC – RO
EMG
PULSE
LIGHT
/
MEDIUM
/
HARD

Fig. 5

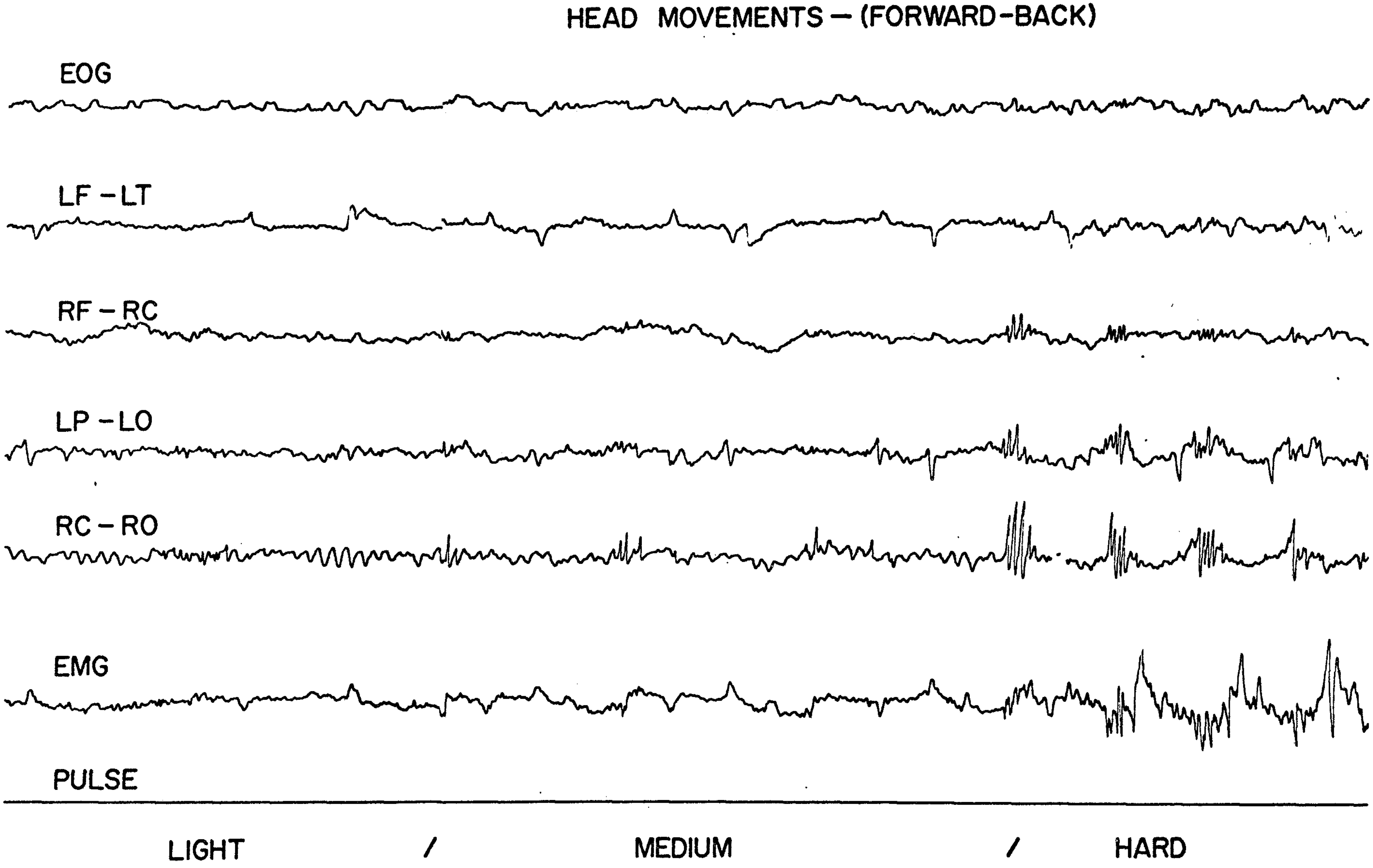

HEAD MOVEMENTS — (FORWARD-BACK)
EOG
LF - LT
RF - RC
LP - LO
RC - RO
EMG
PULSE
LIGHT
/
MEDIUM
/
HARD

Fig. 6

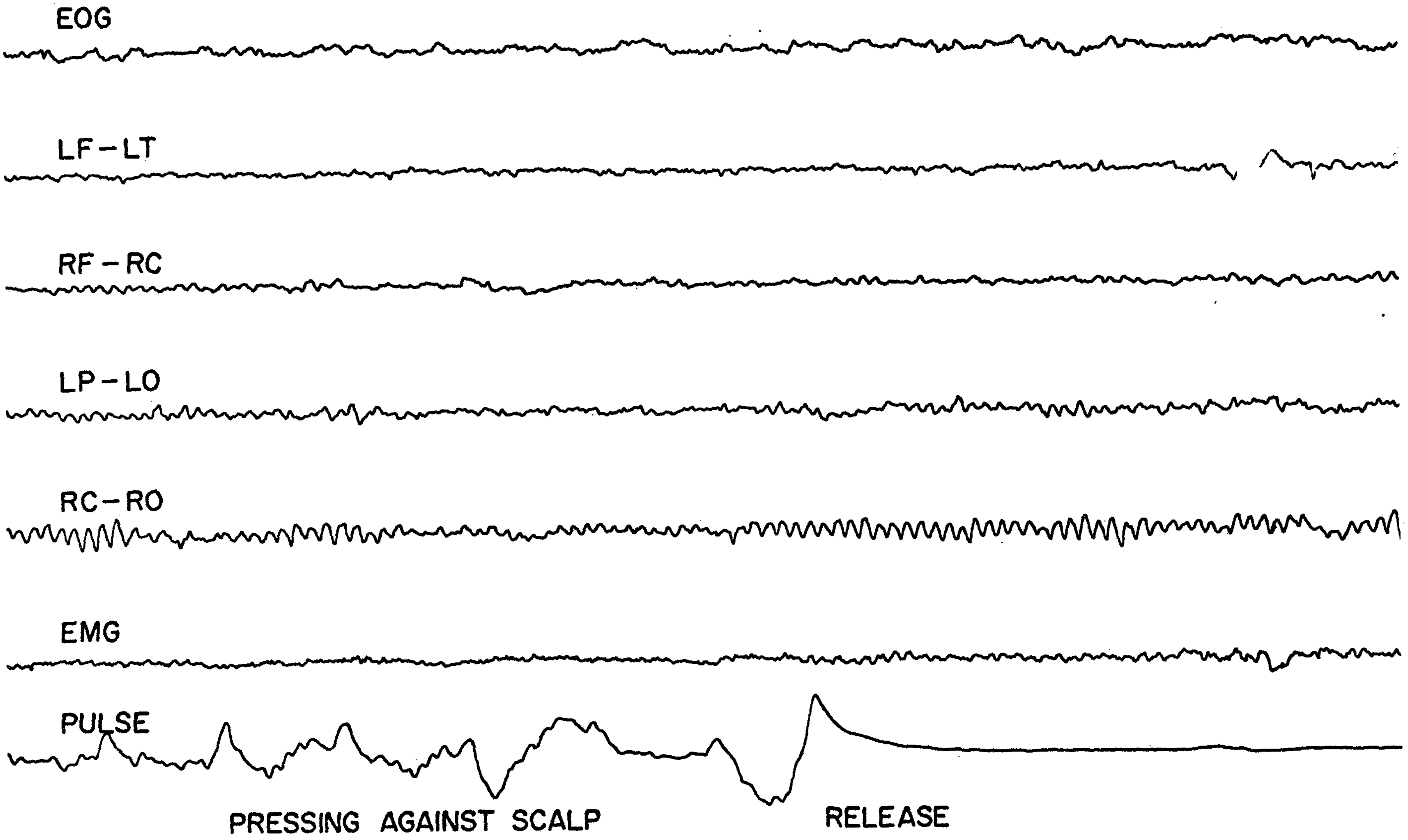

EOG
LF-LT
RF-RC
LP-LO
RC-RO
EMG
PULSE
PRESSING AGAINST SCALP
RELEASE

Fig. 7

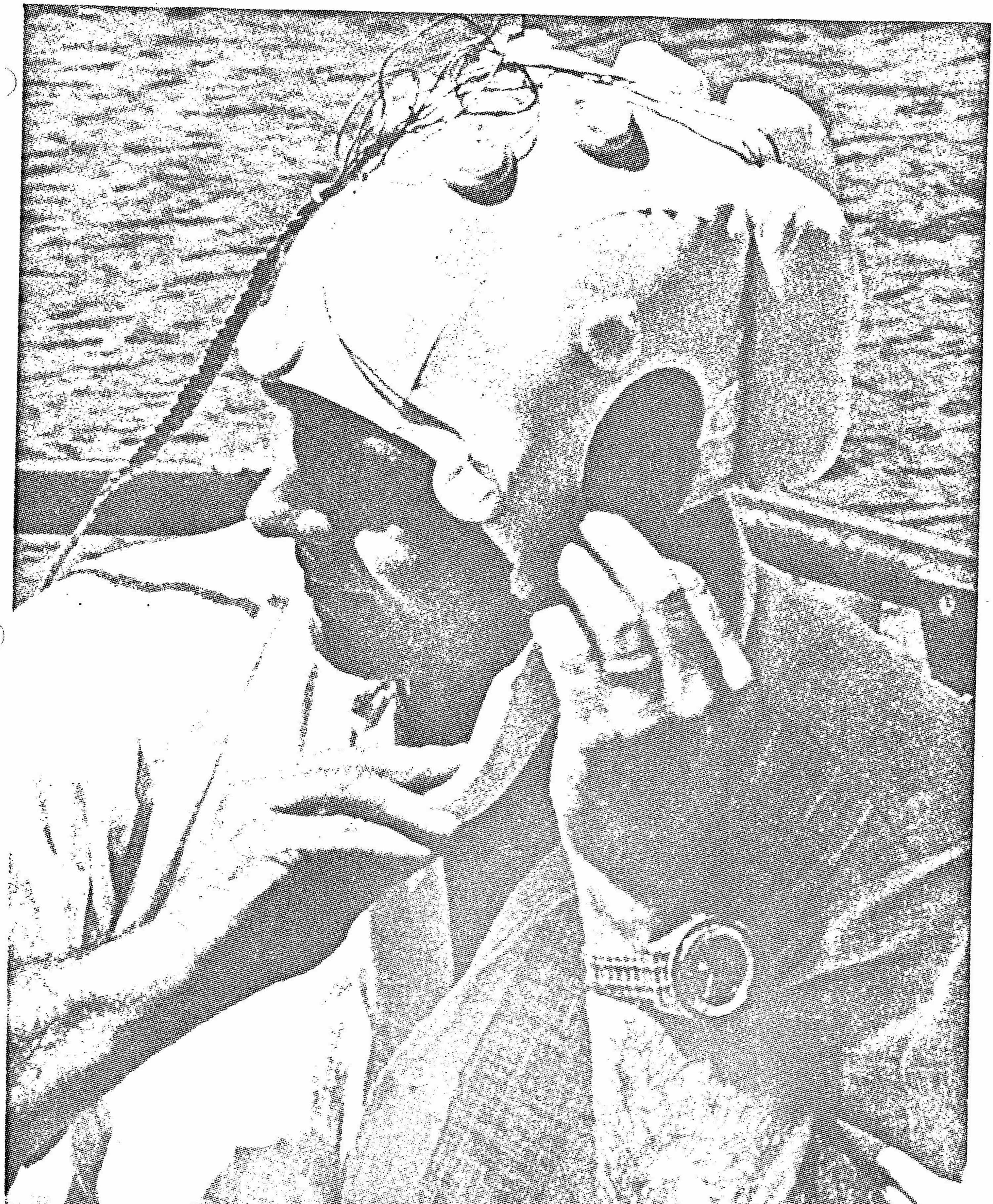
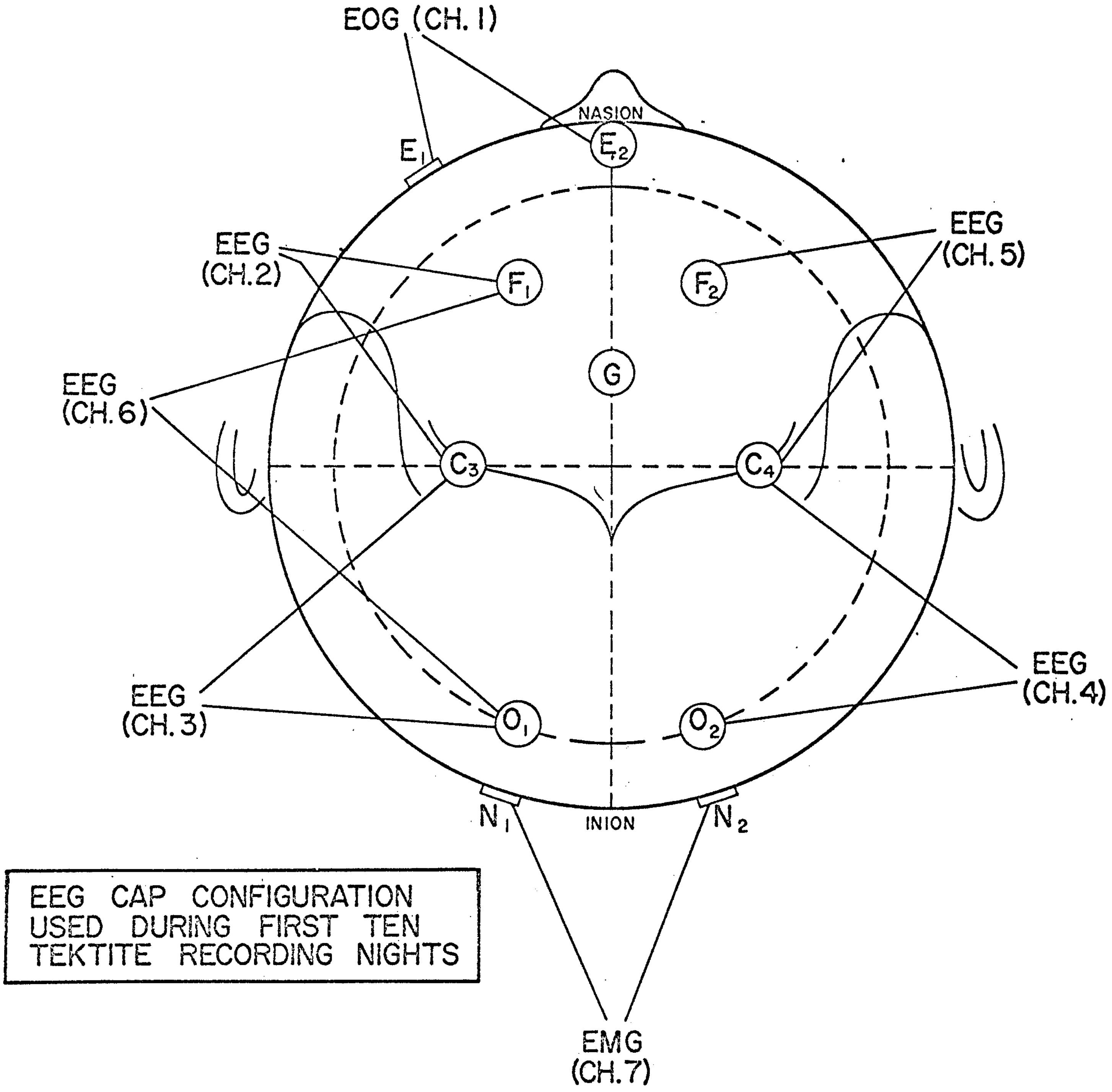


Fig. 8



EEG CAP CONFIGURATION
USED DURING FIRST TEN
TEKTITE RECORDING NIGHTS

Fig. 9

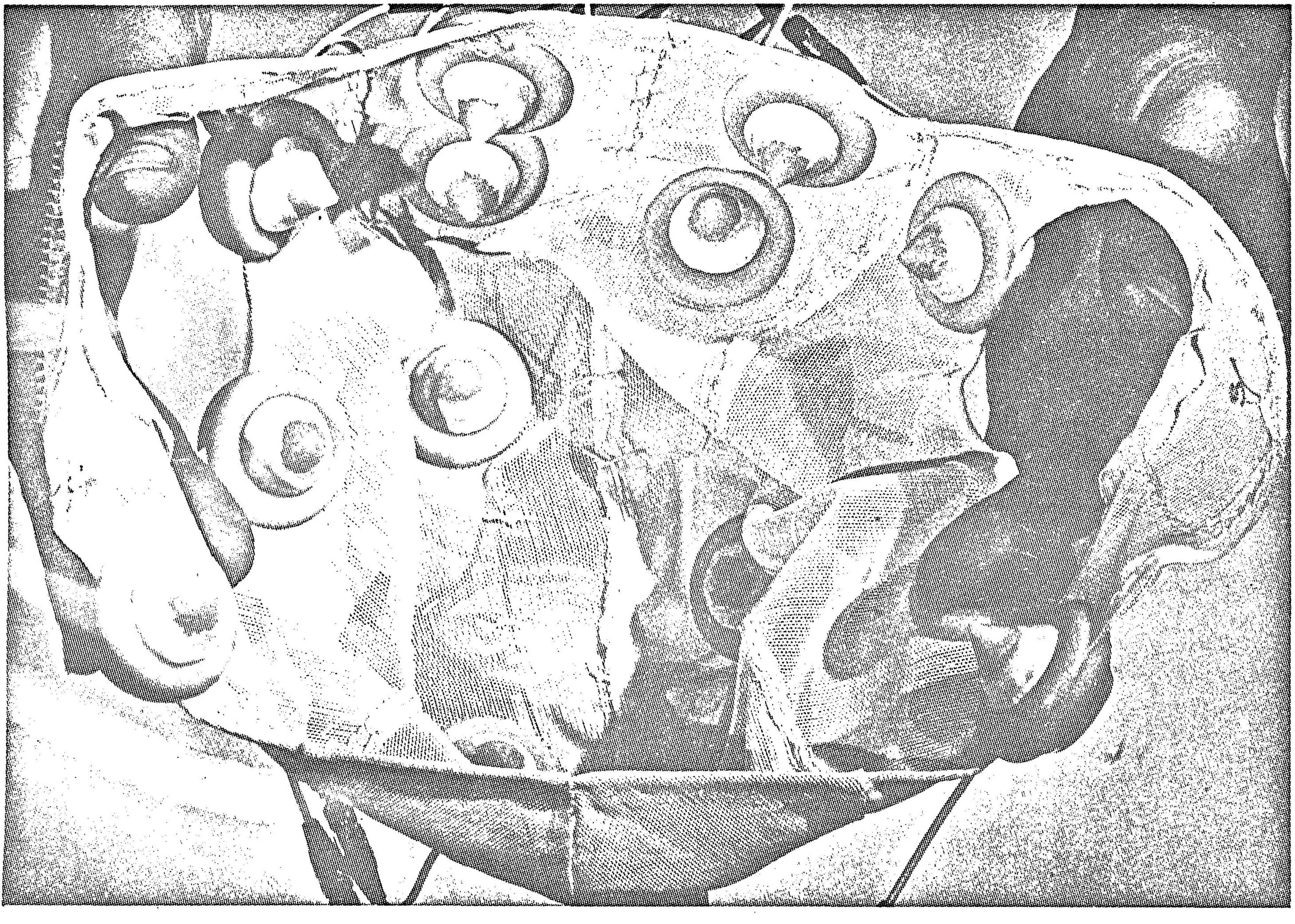


Fig. 10

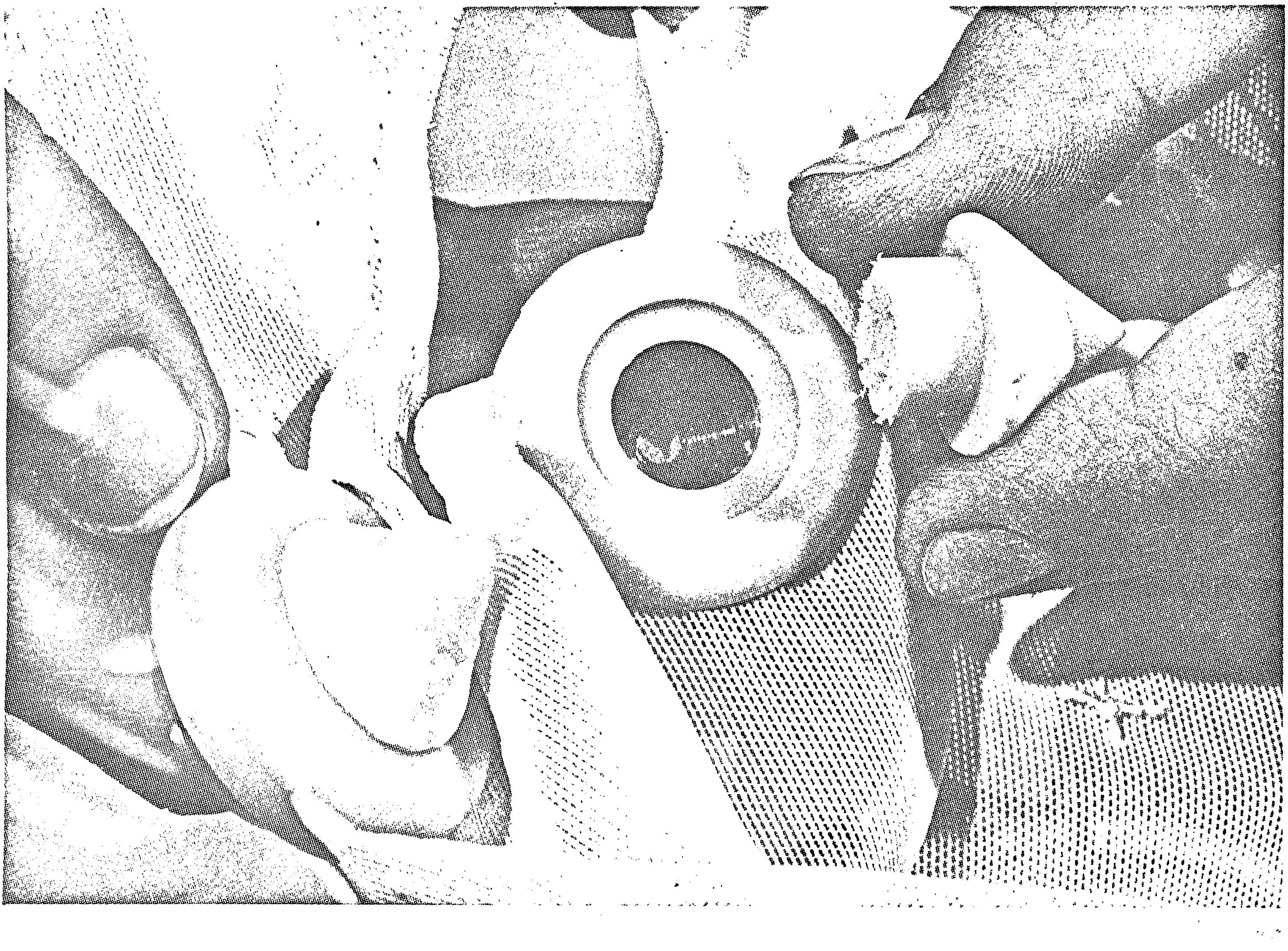


Fig. 11

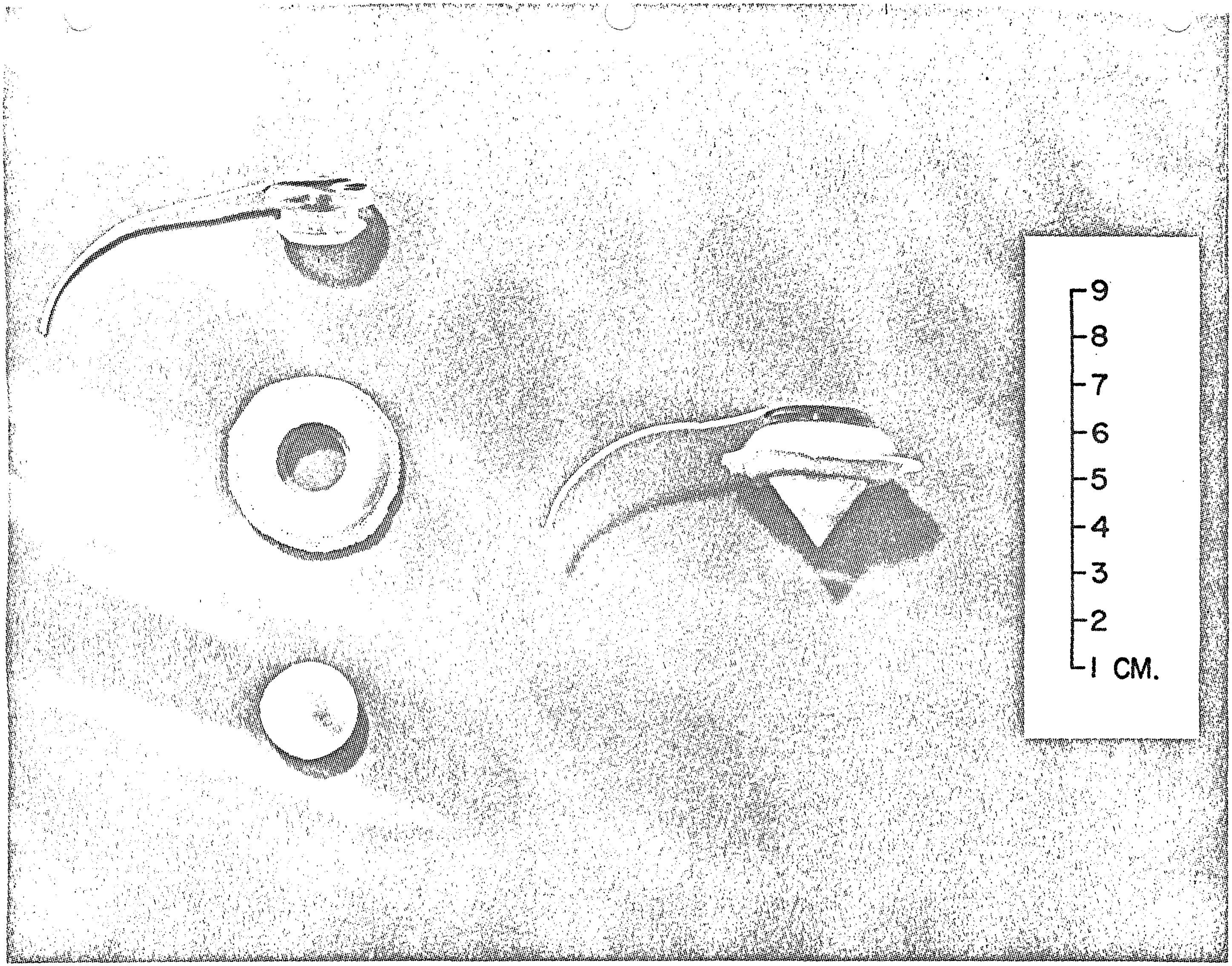
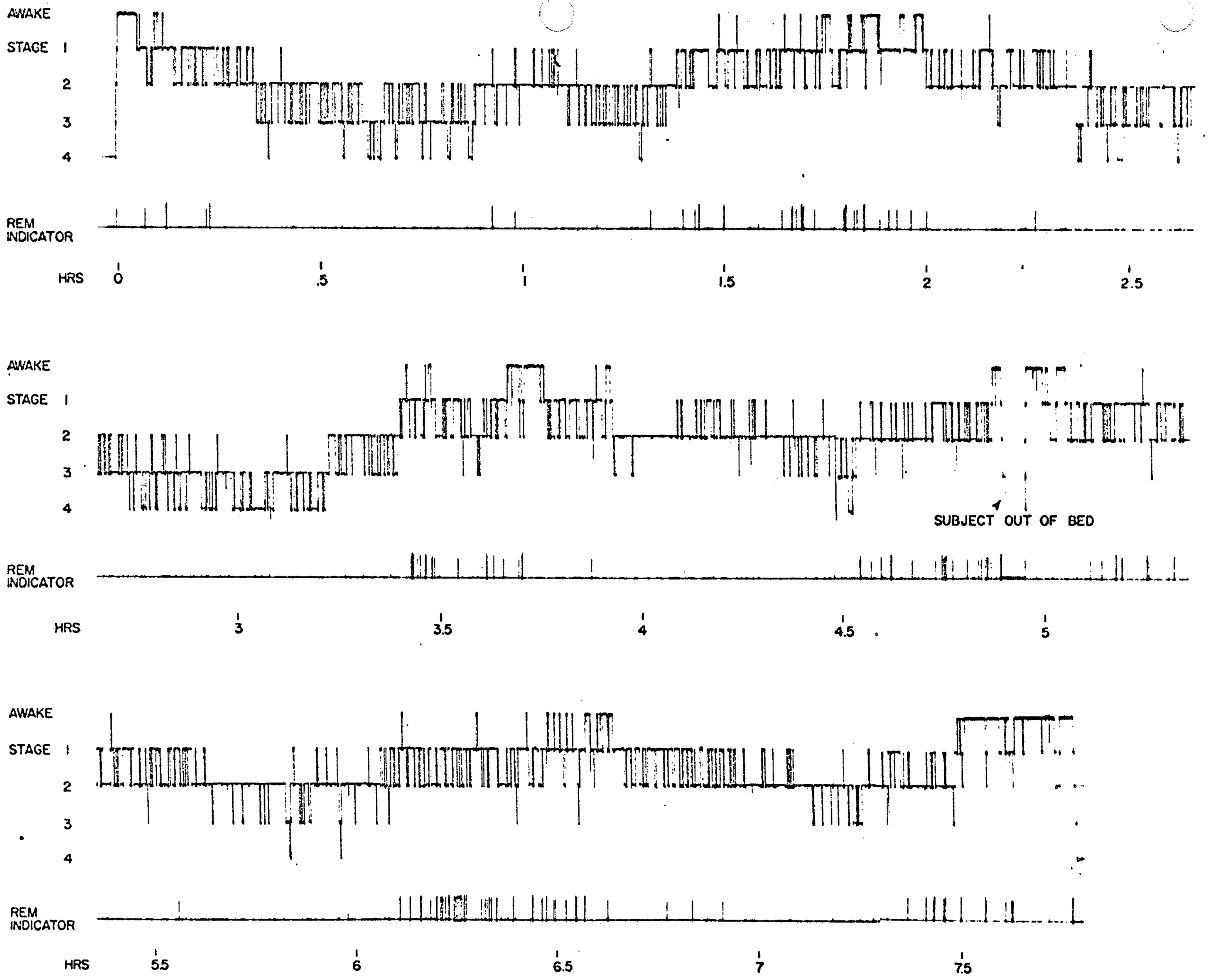


Fig. 12



AUTOMATIC SLEEP ANALYZER OUTPUT
CONTINUOUS RECORDING - NIGHT 50

Fig. 13

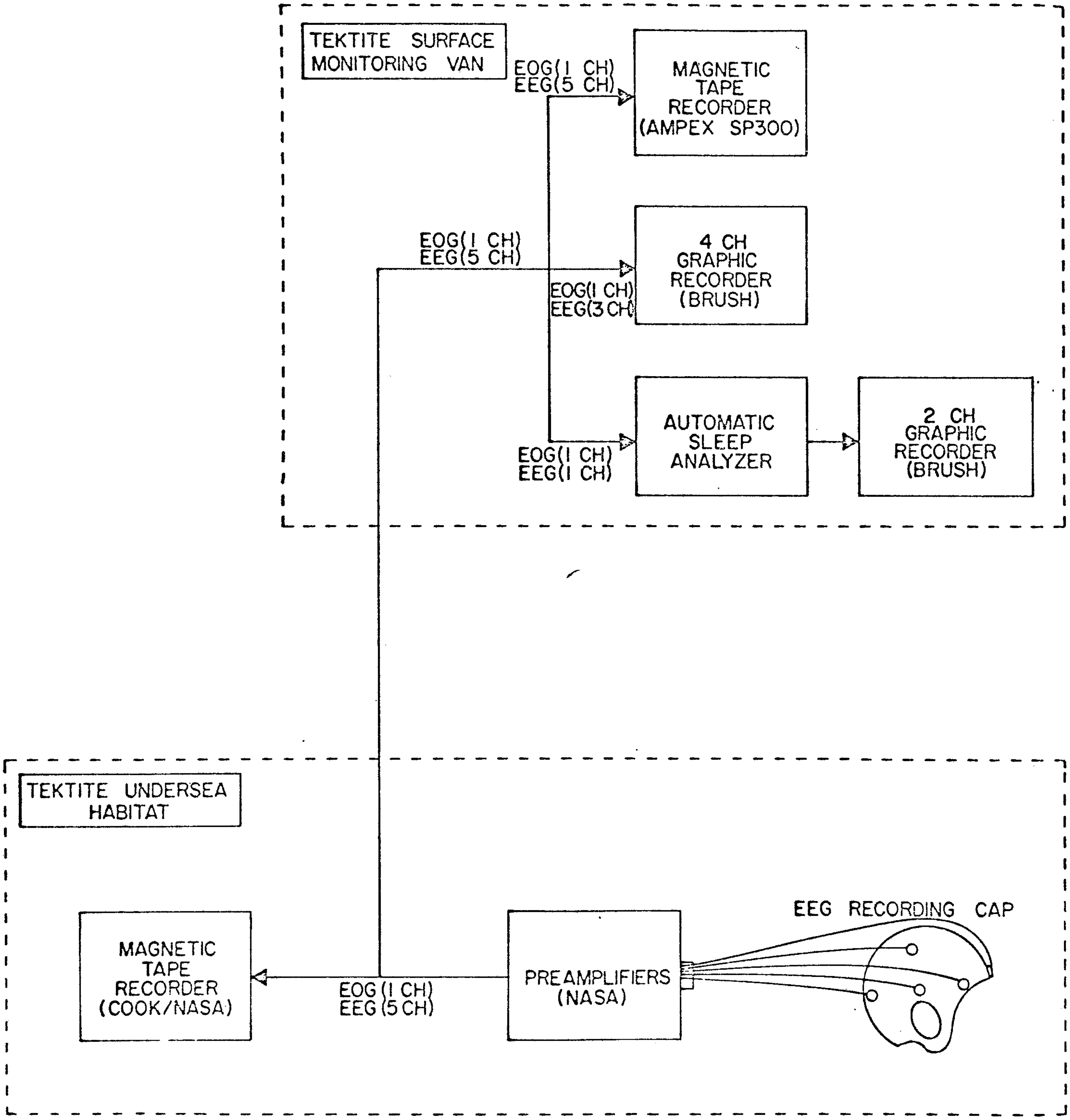

TEKTITE SURFACE MONITORING VAN
EOG(1 CH)
EEG(5 CH)
MAGNETIC TAPE RECORDER (AMPEX SP300)
EOG(1 CH)
EEG(5 CH)
4 CH GRAPHIC RECORDER (BRUSH)
EOG(1 CH)
EEG(3 CH)
AUTOMATIC SLEEP ANALYZER
EOG(1 CH)
EEG(1 CH)
2 CH GRAPHIC RECORDER (BRUSH)
TEKTITE UNDERSEA HABITAT
MAGNETIC TAPE RECORDER (COOK/NASA)
EOG (1 CH)
EEG (5 CH)
PREAMPLIFIERS (NASA)
EEG RECORDING CAP

Fig. 14

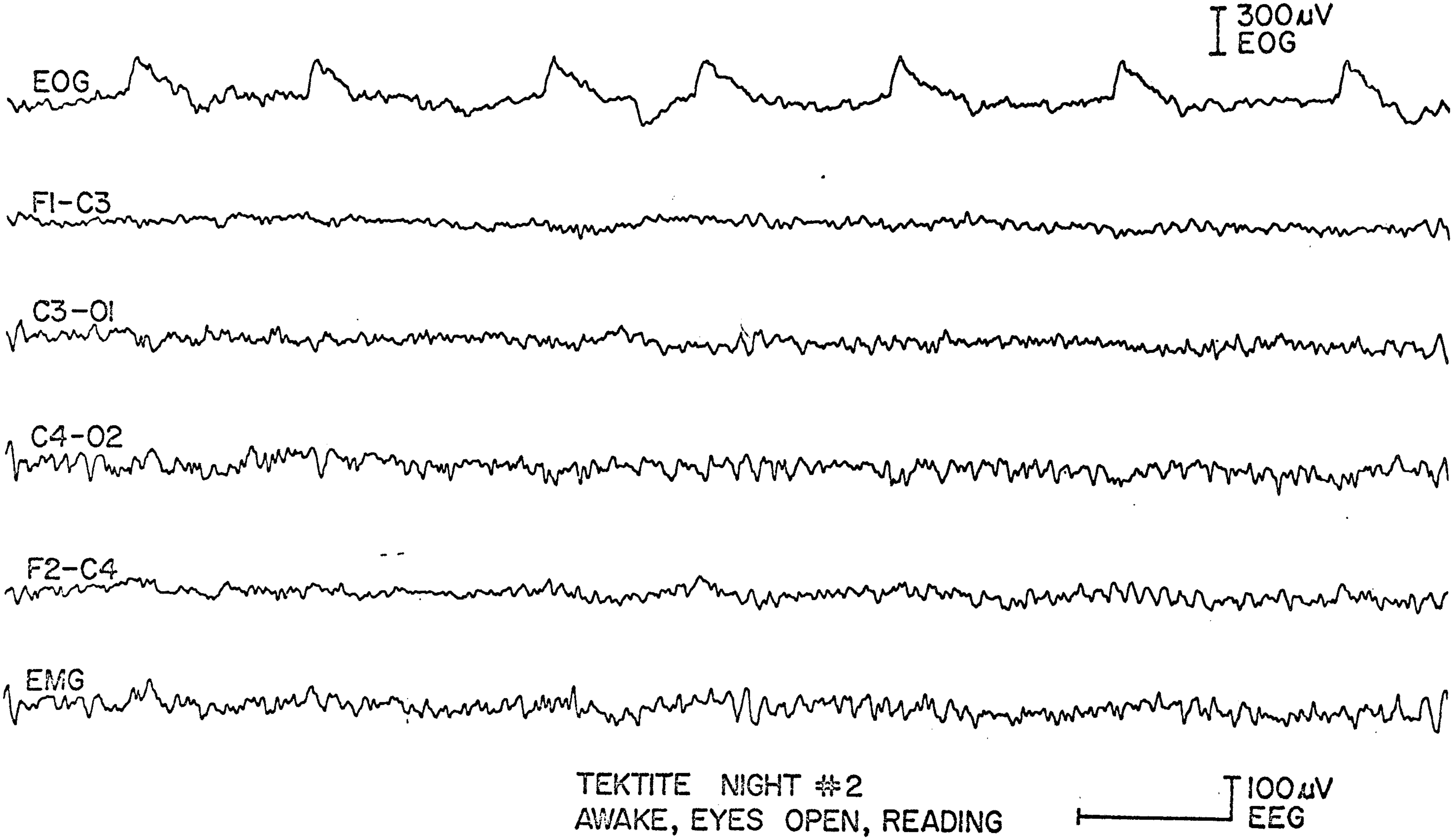
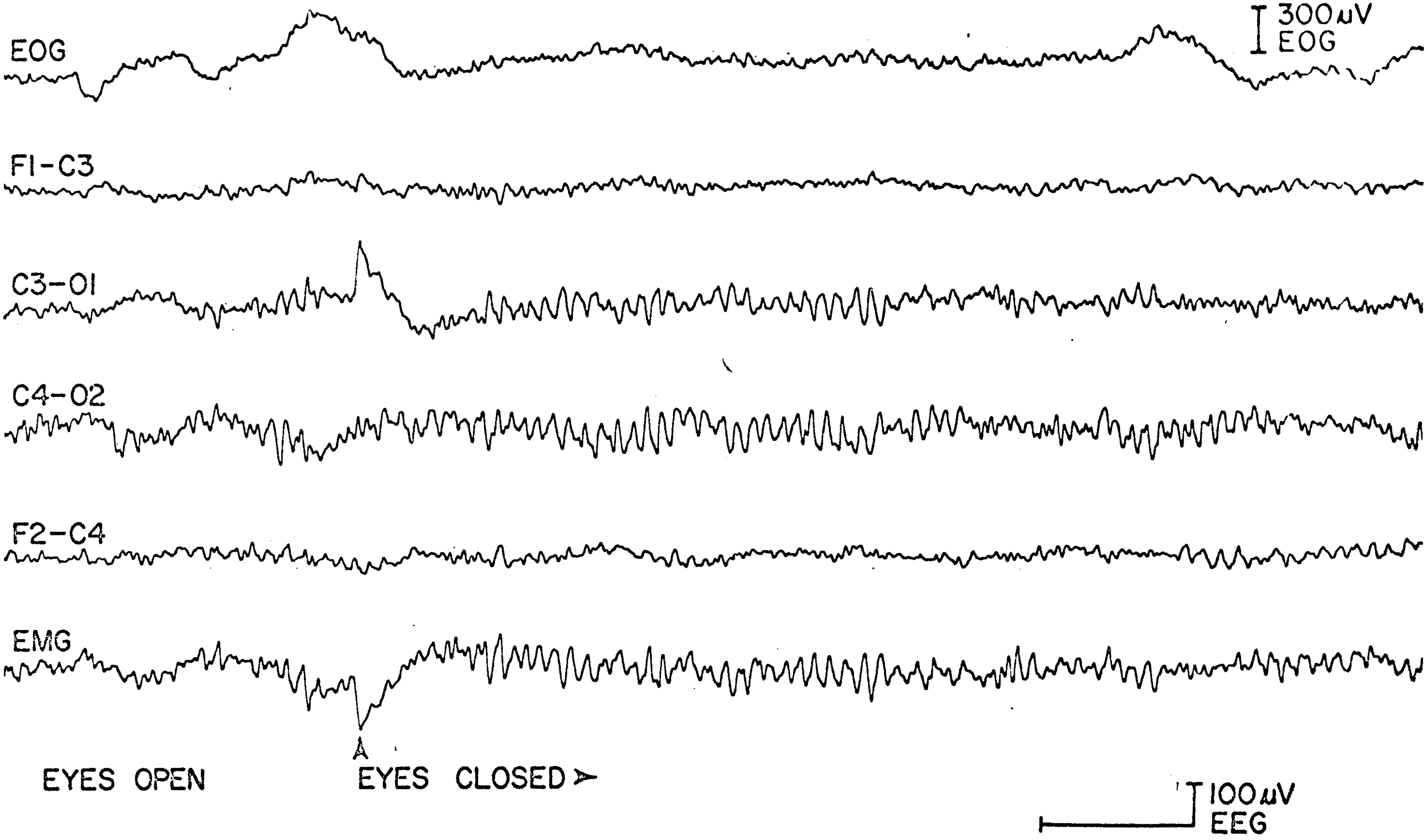
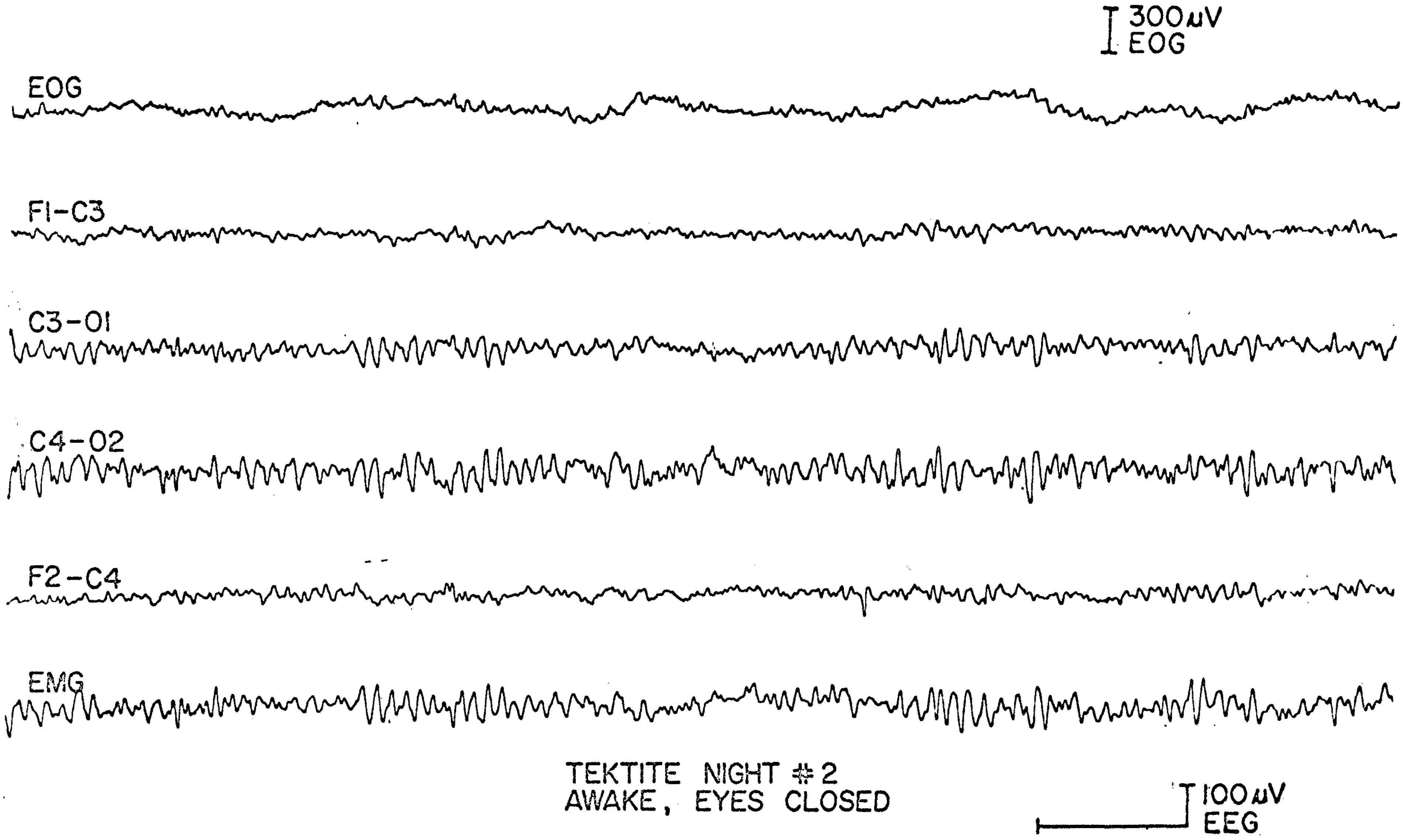

300µV
EOG
EOG
FI-C3
C3-OI
C4-O2
F2-C4
EMG
TEKTITE NIGHT #2
AWAKE, EYES OPEN, READING
100µV
EEG

Fig. 15



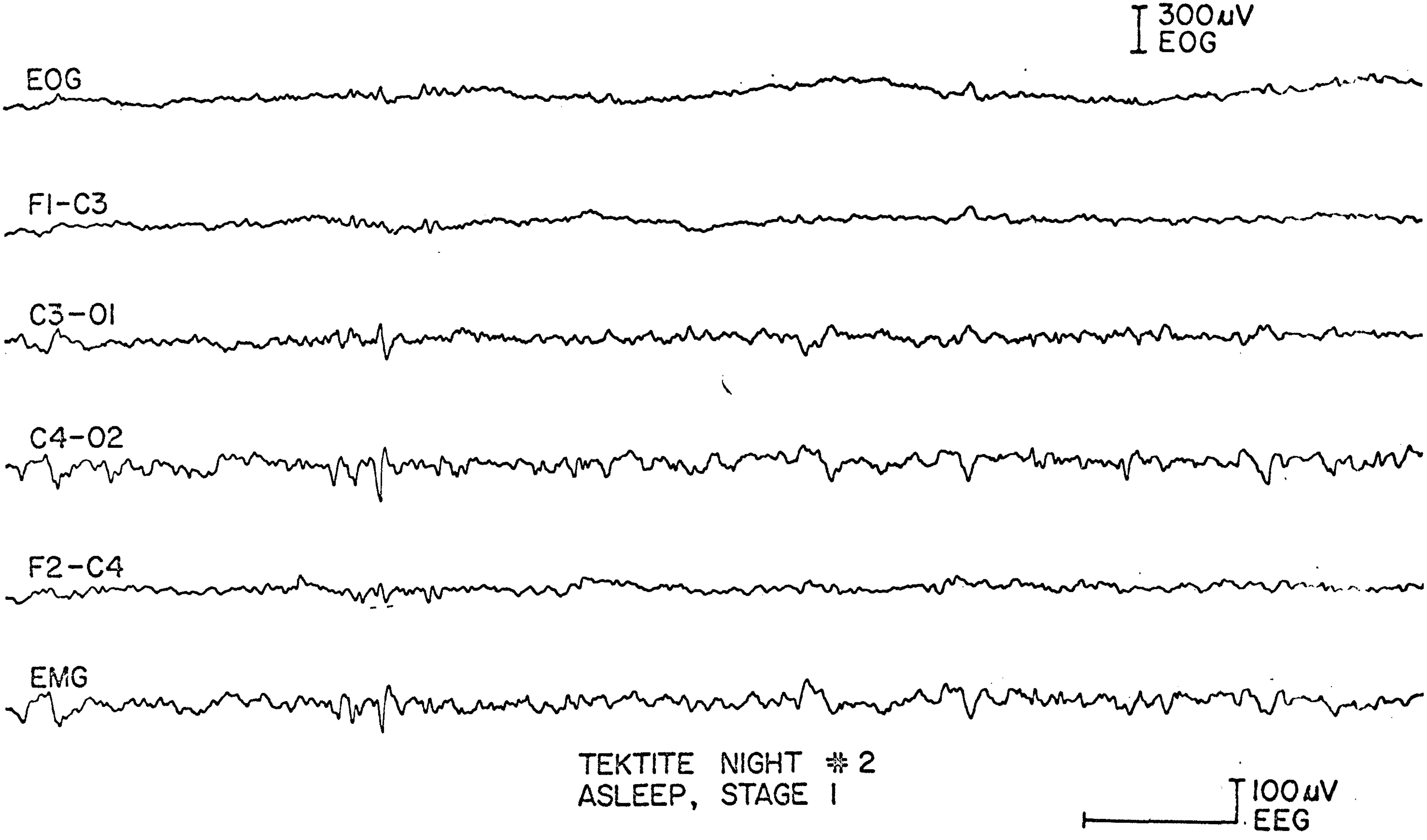
TEKTITE NIGHT #2
AWAKE, CLOSING EYES

Fig. 16



TEKTITE NIGHT #2
AWAKE, EYES CLOSED

Fig. 17



TEKTITE NIGHT # 2
ASLEEP, STAGE I

Fig. 18

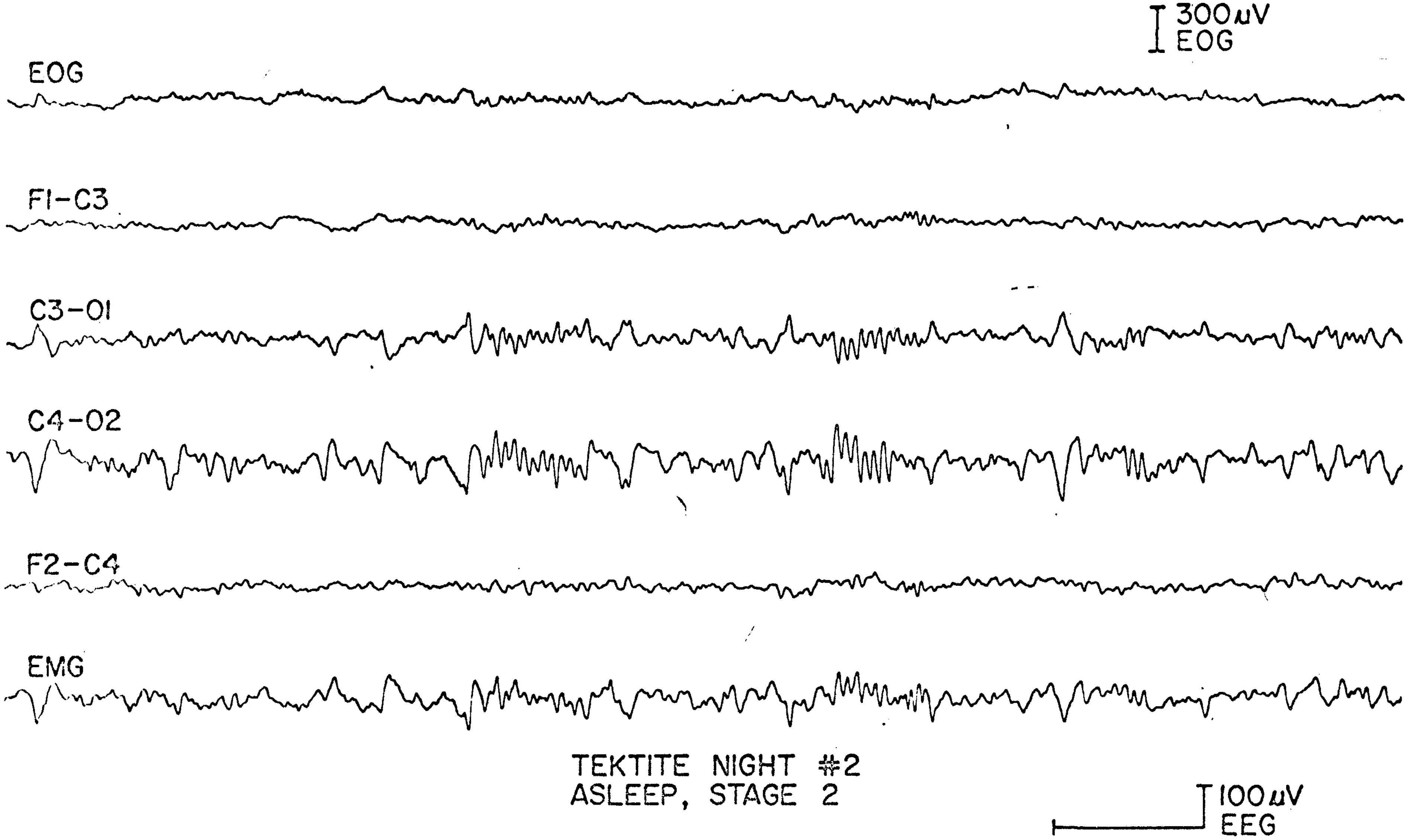
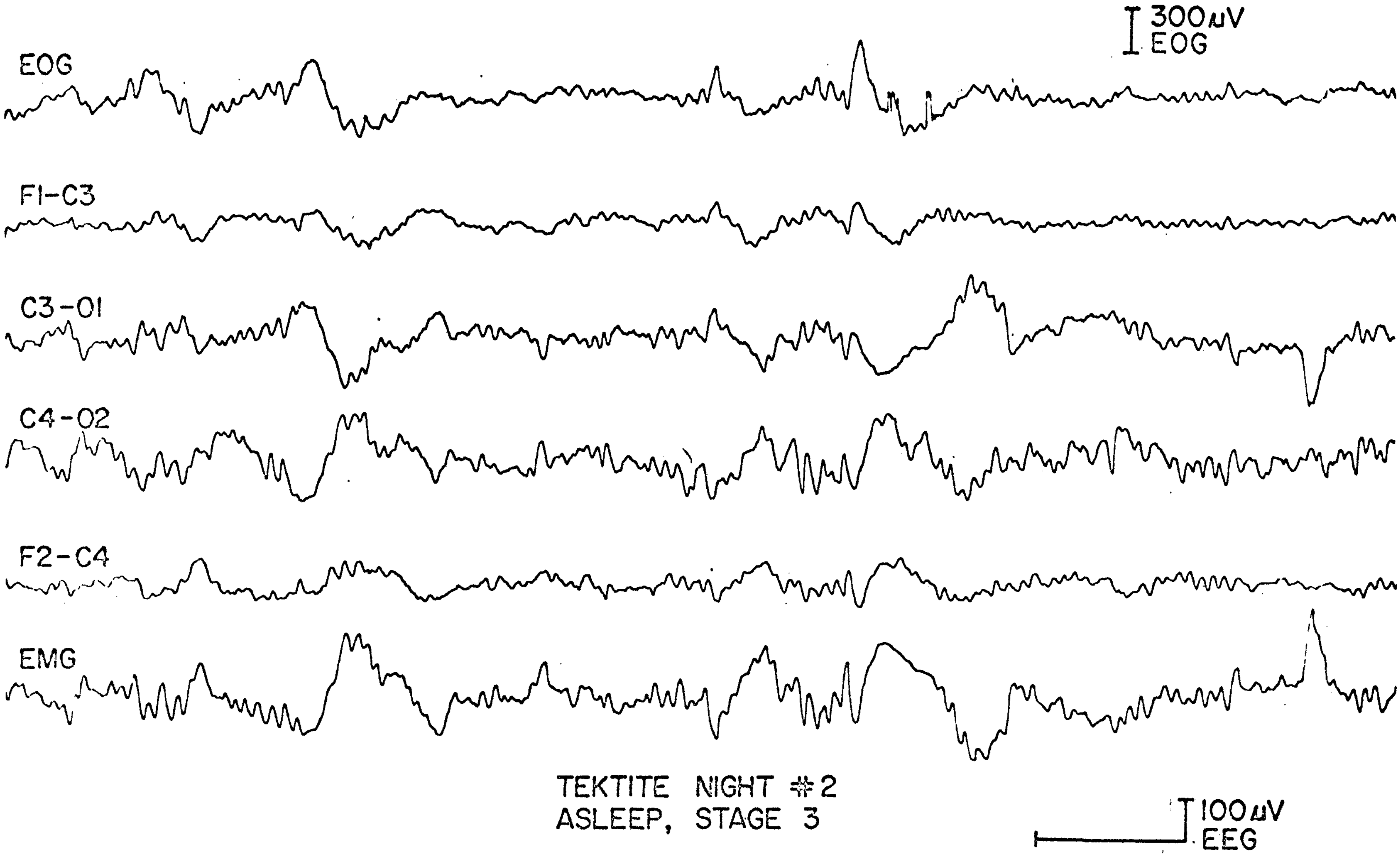

300µV
EOG
EOG
FI-C3
C3-OI
C4-O2
F2-C4
EMG
TEKTITE NIGHT #2
ASLEEP, STAGE 2
100µV
EEG

Fig. 19



TEKTITE NIGHT #2
ASLEEP, STAGE 3

Fig. 20

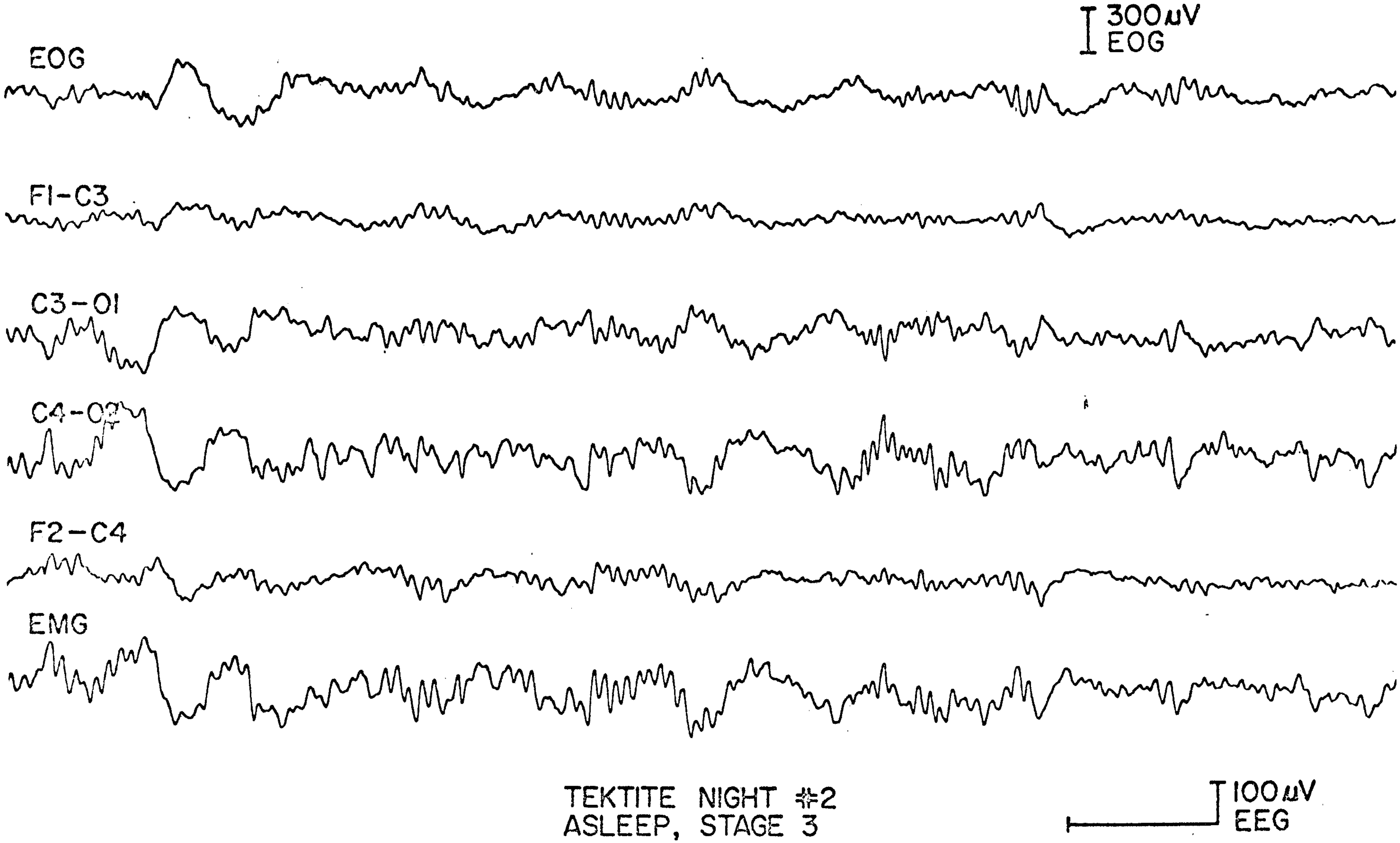

300µV
EOG
EOG
F1-C3
C3-O1
C4-O2
F2-C4
EMG
TEKTITE NIGHT #2
ASLEEP, STAGE 3
100µV
EEG

Fig. 21

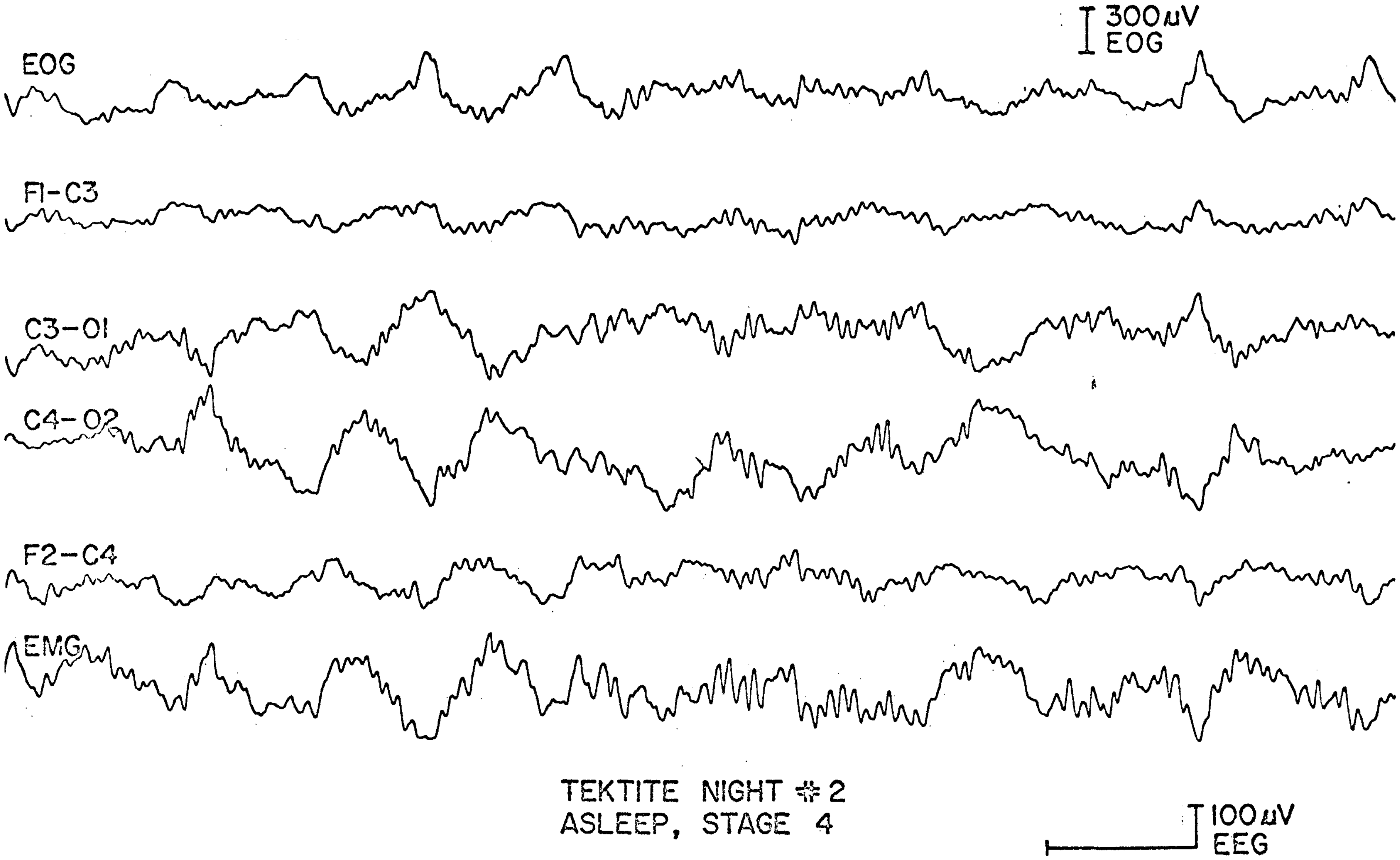

300µV
EOG
EOG
FI-C3
C3-OI
C4-O2
F2-C4
EMG
TEKTITE NIGHT #2
ASLEEP, STAGE 4
100µV
EEG

Fig. 22

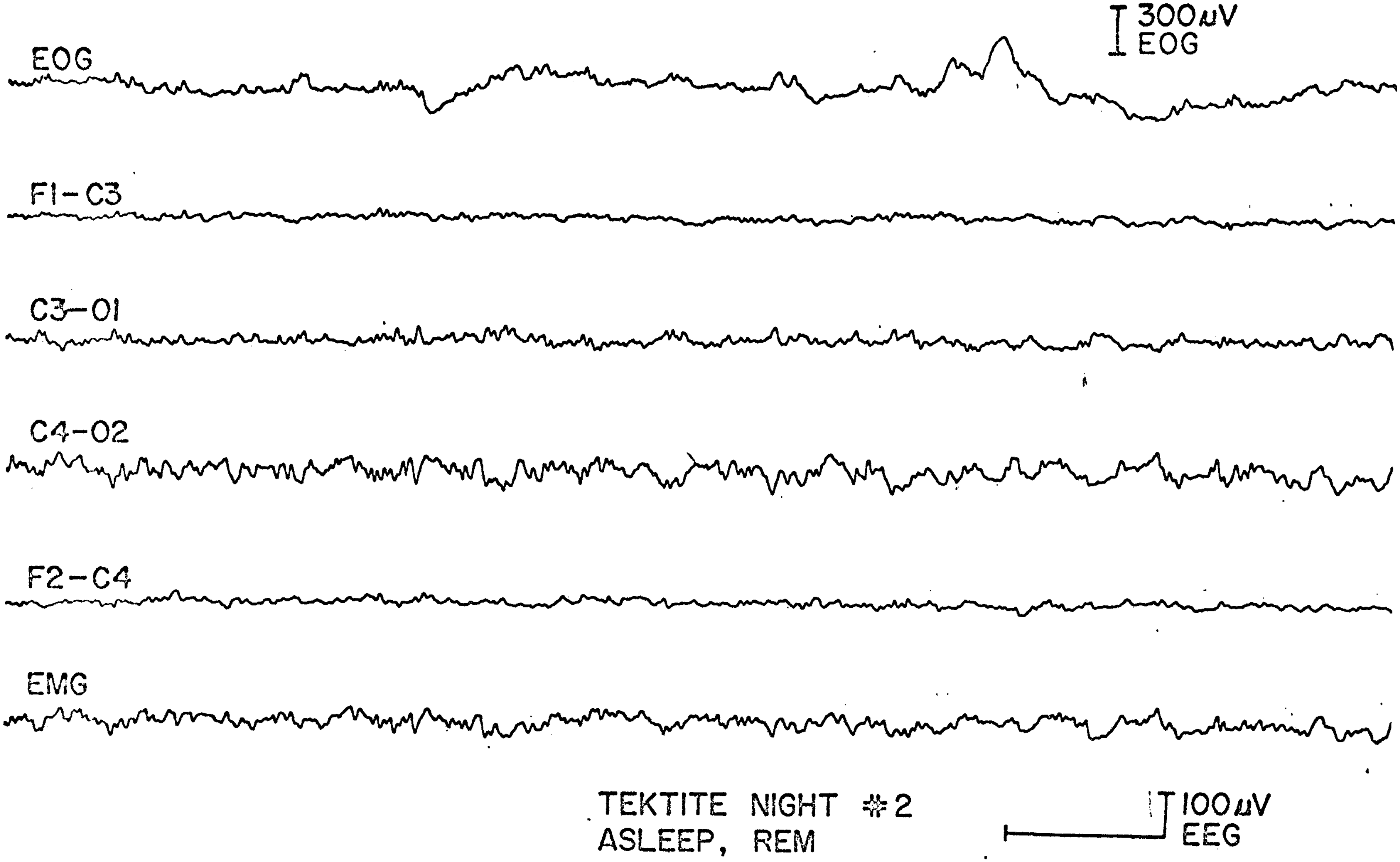
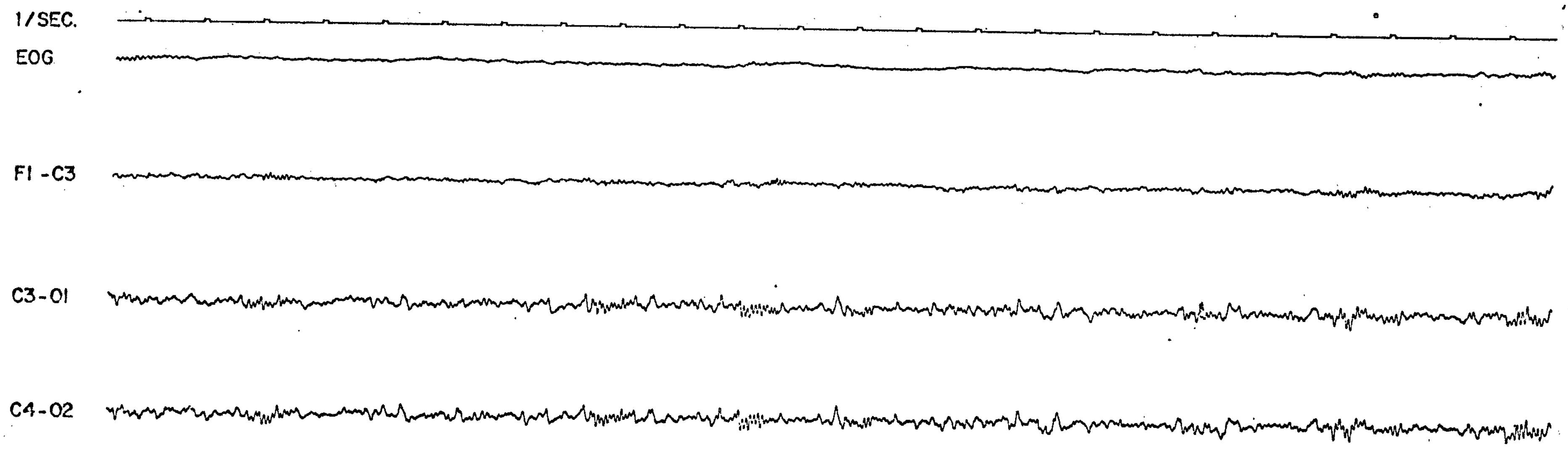

EOG
F1-C3
C3-O1
C4-O2
F2-C4
EMG
300µV
EOG
TEKTITE NIGHT #2
ASLEEP, REM
100µV
EEG

Fig. 23



TEKTITE NIGHT #2, STAGE 2 SLEEP

Fig. 24

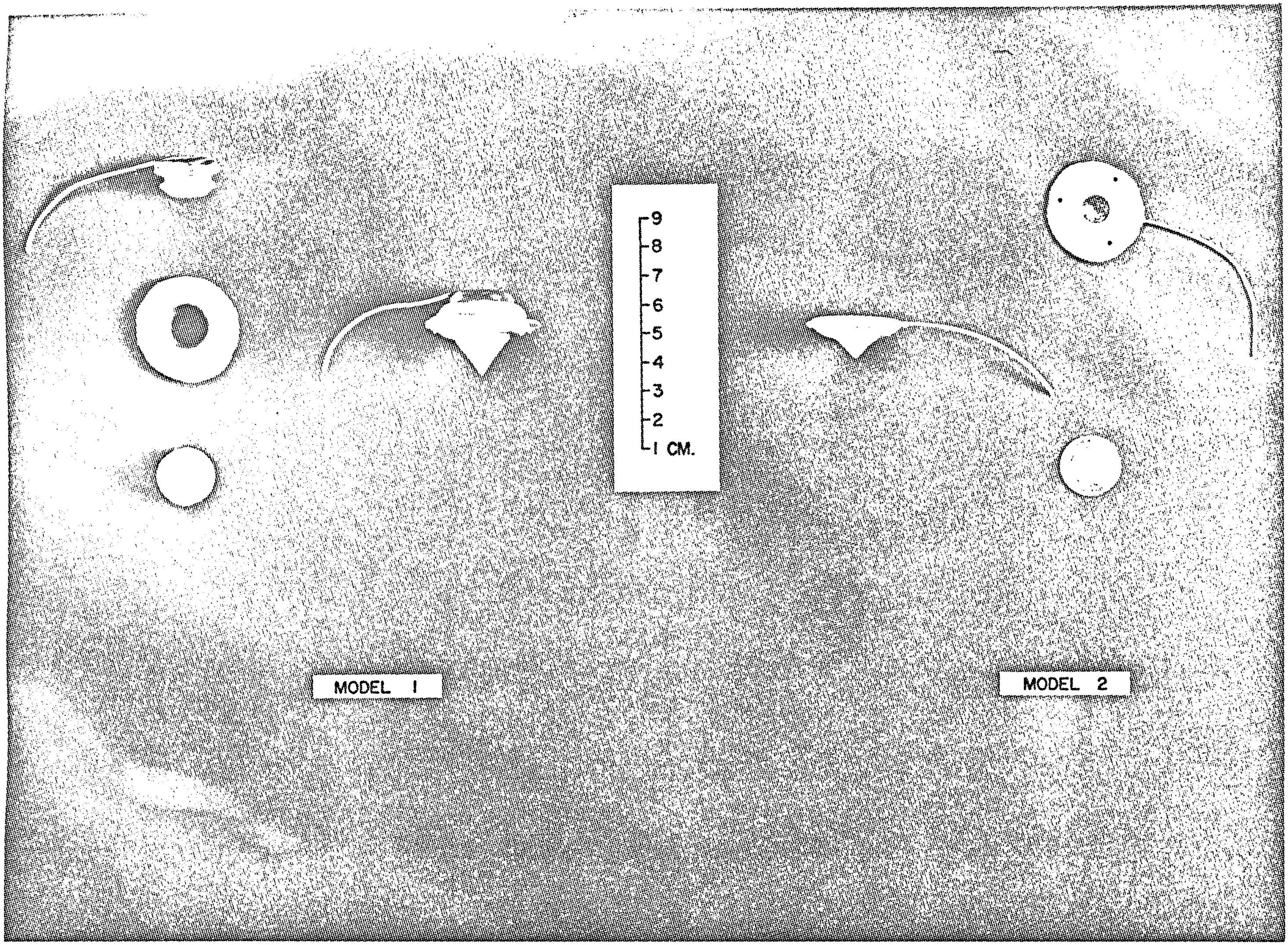


Fig. 25

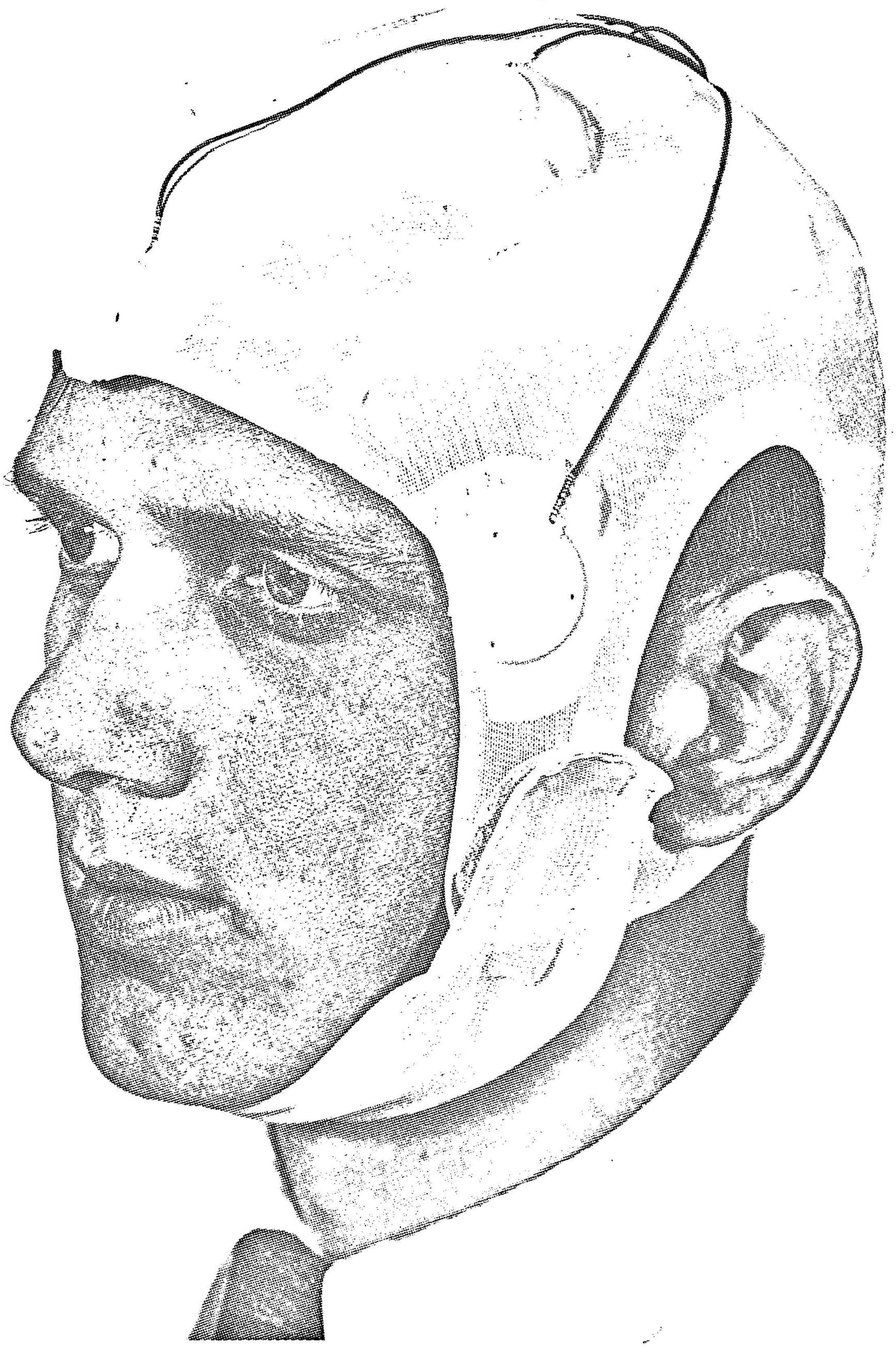
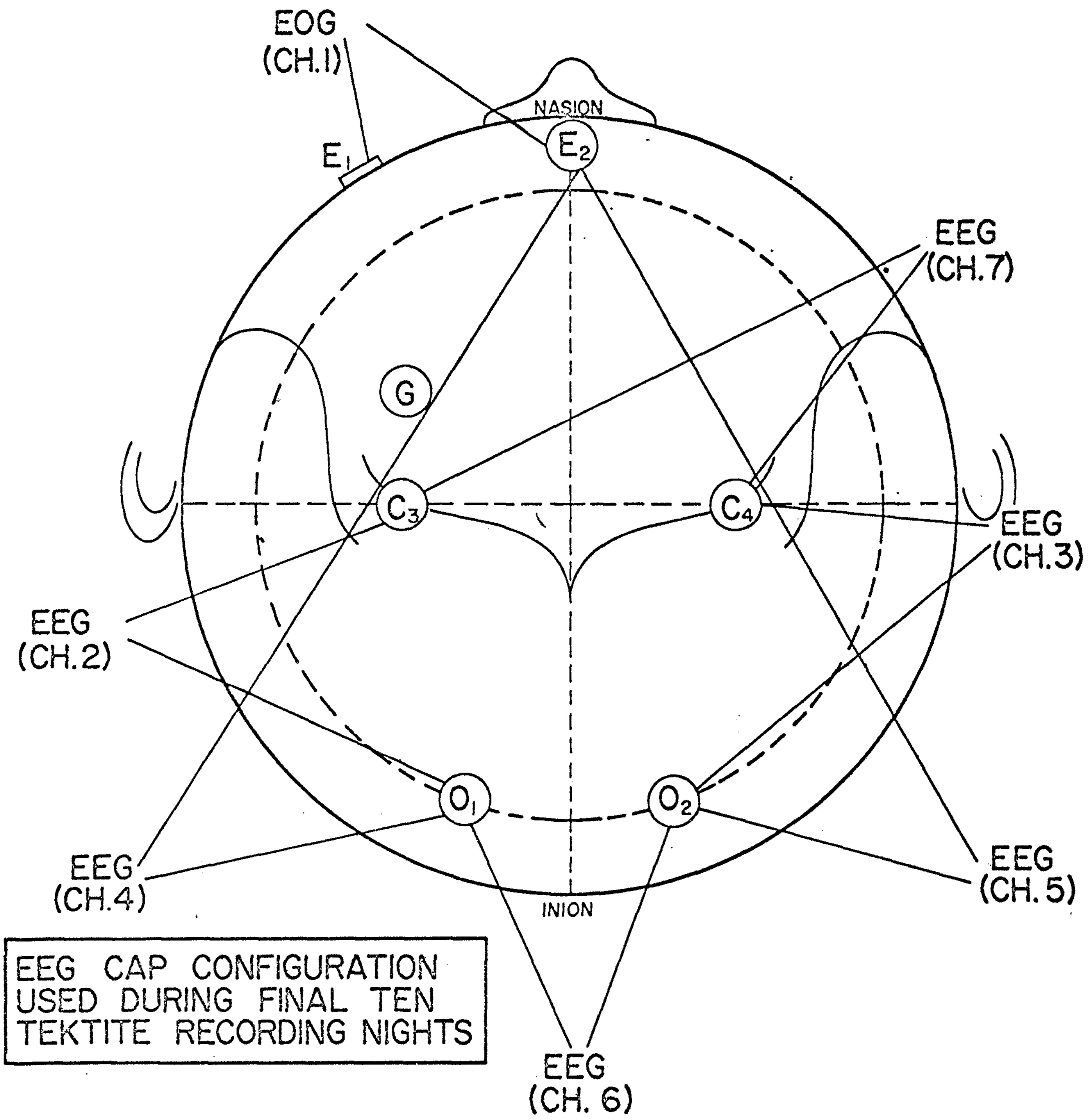
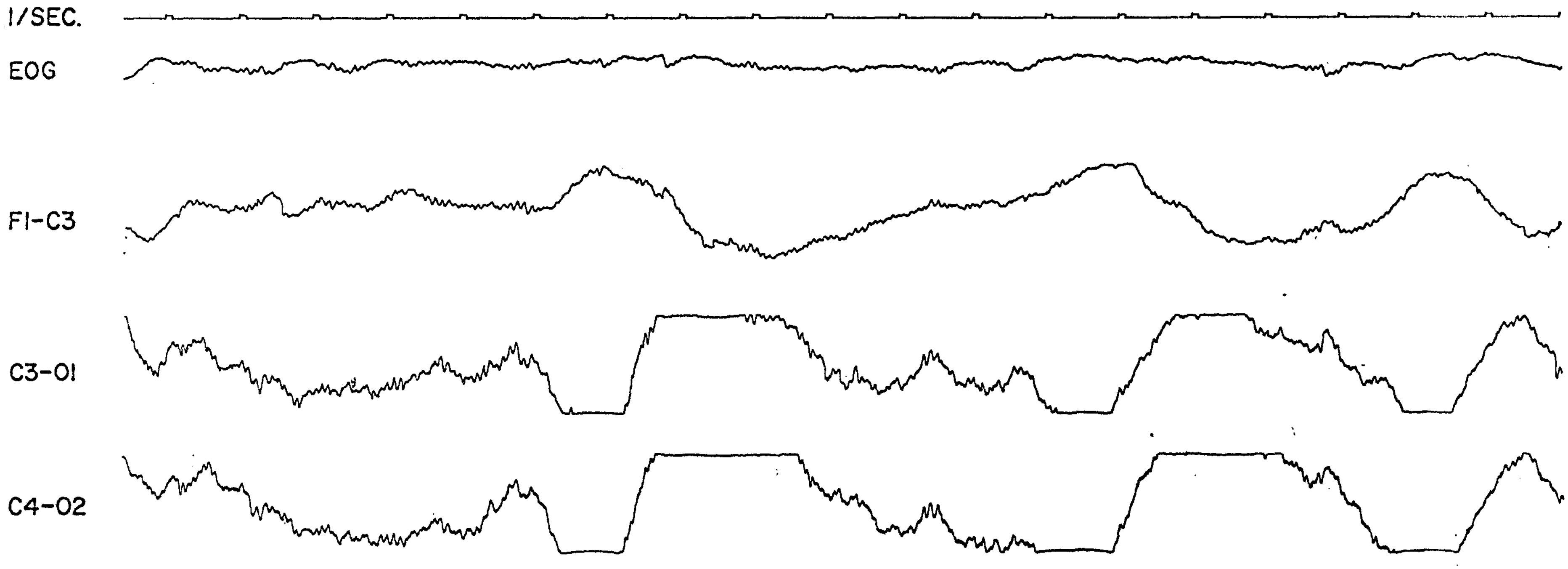


Fig. 26



EEG CAP CONFIGURATION
USED DURING FINAL TEN
TEKTITE RECORDING NIGHTS

Fig. 27



TEKTITE NIGHT # 2

Fig. 28

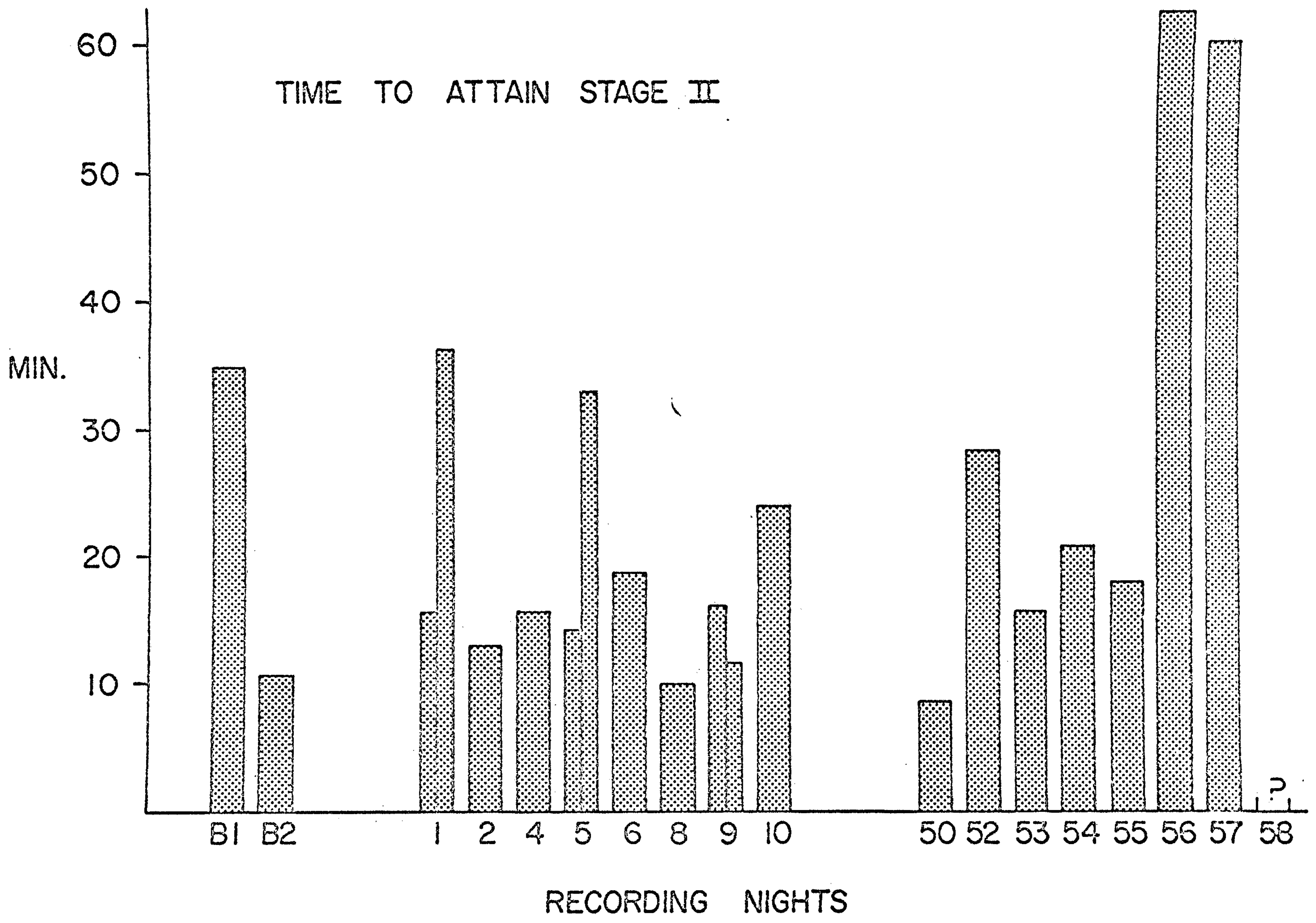

TIME TO ATTAIN STAGE II
MIN.
60
50
40
30
20
10
B1
B2
1
2
4
5
6
8
9
10
50
52
53
54
55
56
57
58
?
RECORDING NIGHTS

Fig. 29

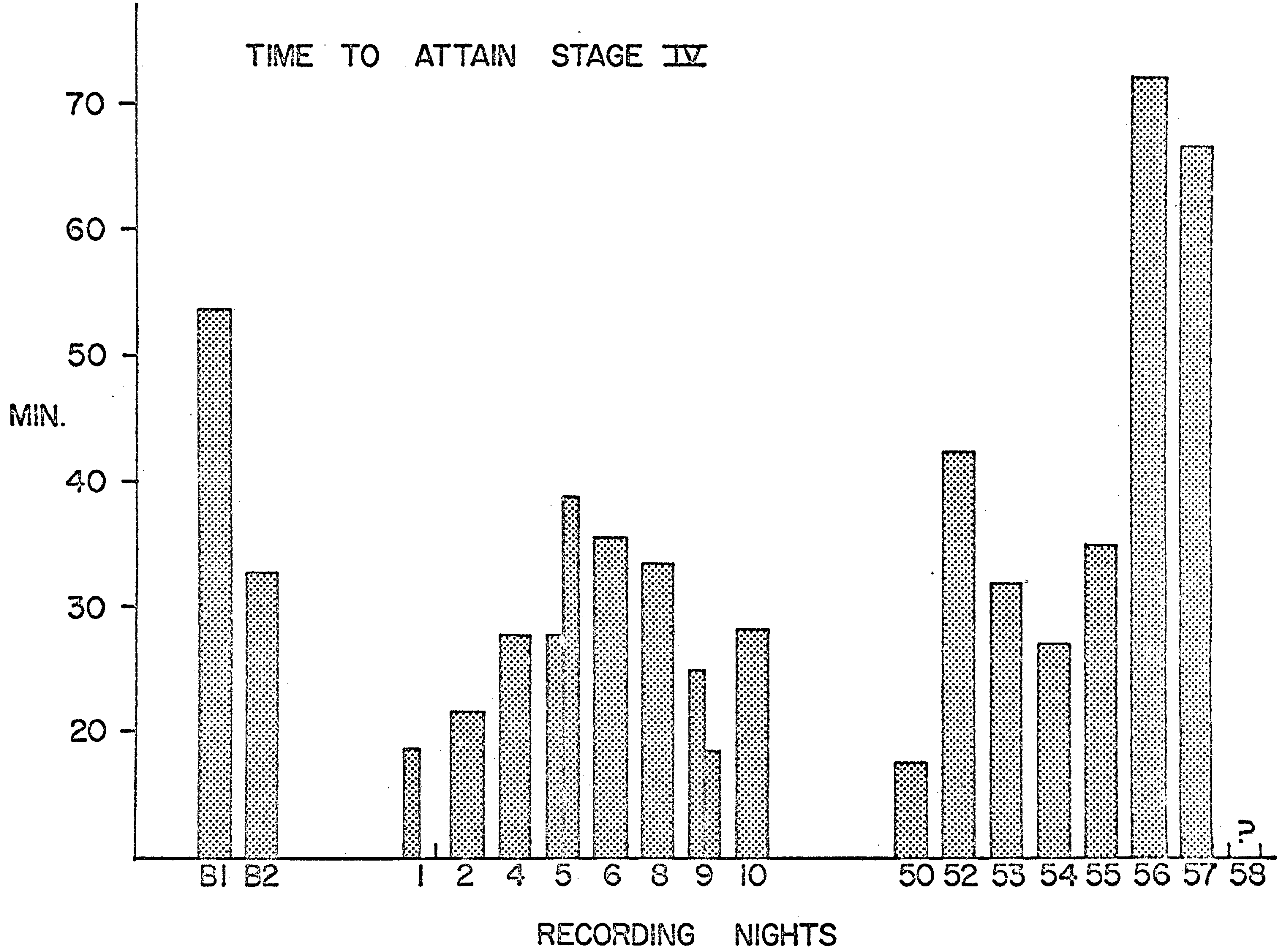

TIME TO ATTAIN STAGE IV
MIN.
70
60
50
40
30
20
B1
B2
1
2
4
5
6
8
9
10
50
52
53
54
55
56
57
58
?
RECORDING NIGHTS

Fig. 30

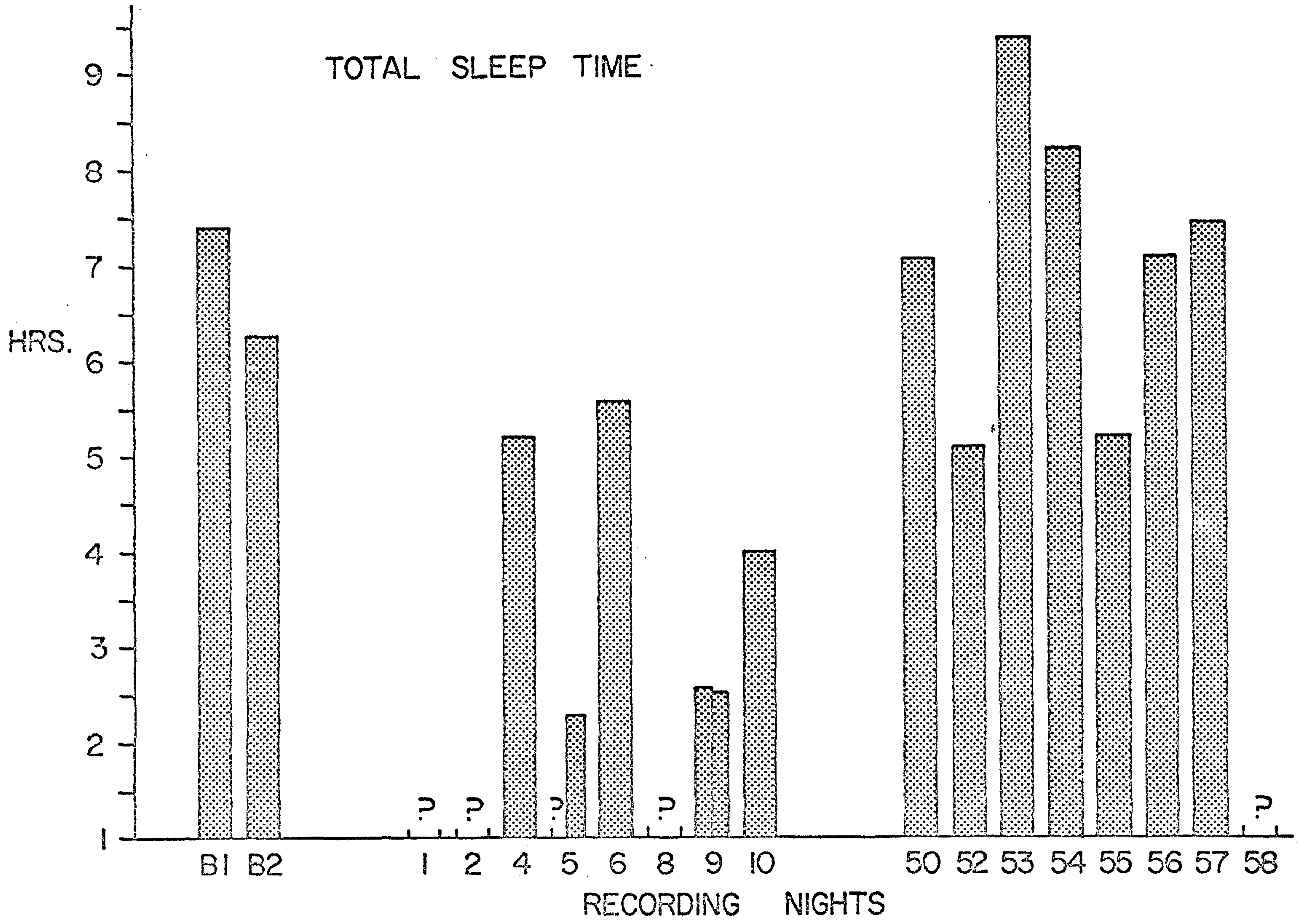

TOTAL SLEEP TIME
HRS.
9
8
7
6
5
4
3
2
1
?
?
?
?
?
B1
B2
1
2
4
5
6
8
9
10
50
52
53
54
55
56
57
58
RECORDING NIGHTS

Fig. 31

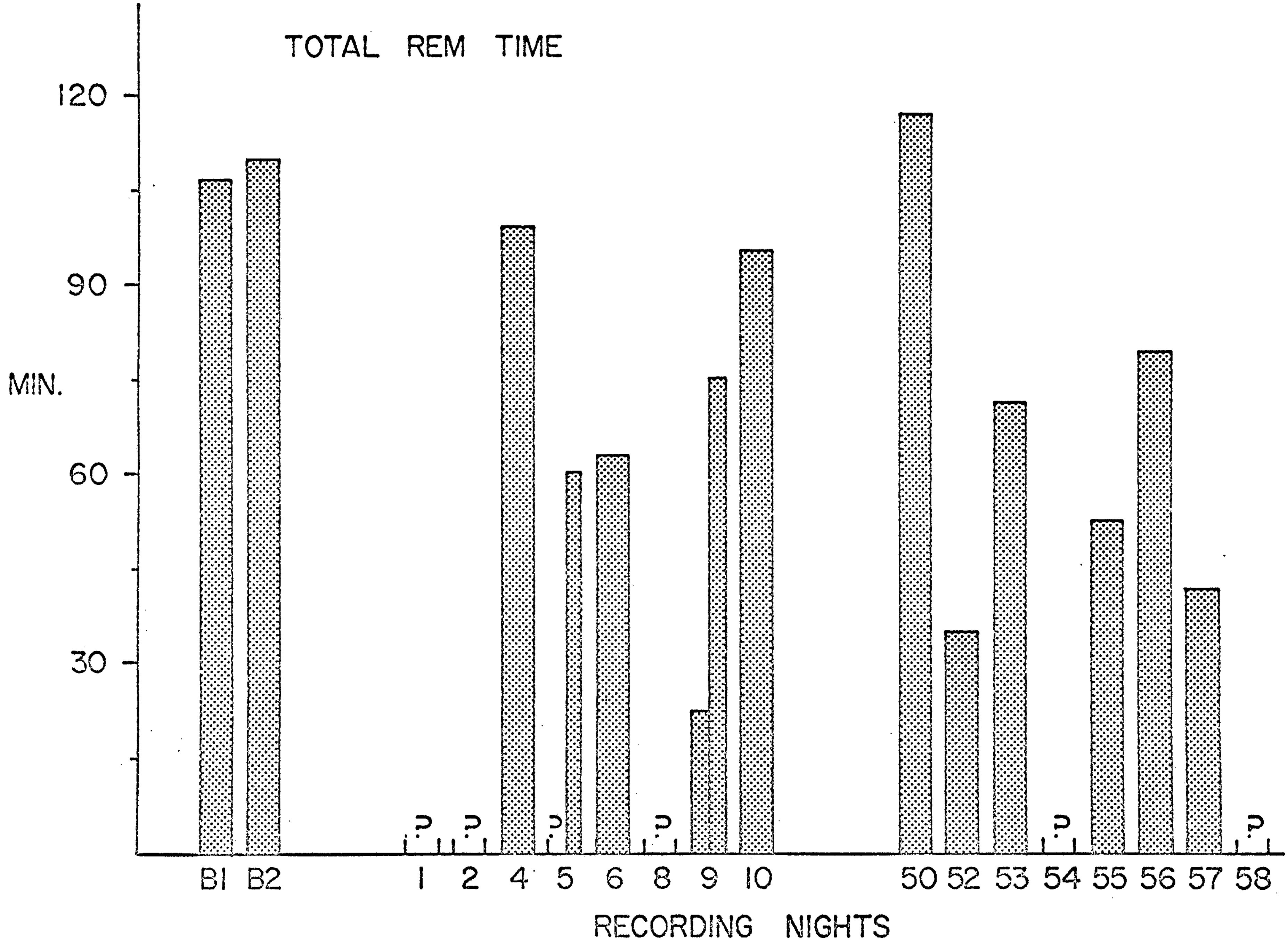

TOTAL REM TIME
MIN.
120
90
60
30
B1
B2
?
1
?
2
4
?
5
6
?
8
9
10
50
52
53
?
54
55
56
57
?
58
RECORDING NIGHTS

Fig. 32

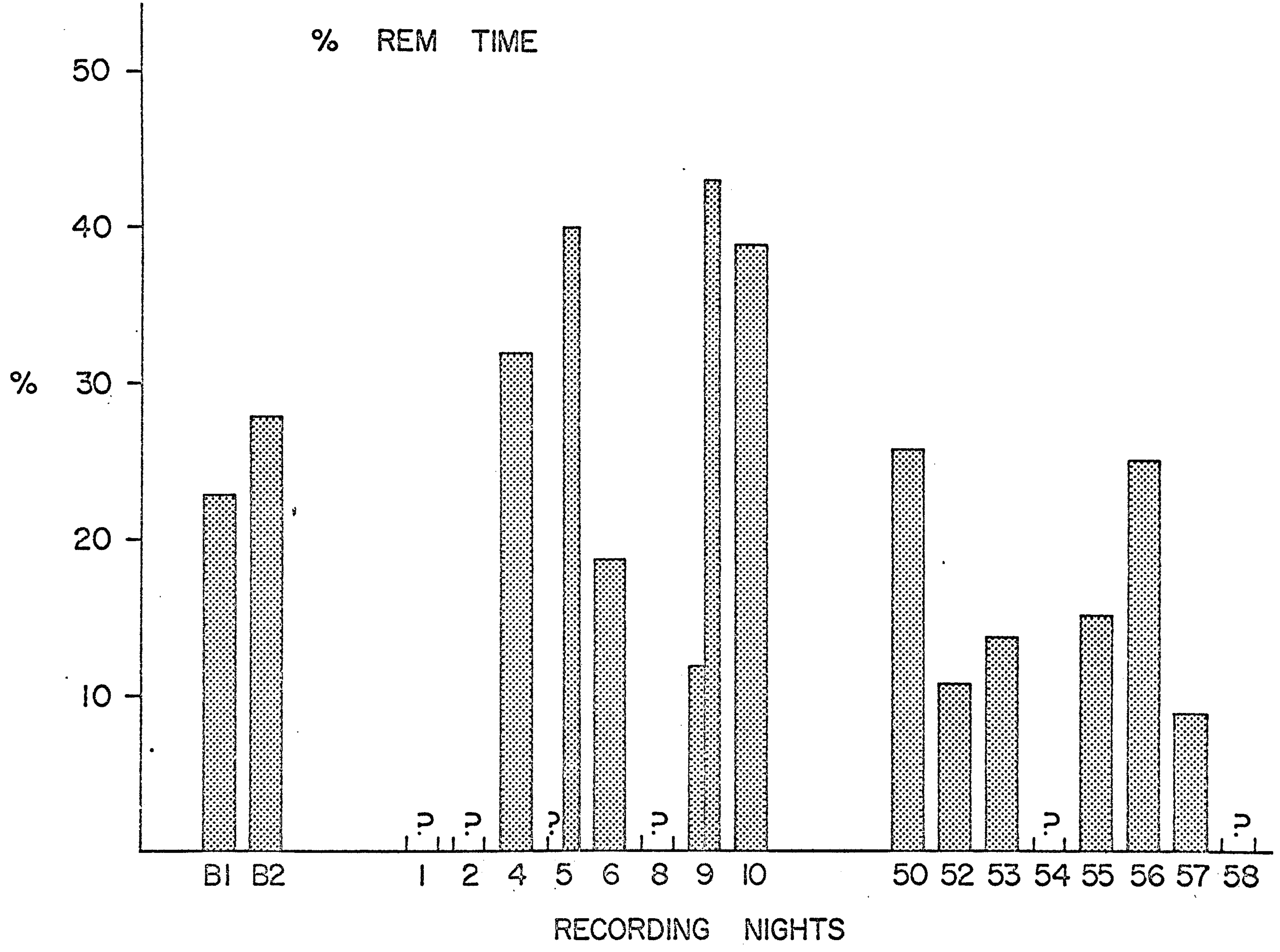

% REM TIME
%
50
40
30
20
10
?
?
?
?
?
?
B1
B2
1
2
4
5
6
8
9
10
50
52
53
54
55
56
57
58
RECORDING NIGHTS

Fig. 33